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HISTORY OF THE SECOND WORLD WAR

UNITED KINGDOM MEDICAL SERIES

Editor-in-Chief

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SURGERY

EDITED BY

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FOREWORD

by the Editor-in-Chief

This volume of the Official Medical History of the War of 1939–45 chronicles the chief advances made in Surgery during that War.

The History owes much to all those distinguished contributors who, often at great personal inconvenience, have written these records of their war experiences.

Surprise may be expressed that it has been possible to record the advances of War Surgery within the compass of a single volume. This has been effected by the non-inclusion of a great deal of clinical information which is already available in the standard British textbooks.

The preparation of material for this volume was begun by Dr. Charles Newman and Dr. N. G. Horner. To Sir Zachary Cope, alike as contributor and editor, under whose skilled direction the volume took shape and form, I would express my grateful thanks.

ARTHUR S. MACNALTY

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PREFACE

Everyone agrees that the results of the surgical treatment of wounds were very much better in the War of 1939–45 than in any previous war. The many reasons for this improvement will be clear to those who study this volume. Shock and sepsis were for the first time brought under early control, and technical advances were made in almost every branch of surgery.

The amount of space given to the various sections has necessarily been unequal but it is hoped that there has been no omission of importance.

The editor wishes to express his gratitude to the many distinguished contributors who have helped to produce what, it is hoped, will be regarded as an authentic and reliable account of surgical progress in the War of 1939–45.

In producing this volume some published records have been drawn upon, and we would express our thanks to those who have permitted this to be done, particularly to the editor of the British Journal of Surgery.

V. Zachary Cope

GENERAL INTRODUCTION: SURGERY IN WAR-TIME

By SIR W. HENEAGE OGILVIE
K.B.E., D.M., M.Ch., F.R.C.S.

SURGERY and war have always been interlinked. To prehistoric man the coughs, the aches, the fevers, the wasting diseases and the madnesses were clearly the work of some malevolent spirit or some human enemy, and their treatment was the business of the priest, the witch doctor, the physician—for the three rôles have only lately become partially separated—who advised him how to propitiate the evil spirit or to detect and deal with the evilly disposed neighbour. But the wounds of battle were the work of known enemies, of hostile but not evil men, and their treatment was entrusted to a handy comrade who had made a special study of this craft. It is true that in the Agamemnon-Priam campaign in Gallipoli the wounds of some of the heroes were treated by unqualified superhuman interveners, but the injuries of the generals, officers and common soldiers were dealt with by Machaon and Podalirius, the sons of Aesculapius, who probably had working under them a corps of trained assistants. For the next two thousand years, while medical teaching was traditional, while pathology awaited the invention of the microscope, and while planned operations were prohibited by the fear of infection, the work of the surgeon was in the main limited to the treatment of wounds and injuries and the chief school of surgery was the battlefield. During the wars that swept Europe throughout the dark and the middle ages, wars of religion and wars of succession conducted for the most part by professional armies, wars that flared up and died down, separated by uneasy truces but never by lasting peace, surgeons learned their work with the armies. The only men whose names have come down to us, the men who thought rather than copied and who added to the knowledge of their time, men like Henri de Mondeville, Guy de Chauliac, John Arderne, Ambroise Paré and Richard Wiseman, served with the armies of their countries; and when they came back from campaigning, with their unrivalled experience and with the patronage of the kings and princes whom they had accompanied to war, they became the leading surgeons in civilian practice, the surgeons to the hospitals, the teachers of the next generation.

It is only since the discovery of anaesthesia in the first half of the nineteenth century, and still more with the discovery of the cause of infection in its latter half, that civilian surgery and the development of planned operations for the treatment of disease, have appeared, but even so, the influence of war upon surgical thought and practice has remained paramount. It is now eighty-five years since Lister began to preach his gospel, and it is about sixty years since the outlines of surgery as we know it to-day first began to take shape. Looking at this epoch, as we now can, in a broad survey, we see that it falls into three distinct periods; that of exploration and anatomical enterprise, that of cultivation and physiological outlook, and that of detailed polishing and biochemical study. Each of the first two periods lasted for a quarter of a century, and the transition from the first to the second and from the second to the third was contemporaneous with, and largely caused by, a world war.

There are many reasons why a war should initiate a phase of surgical advance, but underlying them all is the fundamental fact that war brings surgeons back to a study of the basis of their craft, the reactions of the human body to injury and infection. Surgical advance in peace-time is conducted by a number of independent men or groups, working at problems of their own choosing, often without the knowledge that men in other countries are facing the same difficulties and finding solutions only slightly different. The integration of advance is impeded by difficulties of distance, of language, of training and of outlook, and by the differences in method and material that affect the results of experiments, and in anaesthetic technique and fitness of patients that affect the result of operations. Years go by before unsuccessful ventures are abandoned, before dishonest claims are unmasked, before the common factor in several lines of research is discovered and the best of several alternative lines of procedure is finally standardised. There is no integrating force other than that natural selection that tends, at long last and after much waste, to lead to the survival of the fittest. In war the surgeons of many nations are united in a common effort to give the men of their fighting forces the best possible treatment, and in that effort each is prepared to sink his individuality, to take the task that is allotted to him, to learn from others and to share with others his knowledge. In this effort experts in every branch of science are prepared to work at any problem requiring solution as soon as it appears; manufacturing firms will devote their whole resources to providing some drug, material or piece of apparatus that may be needed with the least possible delay; supplies, transport, equipment, are all available as they are needed.

In addition to this general stimulus to study and research, there is the wonderful urge that each surgeon experiences to give of his very best in the common cause. It is one of the anomalies of human nature that men are conscious of and animated by a common brotherhood only when they are united by a common danger. Service in one of the armed forces abolishes all distinctions of class, creed, and upbringing. The medical officer of a battalion comes to know his men, their home surroundings and their families, their worries and their hopes, their beliefs and their habits of thought, far better than the padre and the psychologist, whose approach is unavoidably professional and therefore unavoidably meets with resistance. The surgeon commanding a field surgical unit works with its other members in the spirit of complete comradeship and understanding. His feeling towards the wounded soldier who is brought in on the stretcher is one that he would be ashamed to put into words, but he knows without saying so that he will use all the skill he has learned, all the care he can exert, and that he will work with every power that is in him, to see that this fellow countryman whose life is now in his hands, gets every possible chance to recover and return once more to a normal happy life.

Further, while in war-time individual surgeons are spurred on to doing more work in a given time than they would have done in twice that time in the surroundings of peace, and better work than even their most glowing testimonials pictured as within their capacity, the whole sum of experience and of knowledge gained from experience is employed and made available in a way that it never is outside a war. Service surgery is based on the pyramid of responsibility. In each area there are consultants advising the command on matters of policy, co-ordinating the work of the surgical formations, visiting units at different levels in the zone of combat, distributing the news of which methods are proving successful and which disappointing, talking of new research work that may influence ideas already under discussion, reporting the subsequent progress of particular patients. In the individual formations experienced surgeons are responsible for observing, guiding and encouraging others at a more junior level, for co-ordinating their work, and for bringing the lessons they have learned to the notice of those at a higher level. The junior surgeon is encouraged to work in turns at different levels; in the forward areas, where he learns decision, manual skill, confidence and self respect, and in the base, where he is able to assess the soundness of the primary wound treatment he has practised in the field, where he learns to work as one of a team and to undertake planned surgery of increasing difficulty, and in the special units where he learns the essentials that will allow him to undertake surgery of every kind should he find himself at any time in charge of a unit cut off by time or distance from the main force, but also the sense to refrain from undertaking intricate operations when others with greater skill and experience and better equipment and assistance are available.

A fallacy that appears in all literature on war surgery is that war surgery and traumatic surgery are synonymous. They are not. War surgery is traumatic surgery applied under conditions of war, and those conditions cannot be dictated or modified by the surgeon, or even by the high command. The aim of those responsible for the surgical services of any army is to give the wounded man the best possible treatment; but 'best' is a qualitative adjective while 'possible' is a limiting condition. War is tough. War can be incredibly tough, so tough that conditions may easily arise when one or two surgeons whose supplies are exhausted may find themselves responsible for a couple of thousand wounded for whom they can provide nothing but first-aid treatment in its simplest form. The surgery of any campaign will depend on very many things besides the surgical knowledge of the time; on the terrain, on the climate hot or cold, the weather wet or dry, on the fitness of the troops, the adequacy of their supplies of food and water, the hygiene of the army and the prevalence of endemic or epidemic diseases at the time, on the weapons in use, on the quantity of supplies and the adequacy of supply lines, on the liability to air attack, on the severity of the fighting, on the time-lag between wounding and primary surgery and between primary and secondary surgery, on the lines of evacuation, the distance to the base, the quality of the transport, and the opportunities for staffing and supervision *en route*, above all on whether the force is fighting a winning or a losing battle. Britain's wars have hitherto followed a set pattern. We have started prepared on a totally inadequate scale to fight a war on the lines of the previous one; we have taken a pretty bad beating in the initial stages; we have learned our lessons, tightened our belts, built up our supplies, and at long last have won handsomely. Our surgical services during each war have followed much the same course; lessons have been learned and better methods have been elaborated, and during the final stages of superiority passing on to victory, they have reached a pinnacle of excellence in personnel, housing, equipment and supplies surpassing the best of contemporary civilian surgery. There is an inevitable tendency, and it will be found in some of the contributions to this history, to regard the final state as evidence of surgical advance, as indicating the level from which the surgery of any future war should start. There are, however, three aspects to the matter, advances in surgical method, advances in accessory methods that help surgery, and improvements due to altered conditions of warfare. Of these the last is the most important, the first the least.

The surgery of wounds in the Second World War passed through three phases. In the first, treatment by closed plaster, after the method of Winnett Orr and Trueta, was the rule; in the second, wounds were excised and drained, the limb was immobilised for transport in a padded plaster or some form of plaster box splint, and closure by secondary suture or skin graft was undertaken as soon as the surface was covered with healthy granulations; in the third the wound was excised at the forward units and closed by delayed primary suture at the base between the fourth and sixth day.

These phases were to a certain extent prompted by the development of chemotherapy, first with the sulphonamides and later with penicillin, but they were above all an evolution to meet changing circumstances of warfare. Each method was the right one at the time, and each would be right again were similar circumstances to recur. The closed plaster method is safe where the wounded are not to be evacuated, and it gives excellent results under desperate conditions when the disproportion between the numbers of wounded and those available to look after them is so great that frequent supervision after operation is impossible. Free drainage, immobilisation without constriction, chemotherapy, and the provision of skin cover at a later date, are the only possible lines of treatment in a swiftly moving campaign over open country, where all supplies are poor and where many days of rough travel separate the forward surgical units from the base hospitals. Such conditions are liable to recur, and, when they do, three-hourly penicillin, wound dressing under theatre conditions, and all the ritual of the British surgical services in Italy and Europe towards the close of the war, will be out of the question. Early closure by delayed primary suture or skin graft becomes the rule when conditions become good in a surgical sense, that is, when advance is steady and retreat unthinkable, when air superiority ensures uninterrupted supplies, when advanced surgical centres are close to the fighting and dealing with moderate numbers, and when base hospitals are within easy reach by a good evacuation route. To have carried out two-stage closure in the Western Desert would have been impossible; to have attempted it in Abyssinia would have been dangerous folly.

That this war differed profoundly from previous wars, particularly from the First World War, the only one of which any of us had first hand knowledge, is undoubted. That the results of war surgery in the Allied forces were better than any known heretofore is equally certain. That the surgery, that is, the work of the surgeons themselves, was any better is certainly untrue.

This was the first total war in history. Men, women and children, civilians and combatants, the aged and the sick as well as the young and the healthy, suffered privations and were liable to injury by bombardment, but this cannot be regarded as a factor appreciably affecting the surgery. It was also the first war that was largely mechanised, and this had a profound influence on the nature of the fighting, the supplying of the medical units and the transport of casualties. The number of men actually fighting was less, the number of men supplying them greater. The decisive actions were usually between armoured vehicles, and a break through, though it might mean very few men killed and wounded on either side, could force a retreat or even decide a campaign. The infantry and all combatant and supply units were transported to the line in vehicles, and shifted to fresh sites or back to rest by the same means. Long exhausting marches, spells in the trenches subject to constant bombardment, periods of exhaustion, hunger and thirst, which were common in the previous world war, were the exception in this one. After an action wounded men were picked up on the battlefield, as they were before, by stretcher parties, but thereafter their journey was by motor ambulance, or in favourable circumstances, by aeroplane, and they reached a surgical centre with little delay. The main result of mechanisation in so far as it affected surgery was that the men were fitter when they went into battle, that many fewer of them were wounded and that they reached the surgeon very much earlier. One distressing concomitant was the high proportion of burns among the casualties—many sustained in tanks or aeroplanes, but still more due to the careless use of petrol for cooking or cleaning.

The weapons in use were very different. High explosive shells and aerial bombs, mortars, land mines and rockets, were those chiefly used. Machine guns were used less than in the first war and rifles much less, while cutting weapons had virtually disappeared. Thus the common wounds were multiple and lacerated, and retained foreign bodies were the rule; many casualties in addition to their wounds had suffered crushes from falling masonry or overturned vehicles; clean wounds, incised wounds, single wounds, and simple through and through wounds were seldom seen.

The surgeons who were entrusted with the care of these wounds started the war with many advantages that their predecessors in the War of 1914–18 lacked. First, they inherited the physiological outlook that the surgeons of the first war had to learn for themselves—often in the face of bitter opposition by some of Lister's disciples who remembered the conquest of hospital gangrene by the liberal use of powerful antiseptics—an outlook they had developed during the inter-war years and handed on to their successors as a living faith. At the outset this post-war generation realised that the best protection against disease is a healthy body, and that the surest guard against wound infection is the resistance of healthy tissues. They practised wound excision from the start by methods that hardly differed from those developed in the casualty clearing stations of Flanders in 1917. They did not at first appreciate the folly of primary suture, but they soon learned their lesson.

Secondly, they had to deal with far better human material. The average soldier of 1939 was in every way a fitter man than his father had been in 1914. He had grown up under better conditions of housing, nutrition, work and leisure; he had been carefully selected, and after enlistment was trained to the highest pitch of physical fitness before being sent to a theatre of war; during his service he was well fed and well housed, and exposed to privations for short periods only; when wounded he reached a surgical centre in good condition after a minimal delay. The surgeons of the British Expeditionary Force in the first war were treating men brought down after weeks in the trenches; men who had been short of food, water and sleep, constantly wet, smeared from head to foot in manured mud. At times, as during the last German thrust in 1918, the majority of the casualties were received after several days, untended, heavily infected, and in many cases already dying from gas gangrene. The over-riding importance in assessing results of the condition of the patient is recognised by all surgeons who worked in several theatres of war. Those who had established a datum line for results in the Western Desert found that the mortality and morbidity among the wounded increased greatly during the first few weeks of fighting in Sicily when the troops were operating under conditions of great hardship.

Thirdly, the surgeons in the Second World War had at their disposal several accessory methods unknown in the first, or greatly improved in the interval. Continuous intravenous transfusion was introduced by Hendon and Matas in 1926. Gastric, and later intestinal evacuation by continuous suction, a logical sequel to the use of the gastric tube for fractional test meals, was first practised by a number of surgeons, chief among them Wangensteen, about the same time. The principle of alimentary rest, made possible by the combined use of suction and intravenous therapy, became the accepted treatment for peritonitis, and a prophylactic measure where soiling or injury rendered ileus likely. Following on the routine administration of parenteral fluids in large quantities, the problems of salt-balance had been carefully studied. Chemotherapy made its appearance in 1935 with the discovery of prontosil by Domagk, and by 1939 several sulphonamide preparations were in common use.

Transfusion as an accepted and scientific procedure had its origin in the First World War, but by 1918 one or at most two pints of blood, drawn from donors on the spot, was the largest amount that was ever given at a time. If this amount failed to restore the shocked patient his shock was pronounced irreversible. By 1939 stored blood had become a commodity in all main centres, and familiarity with intravenous medication had led to its use in large quantities in conditions of severe blood loss such as bleeding from duodenal ulcers. In 1914 anaesthesia was reaching the end of its seventh decade, but there were few professional anaesthetists and their methods were crude compared to those of even twenty years later; intravenous and intra-tracheal anaesthesia were unknown, and nitrous oxide, the only anaesthetic gas then available, was seldom used except for dental extractions. The surgeons of the Second World War were supported by a transfusion service that could supply blood and plasma in any required quantity, and that sent its trained transfusion officers to take charge of resuscitation in all surgical formations. They had with them a corps of anaesthetists skilled in modern methods and supplied with modern apparatus. With first-class resuscitation and first-class anaesthesia they were able to operate upon, and not merely save but restore to useful health, men so gravely wounded that they would certainly have died in previous wars.

To claim, however, that the surgeons or the surgery of the recent war were better than those of the previous one, would be foolish. They were not, because they could not be. The casualty clearing stations in Flanders and Northern France in 1917 and 1918, where men like William Anderson, Richard Charles, Claude Frankau, John Fraser and Gordon-Taylor worked and laid down the principles of post-Listerian war surgery, set an example that can hardly be surpassed. That their successors in the field surgical units, casualty clearing stations, specialist units and base hospitals in this war worked with the same selfless devotion, and attained a standard that can compare with theirs, is the highest praise that can be offered them.

The steady improvement that took place in war surgery during the years of combat was the sum of many influences, some of which have been briefly touched upon. A few of the more obvious advances in detail may be mentioned. In the general handling of wounds one striking difference between the two wars has been the lessened incidence and lowered mortality of gas gangrene. The sterility of desert soil, the absence of trench warfare, and the efficiency of anti-sera and of chemotherapy, have all been given the credit; the fitness of the modern soldier, the short time lag between wounding and surgery, and the free use of blood were, however, more important. In abdominal surgery, the one technical advance on the practice of 1918 was the use of exteriorisation or proximal colostomy in injuries of the large bowel. The most outstanding developments were, however, in the realm of accessory methods. Anaesthesia progressed at a greater pace during the six years of war, both at home and in the Services, than it had ever done in much longer periods of peace, and the development of closed circuit anaesthesia paved the way for the striking progress in the treatment of thoracic wounds that was one of the most satisfactory achievements of the specialist units in the field, and for the inception of cardiac surgery that followed the cessation of hostilities. Resuscitation and shock treatment were established on the sound basis of early, rapid and adequate replacement of lost body fluids. The most remarkable contribution of the war years was undoubtedly the development of chemotherapy, particularly the isolation, purification, analysis and practical application of penicillin. Spurred on by the desire to help the wounded of their forces, research workers and manufacturing chemists on both sides of the Atlantic achieved more in two years of concerted effort than would have been done in ten years of commercial competition in peace-time.

This volume records what the surgeons of the Allied Nations were able to achieve during a war in which their armies were eventually victorious. We must not forget that these achievements were linked with that victory. War surgery is a branch of military science, and unless the close relationship between the aims of a surgical service and those of the army of which it forms a part are constantly borne in mind, that service will not be efficient. Efficiency in war surgery means the best possible treatment of casualties compatible with winning the war, but if anything is allowed to interfere with military efficiency, the lives of well and wounded are risked alike. Military efficiency at times of hard fighting means speed, simplicity and concealment, and surgical units able to accompany the troops under these conditions must be content with small numbers, limited supplies, light equipment, and simple methods.

CHAPTER 1

TREATMENT OF WOUNDS

(i)

The treatment of war wounds

By SIR ARTHUR PORRITT
C.B.E., M.Ch., F.R.C.S.

SIMPLE or uncomplicated war wounds—involving skin, subcutaneous tissues, fascial planes and muscle only—constituted an average of between 20 per cent. and 25 per cent. of all casualty lists in the War of 1939–45. Add to them concomitant injuries of major nerves and vessels, amputations resulting therefrom, and gas gangrene, and the figure rises by 10 per cent. and with accompanying bone and joint lesions well over half of all war-wound totals are accounted for.

Although this chapter will deal only with uncomplicated flesh wounds the above figures are mentioned, because the principles of treatment are identical in both the simple and the complicated wounds of the extremities, and to a lesser but equally important extent in the more specialised wounds of the head, and the thoracic and abdominal cavities.

The treatment of the straightforward flesh wound is the type of the therapeutic measures used in dealing with any and all wounds, and hence derives its essential interest. The development of such methods of treatment in the course of the War of 1939–45 forms a fascinating story—not only of clinical advances which have produced a permanent effect on and stimulus to post-war medicine, but also of military economics and strategy. The improvements in the treatment of wounds during the war led to such a saving of man-power and such an increase in morale, that it can fairly be said the later campaigns were to a very large, quite unassessable and often unappreciated extent influenced by current medical policy.

HISTORY

To trace the development of this policy over the six years of the war as a chronological sequence is difficult. A latent, negative, initial incubation period which lasted virtually until the end of 1941, was succeeded by an interim stage of again approximately two years during which advances were rapid but staccato, occurring in various directions concurrently but at different rates of progress, to be succeeded by a terminal phase of consolidation of ideas, their routine application to practical purposes and the fruition of much valuable clinical and scientific research carried out often under the most difficult and bizarre conditions, both in a much-bombed home country and in the field all over the world in widely varying climates, terrains and tactical situations.

In brief, these three periods have frequently been called 'the pre-sulphonamide', 'the sulphonamide' and 'the penicillin' eras of the Second World War surgery, but it can rightly be said that these descriptions stress too heavily one only of the major developmental channels—the chemotherapeutic.

At the beginning of the war military surgical methods were essentially those of 1918. In other places other writers have stressed the woeful lack of appreciation in this country between the two wars of the potential effects on future warfare of the tremendously rapid development of the mechanical age. Military surgery was no exception to this *laissez-faire* attitude and even the lightning speed of the catastrophic Polish campaign failed to awaken any appreciation of the fact that the methods of 1939 were twenty years out of date. And so the B.E.F. went to France in 1939 with well equipped but ponderously moving casualty clearing stations and permanently immobile base hospitals. A scheme was evolved by which a somewhat vague 'surgical team' without equipment and without transport from the base hospital could reinforce the C.C.S. in times of stress. Luckily, from the surgical point of view, in that 'phoney war' of 1939 casualties were minimal; unluckily from a policy point of view when the startling and tragic climax of the evacuation of France did come, events moved so fast and organisation was so violently and completely disrupted that few lessons were really learnt.

But even in this initial period the first glimmerings of advances in wound treatment were becoming visible. As has been said, there was little if any appreciation of the necessity for mobilising military surgery, for speeding evacuation of casualties, for developing a more fluid medical organisation. Yet, despite the facts that wounds were almost universally infected and produced a high proportion of systemic side-effects, that only a small minority of the surgical personnel had former experience of war wounds, and that such primitive and cardinal sins as primary suture of wounds, limb-encompassing plasters, and the lack of appreciation of the difference between gas-gangrene myositis and the infection of a wound with gas-forming organisms (leading to many unnecessary amputations) were of everyday occurrence—nevertheless, at least three important developments were beginning to take shape.

The inter-war period had seen a greatly increased use in civilian practice of blood transfusion and other intravenous infusions, and these methods and the even more important problems of blood storage were tried out initially in B.E.F. days. The intervening Spanish war had proved the value of closed plasters in the treatment of wounds—a method associated for ever with the name of Trueta—and it was used extensively in these early days. Although its life as a definitive method of treatment was relatively brief, it served to inculcate the invaluable lesson of the importance of immobilising and resting a damaged limb. And thirdly, the early sulphonamide drugs were being used somewhat experimentally, both locally and parenterally, but to a rapidly increasing extent and without doubt in by far the majority of cases to the benefit of the patient.

In the all-too-brief campaign in Norway, in the early desert campaigns in Libya and in the disastrous Grecian and Cretan expeditions, little change in surgical methods was apparent, but in all the above mentioned three directions advances were slow but definite. It was increasingly appreciated that the sulphonamides were a valuable agent in controlling generalised sepsis from wounds, but equally that their local effect was disappointing. The long lines of evacuation from desert forward areas underlined the importance of wound immobilisation during transit, and at the same time stressed the dangers of the completely closed plaster, at any rate until a static stage in treatment had been reached. Hence the birth of the 'split and padded' plaster for transport purposes. Blood and intravenous fluids were being used more and more widely, the necessity being enhanced by the dehydration of patients, inseparable from campaigns in hot climates; and the solution of storage-problems, allowing not only preservation in sub-tropical countries but also shipment from the United Kingdom to bases abroad, was being rapidly reached and was accompanied by the extensive formation of local blood banks. In all these rapid developments of the blood-transfusion service—a service undoubtedly responsible for the saving of many hundreds of lives and the satisfactory treatment of many thousands of major wounds—two names should go down to military history, those of Whitby in the United Kingdom and of Buttle in the Middle East.

And so there was reached the second stage of the intermediate period —a stage when two major developments dominated the scene—the date now being early 1942. First came the translation into practice of the conception of mobile war surgery to the patient rather than the patient to surgery. In effect this was the appearance of the field surgical unit (with its essential offspring the field transfusion unit)—a small self-contained unit with complete facilities in personnel and equipment for forward surgery and possessed of its own transport. This unit in various shapes and forms with various names and in various combinations became increasingly from that time onwards a prime necessity in forward areas. With its arrival on the scene came development of the basic forward medical unit (the C.C.S.) into a rapidly mobile entity—a process which ultimately spread to the smaller so-called base hospitals and even convalescent depots and a great speeding up along lines of evacuation, making it possible to co-ordinate forward and base treatments of a wound into one composite whole. In this connexion early and sporadic evacuation of casualties by air began about the end of this year (Alamein, 1942)—a system which developed to a remarkable extent towards the end of the war particularly in Normandy, Burma and the closing stages of both the Italian and North West European campaigns.

Contemporaneously with the last Libyan campaign came the North African landings, and as the two armies joined forces another mile-stone in the treatment of wounds was being passed—the use of penicillin. The pioneer work of Florey and Cairns in Oxford, linked with that of Pulvertaft in the Middle East, led to a large-scale clinical experimental investigation in North Africa. The result was never in doubt; development was limited only by supplies, but the ultimate, almost miraculous improvement that occurred in combating wound-sepsis was unquestionably in very large measure due to the early controlled and scientific experiments of this phase.

The final two years of the war—the middle of 1943 to 1945—saw the consolidation of these various great advances, so that in Italy, in North-West Europe, in Burma and the Far East, there was established a routine treatment in forward areas, in transit, and in base hospitals—all linked, thanks to early initial surgery, adequate resuscitative methods, swift and efficient evacuation, and the help of antibiotic control of infection, into a unified and comprehensive treatment of the wound almost from the moment of its infliction until the patient was rehabilitated and fit again for duty. That this could be achieved, in the widely differing conditions of the three final campaigns mentioned, in about 95 per cent. or more of uncomplicated flesh wounds within a period of a month, affords ample proof of the perfection to which such methods were brought, and expresses a vast amount of detailed work in various spheres of activity directed towards improvements in technique, in organisation and in co-operation. Apart from such consolidation of previously worked out advances in methods and policy, the terminal stages of the war (dominated surgically by abundant supplies of penicillin) saw only one further development and that was the appreciation of the importance of counteracting the physiological and biological upsets produced by wounds. Such questions as those of water, salt and electrolyte balance and of protein metabolism in relation to trauma, received much consideration, and, as a result, a great deal was achieved in expediting healing of wounds after the more technical and mechanical treatment had been effected.

Before dealing in detail with these technical methods it may be of advantage to list the advances in wound treatment during the war and to discuss other factors which may influence such treatment, so that the essential principles should not be lost sight of in a mass of minutiae.

ADVANCES IN WOUND TREATMENT DURING WAR

(1) *Resuscitation.* The literal meaning of the words 'where there is surgery there is blood' came to have a very different significance during the latter half of the war. The Blood Transfusion Service which included the collection, testing, sterilising, storing and transporting of vast quantities of blood and other protein fluids (plasma, serum etc.),

the training of skilled personnel both for laboratory and field work, the formation of special units to cope with the increased mobility of modern warfare, and the organisation which integrated all these various activities —this service was indeed one of the outstanding developments of the war. The blood, collected in one part of the United Kingdom, prepared and stored in another, was transported under ideal conditions, irrespective of climate, by air half way round the world or by special speed-boat across the Channel to bases in the field, whence it was efficiently and expeditiously supplied to the most forward surgical centres by the well-known and much-beloved 'vampire vans'. The personnel of these distributing vehicles often knew more of the situation as a whole in forward areas than many a general! Arrived at its destination it was used by the specially trained Transfusion Officers, young men whose knowledge of giving blood (to whom, when, how much and at what rate) was only equalled by their general clinical acumen, which made them such an essential part of the pre-operative and post-operative organisation in forward surgical units. Let it be put on record that this vital service was given either at the base or in forward areas by men who became deservedly popular in every theatre of war for their unfailing cheerfulness, efficiency, and willingness to co-operate.

2. *Chemotherapy*. There can be little doubt that the advent of the sulphonamides, and later, penicillin revolutionised the treatment of war wounds. So dramatic were the results of treatment by these substances that it had to be constantly impressed upon war surgeons that, invaluable as they were in increasing the scope and lessening the risks of military surgery, they were, nevertheless, only the very important adjuvants of good surgery. In no sense did they replace it. It only has to be realised that neither of them have any effect on the infection associated with devitalised tissue to appreciate the intrinsic necessity for surgical methods as such. In passing, and as a compliment to the general standard of surgical technique, the relatively very low incidence of gas-gangrene infections throughout the war should be noted. It was amply proved in those cases that did occur that no accessory methods (serum, chemotherapeutic agents, transfusions) could *per se* effect a life-saving result without radical surgery. The sulphonamides had their heyday in the Middle East campaigns. It became obvious there that their effect on systemic infections was of the greatest value, particularly in the lethal streptococcal septicaemias, but as time went on it became evident that locally in wounds they were only of limited value, especially in deep wounds. It was left for penicillin to achieve the real conquest of local sepsis and so allow the application of the best wound dressing in existence, namely skin, either by closure or by grafting. Both parenterally and locally, penicillin yielded better results than the sulphonamides. Combinations of the two were in general use until the end of the war, but a large-scale field research in 21st Army Group gave ample proof

that penicillin alone gave equal protection against existing and potential wound infections. It should be realised that in the last year of the war, penicillin was used as a prophylactic to an equal if not greater extent than as a therapeutic agent. Not only was local wound sepsis practically abolished, but post-operative infective sequelae were reduced to negligible numbers. The fact that penicillin was virtually non-toxic was of the greatest importance in treating severely injured patients, a point in sharp contrast to the baneful effects of sulphonamide over-dosage and sensitivity. Again, penicillin retained its activity in pus, it could be injected without fear into infected cavities and its range of effectiveness against different types of bacteria was considerably wider than that of the sulphonamides. Its greatest drawback was that it could not be given effectively by mouth—a fact which led to the development of many and varied ingenious methods of parenteral administration.

3. *Surgical Mobility.* Under this heading must be considered the development of the field surgical unit and its prototypes, which made possible effective primary surgery at an earlier stage than hitherto. This result became relatively more important in view of the rapidly moving fronts of modern mechanised warfare. It allowed also, in conjunction with greatly accelerated methods of evacuation (in particular air evacuation), the conception of the treatment of a wound being one process, carried out in three stages (forward, transit, and base treatments), a conception which, though simple in itself, had until the last few years of the war been absent. This invaluable co-operation between forward and base surgeons and the appreciation that both were carrying out essential parts of one procedure, were fostered by systematic changes of personnel and, whenever possible, by meetings of the two groups. It would seem only just at this stage to remember that the pushing forward of surgical facilities was rapidly followed by a similar movement of nursing services and no one who has either seen or experienced the latter can doubt their inestimable value in attaining good surgical results.

4. *Methods of General Treatment.* Just as important as the unification of forward and base treatment of wounds, was the appreciation of the fact that quickest healing and best restoration of function depended not only on local treatment of the wound itself, but equally on treatment of the body as a whole—whose physical state and physiological functions were far more disturbed by major trauma than was at first realised. Under this head the correction of dehydration is an obvious matter. Not so simple are the necessary adjustments of salt and electrolyte balance, of dysfunction in protein metabolism, and of avitaminosis. Such constitutional factors play a large part in the process of wound healing and an appreciation of this fact did much in the later stages of the war to improve the results of treatment of wounds. Under this heading also should be included all those methods included in the comprehensive term rehabilitation. From the military point of view it is not

sufficient to obtain healing of a wound; the wounded part must be made to function again to the best of its ability, and the wounded patient must be made to feel that this is a desirable aim and one in which he must not only co-operate, but enjoy co-operating. Such rehabilitation, which both mentally and physically should start at a very early stage of treatment, became of increasing importance as the war dragged on and problems of preservation of man-power and of morale cried out louder and louder for solution.

Such then, always in conjunction with well-planned, scrupulous and effective surgical technique, would seem to have been the main advances that became evident as the war progressed; but certain other factors affecting wound treatment are worthy of note before discussing actual methods.

FACTORS INFLUENCING WOUND TREATMENT

Terrain. It is well known that highly-cultivated and heavily populated areas are more likely to cause infection from soil and dirt in wounds than open spaces and sparsely populated regions. Evidence of this was given by McLennan in an investigation of bacterial flora in comparable wounds in the Libyan Desert and in France. It was found that in the former theatre only 30 per cent. of wounds were infected with *Cl. welchii* whereas in the latter the figure was 80 per cent.

Climate. As an example of the effects of climate the dehydration associated with fighting in tropical regions is an obvious one. Again the possibility of infection carried by flies is greater in hot climates where, too, skin resistance seems definitely lowered. In contradistinction to this, the cold and wet of more northerly climes have devitalising effects, both local and general.

Diet. The body's natural powers of resistance depend essentially on a physical fitness, which is difficult to maintain without an adequate intake of a well-balanced diet. Rations during the last war were on the whole excellent, but such campaigns as those in the deserts of North Africa or the forests of Burma often enforced reduced diets, sometimes for prolonged periods, with consequent lowering of general resistance.

Clothing. Thick clothing, particularly woollen clothing, harbours infection to a far greater extent than the cotton drill of a tropical uniform. Hence in-driven particles of battle dress were potentially much more dangerous than those of bush shirt or shorts.

Hygiene. The principles of elementary hygiene were well instilled into troops in all theatres of war, but here again the possibilities of infection from excreta and rubbish (particularly in fly-ridden countries), in terrain recently and rapidly evacuated by the enemy or by civilian population have only to be mentioned to be appreciated.

Immunisation. Routine immunisation against typhoid, dysentery, cholera, etc. was admirably carried out and major epidemics were conspicuous by their absence. The possible effects of such infections on the wounded are obvious.

Welfare. It may seem a far cry from wound treatment to welfare, but the morale of the wounded man, dependent to a large extent during war on these services, is a factor of vital importance. Every surgeon of experience must have met the case of the man badly but not mortally wounded who despite all treatment turns up his toes and dies, even as he has many times seen the man, who would not surgically appear to have a chance of living, nevertheless win through by the sheer will to live. It is fair to say that during the last war, even in its most depressing phases, morale remained as a whole extraordinarily high.

Type of Missile. The prevalence of wounds due to fragmentation missiles (and, therefore, multiple wounds) was very noteworthy in this war. C. G. Rob has analysed a series of reports of relative frequency of wounds from various missiles as follows:

	Per cent.
(*a*) Fragmentation missiles (mortar, aerial bomb, grenade, shells)	75
(*b*) Penetrating (solid) missiles (bullets, anti-tank shells)	10
(*c*) Land mines, booby traps	10
(*d*) Blast, crush	2
(*e*) Chemical (phosphorus)	2
(*f*) Other wounds	1

The fragmentation missiles can produce wounds of any size and are certainly responsible for the largest flesh wounds. Tissue destruction is considerable even in cases where the entry wound through skin is small. Mine wounds are also multiple, the classical example being a traumatic amputation of one leg at mid-calf level with spattered wounds of the other leg up to the thigh, and not infrequently concomitant eye injury. Bullet wounds are relatively cleaner, have a rounded wound of entry smaller than the exit wound, if such exists. They are frequently single. Blast, crush and chemical wounds will be noted under local treatment in forward areas.

Time and Distance. Two time-distance factors affect wound treatment:

(*a*) Time between wounding and primary surgery.
(*b*) Time between primary and secondary surgery.

The former interval is relatively the more important and in the latter stages of the war seldom exceeded twelve hours. Such an interval, except in heavily infected terrain or in exceptionally dirty individual wounds, permits full primary excision of the wound. Such factors as multiplicity of wounds in any one man, or an overworked and solitary surgical team, may automatically lengthen this interval to the detriment of both the individual wound and the patient. Generally speaking, the shorter this interval the better the prognosis, but it was found that surgical teams could receive casualties too early—i.e. still in the stage of preliminary primary shock—so that it was necessary deliberately to delay operative procedure until full resuscitative methods had been employed. Examples of this state of affairs were met with in certain planned actions in Italy and the B.L.A. campaign and in Burma. The second interval obviously depends upon the length of the time of evacuation and the method of evacuation employed. In desert warfare 10 days or more was not exceptional, in B.L.A. and Burma the rapid and ever-increasing use of air evacuation reduced this to an average 3-4 days (and often less). In Middle East this long delay, with intervening poor conditions of dehydration and inadequate diet, discomfort and usually several needless wound inspections, led to an almost constant infection in wounds despite adequate forward surgery and the use of the sulphonamides—and also to a very debilitated patient. Such conditions were almost non-existent in the closing campaigns of the war and rapid evacuation; the use of penicillin and improved technique permitted efficient secondary surgical treatment to be undertaken in 90–95 per cent. of cases within a week of wounding.

TREATMENT OF A WOUND

It is necessary to consider treatment in the forward area, during the process of transit to the base, and at the base itself.

A. FORWARD TREATMENT

GENERAL. Apart from the fact that the battle-casualty arrives at a forward surgical unit with a wound, he is typically tired and dirty, often cold and wet and usually thirsty. All these states call for simple treatment not only from a humanitarian point of view, but also because the effect so produced has both physically and mentally a very definite and often marked effect on subsequent surgical procedures. Thus such elementary measures as a pillow under the head or the knees, the provision of blankets under as well as over the patient, the removal of boots and of wet and soiled outer garments are all relatively important factors. A partial wash even of face and hands does much to improve the patient's comfort. A mouth-wash can always be given, and, in cases of flesh wounds alone, fluids by mouth can be given freely and with obvious advantage. The provision of sufficient but not excessive warmth requires both judgment and experience. A wounded man is usually, as the result of his previous exertions and strain, relatively dehydrated—a state that may be intensified by the application of too much heat, particularly in a patient whose vasomotor reflexes have been disorganised by shock. Such effects were particularly obvious in campaigns in hot climates.

One other general point about the surgical casualty is worthy of note and that is his willingness and desire to undergo operation.

This preliminary period of rest and the provision of simple creature comforts is well worth the time expended. It also allows the resuscitation officer time to make certain essential observations and to carry out the all-important pre-operative treatment.

The blood-pressure was taken and the pulse-pressure noted; the pulse-rate was recorded at intervals and the state of the peripheral circulation observed. Whenever possible, an attempt was made to raise the systolic blood-pressure to 100 mm. before major surgery was undertaken. It was reckoned that a systolic pressure of 85 mm. Hg implied a loss of a third or more of the total blood-volume. Vitally important observations were made at this stage without undue disturbance of the patient. For example cyanosis and deafness might suggest accompanying blast injury, and a relatively poor and prolonged reaction to resuscitative methods could be expected; the swollen, tense, pulseless, cyanotic limb pointed to crush injury, and in this connexion it has been pointed out that, even without bleeding, an increase of an inch in the diameter of a thigh implied a loss of a pint of circulating fluid from the capillary bed; and again the dead white skin of a patient complaining of excessive pain might perhaps point to the phosphorus burn, a diagnosis which could often be confirmed by luminosity in the dark.

Prophylactic Treatment. Of primary importance was the relief of pain, second only to the first-aid prevention of further haemorrhage either by tourniquet or by pressure dressing.* Undoubtedly the best anodyne was morphine and where possible the best route of administration was the intravenous. Given in ¼-grain doses the result was immediate and complete. On long lines of evacuation the danger of cumulative doses of intra-muscular morphine became more obvious. Little effect was observed in a shocked patient and so the dose was repeated, often several times—only to produce a cumulative and often dangerous result when resuscitation was eventually carried out. Sera were given as a routine at this stage, anti-tetanic always and anti-gas-gangrene serum wherever there appeared the slightest possibility of such infection having occurred. Prophylactic parenteral (intramuscular) penicillin was started at this stage and such stimulants as coramine, ephedrine, and adrenaline given where considered necessary.

Resuscitative Treatment. Resuscitation as such involved the giving of requisite amounts of blood, plasma or glucose saline and where necessary the administration of oxygen. Blood was given in such quantities as was estimated would replace that actually lost, after which plasma could be used to produce the required pre-operative blood-pressure level. The chief indication for intravenous saline was the relief of dehydration. The judicious use of these three fluids, either together or in sequence and in the correct quantities, called for both judgment and experience. That this interim period between arrival at a surgical centre and actual operation was of the greatest importance is indicated by the fact that less than 4 per cent. of deaths occurred during this preliminary surgical

* Tourniquets became unpopular and were used less and less as war progressed; they were so often applied at sufficient pressure to occlude only the venous return and not the arterial supply.

stage (C. G. Rob), and these were accounted for in the main by the major abdominal, cranial and thoracic wounds and only to a very small degree by flesh wounds—i.e. they were patients almost moribund on admission.

LOCAL TREATMENT. Some general principles may be mentioned first. Operative priority was given to cases with a tourniquet still *in situ*, to traumatic amputations and to those with obviously massive muscle disruption and loss. (This list of course refers to flesh wounds only and disregards the high priorities of sucking wounds of the thorax, tension pneumothoraces, penetrating abdominal wounds, obstructed airways, and major fractures). Pre-operative X-ray examination, whenever it could be carried out without great disturbance to the patient, came to have an increasing value and use as the war progressed. It permitted a far more accurate estimation of the track of a missile than could otherwise have been possible, it helped to localise foreign bodies and detached particles of bone, and in thoracic wounds it could give invaluable information as to the state of the underlying lung. As a general rule, wounds of the posterior surface of the body were dealt with before those on the anterior surface, and in all cases, so far as local conditions would permit, the highest standards of aseptic surgery were adhered to.

Anaesthetics. Undoubtedly the great stand-by was intravenous pentothal. This proved the greatest boon to patients who were scheduled for a series of operations and was alone sufficient in many cases of simple flesh wounds. Where necessary it was reinforced by light inhalation anaesthesia. The greatest contra-indications to pentothal were an actually or potentially obstructed airway and major degrees of shock. Spinal anaesthesia found no place in forward surgery and local anaesthesia only a small field (e.g. minor superficial wounds, scalp wounds, tracheotomy).

Cleansing the Wound Area. Clothing, if not previously removed, was cut away carefully over a large area around the site of the wound, and this area was then scrupulously washed with soap and water and shaved, a sterile gauze pad being held over the wound during these procedures. The whole area was then painted with a suitable antiseptic. This cleaning up was not done until the patient was on the table, it being felt that avoidance of any disturbance of the original dressing (except to deal with haemorrhage) was a point of the greatest importance. The area was then towelled off.

Operative Procedure. At one time (approximately 1942) great controversy existed over the details of operative technique, but in essence this was largely a matter of terminology. Whether the operation is called excision of the wound, débridement or wound-toilet matters little provided certain essential details are observed. At the time mentioned the two schools of thought advocated respectively wide and radical excision of the wound, and minimal surgical toilet of the wound. The difference was really one of degree only, and in the later years a standardised routine was adopted in all theatres and was varied only by the time factor. It was felt that after an empirical interval of twelve hours (varying with local conditions) major interference with a wound was likely to do more harm than good by spreading potential sepsis, and hence operative treatment was scaled down from excision to wound toilet. The essential details of all these procedures can be summarised as follows:

Incision. This must conserve as much skin as possible. In clean-cut bullet wounds it is doubtful whether any skin need be removed. In any wound a freshening of the edges, a removal of a maximum of ⅛ in. should be sufficient. In this connexion it is worthy of mention that greatly accelerated healing was obtained by the excision even of simple through-and-through bullet wounds. The incision should be adequate to expose all parts of the wound fully, and this applies equally to skin and fascia; it may require elongation to permit of subsequent easy suture without tension; it must effect good decompression of the depths of the wound and this may necessitate secondary incisions at right angles to the initial incisions to open up pockets deep to fascial planes (e.g. of the thigh beneath the fascia lata); in the limbs longitudinal incisions are preferable to transverse ones; incisions over bone should wherever possible be avoided.

Excision of Tissues. As has been stated, minimal skin should be removed. On the other hand, wide excision of subcutaneous fat is necessary —this layer having a relatively poor blood supply and being liable to gross contamination. The fascial layers certainly provide one of the chief danger points in wound excision. Opening up fascia to an extent at least equal to the skin incision, the careful removal of all damaged and shredded fascia, and the making of such cross incisions as are necessary to relieve compression, to open up deep pockets and to effect complete drainage—these are all vital parts of the successful cleaning of a wound. Beneath this layer, careful removal is necessary of all damaged and devitalised muscle tissue, of blood clot, of all foreign material and debris as methodically, efficiently and expeditiously as possible. In many cases this part of the operation can be assisted by a gentle flow of saline irrigation through the wound; this washes away blood clot and some of the imbedded foreign material, and floats up fragments of muscle and fascia. It must always be remembered at this stage that it is devitalised muscle tissue which *par excellence* provides a nidus for the lethal gas-gangrene organisms.

Foreign Bodies. These fall under two heads: (*a*) introduced foreign bodies (missiles, stones etc.), (*b*) bone fragments.

(*a*) The controversy over the necessity for removal of foreign bodies fluctuated in intensity at various stages of the war. The matter is essentially one of common sense. Obviously if reasonably accessible, the foreign body should be removed, more for the contamination of the clothing (and particularly heavy clothing) it automatically introduces into the tissues than for itself, as the metal itself has often been heated by explosion to the extent of relative bacterial sterility. Again a smooth missile (e.g. bullet) is much less likely either to introduce particles of clothing or contamination by itself than the jagged metallic particles of shell-cases, bombs, mortars etc. The problem case is the one in which the foreign body is not readily accessible in the excised wound. Here judgment and experience are of the greatest value and a consideration of the facts mentioned above will often provide the right answer. To search blindly for a poorly localised foreign body, especially if this process involves opening up undamaged tissue and the expenditure of valuable time, is at this stage often unwise. Such risks can often be avoided by a simple counter-incision, if clinical or radiological localisation make this a feasible proposition.

(*b*) The policy regarding bone fragments changed entirely during the course of the war. In the initial stages practically all bone that had become detached from its parent site was removed wholesale; later a more conservative view was taken and those particles which maintained a soft tissue connexion (and therefore presumably a blood supply) were left *in situ;* and in the closing campaigns—such was the prophylactic anti-infective cover given by penicillin and the sulphonamides—even loose particles of bone were left in place as tantamount to primary chip bone grafts. In the absence of subsequent sepsis, by far the majority of these fragments lived, and thereby was avoided the long weary months of repeated surgical operations and convalescence which inevitably followed major bone loss. Obviously the possiblity of displaced bone fragments pressing on or irritating major vessels and nerves had always to be borne in mind.

Other Points in Forward Treatment. Haemostasis as complete as possible should be the ultimate aim in treatment of the wound. To a large extent this can be obtained by pressure with warm packs. Ligatures should be used as sparingly as possible and in the latter stages there was a general feeling that thread was preferable to catgut as ligature material. The wound having been thus made as 'biologically inhospitable to organisms' (H. C. Edwards) as possible, a further barrier to infection is provided by dusting ('frosting') all the exposed surfaces with penicillin (or penicillin and sulphonamide) powder, 5,000 units per gramme. The powder should be gently rubbed into the depths of the wound with the gloved finger. One of the cardinal rules of war surgery was that there should be no primary suture of wounds. The one exception to this rule was in the case of wounds of the face, which if properly excised healed in 90 per cent. of cases. Perhaps mention should also be made of the occasional necessity for deep sutures, e.g. of muscles in a sucking thoracic wound and of synovial membrane in wounds of major joints. Of course, if for other reasons (e.g. a concomitant abdominal wound) the patient had to be retained in a forward unit for such a period of time that the sutured wound could be under close clinical observation until the stitches were removed, the procedure was perfectly reasonable provided it was not initially too time-consuming. The habit of sewing back the skin flaps of large flesh wounds (and of amputations) which was in vogue to some extent in the early C.M.F. campaigns was of short duration. It had little to recommend it if primary surgery had been efficient, and it was apt to devitalise valuable skin edges. The wound itself was dressed with gauze, gently inserted but not packed, into the depths of the wound. In the early stages of the war vaselined gauze was almost universally used for this purpose. Later a distinct preference was shown for dry gauze. Over this was placed ample wool and the whole was fixed by bandage or strapping, the greatest care being taken to avoid circular constriction of the limb. Finally, in considering this forward surgical treatment, must be mentioned the great value of immobilisation of the wounded limb as a whole in all cases in which tissue loss could be called major in degree, and irrespective of whether bone injury accompanied the flesh wound or not. This immobilisation was effected by various splints, by split and well-padded plasters or by plaster slabs. The administration of parenteral penicillin was begun and the patient was then ready for evacuation and the second stage of treatment.

B. TRANSIT TREATMENT

Methods of evacuation improved steadily throughout the war, culminating in large scale use of air transport. The successful solution of the administrative problems involved in achieving this must undoubtedly be ranked as one of the most important factors in the greatly improved results obtained in treating wounds. The practical fulfilment of the conception of a two-stage single treatment of any wound was essentially due to increased speed of, and comfort in, evacuation from forward to base areas.

Medically the treatment in transit can best be summarised as masterly inactivity. Care of the patient's general condition throughout the journey was obviously vital and was provided by the provision of fluids by mouth or intravenously (the so-called 'travelling transfusion' of ambulances and aeroplanes being a typical example of this) as required, by the administration of morphine when necessary (remembering the likelihood of a cumulative effect in a patient whose peripheral circulation was poor as a result of shock), by the giving of food and water at as regular intervals as possible and by the repeated administration of the antibiotics.

Locally as little as possible was done to the actual wound. Redressing of the wound in transit was forbidden, unless some major complication (haemorrhage, the development of gas gangrene etc.) made it essential. The dictum that 'inspection=infection' was amply proved in the earlier campaigns, particularly those in the Middle East, where a 7–10-day journey, passing through as many staging posts from forward to base units, offered irresistible temptation to redress a wound, with inevitably bad results. In the large majority of cases all that was necessary locally was minor adjustment of the immobilising splints etc. and replacement of the external dressing.

C. BASE TREATMENT

The definitive treatment of a wound at a relatively static unit underwent a drastic change as the war progressed. The days of 1939–41, when wounds were allowed to heal by granulation with or without a surrounding (and usually evil-smelling) plaster, when casualties suffering from chronic toxaemia were numbered by their thousands, when consequent bed-wastage and loss of man-power was rife—all these were now only memories. The factors which produced the metamorphosis—leading essentially to the virtual conquest of sepsis—have been considered above in detail. The ultimate result in the last two years of the war was that 90 per cent. of flesh wounds could be completely closed within a week to ten days of the infliction of a wound, and by far the greater number of patients returned to full functional duty within a month. In some theatres of war this rapid healing of wounds led to unexpected side results. Instead of the casualty finding himself shipped home for prolonged treatment and convalescence with a simple 'blighty' wound, he was back with his unit on full duty in a matter of a few weeks. To 'compensate' for this, so-called convalescent leave was granted after the patient's discharge from the medical services.

The closing and healing of wounds are two closely interdependent processes. The former—either by sutures or by skin-grafting—became a relatively straightforward and simple technical procedure. The latter opened up fields of physiological and biological research which are still being tilled to-day, but which in the latter years of the war produced a crop of invaluable therapeutic methods that undoubtedly achieved a great deal in hastening recovery.

To understand the rationale of general treatment at this stage a few words are first requisite as regards the constitutional effects of wounds and wound healing.

In the normal process of healing there is a latent period of some three to four days before any significant reparative activity occurs. This period can be indefinitely lengthened by certain local and general factors.

Local Factors. Among the obvious causes of delay in healing are persisting infection, traumatised and devitalised tissue, haematomata, a damaged local blood or nerve supply, foreign bodies, the persistence of dead space and pressure effects. It should also be remembered that the normal reaction in a healing wound is acid (pH 5–7). Both above and below this figure local vasoconstriction occurs and healing is delayed. If pus as such is present the reaction is alkaline and bacteria flourish. Normally the local acid both stimulates an exudation of plasma-colloids and cells and activates autolytic enzymes.

General Factors. Again, obvious effects on wound healing may be due to the patient's age, associated diseases (especially such debilitating conditions as dysentery, malaria, broncho-pneumonia etc.), climatic effects, and the individual psychological reaction to trauma. But the general factor of over-riding importance is the upset in protein metabolism, with its associated dehydration effects. Secondary anaemia, and in the more chronic stages avitaminosis, have also to be considered. Normally there exists in the body a carefully balanced and preserved state of equilibrium between plasma proteins and tissue proteins. The normal figure for the former is 6–7 g. per 100 c.cm., the proportion of albumin to globulin being approximately 1·6 to 1. In all trauma there is some loss of protein and this balance is upset, often to a very marked degree. The loss can occur either directly from a haemorrhage or serum-exudation (from a surface or into injured cavities), from the urine, from fistulae or from prolonged gastric suction, or it can occur indirectly from the breakdown of tissue protein following trauma.

From all these sources it is possible to form some estimate of the amount of protein lost and to a lesser extent the patient's weight may also give some guide. But the estimation of serum protein may be most misleading unless repeated, as values are masked by dehydration and it is possible for tissue proteins to be grossly depleted without this effect being reflected in the serum figures. Again there has been ample proof that plasma loss can only be slowly replaced from tissue proteins.

The results of this loss of protein are manifold:

(i) There is some evidence that amino-acids helped in the healing of wounds. The deficiency of protein and therefore of amino-acids may cause delay in healing.

(ii) The normal fibroblastic reaction is late in appearing (a week or more) and less in degree.

(iii) Water and salt balance are upset, leading to tissue oedema (a frequent cause of secondary wound disruption) with consequent decrease in the volume of circulating blood, haemo-concentration, vascular stasis and anoxaemia of the tissues.

(iv) This malnutrition of tissues leads to delayed replacement of damaged cells by new cells and its effect is particularly marked on the reticulo-endothelial system, with a correspondingly lowered production of phagocytes.

(v) A liability to sepsis. This liability is obviously increased by vascular stasis, the vicious circle being completed by the pressure of oedematous exudation from capillaries to intercellular spaces.

(vi) A loss of gamma globulin leads to a loss of immune bodies.

All these considerations therefore dictate the now accepted general treatment at base level.

GENERAL TREATMENT. Protein loss can to a limited extent be made good from endogenous sources—chiefly the liver—but any severe loss demands exogenous replacement.

(i) *High-protein diet*, to include particularly eggs, lean meat, milk, and soya bean products.

(ii) *Intravenous replacement*, primarily by blood transfusions repeated as necessary. A patient with a haemoglobin of below 70 per cent. is unlikely to produce a well-healed wound after suture. Plasma may of course be used as an alternative, depending on the results of actual cell counts. The hydrolysates became increasingly popular towards the end of the war and much knowledge was gained regarding their administration from their use among the unfortunate victims in the German concentration camps. The most commonly used was probably 'amigen', an hydrolysate of 5 per cent. casein in 5 per cent. glucose. It was soon learnt that this had its disadvantages, especially if not given very slowly, as it frequently led to marked general febrile reactions and to local thrombosis of the vein used. However, as one litre of this hydrolysate could provide 50 g. of protein, its immediate value in acute states of protein deprivation was great. A number of amino-acid hydrolysates have also been used on occasions.

(iii) *Vitamin Replacement*. The absence of vitamins leads to the absence of collagen fibres in a healing wound—those particularly concerned being vitamins A and C. Treatment therefore involved the giving of milk, oranges, green vegetables and the administration of ascorbic acid in tablet forms.

LOCAL TREATMENT. In the days before penicillin, frequent attempts were made to stimulate healing by various local applications, of which urea, cod-liver oil and powdered red blood corpuscles each had their day. Mention should be made too of Kerr and Werner's work in the early Middle East era (1941) when they claimed a similar effect from a product known as 'H.E.P.' an aqueous extract of minced sheep's heart.

With the advent of full chemotherapy, however, came the possibility of actually closing the wound and the success of this procedure soon ousted all other methods.

Some misunderstanding arose over terminology, but latterly agreement was reached on 'delayed primary suture' (any suture carried out within the first week to ten days) and 'secondary suture' (any suture performed after this period—irrespective of former attempts).

Wounds as received from forward areas were not inspected (except in cases of emergency) until the patient had recovered from his journey and until this procedure could be carried out in the full asepsis of an operating theatre. (It was estimated that preliminary inspection in the wards increased the percentage of infected wounds from 33 per cent. to 50 per cent). There decision was made immediately as to whether suture could be carried out forthwith, or whether a redressing was a necessary preliminary to a period of general treatment (transfusions, parenteral penicillin, etc.). This decision rested on the clinical appearance of the wound at the time, although for future information routine bacteriological examinations were usually made. Mild infection in an otherwise clean wound did not veto immediate closure. Frank pus and obviously incomplete forward surgery did. Cases with oedema and inflammation of the skin edges were better postponed for a day or two, as were those with pyrexia and toxaemia, which usually indicated locked up pus and probably a retained foreign body. The presence of gas bubbles in the wound was a definite contra-indication.

Experience led to the following conclusions:

In general, wound suture is preferable to skin grafting, but obviously excessive loss of tissue may make the former impossible. Grafting can never give (in war wounds) the same full-thickness cover as can suture.

Skin grafts if used should be either of Thiersch type in obviously clean wounds, or split-skin patch ('pinch') grafts where mild sepsis is present. The technique where applicable is identical.

The ideal time for delayed primary suture is the third to sixth day, i.e. when the natural process of healing is beginning.

Technique of delayed primary suture. The wound having been inspected, a sterile gauze swab is carefully placed over it and the surrounding skin (which is often infected when the wound is not) meticulously prepared. It should be reshaved where necessary, gently scrubbed with soap and water and treated with ether and spirit.

The wound is then gently irrigated with saline to wash out any blood clot, debris or foreign bodies, and any obviously traumatised or devitalised tissue missed at the preliminary operation is excised. The skin edges are then freshened by paring with a knife or cutting off the thinnest possible strip and undermined (preferably by blunt dissection to avoid bleeding) to such an extent that they will come together without undue tension. Tension can often be markedly reduced by a judicious small linear incision at either end of the original wound. A slight degree of tension does not vitiate suture, although it does affect the chances of a perfectly successful result. In secondary sutures the procedure is similar, except that the granulation tissue is first gently scraped off the surfaces of the wound.

Complete haemostasis is of vital importance, as subsequent haematomata can completely ruin an otherwise successful approximation. It should be achieved as far as possible without the use of ligatures.

The wound is then dusted ('frosted') with penicillin—sulphonamide powder, gently rubbed into the deeper parts as required, and the skin edges brought together by interrupted eversion stitches of nylon or fine silk-worm gut. As far as is possible, no deep sutures should be inserted. A pressure dressing is then applied with gauze, wool and elastoplast and, if the wound is a large one, a padded, split plaster of paris splint is again advisable.

If approximation of the skin edges left a tenting over deeper structures or known pockets existed in the wound, it proved to be sound policy to introduce into these spaces fine tubes through small separate stab incisions. Twice daily instillation of penicillin solution (3–5 c.cm.; 500 units per c.cm.) through these for 5–8 days often prevented what might otherwise have been a disappointing result.

Post-operative Treatment. There could be no question of evacuating patients treated by these methods until the stitches were removed. This usually took place about the tenth day. About the fifth day it was the custom in many theatres to inspect the wound under full aseptic precautions and, where necessary, remove stitches—particularly 'wet' ones. Patients who had delayed primary suture were better nursed in separate wards (i.e. away from open wounds) whenever possible. During the immediate post-operative stage, parenteral penicillin administration was continued and transfusion, etc., given where required.

Although outside the scope of this chapter, no account of post-operative treatment would be complete without mention of the vital importance of rehabilitation—both mental and physical. This should undoubtedly be started while the patient is still in hospital and should include occupational therapy and graduated muscular exercises under medical supervision.

CONCLUSION

The foregoing detailed description of technical methods should not be allowed to mask the prime importance of the advances in treatment described therein. Empirical clinical results combined with intensive scientific research produced throughout the war a constantly changing and steadily improving picture of the basic flesh wound of war and its treatment. The principles involved were rapidly applied to more specialised types of wound with equally beneficial results.

Commonplace though the methods detailed above may now appear and simple as may seem the story of their development, the saga of the war wound between 1939 and 1945 is in essence a fascinating piece of military history and one of which the Medical Services may be duly proud and for which the Army as a whole, both directly through its wounded and indirectly through its saving of man-power and improvement of morale, should be duly grateful.

(ii)

On the Excision of Wounds

By SIR JAMES PATERSON ROSS
K.C.V.O., M.S., F.R.C.S.

In the War of 1914–18 the credit for reviving an interest in excision of wounds was due to the late Sir Henry Gray (1915), though John Morley (1915) and others were working along similar lines at the same time. Gray's account of his method of wound treatment began in November 1914 with 'furrow' wounds. After shaving the neighbouring skin, he painted it and the wound with 5–10 per cent. iodine in spirit and then excised all the stained tissue in the wound to a depth of $\frac{1}{3}$–$\frac{1}{2}$ in. *en bloc*. Then changing the towels, instruments and gloves he proceeded to close the wound accurately without drainage. He pointed out that this could only be done soon after wounding, before infection had penetrated deeply forming a 'bank' of inflamed tissue around the wound; even then, vigorous 'salting' for twenty-four hours might permit of excision. Dressings were fixed in position with mastic varnish and not disturbed till the stitches were removed; and the surrounding parts were immobilised to secure 'relaxation' of the wound.

THE OBJECTS OF WOUND EXCISION

Excision of a wound aims at the removal not of every organism, but of unhealthy tissue which is unable to defend itself against infection, and is also a suitable culture medium for bacteria, particularly for the anaerobic organisms. Thanks largely to early excision, gas gangrene was much less of a problem than had been anticipated; but there are records to show that when, owing to unfavourable circumstances, early adequate treatment of the wounds was impossible, there was a significant increase in the incidence of virulent gas infection.

Another object, which cannot properly be dissociated from the first, is to preserve the vitality and nutrition of the neighbouring tissues, which means principally the prevention or relief of oedema. The release of tension by judicious incisions, elevation, early immobilisation, and later the timely institution of passive and active movement, must all be regarded as part of the same process directed to the same end.

THE TIME LIMIT FOR EXCISION

Though it is impossible to give figures for the time limit within which excision may be effectively performed, it is commonly accepted that in limb wounds those treated within six to eight hours may be completely excised. As delay increases, the muscles become dark red in colour and covered by a layer of coagulated fibrin, and excision should be less complete; while later still, when infection has supervened, only simple débridement should be performed (Fruchaud, 1942.)

The time limit for excision may be shortened considerably when there is much crushing or laceration of tissue and heavy contamination with soil, which both favour early infection. The time may be prolonged in certain parts of the body, particularly on the scalp and face, where wounds may be excised safely 24 hours and more after infliction.

Although there is evidence that the local application of sulphonamide after excision can diminish the incidence of infection without delaying healing, there is none to show that sulphonamide used as a first-aid application can prolong the time limit for complete excision of the wound. In fact one of the chief arguments against the routine use of antiseptic powders in first aid is that it might lead to delay in excising the wounds. There is no chemical substitute for excision. 'Surgery is the first line of defence: the drugs are adjuncts' (Stammers, 1944).

An account of the technique of wound excision (as practised during the War of 1939–45) is given elsewhere (*Vide* Part I of this Chapter, page 20).

MODIFICATIONS IN TECHNIQUE OF EXCISION

Perforating wounds of soft parts by rifle or machine-gun bullets can usually be regarded as uncontaminated, and excision will be unnecessary. If the entry and exit wounds are small, and there is no evidence of deep haemorrhage, the skin surrounding them should be cleaned, sterile dressings applied, and the limb immobilised. Ogilvie points out, however, that if there are signs pointing to partial or complete division of a large nerve lying in the course of the bullet track, such a wound should be opened up to explore the nerve; sometimes an intraneural haematoma may be found, which if evacuated at once will leave no permanent damage, but which if allowed to organise will become a diffuse fibroma necessitating resection and suture (Ogilvie, 1944).

Wounds due to incendiary or tracer bullets need special management because the phosphorus they contain causes chemical destruction of the tissues, early and progressive shock, and a risk of fatal hepatic and renal damage if not removed early. If, therefore, the presence of phosphorus is known or suspected the wound must be opened up immediately, when, if phosphorus be there the whole track will smoke. It must be washed out with 2 per cent. sodium bicarbonate solution and then swabbed over with 1 per cent. solution of copper sulphate which will coat any remaining phosphorus particles with a dark deposit of copper phosphide. The walls of the track where the particles remain must be excised radically, and finally the wound is dressed with sheets of gauze soaked in 2 per cent. sodium bicarbonate solution. Oily or vaseline dressings must not be used since oil and grease are solvents of phosphorus and will cause risk of poisoning by absorption (*Treatment of Phosphorus Burns*, 1943).

As to the question of primary suture, there was a difference between military and civilian practice; for whereas primary suture is rarely advisable in the Services, it may be carried out with advantage in many wounds among civilians who may be retained under the care of the same surgeon till healing is complete. The question did not arise if excision had been in any way unsatisfactory, or if the patient had to be transferred to another hospital. But in civilian practice primary suture was permissible in recent superficial wounds; where there was slight or no contusion; where tendons or nerves had had to be sutured; in joint injuries with little or no bone damage; and in wounds of the face or scalp, and craniocerebral wounds.

When these conditions are not satisfied, however, and particularly in wounds of more than 8 to 10 hours' standing, in those showing much contusion, or when prolonged observation is impossible, primary closure should not be performed. Under such circumstances the wound should be lightly packed (not 'plugged') with plain gauze or vaseline gauze, covered with sterile dressings and immobilised. This may mean fixation in plaster or other splints, even in the absence of bone or joint injury.

DELAYED PRIMARY OR SECONDARY SUTURE

The results of closure of a wound within a few days after excision so closely approximate to those of primary suture, that whenever there is any doubt about the safety of primary suture it is wrong to run any risk. The decision should always be against primary suture, knowing that it will probably be possible to perform 'delayed primary suture' in from 48 to 72 hours not only with safety but with excellent functional and cosmetic results. If at this interval after excision the patient's general condition, his chart, the smell of the dressing and the condition of the limb beyond the wound indicate that the wound has remained clean, he should be taken to the operating theatre, anaesthetised, and the dressings should then be removed with full aseptic precautions. If there be no suppuration and the wound appear healthy and fresh, a small strip of corrugated rubber should be placed in it, and the skin and subcutaneous layer should be approximated by mattress or figure of eight stitches placed at least $\frac{3}{8}$ inch apart.

If primary suture, either immediate or delayed, is not possible the wound should be carefully inspected at intervals of a few days till its appearance—small amount of discharge, healthy granulations and normal appearance of the surrounding parts—suggests that it would be justifiable to attempt secondary suture. This operation requires experienced judgment to decide how much of the granulation and scar tissue should be excised, and how much paring of the skin edge and mobilisation by under-cutting the skin is required to bring healthy tissues into apposition without tension. Rotation of flaps, or the application of skin-grafts may be valuable aids in shortening the process of healing.

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(iii)

Field Conditions

By Sir GORDON GORDON-TAYLOR
K.B.E., C.B., M.S., F.R.C.S.

INTRODUCTION

The War of 1939–45 was essentially a mobile one compared to that of 1914–18. New circumstances demand novel methods and it will be profitable to trace the evolution of these methods as exemplified in the development of advanced surgical centres in that testing ground of tactical exercise—the Middle East Campaigns.

1914 to DECEMBER 1940

At the outset of the war the organisation for field surgery was much as it had been left in 1918, based on the well-equipped, but slow-moving and cumbersome casualty clearing station. Thus it remained until the First Libyan Campaign in December 1940 exposed its weakness.

During the War of 1914–18 surgery had on occasion been performed in special hospitals in advance of the casualty clearing stations, when the latter could not be brought up sufficiently near the line; perhaps this arrangement was more frequently explored in the First Army of that War, to which Sir Cuthbert Wallace was consulting surgeon, than in other Army areas, and these advanced operating centres were staffed by such experienced and skilful surgeons as Bernard Maybury, Hamilton Drummond, Charles Saint, Gerald Hughes (of York), the late Sir John Fraser and others. Nevertheless, opinion was almost unanimous that at any rate during periods of intense activity these advanced installations were uneconomical units from every point of view, and that surgery should not ordinarily be attempted forward of the casualty clearing zone. That view was still held in the beginning of the Second World War, but battle surgery was in fact performed at a level in advance of the clearing station in the Eritrean Campaign by E. Grainger Muir, C. H. Bliss and Peter Ingram, and in the Western Desert in the First Libyan Campaign by R. J. Kellar, N. J. Logie, G. A. G. Mitchell and the New Zealanders and Australians.

The First Libyan Campaign revealed weaknesses in the surgical organisation. At a conference convened at Cairo by the D.M.S. (M.E.F.) at the instance of the Consulting Surgeon, M.E.F. in January 1941, there was general agreement that the situation from the surgical point of view was unsatisfactory in that the forward surgical centres were much too far behind the fighting. It was thought that the evacuation back to Mersa Matruh was an experience which no wounded man ought to have to undergo without treatment. Corps and Divisions had been forced to use field ambulances as forward operating centres. The situation had been relieved at Bardia where two Italian field hospitals, erected and ready to receive casualties, had been captured entire, but the general problem remained. It was indeed the accepted policy that the surgery at the forward operating centres should be reinforced when required by teams (surgeon, anaesthetist and operating-room attendant) from base hospitals, as had been done in Europe in the War of 1914–18. This was found to be difficult as an emergency measure. Such teams had necessarily to come from base hospitals which were not at the time busy, namely the ones furthest from the front. Some of these were even in the Sudan. In fact, unless the emergency could be foreseen, such as a planned attack on our part, it was found impossible, on account of the distance they were away and the time taken up in travelling, to get the teams to their destination before the emergency had passed.

There was general agreement that the only solution would be to have forward centres formed by surgical teams, though it was pointed out that a shortage of vehicles would certainly retard the formation of such teams. Nevertheless, an experimental unit was assembled in which the equipment could be loaded into a three-ton lorry. This was the first conception of the 'Middle East Mobile Surgical Team', which on account of lack of transport was not actually born until the early summer of 1942. This suggested procedure was supported by the conclusions of the Hartgill Committee which was set up by the Director General late in 1941 to consider the major defects in medical organisation. As the result two entirely new medical units were formed—the field surgical unit and the field dressing station which came into action late in 1942.

SECOND LIBYAN CAMPAIGN

In the Second Libyan Campaign at the end of 1941 additional teams were posted to the casualty clearing stations in the desert. They were meant by G.H.Q. Cairo primarily to reinforce the surgical potential of casualty clearing stations and, if necessary, to allow the latter to split into two or three autonomous operating units whose dispositions could be somewhat more elastic. However, the medical administrators in the field, (D.D.M.S. 13th and 30th Corps) mindful of what had happened previously, equipped some of the teams with two three-ton trucks from the casualty clearing stations and pushed them forward to work with the field ambulances. The surgeon is more important than his theatre and much good operating work was done in penthouse theatres, but the situation was still unsatisfactory for the first priority cases in what was a fast-moving fluid campaign; the field ambulances were again moving quickly and frequently; *little or no post-operative holding was possible:* the casualties had to undergo a gruelling journey over desert tracks within a day or two of laparotomy, and even while they were 'held' they had to lie on stretchers in a cheerless environment. The field ambulances occasionally found themselves in the middle of the battle; one surgical team (Ian Aird) was captured for a short time by the enemy; for example, at the battle of the Omars ten abdominal casualties were admitted with peritonitis of more than twenty-four hours' duration; five of them had multiple injuries of hollow viscera, and one was a thoraco-abdominal casualty. These patients were destined to experience almost immediately after operation 'enemy attack and capture, the disturbance of artillery and armour in battle around them, the anxiety of partial release, and a precipitate withdrawal from a closely-pursuing and partly-investing enemy less than seventy hours after operation. Seldom can men have endured greater suffering, and their stoicism is worthy of record. All belonged to the 4th Indian Division; five of them were Sikhs and five English; five of these patients were alive two months later, though one of the survivors died subsequently of a subphrenic abscess unsuspected before his death'. This experience, even if it justified the policy of operating upon all abdominal wounds, proved equally conclusively that a field-ambulance site is not the proper place for the policy to be carried into effect. To be forced to evacuate patients with abdominal wounds on the third day after operation is to set back the clock nearly half a century. Nevertheless, at this time there was no choice other than the possibly distant C.C.S. or the dressing station of a field ambulance for the siting of a forward surgical team, and it required the actual experience of surgical teams in field ambulances to show the disadvantages of so advanced a situation. Work with the field ambulances for some weeks showed clearly that a surgical team moving with a field ambulance works to poor advantage. In that situation it is too far distal in the centrally directed stream of casualties; the tributary on which it lies is small and the area of front which it drains is narrow, and its work is therefore limited. Even if it were possible to attach a fully-equipped team to every field ambulance, the difficulty of holding cases would not be answered. A field ambulance advancing cannot have a nest of wounded at its every halting place. A satisfactory site for the forward surgeon was still to seek.

At this particular period (the autumn of 1941) a surgical team included surgeon, anaesthetist, general duty officer and two orderlies. Choice of surgical equipment was left to the surgeon, within wide limits, and was lent by the commanding officer of the parent general hospital. Supplementary nursing personnel, comprising one N.C.O., two nursing orderlies, two drivers, and a batman, equipment and all transport, were obtained from the casualty clearing station to which the team was nominally attached. Teams were not independent units, but drew rations, water, petrol and expendable stores from the successive units* which acted as their hosts.

* Usually field ambulances.

The outstanding difficulty of surgical teams at this early period of desert warfare was shortage of transport. The equipment of the surgical team was carried in two three-ton trucks, each of which supported in action a 'lean-to', one to serve as theatre, the other as ward; the 'three-tonners' also carried orderlies and all equipment. Medical officers and their equipment travelled in empty ambulances when these were available; when all ambulances were required for wounded, as they usually were in withdrawals, the whole unit travelled in the 'three-tonners'. One surgeon was fortunate in acquiring a staff car when behind the German line at the beginning of a battle and in successfully resisting the enemy's demand for its cession. This campaign proved the absolute necessity of a staff car for the commanding officer of a surgical team. To travel all day in a truck and to operate all night does not make for high surgical efficiency!

The main deficiencies of the mobile surgical units—lighting, heating and transport—were inevitable at this period of the war and were only overcome by lucky finds and ingenuity. The successful adaptation of the lorry headlight for use as an operating lamp showed the way to the dynamo-operated theatre light. There was never any anxiety over the provision of expendable stores, including materials for dressing, transfusion, and anaesthesia. Although the work of these early surgical teams attached to the field ambulances was small, when compared with that performed subsequently by the field surgical units in their final form, the value of the early teams should not be measured only by the number of operations completed. The teams were integral organs of the Divisions to which they were attached, 'and their effect, if unnecessary for the soldier's morale, was important for his peace of mind'. As an instance of their effect on morale the following authentic conversation was reported. Seeing a pal passing him with his battalion which was marching up to the line, a stretcher case was heard to say, 'Watcher, Bill—good luck and watch yourself—and don't worry mate—'alf 'Arley Street is just in front of us'.

FAILURE OF MOBILE CARAVANS

A logical reaction to the needs of the situation was the idea of the provision of mobile-caravan operating theatres, and in this same campaign two such units, gifts from America, were sent to the Desert. These luxury vehicles were at first the envy of the other 'lean-to' surgeons of the Eighth Army, but despite their seeming attractiveness, it soon became evident that the caravan type of theatre with immovable fittings had no advantages except warmth over the truck with a canvas or tarpaulin 'lean-to'. Moreover, until they were fitted with balloon tyres they were confined to the roads and solid ground. Ian Aird writes as follows: 'A mechanical fault in a valuable caravan theatre may mean the loss of all the fitted equipment: if a "three-tonner" develops a fault, the theatre equipment can be transferred to another vehicle. When towards the end of three months' continuous service our "three-tonners" began to limp a little, the theatre equipment could always be sent on ahead in the healthier vehicle, while other equipment followed at leisure. Nor had the caravan theatre any advantage in speed of opening, since it was found easy to be ready to operate in a "lean-to" 25 minutes after halting, if sterilisation was begun immediately and the theatre built up around its sterilisers. Moreover, the floor-space of the caravan theatre was limited, and work was therefore carried on under cramped conditions: only one patient could be dealt with at any one time. Finally, the caravans were too valuable, and no forward surgeon should be burdened with the responsibility for irreplaceable equipment.'

The advantages of the lorried type of theatre may be well illustrated by a comparison of the facilities for forward surgery in the Eighth Army and in the Afrika Corps at this period. In the final stages of the action on November 25, 1941, near Bir Sheferzen, the 5th German Panzer Regiment, while still engaged with the 11th British Battery, took up a position for a time between the tents of Aird's surgical unit. The enemy formation included in its transport a beautifully fitted theatre with every surgical convenience—too beautiful to risk its loss by opening it, though ultimately it was in fact captured.

Even had the enemy been prepared to risk the loss of his theatre, the personnel for, and the habit of forward surgery were lacking, and the German commander, a shell hole torn in his lung, had to be brought to the 'lean-to' of the British unit for operation. Enemy officers, standing only a few yards from one of the most luxuriously appointed mobile theatres ever built, were astonished that facilities for transfusion and for major surgery should have been available in the unlikely environment of a 'lean-to'.

In fairness, it should be noted that the mobile caravan theatres did find their ultimate function as operating theatres attached to casualty clearing stations. In one field hospital in the Middle East the caravan theatre was improved on in the matter of space and amenities, but it never got further than the casualty station which it adorned.

A peep behind the curtain which veiled the future of forward surgery was vouchsafed us in January 1942, when the Eighth Army was preparing its attack on the Afrika Corps at El Agheila. In preparation for the impending battle the D.D.M.S. of 13th Corps, the late Brigadier F. Smythe, had deployed his medical services in the neighbourhood of Msus. The light section of 14 C.C.S., with Aird's surgical team and a field transfusion unit, lay alongside a M.D.S. at Msus; the light section of 15 C.C.S. (Kellar) with Ingram's surgical team was open beside a main dressing station at Antelat, where a New Zealand tented hospital (Colonel Ardagh) was also located. The available surgical units were thus grouped for an advance in two highly mobile surgical centres organised for leap-frogging, the patients to be taken over in due course by the heavy sections of the C.C.Ss. This arrangement, disregarding the old arbitrary separation of field ambulance from C.C.S., was the skeleton of later surgical strategy. Without a doubt the arrangement would have been adequate for an advance, and it functioned perfectly in the disaster of Antelat and the subsequent retreat! The forward surgical centre at Antelat was kept busy during the fighting there, and Ingram finally closed and withdrew under enemy fire. During the succeeding night, the formation at Msus, forty miles to the rear, kept open, Aird's team performing 21 operations between dusk and daybreak, applying the last dressing at 0745 hours and moving before the appearance of the enemy later in the morning.

Conditions at Msus were ideal, and their success proved that the best formation for forward surgery is a combination of two surgical units together with a transfusion unit, lying close to a dressing station. The arrangement of shifts was simple and could be varied to suit circumstances. Both teams were able, if necessary, to operate simultaneously, leaving pre-operative and post-operative treatment under the control of the transfusion officer.

For the Third Libyan Campaign, starting at El Alamein in October 1942, fresh surgical tactics were deployed to deal with the priority casualties. Some casualty clearing stations were made completely mobile on a different, less cumbersome, scale from the others. Their 'light section' was a well-equipped flying squad which could function independently with many of the advantages of its parent unit. Before the campaign began the War Office had created two entirely new medical units each of which with its own war establishment was independently mobile and self supporting. The first, the field surgical unit, which eventually replaced the mobile surgical team (Middle East) was exactly what the medical services in the Middle East had been looking for. The other was the field dressing station, a light holding and nursing unit which could function alone or in partnership with a field surgical unit. The introduction of these two units greatly increased the flexibility of the field medical organisation and solved most of the difficulties which had existed. Each field surgical unit consisted of a surgeon, anaesthetist and some six other ranks. They were now made mobile by the provision of a staff car and a three-ton waggon. In the latter they carried their equipment, stores and operating tent. They required a host unit, a field ambulance or casualty clearing station, at which to work, to provide for and nurse the casualties. They carried no beds, nor does a field ambulance. They were intended to function wherever the need was greatest, at casualty clearing station level or in front of it. The ten such teams available at El Alamein, together with the four casualty clearing stations which had been put on wheels, constituted now a mobile surgical potential of some magnitude, backed up by the ordinary, movable but not mobile, casualty clearing stations.

In the ten days before the break-through at El Alamein the ordinary casualty clearing stations received the bulk of the casualties direct. They had been grouped some 30 miles behind for the purpose. In front of them about half of the field surgical teams were attached to field ambulances and picked out the most urgent casualties. The remaining field surgical units were attached either to the fixed casualty clearing stations as extra teams or to the mobile casualty clearing stations, which were waiting to follow close upon the expected rapid advance. When the break-through occurred, these, and the teams with the field ambulances, moved forward in a strung-out line. The urgent casualties thus obtained more immediate attention than had hitherto been possible.

None the less, because of the long distances and poor desert tracks, it was too often more than twelve hours before they were operated upon. In the progress of this campaign certain points were obvious long before Cape Bon was reached. One was that a single field surgical team attached to a dressing station was much less than half the value of two grouped together at a similar unit. The combination could rotate turns of duty and have proper rest, could often be supplemented by a field transfusion unit, and the nursing, done by orderlies, could be better observed. The drawbacks of early post-operative evacuation were painfully obvious and medical administrators were gradually persuaded to acquiesce in the clinical policy of retaining these severe casualties in the field for an increasing post-operative period. This was an important step since the administrator has ever to be on his guard against contingencies and keep his lines clear. But the concession needed only to apply to some 5 per cent. or less of the total casualties and to that small proportion the benefit was inestimable.

In this campaign there was still the drawback of forced movement at short notice of the units concerned, but very often its place on the same site was taken over by a rearward unit also moving forward. Another feature which stood out clearly was the necessity for the field surgical teams to carry a small number of beds for the post-operative nursing.* Nursing had to be done by male orderlies and required very active supervision by the surgeons; the casualties were often nursed on stretchers under a tarpaulin roofing suspended over goal-post like frames from the rear of a lorry; it was rather a dismal setting for the seriously ill.

Most of these deficiencies and defects were made good before the Desert campaign finished, and the Sicilian and early Italian campaigns, both fast-moving, confirmed the lessons learned. As affairs stabilised in Italy and many more field medical units became available, better advanced centres were devised, with even three or more field surgical units and specialist teams, often housed in fairly suitable buildings.

* The later War Office field surgical units carried ten proper beds and ten folding canvas ones.

These field surgical 'aggregates', and the fact that there could hardly be the chance of a military reverse, obviated the necessity for mobile casualty clearing stations; the ordinary casualty clearing stations, now in plentiful number, were sited reasonably well forward. From El Alamein onwards, in the series of set battles which preceded retreats on the part of the enemy, the casualty clearing stations had been sited forward to receive the great bulk of the casualties of high priority and otherwise. A proportion of field surgical units was kept packed up and ready to move forward with field ambulances or, later, field dressing stations.

In the Normandy invasion in the summer of 1944, these field surgical tactics were followed. There was by now an abundance of medical units of all types. Many 'field surgical units' crossed the Channel on the first and subsequent days and coped with the first priority casualties, all else being returned to England by sea; the casualty clearing stations moved over in turn as the tactical situation improved. There was the considered opinion based on realistic experience, that the casualty clearing station should, if possible, be the surgical centre for serious casualties, that smaller advanced centres should be set up only where that was impossible, and that these smaller centres should consist of at least two field surgical units and a field transfusion unit attached to a dressing station.

THE SITING, INTERNAL ARRANGEMENTS, AND STAFFING OF FIELD SURGICAL CENTRES

Field surgical centres may be divided into those composed of one or more casualty clearing stations, and those composed of one or more field surgical units based upon a host unit, either a field dressing station or a field ambulance, generally one temporarily performing a static rôle. There is much elasticity about field arrangements, and it does not follow that there need always be an advanced surgical centre in front of the casualty clearing stations.

Siting. The siting of field surgical centres of either variety will depend upon the tactical situation, upon the local topography, especially in regard to roads, and upon the availability of buildings or space for tentage. A casualty clearing station requires a large building such as a school or civil hospital, or alternatively a roomy area for its tents. Advanced centres, on the other hand, can be made as small as will fit suitable accommodation.

There is general agreement that surgical centres should not be sited too far forward, among the noise of our own guns and possibly within range of those of the enemy. Any advantage so gained in the time-lag before operation, and it is usually a small one, is offset in the important immediate post-operative period. However courageous the surgeon may be, a helpless casualty is in no mind to be brave when there is shelling around, and he requires peace and quietude. The most advanced centres, unless there happens to be a well protected underground space available, should therefore not be placed in front of our own heavy guns; the operation is only part of the treatment. In exceptional circumstances, as in beach-head operations, work has to be carried out amid the clang of battle, but unless evacuation, e.g. to a ship, be impossible or too time-consuming, this should be restricted to cases of the highest priority only. There is some belief that the post-operative casualty suffers less from further journeying if the latter takes place immediately, that is while he still recovering from anaesthesia.

Because of the risks of air attack there is need for the dispersal of tents. The need for, and the degree of this, will vary with the conscience of the enemy, with his air power, and with the presence of lighting or supply installations in the immediate vicinity. Dispersal in buildings is not so practicable, but here there is not the same danger from near-misses. Some dispersal of stores, however, is always desirable to guard against the disaster of a direct hit.

Internal arrangements under different conditions. The essential internal arrangements in field surgical centres, whether in building or in tents, gradually evolved to a fairly clear and constant pattern in relation to the treatment of first priority casualties. These were brought to a common pre-operative ward situated conveniently near to the unit's reception station. In a tented unit, the pre-operative ward had brigaded to it the various operating theatres; in a building, matters were so arranged that rooms used as theatres were in as close proximity to the pre-operative ward as could be arranged. While not so imperative, the site of the post-operative ward was again as near as possible in each instance.

The importance of a common pre-operative ward is that the most urgent casualties will obtain the needed priority; but it means also that resuscitation can be carried out under the direction of a transfusion officer whose energies and skill will not be wasted by the need to travel round several such wards. The value of the juxtaposition of the ward to the theatres lies not only in minimising the strain to the patient and work to stretcher bearers, but also in the easy access which it allows to the surgeon to view and examine patients between operations. In a tented unit the latter is often simply a matter of passing through a flap in the wall of the pre-operative tent.

In the pre-operative ward are all the facilities for resuscitation. If an X-ray set is available and the pre-operative ward is large, the apparatus, with the exception of its motor, which should be left outside, may with advantage be placed in one corner. Beds are not usually available, and casualties lie on stretchers which are raised from the ground on trestles, biscuit tins, or petrol cans.

By such planning, the closest liaison is possible between surgeon, transfusion officer, and radiologist. The order of priority is essentially the surgeon's responsibility but, in busy periods he must rely much upon the transfusion officer; in practice he usually did, because they became very sound judges, since new casualties were constantly arriving to upset arrangements already made.

BASE AND ADVANCED BASE HOSPITALS

All casualties, excepting those with trivial complaints or illnesses, were passed back along the chain of evacuation to large base hospitals and subsequently to convalescent depots where they were treated until fit to return to duty or well enough to travel to a home base for invaliding.

Bases may be far distant from the fighting line. In the Middle East campaigns the great base set up in the Nile Delta was at one time within fifty miles of the fighting; but at the end of the last Desert Campaign it was some 2,500 miles in the rear. It continued to act as one of the bases for the Sicilian and, for some time, for the Italian campaign.

In Burma, the Command instituted 'Hospitals for Light Casualties' which were sited well forward, usually at Corps or Division level. In this tropical climate where sick wastage from such conditions as malaria relapses, diarrhoea, septic sores and pyrexia of unknown origin, was considerable, these units which acted as detention and observation centres succeeded in screening evacuations to the base with consequent saving in effective man-power and medical transport.

In North-west Europe the distances were not so great and the bases were at the most only a few hundred miles distant.

The great base hospitals ranged in individual size from 600 to 2,000 beds. In all there were general surgical units, except in a few devoted exclusively to psychiatric work; at one or other of them there were orthopaedic, chest, maxillo-facial, and neurosurgical centres. The hospitals were either tented, hutted, a combination of these two, or housed in such buildings as large hotels and schools; civil hospitals were occasionally available and taken over for the purpose.

Good service could not be given if these ancillary specialist teams worked only at the base and the fighting line was far away. The organisation developed to offset this in the final Desert and Sicilian Campaigns formed a pattern which was closely followed later. Neurosurgical, maxillo-facial, and ophthalmic teams were sent forward to work at casualty clearing stations sited to receive such specialised casualties. As the line lengthened and as suitable sites became available, advanced base hospitals were set up in small, but increasing numbers. At first they served mainly as advanced casualty clearing stations, but they could and did accommodate orthopaedic and thoracic teams, and it was found most convenient to split the forward neurosurgical and maxillo-facial teams to keep half of each of these at this level. This diminished the size of the combined neurosurgical, maxillo-facial, and ophthalmic teams working nearer the fighting line and so allowed of their more easy accommodation at the same casualty clearing stations. The half-units at the advanced base hospitals were a further filter for their speciality; they also acted as a staging post for the patients treated by their other halves. Had more chest-surgery teams been available or had the team been capable of being split, the experiment would have been tried of having a chest unit at a more forward level. In general, however, the chest teams were called upon to deal with the more serious cases of their speciality rather than with all. These were all necessarily long-term cases, and thus chest teams were best sited where operative, radiological, and holding facilities were best, and that in the field was the advanced base. There was, however, liaison between such teams and the general surgical units ahead. It would seem, therefore, that unless there are plenty of them and that conditions are favourable for their employment in more forward areas, chest units should operate at advanced base and base levels.

CO-OPERATION WITH THE PARENT UNIT

The following paragraphs are almost entirely from the pen of Lt. Colonel Brian Truscott, who had very great experience of field surgical units:

A field surgical unit may be considered as a graft on a larger medical formation and, like a graft, retains its entity and should work in happy symbiosis with the host; unlike a graft, however, the host may be changed repeatedly, and the unit must be self-contained, but adaptable. It should be an operating unit pure and simple, able to handle its own equipment without calling on any outside aid; there is a danger that over-elaboration and attempts to increase the facilities carried and the scope of its capabilities may cause this essential to be forgotten. No host unit welcomes a request for help in setting up a theatre when its own personnel are fully engaged in their proper and routine duties, nor will every host unit have had previous experience of working with a surgical unit, and every team has its own peculiarities and foibles. If these were adjusted at the outset and co-operation started on the proper basis, small difficulties and minor frictions were avoided.

Valuable time in the operating theatre could be saved by the proper preparation of the patient in the pre-operation or resuscitation ward: this did not mean the whole routine of shaving and washing the affected area, which was better done under the anaesthetic, but rather attention to the sufficient removal of clothing, the adjustment of clean blankets, and adequate premedication. It was not enough to cut away the sleeve of a shirt or the leg of a trouser; each garment needed to be removed completely. A blanket which was heavily soiled with blood was a hindrance to resuscitation and a discomfort to the patient after operation, and was much better removed in the pre-operation ward than in the theatre.

Regular pulse and blood-pressure readings formed an invaluable guide in assessing the response to resuscitation and the optimum time for operation. Intelligent orderlies could easily be trained to do this and record the readings for each case of any severity. In carrying the patient to and from the theatre our R.A.S.C. personnel were employed, thereby promoting greater speed and efficiency. The pre-operation ward must be as close as possible to the theatre and preferably should adjoin it, since the surgeon will need to make frequent visits between operations to estimate the numbers still requiring operation and to watch the progress of cases being resuscitated. If these visits involve a long walk down a dark corridor or across the open, tripping over guy ropes at night, there will be increased fatigue, waste and loss of time, and it was noticeable how slowly one accommodates to the dark after concentrated work in the theatre.

The post-operation ward, if accommodation permits, should be reserved for the seriously wounded patients who will need special care and attention. If every minor injury awaiting evacuation be sent there, the nursing staff will be unable to devote proper time to the more anxious cases.

Post-operation instructions should be written in fair detail on the field medical card for all serious cases. Orderlies are all keen to learn and soon develop an appreciation of the various procedures, and once this appreciation has been achieved things are easier, but they must be watched very carefully during the interim stage. Although the parent unit would usually detail an officer to look after the cases after operation, the responsibility naturally rested with the surgeon.

One of the most pressing problems of forward surgery was the mental and physical fatigue inevitable during a heavy rush of casualties extending over several days. This was especially so when the team was the only operating unit attached to a field ambulance or field dressing station. An operating team could 'carry on' for many hours before the members became so tired that they had to stop from sheer exhaustion, but there was a stage when judgment and operative skill fell far below a satisfactory standard. This acute fatigue must be distinguished from the chronic variety which developed insidiously after weeks of steady and unrelieved operating.

During a prolonged spell of work there was a great temptation to get away to rest or to bed when a lull occurred, since the anxieties and repeated requests for opinion and advice from a ward full of 'belly' cases could become a great strain. This almost hour-to-hour supervision had to be done, however, if tragedies were to be avoided.

MINIMISING FATIGUE

When there was more than one team, the onset of fatigue could be postponed by adopting the 'shift' system, but there were also several ways in which the powers of the team could be conserved. It is not only the surgeon who bears the strain, but the team as a whole; the operating-room staff will have to spend much time preparing the theatre before operating and cleaning up after the last case. Probably the most important factor is the strict working to a routine; every man should have his place in the scheme and keep that place. The surgeon will then be able to relax until everything is ready for the start of the actual operation. In a short time the orderlies become remarkably efficient, not only in preparing the patient, but also in spotting unadvertised wounds and subcutaneous foreign bodies. It should only be necessary to tell the operating-room attendant the nature of the next case for him to have ready all the routine splinting, plaster slabs, and bandages that will be required. To achieve this routine it is as well to practise during any preliminary training period many of the more important duties. This should include such things as tent-pitching, the off-loading and loading of lorries, the setting up of the theatre, and the preparation and application of some of the larger and more intricate plasters.

Any extraneous noise is distracting, and there should always be at least a short passage and a double screen between the theatre and the ward. Instruments are used on the cafeteria system: a complete set is laid out on the Mayo table and sufficient taken for each operation; this reduces sterilisation as much as possible. For the ordinary case it was not always necessary to have a 'washed-up' assistant; with the limited numbers of orderlies available it was better to keep them free to help in moving the patient, to put on bandages, or clean and sterilise the instruments used on the previous case. Hot sweet tea is excellent for reviving a flagging team, and a constant supply between cases is most welcome and valuable, and the desirability of having a latrine fairly close to the theatre is not unworthy of mention.

There is some difference of opinion on the question of using one or two tables. A team working with two tables could achieve a faster rate of turnover, but there was a greater strain on all the orderlies, and the practice was apt to introduce an atmosphere of rush and hurry that must be avoided at all costs. There is a limit to the number of cases that can be 'cleared' in a given time, and working with two tables is liable to hasten the onset of the danger-point of fatigue.

When working as a solo team it may be very difficult to get enough time for sleep. Every lull must be utilised to the full, and even then it may become a matter of short sleeps at irregular intervals. The men should have sleeping quarters which are close to the theatre and quiet at all times; their rest periods must not be disturbed to attend the routine unit meal-times, and the parent unit will usually arrange that something is available for them at the cook-house at any time. Much of the strain falls on the operating room attendant, and he will benefit by a morning or afternoon right away from the camp every now and then; a trip to the medical stores or with a patient to another medical unit makes a good break, and has the further advantage that it accustoms the other orderlies to working without him, a safeguard in the event of his becoming a casualty.

NOTE-RECORDING

It need scarcely be pointed out that operation notes must be full, accurate, and easily read. This last requirement is the most difficult; even with the clearest of writing it is not easy to make the essential features of a case stand out from a closely written card. When a convoy arrives at a base hospital, rapid survey of all cases has to be made, and it can be very wearying to read through a long description, trying to pick out the salient points. Typewritten notes with bold underlining of all facts of importance are by far the most satisfactory, and a typewriter, if it can be obtained, is invaluable. A point often overlooked is the filling-in in block capitals of the diagnosis on the envelope. In addition to any relevant special labels, it is a good practice to print on this envelope any special instructions for the medical units on the line of evacuation; as examples of this one may mention such headings as 'suprapubic cystotomy', 'watch circulation in foot', 'potential gas gangrene'. This ensures that these points will not be missed.

During operations the unit clerk has a table reserved for his use in the theatre. His duties are: (*a*) To check up the particulars of the patient and discover the time of wounding before the start of the anaesthetic: these are entered in the operating book. (*b*) To type the operation-notes as dictated to him during or after the operation. (*c*) To write a short précis in pencil in the operation book. It is more convenient to write up all the cases at the end of a list than at the end of each operation, since the interval between operations may well be taken up in reviewing the pre-operation ward. It is surprising how easy it is to forget the detail of some of the earlier operations, and these pencil notes are a great help. (*d*) To search the pockets in any discarded clothing, collect the contents, and see that they leave the theatre with the patient.

EXTRA EQUIPMENT AND COMFORTS

In addition to the ordinary scale of active service equipment there are a few extras that make the difference between discomfort and moderate comfort, but the mobility of the unit is of primary importance and the accommodation on the transport is limited: any large accumulation of non-essential stores will mean that a corresponding quantity of essentials cannot be carried without overloading the lorries. On the other hand, prolonged spells of operating on severe and mutilating wounds are somewhat depressing, and the efficiency of the unit will suffer if a few extras are not available to allow recreation, relaxation, and an occasional 'brew-up' during quiet times. A personal visit to the N.A.A.F.I. will usually secure sufficient tea, milk, sugar and other minor comforts, and it has been found of value to carry a small library for the men, which is changed when possible: small books which can be put in the pocket are convenient and can often be exchanged with other units. Gum-boots, a leather jerkin, a small primus stove of the collapsible type, a clasp knife with a strong tin-opener and a spare roll of toilet paper are all items well worth carrying, if they can be obtained.

'The forward surgeon must be a reasonably competent surgeon, capable of long hours of work, not slow, not too meticulous, easily adaptable and blessed with plenty of common sense and human understanding. Character is as important as surgical ability during dull and boring periods as well as during a battle' (Brigadier Debenham, C.B.E.).

CHAPTER 2

THE TRANSFUSION OF BLOOD AND OTHER FLUIDS

(i)

Blood Transfusion

By Sir LIONEL WHITBY
C.V.O., M.C., M.D., F.R.C.P.

ONE outstanding reason for the greatly improved results of treatment of casualties in the War of 1939–45 was the fact that restoration of the general condition of the wounded man was made possible by the ready availability of blood (or its derivatives) which could be transferred into the circulation of the patient. It is true that in the War of 1914–18, many patients were transfused and many lives saved by this means, but blood was not so generally available near the front line, and there was nothing like the wonderful system whereby blood was obtained from thousands of healthy donors, kept in store, processed and despatched to the various places, all over the world, where it might be needed. It is quite certain that in no previous war had there been anything approaching this system of blood transfusion. The organisation worked extremely well although for convenience it was managed by different authorities. The Medical Research Council controlled the four main London blood supply centres, the Ministry of Health arranged for the centres in the various Regions, while the large centre at Bristol (under Brigadier Whitby) provided the Army with all the blood it needed and at the same time did the same service to Region 7. The Air Force was mainly supplied from the Army blood transfusion service and from the depots staffed by the Medical Research Council. Later the R.A.F. had a special mobile blood transfusion unit. The Navy was at first badly supplied with transfusion apparatus, but in 1942 most ships were given blood or plasma for emergency use. (See later in Naval section.)

The organisation, administration and general development of the blood transfusion centres in the Emergency Medical Services have been fully described in the E.M.S. Medical History, Volume I, Chapter 11; it remains to sketch the outline of the British Army blood transfusion service and to show how, from small beginnings, it grew to a very big organisation, meeting the enormous demands made upon it from the numerous theatres of war. Next appears a review of lessons learnt from transfusion on the European battlefields at different levels. This is followed by a very brief note on the R.A.F. mobile transfusion team; and an account, in chronological order, of experience in the Royal Navy, showing how transfusion therapy developed during the course of sea warfare.

THE ARMY BLOOD TRANSFUSION SERVICES

The British Army can claim that it was the only army (Allied or enemy) linked with a transfusion service capable of producing its own blood, fluid blood substitutes or dried blood substitutes, grouping serum and crystalloids suitable for use in any field of operation.

Experience of modern mobile warfare soon showed that it was usually impossible to find time to obtain blood from donors during the course of a heavy battle. The American forces had eventually to abandon their elaborate equipment for collecting blood on the spot, and adopt the British method of a central blood bank, furnished with blood obtained from their troops in England, and later, by delivery from the United States of America itself. Mass grouping of troops presents great difficulties; errors, technical or clerical, may readily reach 10 per cent. Yet in order to stifle criticism or to provide some measure of blood locally obtainable, Army Council Instruction 2392/42 laid down that the following personnel should be carefully blood grouped, with the result recorded in A.B.64 and on the identity disc:

1. All medical units.
2. Base troops.
3. Special troops such as commando or airborne who were likely to work in isolation.

The service drew its small original technical staff almost entirely from the laboratories of the Royal College of Surgeons of England and the Middlesex Hospital, and soon after the outbreak of war improvised premises were arranged near Bristol where the unit was accommodated. A panel of 5,000 donors was obtained even before war broke out and, during the first six months of war when there was little or no fighting the unit raised a much bigger panel of donors, and carried out research work on the keeping properties of blood, on the merits of the various blood substitutes, and the best technique for the filtration of plasma. It was from the temporary premises that the early French and the Norwegian campaigns were provided with transfusion fluids and equipment. Separate and more adequate buildings were completed early in 1941. It was in the latter year that the service was presented with its own plasma (or serum) drying plant by the Silver Thimble Fund of the Women of India. This drying plant had by 1944 attained an output of twelve to fourteen hundred 400 c.cm. bottles a week.

In 1942 the needs of the Army were so great that the donor service had to be enlarged. By 1944 the Donor Registration and Publicity Department had a panel of about 350,000 persons. The provision of blood was the basic function of the service, and the size of the problem grew to exceed all reasoned forecasts. Whereas in 1939 the original war establishment catered for the production of about a hundred pints of blood in a day, towards the end of the war the service was collecting 1,200 or 1,300 pints a day with regularity; the 'record' figure for day collection was 1,657. At the outset the only product catered for was stored blood, with a life of some 10 to 14 days. With the advance of knowledge, this storage period became prolonged, but it also became necessary to obtain vast quantities of blood for the preparation of plasma. There were nine hundred different donor centres, while the staff consisted of about 400 persons of whom 80 per cent. were women (V.A.Ds. and A.T.S.). The service supplied transfusion fluids (protein and crystalloid) and equipment to the whole British Army oversea in every theatre of war and in every outlying station from Iceland in the North to Capetown in the South and Malaya in the Far East; in addition the service equipped and trained special transfusion units for service oversea and trained all ranks of the R.A.M.C. in resuscitation work. (Plate I)

In the French and Norwegian campaigns a whole-blood service was maintained to the oversea forces, but in the later campaigns, with the exception of the B.L.A., the whole-blood service was provided by base transfusion units, which were to be found in every theatre of war. The majority of the blood taken by the home depot was then processed to form plasma, which was either dried for export to distant war centres (especially in the tropics), or supplied in fluid form for use in temperate climates, and particularly for commando raids. Plasma was found to have advantages over serum and was proved to be safe. It was impracticable under active service conditions to siphon off the plasma in a closed system and to store it in a frozen solid state; clarification and filtration was the method used, but to prevent clotting it was necessary to wash the Seitz asbestos pad frequently with weak alkali to remove the retained prothrombin, or better still to filter at such a pH that prothrombin could not be activated. The plasma so obtained was clear and stable and, so long as it was kept moderately cool, was able to be exported to India or Burma without detriment. The bottles were filled right up to the top, for shaking tended to encourage clotting. The dried plasma was made from the filtered plasma (Bushby and Whitby, 1941, 1942).

The Army issued dried grouping serum (human) which needed no refrigeration. Group A serum was coloured amber with acriflavine; group B serum was coloured blue with methylene blue.

The home depot was the headquarters for the mobilisation, equipment and training of all transfusion units proceeding oversea, and also held courses of instruction in resuscitation and transfusion work for other ranks and for officers from all the Services, and many officers from the United States Army also attended for training.

M. W. Dunscombe, Bristol.

PLATE I. The Army Blood Bank at Bristol at the time of the Battle of Caen, showing insulated boxes in which blood was transferred to the Continent by air.

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PLATE II. Parachute Basket with shock-absorbing lining.

It will thus be seen that the British Army had its own separate transfusion service with its specially trained oversea units in direct communication with the home depot; the base unit representative met the supply plane which came direct from the home depot and there was thus no delay in distribution of the blood. Though all medical units were necessarily equipped for transfusion work they could only do this on a limited scale and the specially trained full-time officer and staff were definitely needed. The skill and activity of the field transfusion units became renowned in all theatres of war. This organisation, which was adopted by the Canadian Forces, permitted of much more efficient transfusion work than that carried out by the enemy countries, who relied on mass blood grouping of troops, from whom blood was obtained on the spot, and on synthetic blood substitutes not far in advance of the acacia saline solutions of the last war and greatly inferior to natural blood plasma. (Plate II)

THE CHOICE OF TRANSFUSION FLUID

Transfusion was not a mere mechanical procedure. Transfusion officers, by reason of their special training were able to display art in the selection of cases, the choice of correct fluids and their administration in appropriate volume at an optimum rate. Until the more elaborate methods of laboratory control had been reduced to a bedside procedure, reliance had necessarily to be placed upon clinical judgment of the individual case; here the trained and experienced transfusion officer paid a handsome dividend for his training; he frequently could obtain a desirable result with far less material and considerably less anxiety than his less practised colleague.

With regard to the selection of fluids there were many swings of opinion. Some stated dogmatically that when blood was lost, blood was essential; others equally dogmatic, maintained that results just as good could be obtained with plasma or serum, despite their lack of oxygen-carrying power. Much depended on the nature of the individual case and upon the available material. The vital need in the majority of cases was the restoration of blood volume. This could be accomplished with either blood plasma or serum. But since a man with haemoglobin below 60 or 70 per cent. would not stand an operation so well, it was wise to mix blood with the plasma in many cases. There was a great difference between fresh blood (rarely obtainable in a forward area), young stored blood, and old stored blood. If only old stored blood were available it was inadvisable to give large quantities to those whose renal excretion might be poor, for with such blood there was always some haemolysis and the released pigment in the circulation would put a heavy extra load on the kidneys. With abdominal wounds Grant's work showed that plasma loss was more important than blood loss. There was also a useful field for saline infusion.

The volume to be administered and the rates of administration were individual matters. Most medical officers knew that massive limb injuries might require large volumes, say some five or six pints as a pre-operative measure, but some were diffident of giving at a fast rate. Anyone who had suffered a blood loss serious enough to demand instant transfusion, unless the injury were to the lung, could not have the first three pints administered too fast. Unless the rate were fast, the response was often delayed and disappointing. Transfusion did not stop in the pre-operative ward but was continued during the operation and, if necessary, during the post-operative period if the best chance were to be given the patient. In principle, once a response had been elicited, the later transfusions were given in a volume and at a rate appropriate to the general condition. It was of great importance to realise that surgical intervention was imperative when there was massive tissue-damage. These cases could only be partially restored by pre-operative transfusion. When the patient's condition did not continue to improve, despite continued transfusion, then his only chance of life was to take the risk of immediate operation while the transfusion was in progress. There was the same need when gross infection was present, for until the toxic focus had been removed one could not expect a satisfactory response to transfusion.

Transfusion also had a place during convalescence, but tragedies sometimes occurred due to insufficient care in grouping for intra-group incompatibility, owing to the immunising effect of a transfusion previously administered in a forward area. It was desirable that the deliberate work of a back area should be carried out with fresh blood of appropriate group, and particular care was needed to exclude intra-group incompatibility (rhesus factor etc.). Occasionally a life was lost unnecessarily, when a transfusion was made with somewhat old Group O blood.

FAILURES, DISAPPOINTMENTS AND DISASTERS

Experience showed that the response to transfusion was not merely mechanical, and in some cases surgical procedures had to take precedence to obtain the best result. Supplies were so abundant that at one phase of the war a wounded man was almost lucky if he escaped a transfusion and certainly a number of unsuitable cases were submitted to the operation. Injuries to the brain and central nervous system responded poorly and, unless there were serious injuries elsewhere, it was best not to transfuse these cases. With bone injuries there was always present the risk of fat embolism and, when unexplained pulmonary or cerebral symptoms arose during the transfusion of a case with bone injury, the transfusion had to be stopped, for it tended to increase the amount of fat in the circulation. Such cases needed immobilisation and rest.

Certain groups of cases either did not benefit from or were actually harmed by transfusion. The transfusion of any patient with chest injury needed to be undertaken with caution on account of the danger of pulmonary oedema. Some degree of blast injury was not uncommon; when there were prominent injuries elsewhere blast-lung might easily pass unobserved until pulmonary oedema occurred, but the diagnosis could often be supported by finding a ruptured tympanic membrane. When the circulation was embarrassed by haemopericardium or other mechanical causes it was unwise to transfuse.

Disasters from incompatible blood were almost unknown. This was a tribute to the complete group-checking system which was rigidly enforced, whereby both agglutinogen and agglutinin content of all Group O blood was tested before release. Trouble occasionally arose from the use of massive quantities of somewhat old blood, but there were only four, fortunately minor, occasions in which blood was infected though the armies operated in all climates and under most difficult conditions. There were exceedingly few accidents or complaints in connexion with the collection of blood. The records show that only one donor in 3,838 made any complaint, while only one in 23,626 suffered sufficient discomfort to make a claim for compensation. Many people accepted a minor complication, such as a haematoma, without comment or complaint, and almost all the claims for compensation were of a very minor character.

FACTS AND FIGURES

Approximately 10 per cent. of wounded required to be transfused—a figure which tallied with that for air-raid casualties in Great Britain.

The variation in the amount of blood or plasma used in the average case was partly a function of the supplies available and partly dictated by the prevailing fashion. It will be seen that the average total protein requirement was about 4 pints per case and that, in the most experienced force—the B.L.A.—this was made up of approximately 2½ pints of blood and 1½ pints of plasma, so far as the acute phase of the wounding was concerned. In the B.L.A. there was a considerable amount of transfusion work at general hospital level as well as in the forward areas.

As to the supplies provided (Table II), there was no period of the war in which the demand ceased to be on an increasing scale, culminating with a figure of 124 pints of protein fluid and 134 pints of crystalloids for every hundred wounded in the B.L.A.

This is eloquent testimony to the inevitable waste of war. That such supplies were freely given without question was a tremendous tribute to the magnitude and constancy of the public effort, typified by the ordinary civilian blood donor, which gave to our wounded the 80 to 90 per cent. chance of life which they enjoyed.

Dunkirk Campaign. The records obtained from surviving members of the Army transfusion service showed that some 400 pints of blood were used during the short Dunkirk campaign; this blood had been

TABLE I

Utilisation

Theatre and period	Wounded admitted	Number trans-fused	Per cent. trans-fused	Fluids used (pints)		Average per case (pints)		
				Blood	Plasma	Blood	Plasma	Protein
8th Army M.E.F. (Forward Areas)	11,732	1,119	10	2,171	1,323	1·9	1·2	3·1
1st Army B.N.A.F. (Forward Areas)	16,674	1,604	10	1,084	4,000	0·7	2·5	3·2
C.M.F. Anzio, 1944 (Forward Areas)	3,904	414	10·6	1,305	491	3·1	1·2	4·3
B.L.A. (a) Forward Areas:	129,680	15,148	12	39,057	29,495	2·6	1·9	4·5
(b) Back Areas:		9,468	7percent. re-trans-fused	12,680	10,917	1·3	1·1	2·4

Notes: 38 per cent. of the cases transfused by B.L.A. required 4·5 pints total protein per case.

62 per cent. of the cases transfused by B.L.A. required 6·9 pints total protein per case.

TABLE II

Supplies

Force and Period	Total wounded	Blood	Plasma fluid and dried	Crystal-loids	Supplies per 100 wounded		
					Blood	Plasma	Crystal-loids
M.E.F., 1940 to June 1943	63,190	10,379	41,383	57,399	16	65	91
B.N.A.F., 1942–3	16,674	1,094	5,000	5,000	6	30	30
C.M.F., August to September, 1944	14,580	7,480	9,507	17,630	51	65	121
B.L.A., June 3, 1944 to May 31, 1945	144,649	90,975	88,653	193,948	63	61	134

supplied by air from the home depot. But several important lessons were learnt from the experience of transfusion in the British Expeditionary Force. It was shown that the organisation in an oversea theatre of a supply of stored blood and durable blood substitutes, and the provision of specially trained units and personnel for their administration and for technical advice, were practicable undertakings of immense value to an army in the field. The value of field transfusion units was also demonstrated, and it became clear that there was need for a self-contained resuscitation ward with its own equipment and staff, and preferably placed in sole charge of the transfusion officer.

Middle East. An analysis of 11,732 admissions for wounding (not total casualties) in the battles from El Alamein to Enfidaville showed that 1,119, approximately 10 per cent., required transfusion with 2·9 pints of protein fluid (blood or plasma) per case. This was the overall figure. But when wounded were selected by reason of severity, as at an advanced surgical centre, the proportion requiring transfusion was almost double, and likewise the amount of protein fluid per case; here, too, a higher proportion of blood was required.

In North Africa almost similar figures were obtained. There, of 16,674 admissions for wounding, 10 per cent. required transfusing with 3 pints of protein fluid, and here again, at selected centres where severe casualties were admitted, the rate rose to as high as 25 per cent.

In the Sicilian and Italian Campaigns the work of the base transfusion unit and field transfusion units, despite many handicaps, was on the whole successful. Solutions prepared by the transfusion service were made available for between fifteen and twenty thousand battle casualties who benefited by the safe and skilful intravenous administration of these fluids.

In the Burma Campaign (1942–45) many difficulties were met with. The policy which was adopted in 1943 whereby a certain number of hospitals prepared their own crystalloids did not prove satisfactory since they lacked adequate quantities of distilled water, and reactions were frequent. There were also many reactions after transfusion of many Indians suffering from anaemia; investigation showed that these reactions were in most cases due to insufficient cleansing of the apparatus. In spite of all difficulties, however, a useful transfusion service was organised.

All surgeons with active service experience found it necessary to have a proportion of blood available with which to supplement their ample supplies of plasma. This was required especially for abdominal cases, for those who had to receive a massive transfusion exceeding 4 to 5 pints of protein fluid, for those who had been resuscitated in a forward area and had subsequently deteriorated again during evacuation, for septic patients and, with advantage, for any transfusion required during operation or as a post-operative measure. In general terms, if a protein fluid was supplied on an overall basis of 3 pints per 10 per cent. of casualties in the proportion of one pint of blood to two of plasma, the supplies were sufficient, provided they were distributed so that selected centres received double quotas. Between July 1940 and June 1943, the base transfusion unit of the Middle East forces provided 10,379 pints of blood obtained from base troops, while in North Africa during six months' campaign 1,094 pints were so provided.

As to crystalloid fluids the utilisation appeared to be on the same scale as protein fluid, namely 3 pints per 10 per cent. of wounded admissions. The large consumption was accounted for almost entirely by the requirement in abdominal cases during the post-operative period when they were treated by gastric suction and hydrated by the intravenous route. Each patient might require 15 to 30 pints in the four or five days after operation.

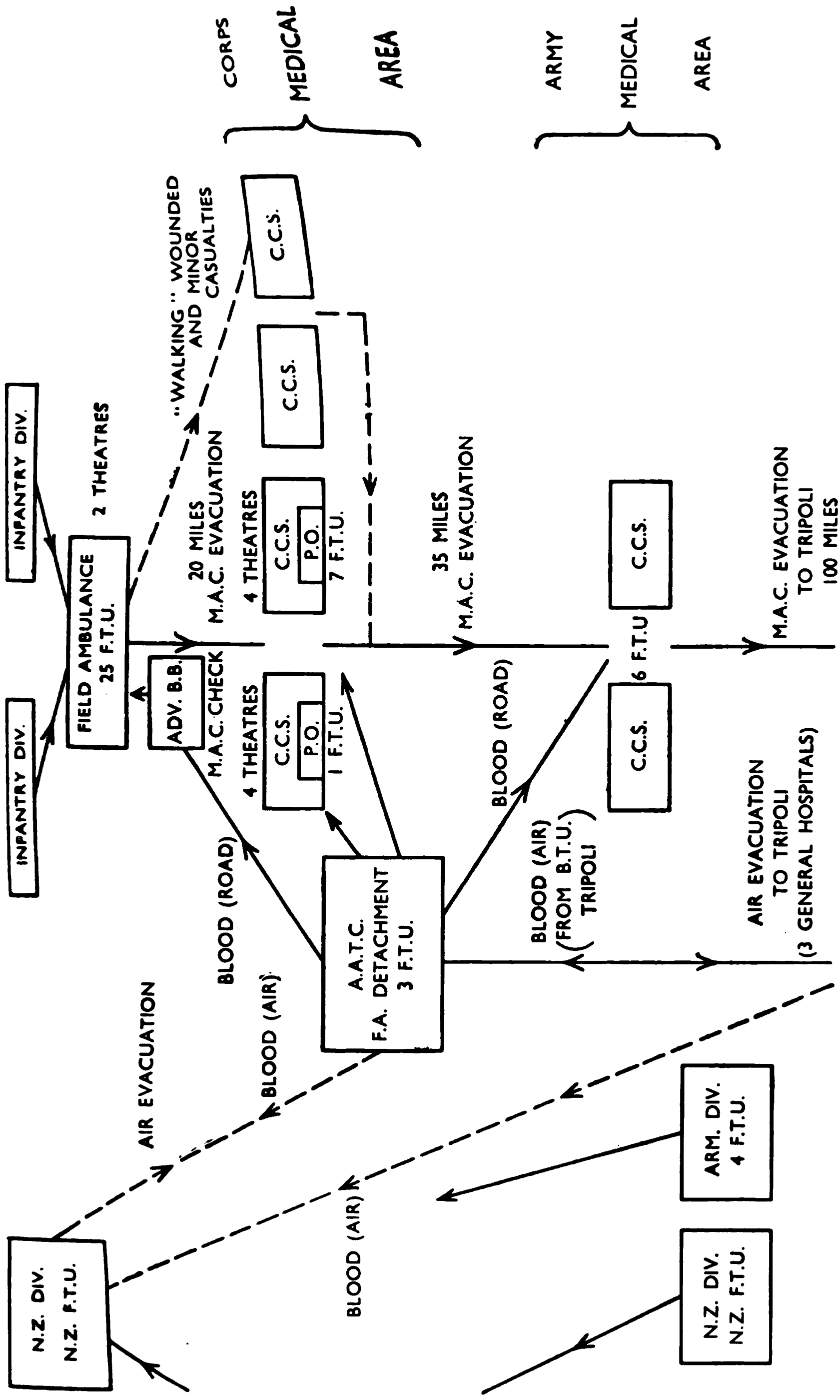
THE STATUS OF THE TRANSFUSION OFFICER

Transfusion and resuscitation work is such that all regard it as easy until they have essayed it; it invades the province of the surgeon, the physician and the pathologist; it therefore occupies an unfortunate position from the point of view of recognition as a specialist employment, in that none of the triad of the three main specialities will speak on its behalf. In times of stress, the first call is for a skilled transfusion officer, nimble with the needle or cannula, experienced in clinical judgment and medical measures, and equipped with fundamental pathological knowledge concerning the intricacies of blood groups and the technique of haematological investigation. In quiet times this same officer is quickly made aware of his lack of specialist status.

At the end of the War of 1939–45 the principle of regarding the transfusion officer as a specialist was accepted, but it was not effective until after the cessation of hostilities in Europe.

By the end of European hostilities, the volume of work performed by a transfusion officer during a busy period had become overwhelming. This was because of the full exploitation of this life-saving measure, as well as the practice which surgeons had come to follow, namely, the leaving of pre-operative selection and post-operative care completely in the hands of the non-specialist but highly skilled transfusion officer. Yet, during quiet times, the transfusion officer was relatively unemployed, and worked at the general duties of the hospital.

It may be finally concluded that efficient transfusion work can only be performed with skilled and trained personnel generously allotted. Overworking, even for short periods, leads to inefficiency. Any future establishment of a blood supply depot, a base transfusion unit, and a field transfusion unit should be amply staffed to permit of relays of work. When some estimate of the number of lives saved by the service is finally made, there will be no doubt that it has constituted a very fine investment of medical man-power.



THE BATTLE OF MARETH. Lay-out of medical services with especial reference to the Blood Transfusion Service.

THE ARMY BLOOD TRANSFUSION SERVICE

PLASMA AND BLOOD BANK BALANCE SHEET

Period: The European War September 3, 1939 to May 8, 1945

IN		OUT	1939–40	1941	1942	1943	1944	1945 to May 8	GRAND TOTAL	Correction factor for plasma yield	Equivalent in Donors
DONORS BLED (ONE PINT)		BLOOD (PINTS)									
1939–40	33,845	Overseas	2,580	—	—	—	59,827	38,300	100,707		
1941	77,694	Home Forces	212	63	427	—	688	167	1,557		
1942	124,241	R.A.F. and R.N.	189	36	136	520	1,229	654	2,764		
1943	172,074	U.S. Hospitals	—	—	—	—	69	58	127		
1944	267,595	E.M.S. Hospitals	971	687	3,472	3,877	4,911	1,986	15,904		
1945, May 8	80,597	Unexported stock	—	—	18	69	321	1,456	1,864		
	756,046		3,952	786	4,053	4,466	67,045	42,621	122,923		
		Less gifts	—	—	—	—	28,152	23,681	51,833		
MARGINAL NOTES: GIFTS OF BLOOD (pints) during 1944–5 from:		Totals	3,952	786	4,053	4,466	38,893	18,940	71,090	× 1	71,090
N.W. London Depot	18,163										
Leeds Region	21,381	FLUID PLASMA (PINTS)									
Cardiff Region	5,874	Overseas and Home Forces	6,980	11,459	25,325	9,105	55,496	19,695	128,060		
Nottingham Region	2,480										
Royal Navy	3,935	R.A.F., R.N., and Troop Ships	325	581	218	152	60	24	1,360		
	51,833	E.M.S. Hospitals	1,427	2,998	4,537	975	12	—	9,949		
		U.S. Forces	—	—	1,273	338	—	—	1,611		
		Canadian Forces	—	—	256	914	3,734	—	4,904		
GIFTS OF FLUID PLASMA (pints) from: E.M.S. and M.R.C.		Other Allied Forces	—	80	—	—	—	—	80		
1939–42	5,300	Stock and awaiting shipment	—	—	6,143	5,582	11,354	5,464	28,543		
1943	1,419										
1944	*18,000		8,732	15,118	37,752	17,066	70,656	25,183	174,507		
1945, May 8	*9,905	Less stock 1942–4	—	—	—	6,143	5,582	11,354	23,079		
	34,624		8,732	15,118	37,752	10,923	65,074	13,829	151,428		
		Less gifts	—	—	5,300	1,419	18,000	9,905	34,624		
		Totals	8,732	15,118	32,452	9,504	47,074	3,924	116,804	× 1·9	221,928

* Kaolin plasma for drying received from Leeds and Oxford.

GIFTS OF DRIED PLASMA (× 400 c.cm.) from:

M.R.C. and E.M.S. 1939–42	11,915
M.R.C. and Regions 1943	16,689
M.R.C. 1944	18,631
M.R.C. 1945	9,562
Scottish Service 1944	3,150
Canada 1943	8,580
Canada 1944–5	100,767
	169,294

DRIED PLASMA (× 400 c.cm.)

Overseas and Home Forces	2,249	17,052	28,412	85,196	169,155	25,261	327,325
R.A.F., R.N., and Troop Ships	—	—	—	—	4,540	275	4,815
E.M.S. Hospitals	—	—	—	1,174	3,216	790	5,180
U.S. Forces	—	—	1,110	—	—	—	1,110
Canadian Forces	—	—	—	353	669	—	1,022
Sundries	—	38	47	53	267	378	783
Awaiting shipment	—	—	—	8,992	11,245	6,319	26,556
Stock	—	—	5,446	24,907	39,085	148,316	217,754
	2,249	17,090	35,015	120,675	228,177	181,339	584,545
Less stock 1942–4	—	—	—	5,446	33,899	50,330	89,675
	2,249	17,090	35,015	115,229	194,278	131,009	494,870
Less gifts	—	—	11,915	25,269	122,548	9,562	169,294
Totals	2,249	17,090	23,100	89,960	71,730	121,447	325,576

Adjustment to convert × 400 c.cm. bottles to pints: 325,576 × 400 c.cm. = 230,496 pints × 1·9 — 437,942

GIFTS OF GROUPING SERUM from Galton Laboratories:

1939–42	1·75 pints
1943	2·0 ”
1944	5·2 ”
	8·95 ”

GROUPING SERUM (PINTS)

Overseas	1·50	3·80	3·95	16·80	10·25	11·30	47·60
Home Forces	5·45	5·75	5·05	9·60	10·50	1·35	37·70
Used by A.B.S.D.	8·30	6·20	9·20	12·30	17·50	9·10	62·60
R.A.F., and R.N.	0·30	0·20	—	—	1·00	—	1·50
E.M.S.	4·50	2·10	0·30	—	6·00	0·50	13·40
Canadian and U.S.	—	—	—	—	3·00	—	3·00
Stock	—	—	14·25	5·10	7·73	10·15	37·23
	20·05	18·05	32·75	43·80	55·98	32·40	203·03
Less stock 1942–4	—	—	—	14·25	5·10	7·73	27·08
	20·05	18·05	32·75	29·55	50·88	24·67	175·95
Less gifts	—	—	1·75	2·00	5·20	—	8·95
Totals	20·05	18·05	31·00	27·55	45·68	24·67	167·00

× 1·9 — 317

Accidents and complaints September 3, 1939 to May 8, 1945:
Number: 197
Incidence: 1 in 3,838
Compensation claims: 32
Incidence: 1 in 23,626

UNACCOUNTED FOR (Technical faults, contaminations, breakages and other discards) — 24,769

PERCENTAGE WASTE: 3·27

756,046 — 756,046

(ii)

Lessons Learnt from Experience of Transfusion in the European battlefields

By HUGH CONWAY
B.Sc., M.B., M.R.C.P.

MEDICAL LESSONS

AT DIVISIONAL LEVEL

At this level the policy was one of rapid evacuation. Only life-saving transfusion was undertaken and, for this purpose, plasma was usually adequate. There were many dangers associated with the use of blood in units which had no facilities for refrigeration and these dangers outweighed the advantages which blood has over plasma in resuscitation. Most forward units did not hold more than 2–3 pints of blood at any one time and this was used only in the special cases, e.g., gross exsanguination following arterial injury. The blood was stored in small insulated boxes and, if unused in 24 hours, was exchanged for a fresh supply from the nearest forward transfusion unit. All medical personnel were blood-grouped and each unit carried an adequate supply of bleeding-sets so that a few donors could be utilised in an emergency. If forward units carried a large supply of blood there was, in addition to the dangers associated with bad storage conditions, the further danger that medical officers might be encouraged to adopt a too enthusiastic transfusion policy; provided that all haemorrhage had been stopped, it was unwise to delay evacuation after rapid transfusion of a few pints, even if the response was not satisfactory. Lack of response in most cases was due to some factor which could not be rectified at this level—e.g. toxaemia from gross tissue injury. Resuscitation should not be dissociated from surgery.

Travelling transfusions were sound in theory, but did not work well in practice. Orderlies could not usually be spared to accompany the patients and, during the journey, the needle often came out of the vein. Frequently also, the patient arrived with an empty bottle attached to his arm.

It was important that forward medical officers should concentrate on first-aid measures in the treatment of their patients and transfuse, usually with plasma, only when there was a definite indication. The ideal transfusion was rapid and small in amount, for the guiding principle which governed all divisional work was one of evacuation to the nearest surgical centre at the earliest possible moment compatible with reasonable safety.

AT CORPS LEVEL

Resuscitation facilities were concentrated at this level and were closely associated with surgery. To the transfusion officer was entrusted responsibility for pre-operative diagnosis and treatment and the selection of priority patients for operation. He could not also be responsible for post-operative treatment, but was always available in an advisory capacity.

Pre-operative care. Rapid examination of the whole body surface was essential, for injuries were commonly multiple and it was easy to miss a small penetrating wound. Clothes had to be sacrificed by cutting them down the mid-line in front; this gave adequate exposure with the minimum of discomfort. Undressing was not attempted unless the clothes were wet or very dirty; this procedure was best postponed until the patient was in the theatre and under the influence of the anaesthetic. Warmth was supplied by the efficient use of blankets; forced heating was not employed except when the atmospheric temperature was very low. If fluids were given by mouth in large quantities troublesome vomiting occurred commonly during the induction of anaesthesia. Anaesthetists were not in favour of hot sweet tea. Fortunately, dehydration was not a problem in North-west Europe. Vomiting was sometimes a symptom of morphine poisoning.

The X-ray screening of potential abdominal cases was one of the resuscitation officer's most responsible duties. The wound of entry could be anywhere between the clavicle and the knee. The portable X-ray apparatus supplied to casualty clearing stations was of great value in this respect.

Indications for transfusion. In deciding to transfuse it was found that the most reliable guide was the nature and extent of the injuries. During battles it was not possible to take even single blood-pressure readings on all cases and, frequently, the one sound arm was utilised for transfusion so the blood pressure could not be followed as a guide to progress. Reliance had to be placed, therefore, on criteria other than the blood pressure, and it was found possible to work efficiently without a sphygmomanometer. The condition of post-traumatic hypertension was not uncommon. It occurred especially in healthy young subjects with limb wounds of moderate severity. Transfusion was still indicated in these patients if the wounds were in any way severe, otherwise there was a great danger of collapse either during operation or immediately afterwards.

TYPE OF CASE

Penetrating abdominal wounds. These were of all grades of severity. It was sound policy to transfuse all cases before and during operation. Unless there was obvious gross haemorrhage, plasma was the fluid of choice before operation, and if much blood was found in the abdomen, blood could be given during operation. Blood was also very useful in small quantities in the immediate post-operative and convalescent periods.

Penetrating chest wounds. The management of these patients was very difficult. Experience showed that they did better on the average when transfusion was given. Blood was used in preference to plasma and the transfusion was given slowly and in small quantity. There was always a danger of precipitating pulmonary oedema but, with adequate care, this outcome was very rare in uncomplicated cases. The problem was even more difficult in patients suffering from a penetrating chest wound complicated by other severe injuries. The nature and extent of the latter wounds might indicate the necessity of rapid transfusion in large dosage; the danger of developing acute pulmonary oedema was then great. In a series of 1,000 cases requiring resuscitation, three of this nature developed fatal pulmonary oedema—in two the presence of the chest wound was unsuspected.

Head wounds. These patients travelled well to neurosurgical centres and only required transfusion at corps level if there had been large external haemorrhage.

Limb wounds. All patients with severe limb wounds required transfusion before, during, and after operation. In the average, more blood was given to these patients than to any other type of case.

Thoraco-abdominal wounds. These wounds were associated with a very high mortality which was greater in left-sided than in right-sided trauma. The difference in prognosis was due to the vulnerability of the spleen and the buffer action of the liver. The patients presented a great problem both to the resuscitation officer and to the surgeon. As a general rule the former treated them mainly as chest cases and the latter as abdominals.

Burns. Copious plasma transfusion was required. In the most severe cases as much as 18 pints were given in the first 24 hours. Surgical intervention was not attempted at corps level.

Prophylactic transfusions. Many soldiers suffering from severe wounds were found, on arrival at the casualty clearing station, to be in surprisingly good general condition. If transfusion was withheld from these patients the danger of operative or post-operative collapse was increased. A large proportion of the transfusions given at corps level was of this prophylactic nature in patients not suffering from clinical 'shock'.

CAUSES OF POOR RESPONSE TO TRANSFUSION

(1) Patients with severe limb injuries associated with gross tissue damage sometimes did not respond to massive rapid transfusion. This was especially so if there was a long interval between the times of wounding and arrival at the casualty clearing station. In these cases, operation

could not be delayed, great though the risk was. If transfusion was continued in the theatre and after operation, improvement often began almost at once. It was better to concentrate on post-operative rather than pre-operative resuscitation.

It was considered, on the basis of H. N. Green's theory, that this lack of response might be due to absorption of toxic substances from the damaged tissue. However, application of a proximal tourniquet was seldom followed by any improvement. But if a tourniquet had been *in situ* during the journey from the advanced dressing station, its release at the casualty clearing station often caused a dramatic collapse. Experience showed that if a tourniquet had been applied for some hours at a pressure sufficient to obstruct the venous return (and most tourniquets did only this) the patient's life was saved only at the expense of his limb by not releasing the obstruction.

(2) *Over-morphinisation.* If an excessive amount of morphine was given during evacuation, mild degrees of poisoning developed after the circulation was restored by transfusion. This masked the good effects of the transfusion.

(3) *Continuous haemorrhage.* This was especially important in penetrating abdominal wounds.

(4) *Fat-embolism.* In 1,000 successive cases requiring resuscitation, six proved cases of fat embolism were encountered—one presented with pulmonary signs and five with cerebral. The time of onset of the condition after wounding varied.

> (*a*) One patient, suffering from a soft tissue injury of one leg with an undisplaced fracture of a femoral condyle, was in moderately good condition on admission, but developed pulmonary oedema insidiously during slow plasma transfusion. At necropsy a massive pulmonary fat-embolism was found.
>
> (*b*) Two patients, suffering from unilateral below-knee traumatic amputations of the leg, responded well to pre-operative transfusion, but after operation they did not recover consciousness. At necropsy both were found to have cerebral fat-embolism.
>
> (*c*) Three patients with multiple injuries including bone trauma made good initial recoveries from the anaesthetic, but 24–28 hours after operation, they became confused, apathetic and drowsy. One died in coma on the third day and was found to have a cerebral fat-embolism. The other two patients developed other evidence of the condition, such as retinal and urinary changes and petechiae on the chest wall. Both recovered after presenting for 5–6 days a clinical picture which was predominantly psychotic.

Probably many cases of fat-embolism were undetected and this diagnosis should stand high in the list of causes of mysterious post-operative death.

(5) *Infection*. Sepsis was rarely seen at casualty clearing station level. Gas gangrene occurred occasionally and prevented the usual response to transfusion.

(6) Very rare causes of poor response were blast injuries of the chest and abdomen and lesions of the central nervous system.

Blood or Plasma? When blood was plentiful it was used in much greater quantity than plasma. In a series of 100 successive cases transfused in a casualty clearing station in Normandy the ratio $\frac{\text{blood}}{\text{plasma}}$ was $\frac{3.5}{1}$. In July 1944, during the battle for Caen, 194 cases were transfused by one forward transfusion unit. The ratio of $\frac{\text{blood used}}{\text{plasma used}}$ was $\frac{3.9}{1}$ and an average of 3·7 pints of protein fluid was given to each patient. Haemorrhage from wounds was usually considerable and, for this reason, most surgeons preferred blood to plasma. However, plasma is easier to transfuse than blood and can be given at a much faster rate; as a general rule in the most urgent cases 1–2 pints of plasma were transfused very rapidly while blood was being obtained from the refrigerator. This preliminary plasma transfusion was found to be of great value.

COMPLICATIONS OF TRANSFUSION (analysis of 1,000 successive cases).

(1) *Rigors*. This reaction was very common during the administration of both blood and plasma and the rigors were usually an accompaniment of rapid transfusion. They had no relation to the temperature of the blood, which was always given without previous heating. When the speed of the transfusion was decreased the rigor invariably stopped. This reaction was quite innocuous and was not an indication for stopping transfusion. Unless the rigor was exceptionally severe, the rapid rate of administration was continued if circumstances demanded, and $\frac{1}{8}$–$\frac{1}{4}$ gr. of morphine was given.

(2) *Haemolytic reactions*. One suspected case was seen. The patient became mildly jaundiced 24 hours after transfusion of two pints of blood. There were no general symptoms and recovery was rapid. No investigations could be undertaken in the circumstances.

(3) *Air-embolism*. One case occurred in the post-operative ward due to the carelessness of an orderly in applying positive pressure to a bottle which was almost empty. The patient died almost immediately.

(4) *Overloading*. In three patients—all had penetrating chest wounds —pulmonary oedema developed during transfusion.

Apart from these cases no ill effects followed the very massive transfusions which were undertaken.

(5) *Wrist-drop*. Following operation two patients, both of whom had been transfused before and during operation, were found to be suffering from wrist-drop affecting the transfused limb. The cause was thought

to be long-continued pressure by the splint on the musculo-spiral nerve.

Drugs

(1) *Morphine.* To ensure rapid action, morphine was always given intravenously. Doses of $\frac{1}{4}$ gr. repeated as necessary were considered to be better than less frequent doses of $\frac{1}{2}$ gr. Over-morphinisation was a common syndrome and was due to frequent administration by non-medical personnel and to faulty recording of dosage during evacuation.

(2) *Sodium Amytal.* This drug has a rapid sedative effect and, given intramuscularly was of great value in cases of head injury. These patients, often restless in the extreme, usually required sedation, especially if transfusion was necessary. Intramuscular paraldehyde was found to be a good substitute if amytal was not available. These sedative drugs were particularly useful when head injury was complicated by other extensive injuries which necessitated transfusion and required operation; the latter could often be carried out without further anaesthetic.

(3) *Methedrine.* This pressor drug was sometimes used in severely collapsed patients with extreme hypotension. In these circumstances, plasma transfusion was instituted urgently and methedrine was given intravenously during the administration of the second or third pint. Often there was a dramatic improvement as noted by the blood pressure readings. This level was then maintained by continuous blood transfusion.

(4) *Alkalies.* Alkalinisation was advised for treatment of traumatic anuria. An alkali solution, prepared for intravenous use, was also available for treatment of haemolytic reactions.

Priority for surgical treatment. As far as possible patients were selected for surgery in the following order:

(1) Those with severe tissue damage, usually with extensive limb injuries, who showed a poor response to resuscitation.
(2) Those with wounds penetrating the abdomen (including thoraco-abdominal wounds).
(3) Those with limb injuries who showed a satisfactory response to resuscitation.
(4) Those with sucking chest wounds, provided that the wound could be adequately sealed in the interim.

AT BASE LEVEL

A considerable amount of transfusion work was carried out in general hospitals. The main indications were the treatment of sepsis and post-traumatic anaemia. The latter was a relatively common condition of unknown aetiology. Reactions were more frequent at this level; this was mainly due to the nature of the primary conditions; but, as very many of the patients had already had repeated transfusion in forward units, intra-group incompatibilities due to iso-immunisation were probably not uncommon.

TECHNICAL LESSONS

1. ORGANISATION OF A RESUSCITATION DEPARTMENT

To maintain a continuous 24-hour service and supply four surgeons, a resuscitation team must have a minimum staff of two officers, two senior N.C.Os., and eight trained orderlies. It was customary to form two teams from the personnel available; normally one worked while the other rested, but in periods of great stress both functioned together for limited periods. The senior N.C.O. in each team was responsible for general supervision and for the compilation of adequate records. One orderly on each shift was detailed to look after the sterilisation and loading of syringes at a central table and to supervise the general state of maintenance and cleanliness of apparatus and equipment. The remaining three orderlies on each team could then give their undivided attention to the care of the patients.

In the field a 4-section tent made an ideal ward. Light was supplied by the ordinary generating set and the electric power was distributed to a series of lamps placed along one side-wall in opposition to the heads of the stretchers as well as to the usual overhead lamps. The former had long flexes and were, therefore, mobile inspection lamps. (Plate III)

2. EQUIPMENT AND APPARATUS

'Giving' sets required to be of great strength. Many of the sets supplied were very satisfactory for drip transfusion but were incapable of withstanding the strong positive pressures necessary in casualty work. The standard non-return valve was often unsatisfactory. This may have been due to defects in the rubber membrane. If a number of spare sterile valves were available for substitution when defects occurred a great economy was achieved in the use of 'giving' sets.

The refrigerator was mechanically sound but of inadequate capacity. When a big supply of blood was held in stock it was necessary to lay the bottles horizontally. In such circumstances, if the general principle of using oldest blood first was followed, there was so much disturbance that it was impossible to tell before administration whether haemolysis was present or not.

3. TRANSFUSION METHODS

Except in special cases the vehicle of transfusion was the needle. When the main consideration is urgency, cannulisation must occupy a very secondary rôle. In 100 successive cases requiring pre-operative resuscitation the insertion of a cannula was necessary only twice. In certain rare circumstances needling was impossible—e.g. severe injuries to both arms, extensive burns, triple amputations, destruction of arm

PLATE III. A C.C.S. Nurses with a F.S.U. and F.T.U. attached. Note the number of transfusions in progress.

[*Facing page* 64

PLATE IV. A Field Transfusion Unit in Normandy.

PLATE V. A C.C.S. in Normandy.

veins by previous transfusion or by transfusion during travel—but with experience, cannulisation was not indicated because of simple venous collapse in severe shock.

Emphasis was laid on speed of administration and, in severely exsanguinated patients, it was sometimes necessary to transfuse rapidly in both arms simultaneously. If the upper limbs were damaged the jugular veins offered an excellent alternative route. These veins can be needled with little difficulty but an orderly must be available to hold the head in a fixed position. A rapid enough flow of blood could not be obtained with any degree of certainty via the ankle veins so, on the few occasions on which cannulisation was necessary, the forearm and thigh were the sites of choice.

It was a general principle to conserve veins, and first transfusions were performed as far peripherally as possible on the forearm. It was bad technique to utilise elbow veins as a primary route, and cannulisation at the bend of the elbow was always contraindicated. If the elbows were left relatively intact the transfusion work in post-operative wards and in general hospitals was much easier. But even with the most careful work veins could not always be conserved and, especially in abdominal cases, an indwelling cannula was found to be an advantage for the routine post-operative administration of intravenous fluids. The cannula could be inserted by the anaesthetist while the surgeon was closing the abdominal wall. The ankle veins were suitable for this purpose because drip-rate of infusion was satisfactory.

The sternal marrow was seldom used as a route for transfusion because a fast rate of flow could not be obtained. However, the prolonged slow drip of plasma required in cases of severe burning was well maintained by this method; this was its main indication.

4. SUPPLY AND STORAGE

The system of supply in the field from advanced blood banks to field transfusion units never failed. Blood was not held for more than 24 hours by units without refrigerators. These units had to rely chiefly on plasma.

The blood survived well and was used up to 28 days from the time of collection. When the turnover was rapid it was impossible to tell, by inspection before use, if haemolysis was present. No time was available to allow the cells to settle. The same difficulty arose from much handling and movement in the refrigerator, and in the early stages of the campaign in North West Europe much blood was needlessly discarded as haemolysed.

Experience taught, however, that the blood could be taken on trust and it says much for the Army blood supply depot staff at Bristol that haemolytic reactions never occurred. (Plates IV and V)

(iii)

Blood Transfusion in the Treatment of Shock in the Royal Navy

By Surg. Cdr. F. P. ELLIS
O.B.E., R.N.

At the beginning of the War of 1939–45 many thought, with the naval surgeons of the War of 1914–18, that blood transfusion in ships was not a practical proposition. In the closing years, however, blood and serum transfusions were undertaken as a routine in all classes of warship, and members of the sick berth staff had acquired a degree of dexterity in manipulating transfusion equipment that was seldom encountered among medical officers at the outset of the war.

The naval problem was largely one of administration, and research was left to others better equipped to carry it out. The difficulties, described more fully elsewhere (Ellis, 1946), were in some ways more complex than those facing the land forces or civilian services. A warship might be in action in the Arctic one week and operating off Dakar a few days later. The resuscitation facilities deemed necessary for any ship's company had to be available therefore at all times. Medical units in ships were small and isolated and the ship's medical officer acted as general practitioner, public health officer, and emergency surgeon in quiet times, while in action he might be overwhelmed by a sudden influx of casualties. In action the medical organisation of a ship embraced the functions of first-aid post, casualty clearing station and field ambulance. Whereas the Army might concentrate stores and trained transfusion teams in preparation for an advance or behind a static front, or a network of civilian hospitals might work in close co-ordination, the small medical departments in warships were scattered all over the world and had to be self-contained and self-reliant.

The problems of supply, especially of a delicate commodity such as blood, were difficult, and the provision of specialised resuscitation teams was generally out of the question, except in hospital ships, which were often far away from the field of action and received casualties only after the acute phases of shock had passed. The method adopted, therefore, was to train and equip as many of the total medical force as possible. In practice this took longer to become effective than the organisation ashore of specialised resuscitation units, and was sometimes hindered by a tendency to conservatism in authoritative quarters. Thus in the early years of the war, naval experience of transfusion methods was mainly acquired in shore-based units and the practice and organisation for carrying out transfusions at sea was built up during the last three years of hostilities.

There is still much discussion as to what can and what should be done in ships, and many variables must be considered. For example, in the Mediterranean it was unusual for casualties to be retained in operational ships for more than two or three days, whereas, in the Japanese campaign, ships remained at sea far from their land bases for weeks on end and depended on the base ships of the Fleet Train. The sequence of events throughout the war will therefore be reviewed in chronological order, and their significance to naval medicine in the future will be briefly discussed.

1914–18

In the War of 1914–18 the experiences of the Naval Division in France and at Gallipoli, and of the Royal Marine Battalions ashore, were similar to those of the Army. It was appreciated that blood transfusion was the logical method of treating men who had lost much blood, but in practice the difficulties were often prohibitive.

At sea, blood transfusion was thought to be quite out of the question, and reliance was placed on heavy dosage with morphine, warmth, early and efficient control of haemorrhage, fluids by mouth, and the reduction of the transport of wounded to the minumum, while chloroform was then the anaesthetic of choice. The view held by many was expressed by a naval surgeon with four years' experience of war surgery: 'If a patient does not improve with the application of warmth and stimulants, he will most certainly die'.

Sea warfare was confined for much of the time to the North Sea and, on an average, casualties from an action reached base hospitals within forty hours. First-aid measures were frequently all that could be attempted on board ship. The retention of wounded in hospital ships varied from just under two days, when carrying wounded from Dunkirk to Cherbourg after the first Battle of Ypres, to three or four weeks when carrying others from the Gallipoli beaches to England.

The small numbers suffering from shock in large batches of wounded admitted to hospital ships at Gallipoli were the subject of comment in the Official History; a finding attributed to the time-lag before evacuation from the battlefield after wounding.

1918–39

Emergencies requiring blood transfusion are not common in warships in peace-time, and there was little change during the next seventeen or eighteen years in the accepted theories from those on which the practices of 1918 were based. The Abyssinian and Munich crises and the experience gained in the Spanish Civil War, however, caused a revision of ideas in certain quarters, and many of the larger ships were equipped with two or three 'funnel and tube' transfusion sets, while others possessed patent devices such as the Sterivac and Vacoliter; but medical and sick berth staff were largely unfamiliar with the technique of transfusion.

1939–40

The Admiralty Instructions for the 'Treatment of Surgical Casualties after a Naval Action' (1940) stated that 'the medical officer may deem it necessary to employ intravenous infusion. The use of saline may be valuable as a temporary measure . . .', but replacement therapy was attempted rarely in the actions which occurred at this time.

No transfusions were given during or after the Battle of the River Plate on December 13, 1939, when 55 men were killed and 82 were wounded in H.M.S. *Exeter* in the first thirty minutes, including 18 who were badly burnt through not wearing anti-flash gear. Blood transfusion was not practised during the first and second battles of Narvik, even in H.M.S. *Warspite* which acted as a clearing station in the second battle for casualties from the destroyers and received 59 cases. Under the chaotic conditions prevailing during the evacuation of Dunkirk which began on May 24, 1940, and later, after Italy entered the war in July, when H.M.S. *Gloucester* was bombed off Calabria, no reference can be found to transfusion being carried out in ships.

The main activity at sea spread to the Mediterranean in the autumn of 1940 and resuscitation organisations with blood and plasma banks were established in the Hospital Ship *Maine* and at the 64th General Hospital—the Joint Services Hospital at Alexandria. Interservice co-operation was excellent on this station, and the Navy both ashore and afloat owed much to the advice and assistance of Major G. A. H. Buttle, R.A.M.C., the Officer Commanding the Army Blood Transfusion Service in the Middle East.

In default of supplies of more reliable blood products, both these blood banks stored unfiltered plasma, decanted from blood with maximum precautions to ensure sterility, and this was put to good use in the treatment of cases of severe burns after several fleet actions. (Wolfe and Clegg, 1942; Ellis, 1942.) The *Maine* even supplied some of the cruisers with this unfiltered plasma which was stored in the frozen state until required, and was used with success. Thus, the adoption of practices, which in normal times would have been inexcusable, was justified by the results.

1941

The experiences of aerial bombing in England during the first two years of the war, and to a less extent of the British Expeditionary Force in France (Maycock, 1940), demonstrated clearly the importance and general practicability of adequate and efficient replacement therapy. Plasma and serum in both wet and dry forms had passed the experimental stages and were being produced in comparatively small quantities, in the United Kingdom and abroad, for the Army and the Emergency Medical Services. The latter also supplied most of the naval requirements, and naval blood-collecting teams were attached to Regional blood banks in London and Leeds.

Certain facts were becoming apparent. Dry or wet plasma and serum were efficient and safe blood products, and would keep for considerable periods without very special precautions. Blood-transfusion equipment had been simplified and standardised. Burns were an outstanding cause of naval casualties. The majority of ships carried small supplies of dry or wet plasma or serum and a number of sterilised made-up 'giving' sets. Panels of blood donors had been organised in many ships, but the medical staffs had been at sea since the outbreak of war, with few opportunities for obtaining the practice necessary to familiarise operators with even the most simple transfusion equipment. Reports of transfusion at sea were still the exception rather than the rule.

On January 10, H.M.S. *Illustrious* was hit off Malta by a total weight of seven thousand pounds of bombs and suffered many casualties. The medical staff were overwhelmed and no blood transfusions were given. No transfusions were reported during the evacuation of Greece and Crete or after the battle of Cape Matapan. After H.M.S. *Repulse* and H.M.S. *Prince of Wales* were sunk towards the end of the year, it was reported that there was no time to transfuse casualties during the eight-hour passage by destroyer to Singapore.

Accounts were heard occasionally of difficulties in using the various types of transfusion equipment available, and complaints were made about blunt needles, which made venepuncture awkward or impossible. The conservative school of thought still considered transfusion afloat impracticable, and indeed, with some of the equipment available in ships, this was only too true.

By this time the resuscitation organisations ashore were established in naval hospitals in areas where there was much enemy activity. Shepherd (1941) has described the experiences in treating air-raid victims at Plymouth.

The resuscitation unit at Alexandria had been enlarged by the recruitment of members of the Friends' Ambulance Unit, who had lost their ambulances in Crete, and by V.A.Ds. from the local British community, and a store of frozen unfiltered plasma was accumulating in cabinets in one of the meat refrigerators of the Royal Army Service Corps. This store was eventually used up during the battle of El Alamein with satisfactory results. Although the possibility that infective hepatitis may have been transmitted in this way, to become manifest weeks or months later, is a consideration which cannot be disregarded, the immediately toxic properties of these unfiltered products seemed to be surprisingly low.

1942

With the entry into the war of the U.S.A. and Japan, one of the first serious attempts to transfuse casualties afloat was reported when H.M.A.S. *Canberra*, operating with Task Force 44, south of Savo Island in the Pacific, sustained 200 casualties in the first five minutes of an action. Casualties were transfused with American dried plasma in U.S.Ss. *Barnett* and *Patterson*, seven patients being infused within an hour of their reception in the *Patterson*. More could have been treated if supplies had been greater.

In home waters at this time the main activities consisted of actions in the English Channel involving coastal convoys on either side, and raids by Commandos. On March 29, after the raid on St. Nazaire, 31 casualties were admitted to the Royal Naval Hospital, Plymouth. Two of the more seriously injured were transfused with fresh blood and recovered.

Following the raid on Dieppe on August 19, 261 casualties—an unexpectedly large number—were admitted ten to twenty hours after wounding to the Naval Hospital at Haslar through a dislocation of the arrangements elsewhere. Very few transfusions were given, only sixteen bottles of blood being used in the first fifteen hours, but only four patients died in the ten days after admission, and three of these were practically moribund when admitted and died very quickly. This incident showed that the unaided recuperative powers of young and healthy men are still very considerable even without transfusion, if they can surmount the first phases of 'shock'.

The Royal Naval blood transfusion service was established in London in February 1942, and from the outset directed its activities towards supplying the fleets with serum and saline solutions and apparatus for administering them.

1943

During 1941 and 1942 many medical officers who joined the Navy had become expert in the technique of transfusion as senior students or housemen at hospitals in the large towns during heavy air raids. Many nursing sisters and V.A.Ds. with practical air-raid experience were joining the Navy Nursing Service and those already in the Service were familiar by that time with many of the problems.

Towards the end of the year, unit boxes of transfusion equipment were issued to the fleets by the Royal Naval blood transfusion service. Each box contained all the necessary apparatus for collecting two bottles of blood from a donor and transfusing it to a patient, for infusing five bottles of reconstituted dried human serum, and for ascertaining the blood groups of donors and recipients. In the first place they were issued on a scale which ranged from five boxes for a fleet aircraft carrier down to one or two for destroyers or smaller ships, but the supplies of blood products were augmented by further issues later. The outfit was complete in detail, and even included a centrifuge attachment for performing cross-agglutination, which could be operated on the ordinary ship's table or bracket fan when the fanhead was removed. The only items which were perishable, apart from rubber tubing, were the dried serum and grouping serum, and the working life of these was thought to be more than enough to meet the probable war-time requirements.

Thus ships were now equipped with standardised equipment which enabled the sickbay staffs to group and cross-group donors and recipients, to collect blood from donors with a minimum delay, and to transfuse patients with blood, serum or plasma. It can be said therefore that from this time onwards blood transfusion was a normal procedure of naval medical practice afloat. An important question to be decided was the scale on which these boxes should be issued. The first issue, based on Army experience, provided enough protein fluid for one average transfusion for every seventy-five men of a ship's company without allowing for wastage. This allowance was on the low side, but, in view of the restricted supply, the choice at the time lay between providing the total force afloat with some equipment or selecting certain units for preferential treatment. The former course was chosen for the reasons discussed earlier.

Reports on the success of these aids in treating shock afloat were soon forthcoming. The predominance of burns among the injured was noted again, and the value was emphasised of portable electric head-lamps for medical work after the light had failed.

On December 26, H.M.S. *Norfolk* was hit twice, in action with the battle-cruiser *Scharnhorst*, when covering a northern convoy, and sustained 52 casualties. Forty-four cases were dealt with in the twenty-six hour period which elapsed between the damage and arrival in harbour. Fifteen sustained second degree burns and three first degree burns. Twelve pints of serum were given to four of the twenty-two serious cases, with striking results in one man though two others died. Once again preventable injuries occurred because men were not wearing their anti-flash gear. The twelve bottles of plasma available were inadequate for the number of cases to be treated, and it was recommended that a minimum of thirty-six bottles should be made available in future. According to the scales of supply adopted for many ships in the Pacific War, 200 bottles is probably nearer the mark for a cruiser on detached service, if provision is to be made to cover all possible eventualities.

The assistance afforded by sick berth attendants who were trained in recording blood pressures and manipulating transfusion equipment was stated to be an important factor in the smooth working of the resuscitation party in H.M.S. *Norfolk*. The 'giving' sets worked excellently.

Transfusion Methods. The technique of transfusion was in the meanwhile developing along fairly standardised lines. The importance of securing adequate replacement of the lost volume of circulating blood, and the dangers of both under- and over-dosage, led to replacement of 'hit-and-miss' guesses at calculating patients' requirements for protein fluids by systematic methods of evaluating the clinical findings. The Army School of Blood Transfusion at Bristol (Kekwick *et al.*, 1941) were among the first to indicate how this could be done and insisted on assessing the patient's condition as a whole rather than by placing undue emphasis on any particular sign or symptom. They relied more on measurements of the blood pressure than on pulse rate, and found simple haematological investigations useful for checking their clinical impressions. Formulae were devised to assess the probable plasma deficiency in burnt patients. Black (1940) made use of the following relationship which was based on the simple estimation of the blood haemoglobin percentage (Haldane), and the assumption that the average normal circulating blood volume was 5 litres, thus:

$$\frac{\text{Hb. 2}}{\text{Hb. 1}} = \frac{5}{(5 - x)}.$$

where Hb. 1 and 2 were the haemoglobin percentages, estimated before the patient received the burn (assessed 100 per cent. Haldane, or 14 g. 100 c.cm. of blood), and observed after he had received the burn; and 'x' represented the blood plasma deficiency in litres. In the Navy this formula was put to valuable use by Wolfe and Clegg (1942) and its value was repeatedly proved by the former in treating casualties in the naval hospitals at Chatham and Haslar.

Hospital Ships. During this time nearly all the Naval hospital ships were employed for carrying wounded rather than as front-line hospitals. This was the most common rôle of hospital ships throughout the war. The general practice was to carry a good store of dried serum and 'giving' sets, and to build up banks of freshly drawn blood from the donors on board, or from the crews of ships in company, whenever many surgical cases were expected.

Naval Hospitals. A clear cut incident which occurred at the Naval Hospital at Haslar as the result of a bomb on a training establishment on June 6 (Ellis, 1946) showed that, however good facilities might be, it would rarely be a simple matter to save severely shocked and wounded men, and directed attention to unidentified lung injuries and defective renal function as additional hazards which swelled the list of fatalities from aerial bombing.

The disappointing results, when compared with the relatively satisfactory results which followed the raid on Dieppe in the previous August when blood transfusion was hardly practised, caused one to review the value of elaborate resuscitation schemes with some misgivings. In retrospect, however, it appears probable that the men who died as the result of the bombing on June 6, 1943 would not have survived to return from Dieppe, and would not therefore have been among cases treated in hospital. When the results of the two incidents are considered together it appears reasonable to conclude that if young and healthy men are holding their own twelve to twenty hours after wounding, they have a good chance of survival even without replacement therapy, if the effects of further operation or secondary haemorrhage and cases of burns are excluded. Massive transfusion at this stage is rarely required if the above eventualities are excluded, and should only be undertaken after careful assessment of the clinical state of the patient, including accurate recording of the blood pressure and fluid balance and, if possible, measurement of the erythrocyte count, haemoglobin percentage and blood urea. Certain of the effects of oligaemia may have been corrected by the patient's own compensatory mechanisms which control the distribution of the body fluids. Undoubtedly the optimum time, when transfusions are required, is as soon as possible after wounding, and the mortality even then will usually be high for the serious cases. Replacement of the blood which has been lost is only part of the story, and the state of the lungs and the kidneys must always be carefully watched.

1944

THE INVASION OF EUROPE

The opening months of 1944 were fully occupied with preparations for the invasion of Europe and, in conjunction with the Army and the Emergency Medical Service, transfusion arrangements were made to supply the assault forces, most of whom were to be carried in a fleet of landing craft, and the coastal areas, where counter-attacks were to be expected and to which casualties were to be evacuated after the attack. The weight of surgical opinion, after the North African Campaign, was in favour of the increased use of blood wherever possible, as opposed to serum or plasma, for the correction of blood loss. This apparently logical conclusion outweighed the additional administrative disadvantages of providing extra blood. It was intended that most of the wounded should be carried by specially equipped Tank Landing Ships (L.S.Ts.), largely staffed and equipped by the Royal Navy, which would carry tanks to France and return with wounded. Each of these L.S.Ts. carried a surgeon, an anaesthetist and a resuscitation officer. The great value of blood and plasma, the efficiency of the transfusion sets, and the high standard of training of medical personnel, stand out in the medical accounts of this great amphibious operation in contrast with the story of the early war years, and suggest that in future dried plasma or serum will be the naval standby for resuscitation afloat.

The Naval Hospitals. The part played by Naval hospitals is clearly described in the account by Hunot (1946) of the arrangement and experience at the Royal Hospital at Haslar. This hospital received many of the most severely injured cases unfit to travel further inland, and 1,347 severely injured men were treated in just under three months following the landing in Normandy. The important part played by transfusion in the resuscitation of casualties is shown by the figures for the first fortnight of the offensive between June 7 and June 21. During this time 576 bottles of blood and 436 bottles of reconstituted dried serum were used in the treatment of 150 out of a total of 585 casualties admitted (approximately 25 per cent.). The total deaths during this time amounted to sixteen, and ten of these were men who were transfused. Each case received on an average about two bottles of blood and two bottles of serum. Twenty-three patients were transfused twice and four were transfused three times. Group IV (O) blood was used on 98·8 per cent. of occasions, 20 per cent. of the blood was collected less than seven days before use, 70 per cent. between seven and fourteen days and 10 per cent. was over two weeks old. The observed incidence of reactions to transfusion was only 2 per cent. but may have been higher in fact. In addition 247 bottles of glucose saline were infused to patients, with an average of just under four bottles per case. The major injuries were wounds of the upper and lower extremities in 44 per cent. and abdominal wounds in 19 per cent. of cases; chest wounds and burns each accounted for 11 per cent. and 6 per cent. had suffered from head injuries. The average time-lag between wounding and resuscitation in this hospital was about four days, so that on admission the initial phase of acute shock had generally passed. Most of the severe cases were probably survivors from acute phases of shock. Many of them, of course, had been transfused before admission. This very low mortality should be viewed with the knowledge that many acutely shocked men did not survive to reach hospital. The successful resuscitation of this large group of severe casualties was achieved only as a result of considerable forethought and planning. Members of the Naval Voluntary Aid Detachment and of the sick berth staff had been trained in transfusion methods for over twelve months before the invasion started, and for three months before D-Day they were instructed in the recording of blood pressures and in assessing the qualities of the pulse. In staffing the wards it was accepted that on the average one nurse could only look after two severely injured patients and carry out her duties efficiently. Technicians skilled in making haematological examinations were attached to the resuscitation ward and carried out their investigations there. All members of the staff were in two watches. The keenness and team-work shown by the nurses and the sick-berth staff, and the planning which had taken into account the numerous staff required for work of this kind, were well repaid by the high quality of the results achieved.

THE MEDITERRANEAN

From this time onwards the value of replacement therapy ashore and afloat, and the good dividends paid by careful training in resuscitation methods were shown again and again in the action reports from all theatres. Thus in October it was reported from H.M.H.S. *Maine*, standing by at the liberation of Greece, that 'six months training of casualty resuscitation teams was fully justified, and one ward was reserved entirely as a resuscitation ward'. The value of a landing craft as a casualty clearing station and the importance of air co-operation was also demonstrated in this series of operation. H.M.L.C.I.(L) 253, a casualty clearing ship, was employed as a forward surgical unit at Zara in the Athens-Piraeus area from November 2, 1944, till January 6, 1945. During the last three weeks of this period 105 casualties were treated. Bottled blood was flown from No. 5 blood transfusion unit at Bari and also from Colombo, and numerous cases were transfused before evacuating, either to a hospital ship lying farther out, or to a field hospital along the coast. The remarks of the Commanding Officer of the 183rd Field Ambulance testify to the value of this intermediate casualty clearing ship; 'the arrival of the L.C.I.(L) 253 was undoubtedly life saving . . . It would have been of great value at Salerno.'

1945

THE PACIFIC

With the collapse of Germany attention turned to the Far East and the Pacific area, where the difficulties of blood storage, and the mobile nature of the fleet's activities caused reliance to be placed to a greater extent on dried serum and plasma, although fresh blood transfusions were carried out not infrequently. In the first part of the year serum transfusions were performed in many ships.

When H.M.S. *Illustrious* was shelled in January the dried serum was reported to be a great success in the treatment of thirty-eight casualties, and the principal medical officer remarked: 'Time should not be wasted in surgical heroics, but vigorous and prolonged transfusion kept up, so that, if the case survives and improves and the situation permits, deliberate operation be undertaken'.

The frequency of burns in actions and incidents at sea suggest that the scale of issue for serum should be double that allowed ashore, where other types of wounds generally predominate. This would entail a supply of at least six bottles for every anticipated severe casualty, however this latter figure may be assessed. It appeared that one bottle for ten men was an adequate allowance for only one severe action in the Pacific. The excellence of the British 'giving set' was praised, and the high dividends paid by careful first-aid training of the ship's company were emphasised. It was recommended in that area that one bottle of serum should be issued for every two ratings in a ship's company, and that venesection sets should be available for medical distributing stations. With such large requirements the need for replenishing ship's stocks of transfusion fluids, or even for providing complete resuscitation teams, by means of organised air transport, will demand careful consideration in future warfare.

LESSONS FOR PEACE-TIME POLICY

The wise pre-war planning which placed the responsibility for research, and for the direction and administration of large-scale replacement therapy, in the hands of eminent medical scientists yielded a rich harvest of knowledge from the battlefields.

When a man is suffering from oligaemic shock in a pure form this condition can be alleviated by the infusion of blood or protein fluids, provided he is treated early enough and replacement is achieved with accuracy. Unfortunately, this uncomplicated clinical picture is the exception and various combinations of pathological processes must be considered in assessing the therapeutic measures necessary for the treatment of a battle casualty.

From the practical aspect of naval medicine, however, these various considerations shrink in significance beside the important facts, so clearly demonstrated, that oligaemia due to blood loss, and haemoconcentration due to burns, can be treated without delay after injury in all ships by the infusion of either blood or blood products.

The great frequency of flash burns in naval actions, or for that matter whenever explosions of any type occur in the confined spaces of a ship, points strongly to the need for continuing in peace-time the organisation for replacement therapy both ashore and afloat on the lines which proved to be successful in the latter stages of the war.

Though medical and nursing staff are now skilled in transfusion methods, the most efficient treatment of patients, and the smooth co-ordination of the many interests in a hospital will only be achieved if the principle of centralising this work and vesting authority in specially designated persons, which in war proved essential, is perpetuated in a modified form in peace-time. Progress will then be made and, if further emergencies arise, it may not be necessary 'next time' to pick up the threads where they were dropped at the end of the previous war.

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A Note on Transfusion in the R.A.F.

For the most part the transfusion needs of the Royal Air Force were supplied by the Army blood supply depot, by the Medical Research Council, or by the Ministry of Health through the various Regional depots. Just before the outbreak of war, electric refrigerators were installed in ten R.A.F. hospitals and large station sick quarters in which blood obtained from the Army blood-supply depot could be stored. Outfits for taking and giving blood were distributed from the Medical Research Council centre at Luton to certain R.A.F. hospitals, and weekly supplies of blood were flown to these hospitals. At the end of 1940 the Medical Research Council placed the facilities of four London supply depots, including liquid plasma and serum, at the disposal of the R.A.F. Although care had been taken to provide all important station sick quarters with means of transfusion, an enquiry made after the Battle of Britain showed that little advantage had been taken of these facilities, for the medical officers had found that the casualties could be successfully evacuated to hospitals within an hour, and there was seldom time or opportunity for doing the transfusion in the station sick quarters.

In March 1941, a Royal Air Force mobile transfusion team was formed and stationed first at Sutton and later (in 1942) at Nottingham. The team was originally formed in some measure to compensate the main blood-transfusion service for blood and blood products used on R.A.F. personnel, and in addition to provide transfusion facilities for R.A.F. personnel not otherwise provided for. The team also served as an instructional unit and gave specialist advice when required. During the five years of its activity the team collected upwards of 50,000 bottles of blood, and throughout the European campaign fresh blood left Nottingham at the rate of 100 bottles per week for the B.L.A. and its associated Air Force.

CHAPTER 3

SHOCK AND RESUSCITATION

By SIR ZACHARY COPE
B.A., M.D., M.S., F.R.C.S.

THE infliction of a wound is often, if not usually, followed immediately or remotely by a series of symptoms accompanied by a condition of instability or failure of the peripheral circulation to which the term shock has been and still is applied. The word is difficult to define and the condition presents variable symptoms which may be due to so many causes other than trauma that there is ground for the objection sometimes made against the use of the word. Yet, in spite of Cannon's (1919) useful suggestion of 'exaemia', up till now no suitable substitute has been generally adopted. It is, however, customary and advisable to combine with the word another qualifying word indicating the particular exciting cause of the condition; thus one speaks of traumatic shock, hæmorrhagic shock, and in the case of battle injuries 'wound shock'.

During the War of 1914–18 much research was undertaken into the nature, symptoms and treatment of shock. Many of the conclusions then arrived at have stood the test of time, though in some quarters they did not make so much impression as was warranted. It was clearly shown that symptoms varied considerably from case to case and that, although the usual text-book descriptions were applicable to severe cases, there were many less severe yet serious cases of shock which would be likely to be missed if one had to rely upon the classical descriptions for diagnosis. It was shown that the estimation of the pulse-pressure was a more valuable indication of shock than the recording of the systolic pressure only, that shock of a serious type might even exist with a normal systolic blood-pressure, that a rapid pulse was not an invariable concomitant of shock, and that the usual mental lethargy associated with the condition might be replaced by remarkable mental acuity and activity which easily deceived the observer into thinking that shock was not present. Moreover, as the result of a study of the material provided by that war and afterwards, attention was called to the importance of the recognition of latent shock, a condition in which, though the circulation might be very unstable and liable to a breakdown under any slight extra stress, yet the appearance of the patient and the record of the blood pressure failed to give proper warning (Cope, 1944).

Efforts were made to find some symptom or test which could be regarded as pathognomonic of shock. We have already shown from the very nature of shock how difficult or impossible this must be. In Germany however, Rehn (1939) proposed a test which, if accurate, might have been an easy solution of the difficulty of diagnosis—the veritol test. It depended upon the supposed fact that the injection of 0·02 mg. of veritol causes a rise of blood pressure in a normal but not in a shocked person. This was unreliable and such a test could not in any case obviate the necessity of taking into consideration the whole of the clinical picture before making a diagnosis.

As regards the pathology of shock, the main conclusions arrived at in the First World War were that shock in all its forms was accompanied by a diminution of the volume of the blood in effective circulation, and usually by a concentration of the red blood corpuscles in the capillaries at the periphery, e.g. in the skin. An estimate of the degree of shock could sometimes be made by noting the increase in the red-cell-count in blood obtained from a pin-prick in the skin. No definite conclusion was agreed upon as to the place in which the 'lost blood' would be found; some of course was lost by haemorrhage, but this was not sufficient to account for the total fluid lost to the circulation. The common view was that it was pooled in dilated capillaries in the abdominal viscera or in the muscles. This theory was not so applicable to primary shock which came on immediately after the infliction of the wound and was thought to be due at least partly to nervous stimuli; but it provided a reasonable explanation for the occurrence of secondary shock which came on twenty-four to forty-eight hours after infliction of the wound and was due to this and to a combination of haemorrhage, sepsis, pain and possibly a toxaemia.

With regard to treatment, once it was recognised that a main feature of shock was a diminished volume of blood in effective circulation, efforts were made to provide more fluid which would remain in the vessels until the general bodily resources could be mobilised. To give normal saline solution was found to be merely of temporary benefit and the administration of gum-acacia solution, introduced by Bayliss, did not fulfil expectations. So that towards the end of that war blood transfusions came into use more and more in the treatment of haemorrhage and shock.

In the twenty-one years intervening between the two wars the most important work on our knowledge of the pathology and treatment of shock was that of Blalock (1940) who emphasised the fact that a large amount of fluid was lost from the vessels of an injured part into the cellular tissues of that part. He contended that the amount thus lost was in many cases sufficient to account completely for the depletion of the circulation and the consequent shock. Others—e.g. Slome (1937–8) could not entirely confirm these findings and maintained that the undue stimulation of afferent nerves contributed much to the causation of shock.

The work of Scudder (1939) showed that in shocked patients there was a considerable increase of potassium in the blood, but his suggestion that this was one of the determining factors in shock was not generally accepted. The excess of potassium was regarded more as a result than the cause of shock.

When war broke out in September, 1939, the Medical Research Council at once appointed a Committee on Traumatic Shock 'to survey the existing state of knowledge of the subject and to direct a resumption of active research upon it'. The problem was surveyed, preliminary reports received and examined and the decision taken to concentrate in the first instance on clinical and haematological studies of blood volume and the effects of blood loss, the experimental production of shock, and the effects of giving high concentration of oxygen to shocked patients. For the guidance of medical officers on active service either at home or abroad the M.R.C. issued a pamphlet (1940) giving the facts, as then known, about shock and offering advice as to treatment. In this it was pointed out that 'the most important single requirement for arresting the progressive deterioration in general conditions which is such a feature of shock, is restoration of blood volume and thereby of tissue metabolism'.

Furthermore it was emphasised that success depended upon the promptness with which the restoration was made. The importance of the relief of pain, arrest of haemorrhage and protection from cold was insisted upon, and full details were given as to the technique of transfusion. A special sub-committee advised on problems of anaesthesia for severely injured patients. The first series of casualties on which were made accurate clinical investigations were those occasioned by the air raids on London and other cities in 1940–41. Kekwick and his co-workers (1941 a and b) carefully studied a series of patients in whom the obvious severity of the wounds and the failure of the blood pressure to recover to 100 mm. Hg under treatment by rest, warmth and morphine demonstrated that the condition was one of secondary, not primary, shock. They found that the mental state was usually rational, sweating and subnormal temperature were the rule, but only about half the patients complained of pain. As a rule the blood pressure was proportional to the degree of injury and the reduction of blood volume, but occasionally extreme vaso-constriction maintained the blood pressure at deceptive level, for example 95 mm. Hg., although in such cases the pallor was intense. They made the important observation that, in order to get the blood pressure up to 100 mm. Hg. or over, it was necessary to give not less than 50 per cent. of the calculated blood loss, which might amount to anything from one to three-and-a half litres. They recommended that the necessary transfusion should be given more rapidly till the blood pressure had reached 100 mm. Hg, and then continued more slowly by the drip method. It was noted that each 540 c.cm. of transfusion fluid raised the blood pressure, on an average, 10–20 mm. Hg.

Later in 1941, Grant and Reeve published their careful report on 100 air raid casualty patients in whom shock was diagnosed clinically or proved to be present. They found that a few of the patients even presented a raised systolic blood pressure, while of those with a blood pressure of under 100 mm. Hg., some had rapid pulses, others only slightly more rapid than normal. A few, and these generally patients over fifty years, showed a pulse rate under seventy. In younger people the blood pressure was better maintained but the pulse-rate tended to be faster. The severity of the shocked condition was as a rule greater in proportion to the time which had elapsed between the injury and coming under observation. They concluded that a haemoglobin value below 75 per cent. indicated that more than two pints of blood had been lost. Pallor was the rule when blood pressure was low, but with a normal blood pressure the colour might remain good even though other symptoms of shock were present. They made a similar observation to that of Kekwick concerning the mental condition; 'one of the remarkable features of these cases as a whole is the entire consciousness and what might be described as mental alertness tinged with anxiety even with severe and rapidly fatal injuries and although the pulse and blood pressure are unrecordable'. Grant and Reeve deprecated the use of the word 'shock', but the term continued to be used for lack of a suitable substitute.

Clinical researches on the shocked condition were continued in the field by Grant and by Wilson in 1943–4. Towards the end of 1943 the Medical Research Council arranged with the War Office for a special R.A.M.C. team of workers to study shock near the battlefield. This team, known as the 'British Traumatic Shock Team No. 1' was directed by Dr. Grant (with the rank of Lt. Colonel) and worked in Italy from February 1944 till June 1945. It worked mainly in connexion with casualty clearing stations and studied the effect of severe limb and abdominal injuries. This team in Italy reached similar conclusions to those arrived at by Wilson in Africa in that they considered haemorrhage to be in most cases the major factor in the production of wound-shock; they found it was usually associated with blood volumes round about 70 per cent. or less of the predicted normal. They thought however, that although the estimation of blood volume was of great assistance, yet the great majority of cases could be treated successfully without this aid. They made the general observation that bleeding usually varied with and in proportion to the size of the wound, and it was their experience that all patients who displayed the complete text-book description of shock had lost much blood and urgently required transfusion. By the time a patient had reached the C.C.S., torn and bloody clothing has usually been removed and bloody bandages replaced. There was general agreement between the assessments of blood loss made in this way and those obtained from blood-volume measurements, though the latter were generally the greater. Blood volume measurements showed also that when tissue damage was large (i.e. between 1 and 2 fists) a blood loss of 2 to 3 pints must be expected. If tissue damage was 'very large' (i.e. exceeded 2 fists) it was almost safe to assume a blood loss of at least 4 pints and probably considerably more. Though in general blood loss increased with tissue damage, large blood loss might occur with small wounds. They experienced difficulty in recognising those who had lost moderate amounts of blood, for patients who only had 70 or 80 per cent. of normal blood-volume might still maintain a normal blood pressure, though usually (but not always) they at the same time had a fast pulse and a pale face. It was impossible for them to calculate how much of the depleted circulation was due to the escape of plasma into the tissues of the injured part.

The clinical report of Lieut. Colonel W. C. Wilson (1944) on the state of men severely wounded in battle in the El Alamein campaign was another valuable contribution on the clinical side. Like the other observers, Wilson saw many examples of the variation of symptoms from the classical description of the text-books. He came across instances in which the blood pressure was surprisingly high in view of the severity of the wound and the state of the pulse. One man with a pulse-rate of 170 had a systolic pressure of 100 mm. Hg., and another with a weak pulse of 140 had a blood pressure of 108/76. He concluded that 'a rapid pulse of low volume was a more constant indication of danger than a fall of blood pressure; a fall of blood pressure was sometimes a comparatively late event in circulatory failure after wounding'.

In view of the difference of opinion concerning the part the nervous system plays in the causation of shock, the following comment by Wilson merits quotation:—'The most prevalent belief among medical officers seemed to be that shock was neurogenic and that blood loss, though often a contributory factor, was not essential; a distinction was usually made between haemorrhage and shock. The influence of the theory on treatment was in some respects entirely beneficial, for instance the insistence on efficient immobilisation of fractures and a gentle handling of wounded men; in other respects, for instance the use of large doses of morphine, not so much to relieve pain as to "prevent shock", the results were perhaps less desirable. Certain widely held clinical impressions were cited in support of the theory: that serious shock could occur without blood loss or could be disproportionate to blood loss; that certain injuries were specially productive of shock; that transfusion sometimes failed in "shock" though it was nearly always successful in uncomplicated haemorrhage'. Wilson himself thought that there were few cases providing acceptable evidence in favour of these views, but he added, '3 cases did suggest quite strongly the participation of some factor other than blood loss in the causation of wound shock. It would certainly be unwise to ignore the possibility.'

It was at the battle of El Alamein that the first large-scale use of transfusion was made and the results were most encouraging. At the advanced units, where as a rule only plasma or serum was available, it was found that even a small transfusion might tide the injured man over a critical period, and the occasional subsequent relapse became much less common when the practice of continuing the transfusion in the ambulance became general. At the field ambulance and casualty clearing stations patients suffering from severe shock were often given three or four pints of blood before operation was undertaken. Profound haemorrhagic shock which might not respond to ordinary rates of transfusion sometimes responded to more rapid rates of introduction of blood. 'A rate of 1 pint in 5 minutes or less, obtained by applying pressure from a Higginson syringe connected to the inlet tube of the transfusion bottle, was sometimes life-saving since it restored the blood volume in a reasonably short time'. Fast rates of transfusion were dangerous in the presence of pulmonary complications. Wilson pointed out the dangers attached to the current treatment of shock. He observed that morphine poisoning sometimes occurred as the result of rapid absorption of large doses of the drug which had been injected subcutaneously at a time when shock was extreme and the peripheral blood vessels strongly constricted; only when the reaction occurred and the circulation was restored was the morphine absorbed. He recommended the intravenous injection of morphine in cases where adequate absorption from subcutaneous injection was unlikely. He also commented on the danger of over-heating in resuscitation. Heating by cages sometimes did more harm than good. He thought it safer to warm the chilled patient after starting transfusion, not before. The preservation of bodily heat by wrapping in blankets was, of course, necessary. Wilson finally confirmed the view that relapse after successful resuscitation was not infrequent and that the man who had suffered from severe shock remained in a precarious state, abnormally sensitive to noxious agents.

These clinical observations regarding the application of heat were timely. During the War of 1914–18 the methods of resuscitation included that of warming the patients by means of heat applied in various ways, without much consideration of the fact that heat in itself might in some cases be harmful, particularly when it induced excessive sweating which by inducing further dehydration would increase the shock. Blalock and Mason (1941a) tried the effect of heat and cold on dogs suffering from haemorrhagic shock and found that the application of heat hastened death, while cold delayed a fatal issue though it did not increase the chance of survival. A year later Wakim and Gatch (1943) showed that both cold and heat were harmful to animals in a state of shock. Allen's experiments (1943 a) showed a good reason for believing that a slightly subnormal temperature in a shocked or bleeding patient was a harmless and even beneficial reaction. Clinically A. W. Kay in 1944 demonstrated the deleterious effects of applying too much heat in the treatment of shocked patients. Noteworthy also was the experience of J. Devine (1943), who observed that wounded men who had been immersed in cold sea water for several hours arrived in better condition than those who, with similar injuries, had not had such an experience; by experimental work on dogs Devine confirmed the bad effect of undue heat on animals suffering from shock. The conclusion to be drawn from all this clinical and experimental work was that réchauffement should always be carried out in moderation.

We might here note a valuable clinical indication observed by Wright and Devine (1944) in connexion with the recording of temperatures. In conformity with the work on réchauffement they found that the rectal temperature of a shocked patient fell nearly 2° F. after he had been put to bed with hot water bottles for an hour. They advised therefore that the application of heat to shocked patients should be controlled or regulated by the reading of the rectal temperature. Their observations led them to conclude that the difference between the oral and rectal temperatures might be taken as a reliable criterion of shock.

The new observations made by the various investigators during the course of the war were embodied in a second edition of the M.R.C. memorandum on shock, which was issued in 1944. In this publication for the first time there was made an authoritative statement as to the variability in the symptoms of shock. It was there laid down that, in view of the frequent deceptive clinical appearances of the patient, the best guides in judging the need for transfusion and other resuscitative measures were the severity and nature of the injury. The importance and frequency of vasovagal collapse were emphasised and more detailed directions given for treatment.

Though during the war it was clearly realised that the battlefield was the best place to obtain material for the study of clinical shock, yet the laboratory approach to the subject was by no means neglected either here or in America.

In 1942, at the suggestion of the Medical Research Council, a small team, consisting of Professor H. N. Green, Mr. F. W. Holdsworth, and a whole-time assistant, was formed to investigate traumatic shock in industrial accidents. Their investigations showed that a very important factor in treatment was the early surgical extirpation of the damaged tissues. The rapid recovery following amputation of lower limbs with extensive muscle damage induced Professor Green (1945) to renew the search for metabolic factors in normal and injured muscle, which might on release into the circulation be responsible for some part of the shock syndrome.

It will be recalled that during the War of 1914-18 one of the theories which gained many adherents was that which attributed shock, at least in part, to the effect of a histamine-like substance absorbed into the system from injured tissues—particularly muscle tissue. Experimental work did not sufficiently support this view and its importance was discounted. Though Green did not think that histamine played any part in the causation of the later systemic effects of shock he thought it possible that it was responsible in some degree for the reactive hyperaemia and possibly for the immediate general symptoms. The work of Green indicated that local loss of fluid was not always sufficient to account for the whole sequence of general reactions commonly termed shock, following injury, and many methods were tried to determine whether shock-inducing substances could be extracted from muscle. Many previous experiments had failed in this quest, and, in view of the fact that extraction of the muscle with boiling saline solution most frequently produced evidence of shock-inducing substances, it was thought possible that any toxic substance extracted from muscle might under ordinary circumstances undergo rapid enzymic breakdown. Accordingly, normal muscle which was to be the subject of experiment, was rapidly immersed in acetone after its removal from the body in order to inactivate the hypothetical enzymes concerned and thereafter it was dried in ether and extracted with normal saline. This method produced an extract which contained a powerful vaso-depressor substance which induced the gradual development of a condition resembling shock, when it was injected into the body by routes other than the intravenous. The condition induced was very similar to that of ischaemic shock in respect of time of onset, degree of haemoconcentration, subnormal temperature, depressed renal function, and the late fall in blood pressure and respiratory rate. Fractioning of the extracts by Bielschowsky (1943 a and b) followed by pharmacological test showed that adenosine triphosphate, which was finally isolated in large amounts from the acetone treated muscle, possessed both depressor and shock-inducing properties. This substance rapidly disappears from dying muscle and failure to inactivate the enzymes in the muscle may have accounted for previous failures to obtain it. It should be remarked here that several observers in the United States demonstrated shock-inducing substances in muscle, but it was shown that the shock-like symptoms were due to the presence in the muscle of the dogs experimented upon of the *clostridium welchii*, which vitiated the results.

Green made further investigations into the nature and action of adenosine triphosphate. He found that the shock-inducing effect of its injection could be diminished by the prophylactic administration of large amounts of normal saline solution. He also demonstrated that the shock-inducing action of this compound was greatly increased by the presence of the magnesium ion, and showed that the onset of shock (produced either by limb-ischaemia or by the injection of adenosine triphosphate) could, under certain conditions, be greatly accelerated by raising the surrounding temperature.

Following the discovery of the shock-producing effect of the adenosine derivative, investigations were made to see if such products of nucleotide katabolism could be obtained from the injured tissues. It was ascertained that, when shock was induced in rabbits by limb-ischaemia, limb-trauma, dehydration or burns, there was a rise in the adenosine equivalent in the blood. A similar rise was also noted in man after experimental limb-ischaemia.

In 1945 the War Office with the collaboration of the Medical Research Council arranged for Professor Green (1948) (with the rank of Lt. Colonel) to take 'British Traumatic Shock Team No. 2' to forward areas of the battlefield in North-west Europe. He there investigated shock in a number of battle casualties. The mobile laboratory on the spot worked in collaboration with the larger laboratory at Sheffield, to which specimens of blood and muscle were regularly flown for examination. These clinical investigations confirmed the experimental work and showed that trauma led to an increase in the blood plasma of substances which are probably derived from nucleotide breakdown. It became clear, however, that if these products played a part in the causation of shock, their action was conditioned by many other factors such as haemorrhage, local fluid loss, fat embolism, etc. The possible rôle of adenosine triphosphate (ATP) in causing wound shock was discussed by Green in the following words: 'What evidence is there of the rôle of ATP in traumatic shock? It is a physiological substance widely distributed in the tissues, which on injection in many species produces shock; so do histamine, adrenaline and insulin under certain conditions. Unlike the latter substances, however, it is rich in the tissue, i.e. muscle, which, when damaged, is particularly responsible for the development of shock. There is some evidence that adenyl compounds are released from injured tissues, and that there is a close biological similarity between shock induced by ATP and by trauma. Whether it has a specific rôle in shock, or whether it is just one of the many substances capable of producing large-scale tissue injury is not yet known.' See Medical Research Volume in this Series, Chapter 3.

During the course of the war there were many other experimental researches into the causative factors, the symptoms and the best method of treatment of shock. An immense amount of work, especially in America, dealt with the production in many types of animals of haemorrhagic shock produced either by rapid or repeated bleedings; but the clinician was more directly interested in the laboratory efforts undertaken to discover exactly how the circulation was depleted in shock. Blalock (1940) had previously shown that there was a great loss of fluid into the traumatised areas, but there were some who thought that fluid was lost by stagnation in or leakage through the walls of capillaries other than those in the injured areas. Engel and Forrai (1943) however, showed that capillary permeability in traumatic shock was not a generalised change, while Fine and others (1943) actually followed the fate of transfused protein, marked by attached radio-active substances, and provided further evidence against a hypothesis of generalised capillary leakage. This view received conclusive clinical confirmation from the valuable and exhaustive studies of Cournand and his colleagues (1943). However, since in the case of burns Netsky and Leiter (1943) demonstrated that there was a prompt alteration in capillary permeability to horse serum in non-burned as well as in burned areas, one could not be too dogmatic as to the possibility of general capillary leakage.

Since it was realised clinically and demonstrated experimentally that both haemorrhage and shock were indications for making good the fluid lost from the circulation, there was much research, both clinical and on animals, as to the fluid which was most suitable for replacement. At the beginning of the war it was believed and taught that normal saline solution was of little value as a replacement fluid, for it soon disappeared from the circulation and the blood pressure was only temporarily raised by it. There were times, however, when saline was the only readily available substitute and there were some who still maintained that it was of considerable value.

In 1940, R. A. King, basing his conclusions on experimental work on cats, advocated the maintenance of an osmotic gradient between the blood and tissue fluids by giving hypotonic saline subcutaneously at the same time that hypertonic saline was administered by intravenous drip. Though this was a reasonable thesis we are not aware that it was tried clinically on an appreciable scale.

The main advocate of the value of saline infusions in shock was F. M. Allen, who (1943b and c) recommended them strongly on the ground that, since shock was defined as a fluid shift, it might be logical to treat it by giving saline infusions until the fluid demands of the injured tissues were satisfied, so that thereafter the fluid might remain in the vessels. In this way the acute circulatory crisis might be tided over until other measures such as plasma injections, aimed at restoring the normal blood composition, were available. Allen recognised the danger of pulmonary oedema, but considered that there was a 'zone of abnormal but fairly stable equilibrium between fatal shock or haemorrhage on the one hand and fatal pulmonary oedema on the other', which needed to be clinically determined. He went even farther than this. He claimed that the main need for the shocked person was electrolytes and that isotonic sodium chloride solution was superior to plasma in reversing the circulatory change in shock. He regarded the restitution of blood-proteins as strictly a secondary consideration 'unrelated to the problem of immediate fatality from shock'. Though these views were not generally accepted, they provided evidence that there was still some use for saline infusions, at any rate as an auxiliary method of treatment.

For the more permanent restitution of the blood-volume, serum, plasma or blood was necessary, for Hill and others (1940) demonstrated that the rise in the blood-volume depended upon the total quantity of protein injected into the circulation. Clinically and experimentally, early treatment of shock was shown to be necessary. As Dunphy and Gibson (1941) remarked 'The earlier and more adequate replacement therapy, the less fluid is required and the less extensive is the protein loss'. Several experimenters tried to adopt bovine serum for therapeutic use and others tried the effect of methyl cellulose (Hueper *et al.*, 1942), pectin, periston, and even ascitic fluid, but the main fluid substitutes were blood, plasma and serum. Plasma and serum could be dried and reconstituted when required. Blalock and Mason (1941b) after considering salts, glucose, gum acacia, gelatin, haemoglobin, Ringer's solution, and blood and its derivatives, came to the conclusion that liquid plasma and serum were the most useful of fluids even in haemorrhage, since plasma supplied twice as much osmotically active protein as whole blood. They pointed out that there was no need to type pooled plasma and it was readily preserved and easily administered. Since in wound shock there was as a rule a considerable element of haemorrhage, whole blood was very frequently used when available. With regard to gum acacia, Minot and Blalock (1940) remarked 'gum acacia may be used in an emergency but reactions are frequent and its prolonged storage in liver and other tissues makes its use inadvisable.'

Many other investigations were made into the value of various methods of treatment. Experimental and clinical work confirmed the value of inhalation of oxygen in some cases of shock. The general opinion from the laboratory was that extracts of adrenal gland were of very limited, if any, value in shock.

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CHAPTER 4

ABDOMINAL AND THORACO-ABDOMINAL INJURIES

By Sir GORDON GORDON-TAYLOR
K.B.E., C.B., M.S., F.R.C.S.

INTRODUCTION

THE wondrous story of achievement in the treatment of abdominal casualties in the Second World War is no narrative punctuated in arresting fashion by therapeutic milestones showing where this or that technique was adopted or discarded or when some surgical attitude might be doffed or donned. Perhaps no province of military surgery of the War of 1939–45 can be less readily fitted into a sequence of therapeutic landmarks, or worked up according to dates to its final *événement*. A week before the Normandy landing I ventured to write: 'Ideals may be for the pursuit and not for attainment, but he would be bold indeed who ventured to foretell that in this province of surgery the zenith of our achievement has yet been attained; already, indeed, the recovery-rate in the hands of a few individual surgeons, whom Luck has perhaps brushed with her wings or who may have been blessed in the matter of environment or fortunate in other ways, has been of almost astronomical magnitude. There is much, therefore, to substantiate the claim of the young surgeon that in the treatment of abdominal casualties he has surpassed his teachers and the previous generation of war-surgeons'. My forecast that the zenith of achievement had not been reached in the early summer of 1944 was justified by the fine comprehensive recovery-rate of 70 per cent. among over 5,000 abdominal casualties in the B.L.A. from June 1944, till the European armistice; and in some field hospitals a recovery-figure of even 80 per cent. was obtained!

The steady crescendo in recovery from abdominal wounding affords eloquent testimony that despite the greater multiplicity and complexity of the injuries of total warfare, the severity of wounds, the increased velocity of missiles with greater maiming effects, and the multifarious congeries of victims of different sex, age and physique, surgery has far greater power to heal and to save than ever before.

The marked improvement in the results of abdominal war surgery is related far less to any remarkable change in operative technique than to such surgical adjuvants as limitless blood and blood-derivatives, the sulphonamides and other chemotherapy, the proper evaluation of gastric suction and parenteral feeding, and a realisation of the importance of retaining abdominal casualties in an appropriate environment from 10 to 14 days after operation. Skilful anaesthesia and successful abdominal surgery inevitably went hand-in-hand, and the standardisation of operative surgery soon made a veteran of the tyro.

The one important advance in technique was the exteriorisation of colon wounds, and this had been promulgated first and foremost, in precept and practice, by Sir Heneage Ogilvie, and saved lives that are to be estimated not in hundreds but in thousands. The colon-exteriorisation operation came into being in the East African Campaign under Ogilvie's aegis and from there arrived with him in the Middle East.

The removal of the coccyx and incision of the fascia of Waldeyer in extraperitoneal wounds of the rectum, for which Brigadier Naunton Morgan was responsible, and the more conservative methods of treatment applied to the kidney, were also among the advances in technique that yielded dividends.

The scanty experience of that fatal infection of the retro-rectal tissues, so lethal in the First World War, doubtless owed its infrequency to the sulphonamide group and penicillin; improved drainage had not provided the complete answer, since the surgeons of the First World War like Hamilton Drummond and Gordon-Taylor in a despairing endeavour to find an answer to the problem had even committed the enormity of abdomino-perineal ablation for severe and infected rectal wounds. The infrequency of extravasation of urine and infective material in the cellular planes of the pelvis of those with wounds of bladder or urethra was certainly in contrast to the experience of the older generation of surgeons; doubtless routine cystostomy and the banishment of the retained catheter, which early became the vogue, accounted for the rarity of a distressing and menacing experience.

The remarkable healing of laparotomy incisions bespoke the value of chemotherapy ; the practice of surgeons varied in respect of drainage of the abdomen, even to the termination of hostilities, but it might be truly said that the more experienced the surgeon, the more often did he drain. But in addition to changes in technique and therapy mentioned above, the great spirit that resided in the hearts of the forward surgeons counted for much, a spirit that refused to accept surgical defeat, a spirit of men who clung to the belief that there is 'no such thing as a corpse till the funeral', who saw to it that every man who could be resuscitated was resuscitated, and every man who could be brought to the operating table alive was tackled unless there was another with a better chance in urgent need of surgery at the same time. Of the forward surgeons of the Desert, the Burma jungle, the Italian glacis and the plains of North-west Europe, the surgeons who toiled in the islands and atolls of the East and in H.M. ships, those lines of Wordsworth in his 'Ode to the Happy Warrior' ring true:

> 'Who comprehends his trust, and to the same
> Keeps faithful with a singleness of aim;
> Who not content that former worth stands fast
> Looks forward, persevering to the last,
> From well to better, daily self-surpast'.

THE EVOLUTION OF THE SURGICAL TREATMENT OF THE ABDOMINAL WOUNDS OF WARFARE

The belly has ever been an attractive target for foeman zeal, but such reparative surgery as had been practised in far-off days for wounds of the abdominal viscera was limited to the occasional repair of lacerations of prolapsed portions of the gastro-intestinal tract. In cases where viscera were not exposed or extruded, as had been known since the days of Henri de Mondéville and Lanfranc, recovery occasionally took place with non-operative measures, and till the present century wounds of the large bowel were held in better repute than those of the jejuno-ileum. Henri, surgeon to Philip the Fair, wrote: 'I have seen wounds of the colon, which had been immediately closed and dressed, to be cured in a short time'; and Ambroise Paré recorded the two following cases of large-intestine injury:

> The Steward of the Portingall Embassadour whom I cured at Melun of a wound made by a sword running through his body that a great quantity of excrements came forth of the wounded gut as he was dressing. Yet he recovered.

Again he writes :

> Not long ago Giles le Maiston, a Gentleman of Paris was run quite through the body with a rapier so that he vomited much blood at his mouth and fundament divers days. He recovered.

Henri de Mondéville had considered it unnecessary to suture a very small wound in prolapsed small bowel; the herniated gut should merely be returned to the abdominal cavity; on the other hand, a moderate-sized wound of the small gut he thought always fatal. Two hundred years later Paré was more enterprising and less pessimistic; for he wrote that gut which is wounded must be sewn up in a seam, and he also took comfort in local applications to the damaged bowel much as does the modern surgeon, but instead of local insufflation of some sulpha preparation he poured on 'mastich, myrrh, aloes and bole'. Paré also endeavoured to instil the gospel of surgical gentleness into his disciples by writing 'the gut must not be put boisterously together and at once into its place, but by little and little'.

On the other hand, replacement of prolapsed gut had been effected less carefully by de Mondéville, who recommended that the patient be placed on his back in a bath, and that he be raised by shoulders and head at one end and by his feet at the other, and shaken, so as to encourage and coax, though vigorously, the bowel to return inside the belly.

Of the Napoleonic Wars, Guthrie wrote: 'There is a much greater danger attendant on wounds of the small bowel than of the large', and this opinion was also entertained by the French surgeon, Baron Percy; Thomson of Edinburgh saw twelve cases of wounded gut recovering after Waterloo, but of these only two were definitely small intestine.

The contributions of Cloquet, Lembert and Dupuytren to the study of intestinal suture, the advent of ether and chloroform, and the introduction of antisepsis and asepsis into surgical practice in the latter part of the nineteenth century not unnaturally determined an altered attitude towards exploration of the peritoneal cavity. The success attendant on laparotomy inevitably stimulated interest in the possibility of operative repair of visceral injuries caused by gunshot wounds, and from the latter part of last century onwards there arose two opposing schools of thought on the subject of the treatment of wounds of the abdominal viscera. American and German surgeons tended to favour laparotomy and repair; others, among whom the French were most outspoken, were against interference; the doubtful evidence drawn from animal experiments lulled military surgeons into a false state of *laisser faire*; the stopper-like effect of the mucous membrane found pouting through a small clean-drilled hole in the gut of experimental animals and a tendency of adjacent coils of bowel to adhere to and seal off such holes, which were adduced as arguments for abstention from laparotomy, may have existed as a temporary phenomenon, and in Gordon Bell's famous case furnished clear proof of the rare possibilities of natural cure through this mechanism. Nevertheless, occasional operations and the inevitable post-mortem findings in the early phase of the War of 1914–18 demonstrated that the visceral wounds inflicted by bullet or shell fragment were such that spontaneous repair was likely to be a most exceptional event.

The conservative view held the field in the South African War of 1899–1901, supported by the authority of Sir William MacCormac, chief consulting surgeon to the South African Field Force who, though at one time in favour of intervention, executed a *volte face* and declared that 'in this (the South African) war, a man wounded in the abdomen dies if he is operated upon and remains alive if he is left in peace'. This fiat, 'MacCormac's aphorism' as it was known, governed the abdominal surgery of war for the first fifteen years of the twentieth century.

Observers in the South African War may not have been so much impressed by the success of expectant treatment as dismayed by the failure of operative treatment. The failure of surgery in this campaign was in no small measure related to a war carried on in an unsettled country of great distances; many casualties inevitably reached field hospitals after a considerable lapse of time, and unwise late interference in penetrating abdominal wounds only detrimentally disturbed the natural processes of walling-off and repair in such as had survived. Sir Cuthbert Wallace furnished two other interesting, if less weighty, reasons against laparotomy: firstly, the number of abdominal casualties was relatively small and the inevitable runs of bad luck which may beset every operator produced a distorted view; secondly, two well-known R.A.M.C. officers recovered with conservative measures and their survival greatly strengthened the opinion of their colleagues that expectant treatment was, on the whole, the better policy. That sagacious surgeon, Sir George Makins, however, remained firmly of the opinion that, perforating wounds of the small intestine are very fatal: 'every patient in whom the condition was certainly diagnosed died'.

This non-intervention policy was pursued in the Russo-Japanese* War (1904–5), the French War in Morocco (1907–8) and the Balkan War (1912–13). In the first, however, there was a partial breakaway led by the Princess Gedroitz who, trained medically in Germany, organised a railway operating unit close behind the fighting line in which some casualties with abdominal wounds were operated upon early and with success.

No case suffers more than the abdominal case when things go badly against his side, and therefore there was little thought of abdominal surgery in the Franco-British armies during their retreat in the autumn of 1914, with all its resultant confusion in the medical services; yet the Frenchman Pascalis successfully ligatured a bleeding branch of the left colic artery on September 10, 1914.

Away up at a 'British Field Hospital for Belgium', first sited at Antwerp and later, after a crisis evacuation at Furnes, untrammelled by directions from authority, a youthful Guy's surgeon named Pedley, on September 11, 1914 successfully dealt with a shrapnel wound of the belly which had injured a Belgian soldier's small intestine in two places near the ileocaecal junction; on the following day (September 12, 1914) the same surgeon operated on another Belgian casualty, performing what was tantamount to an exteriorisation-resection for a gunshot wound of the colon; the resulting colonic fistulae were successfully closed on September 29, 1914, at this same field hospital by Henry (now Sir Henry) Souttar, a welcome emissary from 'The London' with its great abdominal tradition.

On October 5, 1914, Souttar himself dealt successfully with a Royal Marine, who had sustained wounds of the ileum produced by a shrapnel ball. Between September 17 and the beginning of December, Souttar, by operation, had saved four out of six patients with abdominal wounds.

Louis Bazy, working at a neighbouring surgical unit at Furnes, also saved a patient suffering from a missile wound of the bladder and neck of the femur on Christmas Day, 1914, but had already had some abdominal successes before that date.

These cases perhaps constitute the earliest of the huge number of patients with abdominal wounds destined for laparotomy during the First World War.

The South African War policy still continued to hold sway over the treatment of belly wounds on the British Army Front, producing deplorable results. Those abdominal casualties who survived to reach a field ambulance or casualty clearing station were treated on a more or less standard procedure; the patient was put in the Fowler position;

* The Japanese bullet was a small bullet.

water and food were withheld for three days; morphia was given; thirst was allayed by rectal salines and mouth washes. Many improved greatly in the first three or four days and were then transferred to the base where subsequent deterioration in their condition in base hospitals showed that the early improvement was misleading. The situation would doubtless have been seen more clearly at an earlier period, had the patients been retained longer in the forward areas. Communications and interchange between front and base, however, were poor, and it was not till the early half of 1915 that the real state of affairs was appreciated.

Whether conservatism had been right or wrong in South Africa—and it may have been right for other reasons than the risk of laparotomy itself—it was obviously not right under the new conditions.

Thirty-five years ago military surgical authority was less resilient than to-day; even as late as March 15, 1915, a directive was issued reminding forward surgeons that wounds of the intestine which can be sutured were rare and that resection must be anticipated in wounds involving the small intestine, if indeed an operation were undertaken at all.

Souttar's successes, published in January 1915, went unheeded; Cuthbert Wallace (to whom the abdominal casualty and the forward surgeon alike owe so much, that the writer once suggested that St. Cuthbert must be the patron saint to whom must look those stricken in the belly), was surreptitiously taking in his pockets Spencer Wells forceps for the use of casualty-clearing surgeons of the First Army; and Owen Richards, whose academic stature, surgical judgment and skill naturally entitled his opinion to consideration and respect, with full knowledge and appreciation of the damage irrecoverable apart from operative treatment produced by the missiles of the First Great War, had performed his first laparotomy on January 28, 1915. One of his early successes (March 18, 1915)—the successful resection of six feet of prolapsed shattered small gut in a Scottish Canadian who came back from a trench raid because he 'wanted to die in his own lines'—constituted a milestone in the advance towards an intelligent treatment of wounds of the belly. Then came Frankau's* successful colonic resection at 54 C.C.S. The D.M.S. of the First Army at last directed some of the field ambulances to send patients with abdominal wounds to the nearest casualty clearing station, and in view of the encouraging results, the rapid evacuation of patients with abdominal wounds received official approval in the first week of August 1915. Communications concerning wounds of the belly emanating from surgeons like Owen Richards, John Fraser, Campbell Milligan and Shorney Webb, Basil Hughes and Seymour Barling consolidated surgical opinion in favour of intervention, which soon became general throughout the Armies.

Despite the difficulties attendant on its birth, the rôle of laparotomy

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* Now Sir Claude Frankau.

in the treatment of the abdominal casualty seems to have been firmly established at an earlier date in the British zone than in the French sector of the Western Front. Exceptions to intervention were still admitted; for instance, expectant treatment was regarded as preferable where it appeared certain or highly likely that the visceral damage was confined to the liver; and a similar course was adopted in patients received late, in the hope that the peritonitis might become localised. The great need, however, was for an organisation whereby casualties could be dealt with promptly after wounding. This was not difficult where, as in France and Belgium, the casualty clearing stations were only a few miles behind a static line; for the occasional less static conditions special teams and field hospitals were arranged. Thus this outworn and outmoded policy of conservatism came to an end, this strange attitude of self-confessed defeatism mingled with pious hope. The clock which seemed to have been put back to the days of Ambroise Paré, to the period of Smollett and Roderick Random, to the time of John Hunter* and the surgical practice of the Peninsula and Waterloo, now had its hands brought up to time to move in unison with modern surgical thought and practice. As Rochard wrote: '*La logique a triomphé du paradox; les plaies penétrantes de l'abdomen par projectiles de guerre viennent enfin d'entrer dans la domain de la chirurgie active; et c'est comme un soulagement pour notre entendement*'. Among the great French protagonists of surgical intervention were E. Quenu, Pierre Delbet, Souligoux, Pierre Duval and Rochard. Pierre Duval in presenting the story of the abdominal casualties coming within the purview of Tartois was able to show that of eight treated conservatively all died; of 15 treated between March 23 and June 4, 1915 by suprapubic drainage only 3 lived, i.e. 20 per cent. Between June 4 and July 16 of 11 cases submitted to laparotomy 5 survived—45 per cent. The struggle between these men and abstentionists like Tuffier and Chevassu was not settled until the very eve of the Somme offensive in the summer of 1916, when the Society of Surgery of Paris by formal vote decided in favour of early surgery for the abdominal wounds of war. [The evidence on which this decision rested came from the work and enterprise in the Automobiles Chirurgicales ('Autochirs') of young French surgeons like Bouvier and Caudrelier, Gatellier, Rouvillois, Pascalis, Rouhier, Didier, Paul Mathieu, Lorin, Hourtoule, Boulay, Barbet, Tartois, Stern, Bichat and Louis Bazy. These and many more were the 'F.S.U. surgeons' of the French sector of the Western Front in the War of 1914–18.]

In Germany bias was soon towards laparotomy. Kronig of Freiburg wrote early in 1915 that nothing could be worse than the results of conservative treatment, and by the spring of that year

* 'What is the best practice where it is supposed an intestine may be wounded? I should suppose the very best practice would be to be quiet and do nothing.' John Hunter.

Schmieden reported that out of 94 cases treated expectantly only 4 survived; on the other hand Enderlen strongly advised laparotomy, the wound-time interval and other factors permitting, having obtained 30 per cent. successful results, while Sauerbruch claimed 23 cures out of 54 abdominal casualties treated by operation—43 per cent. recovery. Of another collected series of 322 treated by non-operative measures 258 succumbed—80 per cent. mortality, whereas of 266 submitted to laparotomy 161 died—60 per cent.

Resuscitation in the War of 1914–18 consisted of the simple measures of warmth, rest, morphine and posture, to which were added for the first time as a routine the intravenous infusion of saline and later, as the result of Bayliss's work, of gum saline. There was a wide interest in blood transfusion, but this was still a novel procedure, and the blood was always taken from donors on the spot, for the storage of blood had not yet been perfected and there was no organisation to supply the lavish quantities that were available from the very outset of the War of 1939–45.

The management of the wounded man after laparotomy was much the same as the expectant treatment had been in earlier years. In Fowler's position he was given rest and quiet with the help of morphine, and fluids by mouth were restricted for a few days. Post-operative intravenous fluids were not often given, but rectal salines were used as a routine by some surgeons.

Paralytic ileus was a not infrequent and a formidable complication, which was at one period anticipated by a prophylactically wide resection of bowel or treated with little success by gut stimulants from above or more hopefully by enemata from below. When success failed to attend these measures, an enterostomy or one of the various types of anastomosis was employed, or intermittent gastric lavage with a wider-bored stomach tube; for the most part the necessity for such measures was of ominous portent.

Some surgeons recognised that early evacuation to the base was a dangerous procedure and during quiet periods most of them retained their patients until they had recovered sufficiently to stand the journey, but the practice of retaining abdominal casualties in the forward areas did not become the standard practice until 1942 in the campaigns in Libya and North Africa.

In the years between the two World Wars the major surgical developments which appeared likely to influence war surgery in general were those concerning resuscitation and chemotherapy. The introduction of continuous drip transfusions and infusions, and the conquest of difficulties in storing blood, plasma and serum, had been revolutionary; but important as had been the discovery of the sulphonamides for abdominal work, two features of civil surgery were destined to make a special impress on military abdominal surgery (*a*) the recent innovation of gastric and intestinal suction through indwelling tubes, used chiefly as

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a post-operative measure after abdominal operations and (*b*) for colonic injuries the revival of the Paul-Mikulicz exteriorisation technique as employed for resection of new growths of the large intestine.

The following sections furnish an account of the methods of treatment and the results of surgery on abdominal casualties in the various portions of the globe in which the War of 1939–45 was fought.

ABDOMINAL INJURIES

EVACUATION AND FIELD CONDITIONS

DIFFERENCES BETWEEN CIVILIAN AND MILITARY SURGERY

Although civilian and military surgery have many points in common, there are also important differences, such as the complication in military surgery of the explosive effect of missiles, the almost constant threat of infection, the inevitable delays in treatment, the necessities of evacuation in the field, and the less advantageous conditions in which operation is undertaken, factors which vary with the character of the campaign and depend upon local qualities of soil and climate and the facility of communications. As Major General D. C. Monro has wisely said:

> It is the ability to adapt his surgical procedures to the varying and often trying conditions that may be met with in the field, and to improvise where necessary without departing from accepted surgical principles, that characterises the successful and experienced military (Army) surgeon. He must also learn to appreciate that circumstances may force him to modify his treatment to suit them, and also to accept that it may be necessary for him to work to a definite plan or policy in conformity with others when the local or general tactical situation demands it.

The patient with an abdominal wound is most apt to suffer from the difficulties of communication and the resultant delays in treatment; he is helpless, the preservation of his life entirely depends upon the smooth working of the medical evacuation, and of all casualties the soldier with the wounded belly fares worst when the battle goes against his side.

THE EVACUATION OF THE WOUNDED SOLDIER

Before the abdominal casualty can receive appropriate definitive treatment, he must be evacuated from the battlefield to a place where it is convenient for such treatment to be carried out. Experience has shown that the best spot for this is sufficiently distant from the front line to be beyond the reach of the enemies' land weapons and behind our own heavy guns, yet far enough forward for the delay caused by evacuation not to be too dangerous. It is also of prime importance for the abdominal casualty to be nursed there until he is fit enough to be evacuated to the base, and ten to fourteen days are required for this stage to be attained.

A soldier wounded in the abdomen certainly should not walk and usually must be carried by the battalion stretcher bearers to the regimental aid post (R.A.P.). The only treatment which he can receive here is first aid, such as the control of gut protrusion, the administration of morphine, and in some few instances plasma transfusion; it is most important that he then be quickly and smoothly evacuated either through the normal channels—advanced dressing station (A.D.S.) to the main dressing station (M.D.S.) of a field ambulance (which receives the casualties of a brigade)—or preferably, as happened later in the war under optimum conditions, direct to the advanced surgical centre. The advanced dressing station could begin a plasma transfusion, and the man was often evacuated with the transfusion running ('travelling transfusion'). Sometimes an 'advanced surgical centre' was formed by posting a surgical team to the M.D.S. and the patient received his definitive treatment here, as frequently happened during the last few years of the war: for example, during the fighting at Monte Cassino in Italy such a centre was formed at a main dressing station situated in a well-protected crevice in the mountains known as the 'Inferno Track' at a distance of only two or three miles behind the fighting. At other times evacuation was continued to the casualty clearing station or a centre formed by a surgical unit and a field dressing station; the C.C.S. possessed better facilities of every kind, including adequate X-ray and laboratory facilities, and the nursing was usually supervised by members of the Q.A.I.M.N.S. The field dressing station was evolved during the later years of the war to lie at a point somewhere between field ambulance and casualty clearing station; X-ray or laboratory facilities were lacking at this level, but the nursing was supervised as a rule by members of the Q.A.I.M.N.S. and hundreds of abdominal casualties were successfully treated at forward surgical centres formed by the linking of a F.S.U. and a F.D.S.

Abdominal cases, if not retained in the forward unit which had operated on them until their convalescence was well established, suffered a great deal during evacuation to the base, and at times when premature evacuation had to be carried out owing to urgent military necessity, their early progress was rudely and disastrously reversed; for example, one particular convoy was evacuated hurriedly from the Anzio beach-head, and out of some eight abdominal casualties four died owing to the evacuation: small landing craft had to be used which, in a rough sea, was more than these wounded men could stand; on the other hand, during the smooth working of medical evacuation which accompanied the successful capture of Monte Cassino, abdominal casualties were retained in forward units until they were fit to travel, and in these cases the mortality of evacuation was nil.

DISTANCES AND DELAYS OF EVACUATION

The prognosis of abdominal injuries was, to a large extent, influenced by the hazards of evacuation. The length of time and the roughness of the journey were the important factors. Distance alone had no significance; an evacuation of a few miles involving a long hand-carry and a bumpy ambulance journey was obviously more damaging than a smooth flight in an aeroplane. The shock caused or increased by exposure, dehydration and the trauma of an ambulance journey over bumpy, winding, hilly roads is a factor rarely experienced in civilian practice, yet inseparable from the surgery of war. Evacuation facilities were always bad in unsuccessful or uncertain fighting, and very few abdominal cases were saved during the retreats which were a feature of the earlier part of the war in the Western Desert and Burma.

Soldiers wounded in the abdomen during air-borne operations and commando landings as a rule suffered badly, unless the position was quickly exploited by the main forces. In advances behind which there was undoubted supremacy, the surgical centres were pushed well forward, the surgeons operated on their cases early, were able to retain them with surety until they were fit enough to withstand a further journey, and the results of abdominal surgery were correspondingly gratifying.

PRIORITIES

Most patients with abdominal wounds are of 'first priority', requiring skilled treatment more urgently than other casualties, with the exception of those with asphyxia and severe haemorrhage; they are certainly as urgent as traumatic amputations and other gross flesh wounds.

RESUSCITATION AND PRE-OPERATIVE TREATMENT

Introduction. The process of resuscitation was a continuous one, and every medical formation from the stretcher bearer 'in the line' down to the field transfusion officer at a casualty clearing station had a part to play. The good results obtained in the treatment of these seriously wounded patients were due to the selfless efforts of surgeons to get the injured man into the best condition possible for operation, and the laudable attitude invariably adopted by British surgeons towards abdominal casualties that none were hopeless until they were dead. Occasionally even the most unpromising cases, whose systolic blood pressure was in the region of sixty, recovered as a result of a combination of active resuscitation and rapid and expert surgery, and very rarely indeed was operation denied even to these seemingly hopeless cases, although occasionally in times of stress the more promising were chosen first, thereby adding still more to the jeopardy of those who appeared to be moribund. Resuscitation consisted in making the patient as comfortable as conditions would allow, placing a pillow behind his head and another under his knees and several thicknesses of blanket beneath him; alleviating his pain with morphine, arresting haemorrhage by pressure, restraining or replacing prolapsed gut and transfusing him with plasma or blood. Some of these procedures were carried out at regimental level; all cases of course received a dose of morphine; but the degree of comfort which could be arranged for the abdominal casualty depended enormously on the resource and ingenuity of those who looked after him in the battle area. Transfusion was very rarely started at regimental level, sometimes in the advanced dressing station, but usually it was left to the advanced surgical centre, either field surgical unit or casualty clearing station, to commence the final pre-operative resuscitation of the injured man.

RESUSCITATION

The resuscitation department, which of necessity had to be close to the operating theatre, was usually supervised by a field transfusion officer with his unit. Many lives depended upon his efforts and skill, and the smoothness with which he ran his department influenced the whole working of the advanced surgical centre. In his department the patient was made as comfortable as conditions allowed; boots were usually removed, and in quieter times it was even possible to undress the man and put him properly to bed, although this was as a rule undesirable, since any movement was harmful. In hot climates the removal of the grime of battle from hands and face usually added to the man's comfort, but in cold weather this was difficult and not welcomed by the patient.

Warmth. It was usually possible to replace his dirty blankets with clean ones, and, if he were very cold, to add to his comfort with a hot water bottle or two. The use of electric cradles and special shock cages had been abandoned at an early stage of the war, because it abolished the protective vaso-constriction, and induced sweating in an already dehydrated patient. Care was taken that these evil results were not produced by the zealous, but misdirected efforts of orderlies with hot water bottles, of which most units had a liberal supply.

Fluids by mouth were withheld, but the cleansing of the mouth or the sucking of a wet swab was able to allay the uncomfortable and sometimes almost unbearable dryness from which these abdominal casualties suffered.

Morphine. Nearly all the wounded soldiers admitted to an advanced surgical centre had received a dose of morphine, which usually amounted to ¼ or ½ gr. administered subcutaneously. Gradually, as the war progressed, most resuscitation officers and surgeons became convinced of the greater value of giving morphine intravenously: the drug was thereby immediately absorbed, its action was rapid and the effects of a dose could soon be observed; whereas the subcutaneous route was uncertain in its action and the drug might be given into a cold limb whose circulation was so poor that absorption was delayed, and repeated doses into this limb might lie unabsorbed until rapidly released, when other methods of resuscitation had begun to take effect. All doses of morphine and the route of administration were scrupulously recorded on the field medical card. A dose of ¼ gr. intravenously was found as a rule to be completely safe, and in some robust patients ½ gr. by this route appeared to be only just sufficient to produce the desired effect. It was a common observation among surgeons that the rigidity of the abdomen after gunshot wounds was not as great as that seen with a perforated duodenal ulcer. Undoubtedly the widespread and liberal use of morphine before patients were evacuated to advanced surgical centres to some extent contributed to this impression, and soldiers who had not been so heavily pre-medicated showed a degree of rigidity more closely approximating to that seen in civilian perforations.

TRANSFUSION

One of the early duties in the resuscitation department was the estimation of the patient's degree of shock. Not all abdominal casualties required active resuscitation, and a patient with a through-and-through bullet wound of the flank damaging only the descending colon might well have a normal blood pressure. However, if an abdominal wound appeared to be probable, the blood-pressure was always taken, and when possible, a sphygmomanometer cuff was applied to the arm and repeated pressure readings were taken and recorded, together with the temperature, pulse and respiration. In some units the resuscitation officer commenced a chart which embodied the valuable information usually contained on an ordinary temperature chart, and in addition frequent blood-pressure readings were entered and the estimation of fluid balance was begun.

The Amount of Blood. The transfusion was usually begun with blood, but when this was not easily available plasma was employed. As a rule the amount required was two to three pints, the blood pressure beginning to rise as the first pint was given, and ordinarily the patient was sufficiently recovered for operation to be begun in one to two hours. The rate of transfusion was determined by the needs of the patient; sometimes it was essential to introduce the first pint or two at high speed to overcome shock before it became irreversible, and the first pint was often with advantage given in as short a time as five minutes. Blood and plasma were usually required in the ratio of 2:1.

Desperate Cases. In some patients, four, five or even more pints of blood were given, but there was some danger in over-transfusing with blood. Some transfusion officers, in the hope of saving a desperately shocked case, would transfuse into two or even three limbs at the same time, and on rare occasions this produced the gratifying result which the transfusion officer hoped for; on the other hand if the leakage of plasma continued and the process of haemo-concentration progressed, a blood was produced so viscous that the patient died; so that in these heroic cases it became apparent that some admixture of plasma was desirable.

When the blood pressure did not rise after transfusion, adequate both in speed and in volume, the question of a quick laparotomy had to be decided. A deduction, and usually a correct deduction, was made in these cases that there was continuous haemorrhage from mesenteric vessels, and occasionally rapid transfusion and rapid surgery could, in spite of severe hypotension, save the soldier's life.

Time to Transfuse and Operate. It was usually advisable to wait until the blood pressure had been given every chance to rise to 100 or over; and in the diagnosis of the recovery from shock, signs of lessening pallor and returning warmth to the extremities were also taken into account. 'If the patient has cold feet, the surgeon will do well to develop cold feet also until the patient's feet have improved'. It required much experience to decide when the patient had reached the crest of the wave and was fit enough for surgery. There was a general opinion that resuscitation was much less successful the second time it was attempted than it had been the first, and it was believed that transfusions were better withheld until the casualty reached a surgical centre and that active resuscitation should be begun only when operation could follow at the optimum time. 'Travelling transfusions' rigged up in ambulances on the way from the front line to the operating centre were strongly advocated by some and condemned by others. No general agreement upon this point was ever reached; nevertheless it was obvious on numerous occasions that a 'travelling transfusion' had kept a man alive when in its absence he would have died on the way.

Cold and Warm Hypotension. Lt.-Colonel R. T. Grant made the valuable observation that the appearance of the patient, both before and after operation, might be misleading. While some cases showed peripheral vaso-constriction with pallor, others who had an equally low blood pressure exhibited an anomalous peripheral vasodilation, caused by external heat or some other unknown factor. This clinical condition and appearance was indeed dangerous, since in the urgency of battle conditions a red-faced man might not unnaturally be considered to be in small need of resuscitation and therefore there was the danger that the casualty might collapse and die before adequate measures could be taken to restore his condition. This condition was especially dangerous where the cyanosis which heralded death in cases of warm hypotension could not be seen owing to poor light, since death rapidly followed if treatment were not carried out betimes.

Exhaustion and Dehydration. The casualties were sometimes in a state of complete physical exhaustion at the time of their wounding. Under these condition dehydration might be a very important factor, and it was advisable to transfuse these men, not only with blood, but with glucose saline.

Lowdon and other surgeons were deeply impressed by their experience in Sicily where the mortality in abdominal cases was very high between the third and fourteenth day of that campaign. In that particular period the majority of abdominal cases never appeared to rally after operation and died within the first forty-eight hours, though their visceral lesions were not unduly severe and the usual facilities for treatment were available. At one surgical centre in Lentini, at the end of the second week of the campaign, two field surgical units operated on 12 abdominal cases in one night session, and all died; the only altered factor to which this could be ascribed was the exhausted condition of the men when they were wounded. They had endured unusually continuous fighting and marching, and there was reason to believe the statement made by many of them that their longest period of rest in 10 days had been one of 2¼ hours. In the first 3 days and after the second week of the campaign, the results were as good as at any other times in the experience of the surgeons who had this temporary dismal experience.

Reactions to Transfusion. Reactions to transfusion were not infrequent, especially in a hot climate, and as a rule, if not severe, did not interrupt, but possibly slowed, the rate of transfusion. If the reaction was severe, a new apparatus and a fresh pint of blood were used. A very careful watch had to be kept for intravascular haemolysis, due to either mismatched blood, which was exceedingly rare, or to stale blood. The penalties for overloading the kidneys of these patients might be very great; and if to the burden of dehydration, chloride loss, administration of sulphonamide and toxaemia were added this severe additional burden, it might well prove fatal. If intravascular haemolysis were suspected, 100 c.cm. of an 'alkali solution' (4 per cent. bicarb. and 4 per cent. sod. cit.) were given in a bottle of glucose saline as a rapid transfusion, and followed by 300 to 500 c.cm. of the same solution in saline every twenty-four hours.

Other Injuries. In the resuscitation department a careful watch had always to be kept to see whether an abdominal case had additional serious wounds: a fractured femur might easily be overlooked when a man was covered by layer upon layer of blankets, and an early, thorough questioning and examination of the patient for wounds other than in the abdomen was well repaid; the uncomplaining British soldier would not infrequently keep quiet about a shattered foot when his abdomen was being attended to, and in the stress of battle concomitant damage of this nature could be overlooked.

Blast. Blast injuries of the lung and abdomen were frequently associated with penetrating wounds; *rapid transfusion was probably lethal to a patient whose lungs were bruised by blast.* It was therefore wise to find out how far he was from the explosion, and to proceed cautiously if a blast injury seemed likely.

PRE-OPERATIVE PREPARATION

Before sending the patient into the theatre the transfusion officer saw to it that the pre-medication with morphine, hyoscine or atropine had been given, that the intravenous channel was patent with either blood or saline dripping in, and if no longer required for resuscitation, was running very slowly, but nevertheless going. Finally, if the surgeon and anaesthetist wished (and many of them did), a stomach tube was passed into the stomach and the gastric contents aspirated. This last had the advantage of reducing anaesthetic vomiting, with the subsequent risk of inhalation of food particles. It had the disadvantage of disturbing an already overburdened patient, and, with the use of a pentothal injection, vomiting at this stage of the anaesthesia seldom occurred. The urine, if there was any to collect, should have been examined at least by the naked eye to see if there was any blood in it. If no urine could be passed and there was even a remote chance that the urinary organs were injured, a catheter was passed; and this the transfusion officer would have done, retaining the specimen of urine for the surgeon to examine.

The diagnosis of the wounded man had already commenced with the regimental medical officer, and would very often have been correctly written on the field medical card, but information of value would also be added by anyone into whose care the patient fell, and it was an important function of the resuscitation department, which might have had the patient under their care for several hours, to contribute further important points towards the diagnosis. They had opportunities of examining the patient and of noticing associated injuries, and these were brought to the notice of the surgeon. Not infrequently a transfusion orderly or an undressing orderly would make an important diagnosis such as a fractured femur or tibia associated with the abdominal wound, which had hitherto attracted all the clinical attention. Diagnosis and treatment had always to proceed hand in hand.

GENERAL REMARKS ON DIAGNOSIS OF ABDOMINAL WOUNDS

The decision to explore the abdomen depends upon evidence of injury to a hollow organ or of severe bleeding into the peritoneum. In most of the abdominal wounds the decision was not difficult to make, yet, though the number of needless laparotomies performed, measured against the number of necessary operations, was agreeably small, the total number of unnecessary operations performed during the whole course of the war was considerable. These operations, often performed under circumstances far from ideal, proved to be a major cause of death in very many instances, especially if the subject had sustained other serious injuries; the additional burden of laparotomy in these cases could not be borne. The difficult cases were mostly those in which there was an entry wound only and especially when this was outside the immediate neighbourhood of the abdominal cavity, for example: if the missile entered through the back or thigh or gluteo-perineal region; thoraco-abdominal wounds; and general 'peppering' of the body with a small abdominal penetrating missile. Those abdominal cases which were associated with a wound of the head, and a resulting state of semi-consciousness which masked the abdominal wound, were specially difficult to diagnose. Where there was an entry wound in the anterior or lateral aspect of the abdominal wall, a doubtful diagnosis could be confirmed or refuted at routine exploration of the wound, so that the difficulty here was readily overcome.

As aids to diagnosis, two sources of information were available: (*a*) the estimation of the direction of the track, and ancillary examinations such as radiology; (*b*) the clinical findings.

(*a*) A most important investigation was an enquiry into the posture of the man when hit—information which could very often be obtained from the patient. If this were known and taken into account when the entry wound was examined, an idea could often be obtained of the direction of the passage of the missile.

X-ray examination was frequently not available and many surgeons served in several campaigns without it; yet most agreed that when the diagnosis was obscure, radiology might often have helped, though its use was limited because of the difficulty of obtaining adequate lateral views which would have made localisation more exact. There was a fairly widespread feeling among surgeons that if the facilities for X-ray had been available, they might have been a positive disadvantage because of the disturbance which the examination might cause a man too ill to support any additional burden, however slight; and because delay in operating might be increased. All were agreed that if X-rays were to be taken, they should be done in the pre-operation room; the machine must be brought to the patient.

All abdominal patients were catheterised as a routine and signs of blood in the urine were noted. All lower abdominal and gluteal wounds necessitated careful digital examination of the rectum; some surgeons liked to have a proctoscope available, but most, including the more experienced, found endoscopy of little value and relied entirely on digital exploration and other signs. The doubtful gluteo-perineal wound always needed to be carefully investigated under anaesthesia.

(*b*) The clinical picture, including the degree of shock and general signs of blood loss, was the most important guide to the seriousness of the injury. A sluggish response to resuscitation suggested a serious intra-abdominal lesion.

The signs and symptoms of perforation or laceration leading to severe bleeding are naturally very closely allied to those of the abdominal crises of civilian life, but there are certain important differences which the military surgeon learns to recognise.

All cases have received morphine before he sees them, and though the administration of this is uniform, the effect varies very greatly in different cases. It was commonly found that repeated subcutaneous or intramuscular injections of morphine had little or no effect during the stage of shock, but exerted a profound effect—often the effect was cumulative—as the degree of shock lessened. Thus, all signs and symptoms were often masked, sometimes in marked degree.

Apart from this effect of morphinisation, severe shock itself may reduce susceptibility to pain and the power of the abdominal musculature to contract in response to peritoneal irritation: thus abdominal rigidity may not be as marked a feature as the severity of the lesion might normally produce. The board-like rigidity characteristic of a perforated gastric ulcer was rarely if ever observed. It was also often noted that when an intestinal perforation was examined within the first few hours after wounding, the tell-tale rigidity might be very slight indeed, since the amount of peritoneal soiling was insignificant.

Clinical diagnosis depends on the weighing up of innumerable pieces of evidence. As Bastedo and Johnston point out, there is no one sign of abdominal penetration that can be relied on at all times for all cases.

Vomiting is frequent in all types of abdominal injury, but unless the vomit contains blood, its diagnostic value is slight. Absence of liver dullness is of very small value as a physical sign of bowel perforation. Similarly, radiological evidence of the presence of gas between the liver and diaphragm should not be taken as certain evidence of bowel perforation, since air may be taken into the abdominal cavity by the missile, and the intestine may escape unscathed. The presence of shifting dullness is, of course, significant. Shoulder-tip pain sufficiently characteristic for absolute diagnosis was rarely met, and bowel actions and the passage of flatus after injury were without significance.

One of the most helpful diagnostic methods was auscultation of the abdomen. The method is based on the fact that peristalsis ceases if the intestine is severely damaged, and no peristaltic sounds can therefore be heard on listening with a stethoscope. The sign of the silent abdomen is however fallible: many surgeons have heard peristalsis when subsequent laparotomy has shown a perforating injury of a segment of bowel, particularly in the colon. It is quite obvious of course that this must be so, for the whole of the plain muscle of the gut will not necessarily be paralysed, if there is a small wound in one segment of it.

Lt. Colonel C. G. Rob made a very useful statistical study in an attempt to assess the value of auscultation and also drew attention to the need to distinguish between the splashing of static fluid within the coils of small bowel during movement of the patient, and the sound produced by peristalsis itself; he also stressed the need for listening for a long period—a minute or so—and of repeating the examination at frequent intervals.

Of 166 cases in which his observations were carefully recorded, 95 had a penetrating lesion of a hollow viscus, and in 71 there was no lesion.

Of the 95 cases, peristalsis was absent in 89 or 93·7 per cent. Of 71 cases with no lesion, peristalsis was present in 70, and absent in only one. Rob concluded that the absence of peristaltic sounds, confirmed and reconfirmed, was a positive indication for laparotomy, but that the presence of peristaltic sounds was only a valuable guide and not a positive indication for conservative treatment. The reports of all surgeons who have commented on the matter support this view.

All surgeons had their regrets over conservatism: for example, Geoffrey Wooler recorded the following:

Case: Wound from high explosive: entry left loin 1 in. diameter: exit wound near left anterior superior iliac spine, 2½ in. × 2 in. Wounds excised, joined and opened up widely. No injury seen to peritoneum or to retroperitoneal part of colon. Wound partly closed and dressed. Three days later the man died of general peritonitis. At the autopsy there was a very small perforation on the peritoneal surface of the medial wall of the descending colon with surrounding bruising and contusion of the gut. The part of the colon and peritoneum forming the base of the wound was everywhere intact. The colon must have burst through its medial wall—a type of blast injury caused by a missile passing through the abdominal wall.

Briant Evans wrote of a case where audible peristaltic sounds led to his treating a case on conservative lines: a small perforation of the caecum was found sealed by a foreign body lodged in the aperture, so that there had been no soiling of the peritoneum by intestinal contents.

In diagnosis careful examination of the whole patient is very important in air raid casualties.

Case: A woman who had for a day or two experienced some discomfort in the right iliac fossa was walking homeward during an air raid on a Scottish city, when the pain suddenly increased and her general condition at once became one of anxiety. She was sent to hospital with the diagnosis of acute appendicitis or a leaking duodenal ulcer. The nurse in the course of cleansing operations discovered small wounds in the right and left flank, the latter oozing blood. Her condition never permitted surgery and at autopsy there were disclosed wounds of colon, pancreas and inferior vena cava.

Case: A woman was dining in a fashionable London restaurant when two aerial bombs exploded on the dance floor. She was permitted to leave the first institution to which she had been transported and return home, a small punctured wound of the buttock having eluded the not-too-vigilant eye of doctor and nurse. In the early hours of the morning the late Mr. Carnac Rivett was summoned, realised the gravity of her condition, operated and rapidly sutured four perforations of the small intestine. The woman made a good recovery (Plate VII).

Misdirected modesty was a drawback in the examination of dust-covered air-raid casualties; soap and water and shears were of more value to the patient than *une fausse delicatesse.*

The vertical wound track had a sinister reputation in the First World War and many specimens in the former war collection in the Royal College of Surgeons of England (destroyed in 1941) attested the truth of that view; but in the War of 1939–45 reception officers and surgeons were alive to the potential dangers of the buttock wound (vide the subjacent table).

Analysis of a series of Abdominal Cases involving the Buttock

	No. of Cases	*Deaths*
Penetrating peritoneal cavity	13	3
Penetrating pelvis only	6	2
Total abdominals	19	5
N.B. Simple buttock wounds	20	1
Buttock wounds	39	6

Thus, nearly 50 *per cent.* of wounds of the buttock were accompanied by injury to intraperitoneal or intrapelvic viscera.

Case: A female air-raid casualty sustained a penetrating wound of the left buttock, and an X-ray showed a fragment of bomb high up under the cupola of the diaphragm. Laparotomy revealed a quantity of blood in the coelomic cavity, much retroperitoneal bruising and haemorrhage in the left iliac fossa; two perforations of the jejunum were sutured. The woman made a good recovery.

The serious nature of wounds of the epigastrium is shown in this table:

		Deaths	*Mortality* per cent.
Epigastric wounds . .	11	6	54
Other wounds . .	33	7	21

(Major P. W. Ingram)

REGIONAL DIAGNOSIS

1. *Extraperitoneal Haematoma.* Haematoma of the anterior abdominal wall presents little difficulty, since the wound track will be carefully explored and evidence of peritoneal penetration be directly available. Posterior retroperitoneal haematoma, without gut injury, is a far more difficult problem and has been responsible for the performance of many avoidable explorations. There is usually generalised guarding of mild degree, and peristaltic sounds are present though they may be more faint than in the uninjured abdomen and repeated examinations may be needed to detect them. Deep tenderness is often marked. Later, distension from ileus may arise.

Extraperitoneal haematomata in the pelvis may be diagnosed by digital examination of the rectum; proctoscopic examination may also help. Such cases are usually associated with buttock wounds.

2. *Wounds of the Liver.* The signs are those of peritoneal irritation due to the presence of blood in the peritoneal cavity (haemoperitoneum). These wounds are of especial importance, because a conservative attitude towards them is undoubtedly the correct one. Many surgeons found in their less experienced days that laparotomy frequently restarted bleeding from the liver, and that it was a matter of the greatest difficulty at operation to staunch it. However, if the amount of bleeding is great enough to give the sign of free fluid, it may be necessary to abandon conservative treatment and explore the abdomen.

3. *Wounds of the Kidney.* In many respects, war wounds in which the kidney is directly involved vary considerably from their civilian counterpart. Large perirenal collections are rare, and clot colic exceptional—at least in the early stages. Local tenderness and rigidity, however, are constant, and blood is invariably found in the catheter specimen. Where the wound is in the flank, exploration will make digital examination and estimation of the extent of the damage possible. The majority of cases can be safely treated conservatively, though some in whom early operation is avoided may need nephrectomy at a later date. Excision of the

wound must of course be thorough and free drainage must be established, for such wounds are perhaps especially liable to gas-gangrene. If haemorrhage continues, or is repeated after three to four days, nephrectomy is indicated.

4. *Spinal Wounds, with abdominal signs.* Hyperaesthesia and tenderness of the abdominal wall is a constant feature of spinal injury with cord involvement, the segment affected being that which lies immediately above the injury. In early cases there is little danger of mistaking a spinal injury for an intra-abdominal lesion, but when seen later, after ileus has developed, there may be some difficulty in reaching a decision. The ileus due to a spinal injury, however, supervenes far more quickly than that due to peritoneal contamination.

5. *Late Wounds.* The longer the interval between wounding and examination, the nearer do the clinical manifestations resemble those of civilian injuries. Patients who survive thirty-six hours or longer often have lesions sufficiently localised to enable a diagnosis to be made on the physical signs alone.

TECHNIQUE OF OPERATION

INCISION

The choice of incision will vary for each case; there must be no thoughtless routine, such as a central incision from 'Dan to Beersheba'; the planning of the approach demands much care and thought and an accurate pre-operative assessment of the probable visceral damage. The ideal for each case is that which will enable the surgeon to see everything likely to be injured with a maximum of ease and with minimal addition to the trauma already inflicted by the missile. Speed is of course essential, provided it is not attained at the expense of thoroughness and gentleness; there is no room for the surgical tortoise in the field surgical unit or casualty clearing station: every five minutes beyond the hour load the scales against the patient, although in some cases with multiple injuries it is manifestly impossible to complete the operation within the hour's limit.

In assessing the area to be explored, the probable track of the missile must be studied after ascertaining from the patient—who can often give the information—his particular posture at the moment of being hit. This information is of the greatest use and in conjunction with localising physical signs may enable the surgeon to avoid opening the peritoneal cavity throughout its whole length. The small intestine, in which the element of surprise is most frequent, since the upper jejunum may be injured by a through-and-through wound below the umbilicus, may be fully examined through most of the ordinary incisions; but it is otherwise when the extremes of the alimentary canal, or the solid viscera or sessile parts of the colon are damaged.

The 'general purpose' incision, where there existed an entry wound only, or where entry and exit wound were far apart, was an incision through or near the midline, and centred over the upper or lower abdomen according to the demands of the individual case. A paramedian rectus-splitting incision was favoured by some, but late results showed that it had little or nothing to commend it. As their experience grew, many surgeons slowly gave up the paramedian rectus-displacing incision for one in the mid-line, finding the latter quicker to make, easier to repair, and no more prone to dehiscence than the paramedian type; it could also quickly be extended in either direction. A transverse incision into the flank to secure better exposure, particularly of the spleen, kidney or the colon flexures, was made without hesitation. Such wounds usually healed well and gave no additional anxiety, but the more experienced the surgeon, the less often was this approach employed.

Once the abdomen was opened, a systematic examination was carried out, varying with different surgeons, but designed to avoid unnecessary manipulations and yet to avoid missing any lesion. If bleeding were much in evidence, its source was determined without delay, and the necessary steps taken to control it. If a faecal odour were present, the colon was certainly injured, was examined at once and the extent of the damage ascertained, though its treatment was reserved until the last, if there were other injuries; it was packed off temporarily with moist gauze; examination of the fixed portions might be left till later.

Some surgeons preferred now to examine the solid organs, on the grounds that a perforated small intestine can for the moment be left undisturbed; others commenced at once on a systematic examination, starting from the ileocaecal valve. Most surgeons repaired holes in the small intestine as they were found, considering this less time-consuming and less traumatising than marking each hole with forceps until the whole length had been examined. Resection was preferred to suture only if the blood supply was destroyed, or if there was severe local damage to a segment of bowel, the repair of which would leave behind too great a deformity. As each segment of bowel was examined and, if need be, repaired, it was returned to the abdomen.

The presence and nature of a collection of fluid in the renal fossa or in the pouch of Douglas would be determined by passing into each region a swab on a holder.

If exteriorisation of the colon or a colostomy were needed, the bowel was brought out through a separate stab incision in the flank, never through the original laparotomy wound. A transverse or muscle-cutting incision was frequently used for through-and-through wounds, if both entry and exit were in the same quadrant of the abdomen, sometimes after exploration of both wounds which were then joined by a skin incision between. If the wounds were closer together, it was frequently found that the peritoneum was not implicated, and by thus following the track laparotomy could be avoided.

It has often been stated that in cases of through-and-through wounds, where the orifices of entry and exit are situated between the lineae semilunares, the peritoneum is not penetrated. While this is probably true for fit soldiers, in the case of a female Italian civilian such a wound was found to have produced multiple intestinal perforations, due undoubtedly to her pendulous abdominal wall.

If the track of the missile crossed the mid-line, the incision should be a median one, of adequate length, and centred on a line joining the entry and exit wounds; the latter were excised down to the peritoneum before opening the abdomen, and the peritoneum closed from within.

When entry and exit wounds were in the flank, the peritoneum quite frequently might escape. Such a track needed to be opened up, and the depths carefully inspected; sometimes a small opening of the fixed colon was found which could be repaired and drainage provided, but without the need for opening the peritoneum widely.

For penetrating flank wounds, in which intraperitoneal injury was doubtful, the track was opened and fully explored. Through the track any renal damage, if present, could be assessed and treated by drainage alone, and in some cases the missile could be found.

Kocher's incision proved very popular and useful in left or right upper abdominal lesions, particularly those associated with an entry wound in the thorax.

Removal of the missile, though obviously desirable, was never considered to be of sufficient importance to justify any prolongation of the operation in order that the search should be successful.

When other injuries were present, it was the general practice to deal with these before laparotomy was performed, unless haemorrhage demanded immediate abdominal exploration. Where wounds in the back were present, such were always dealt with first so that no turning of the patient would be necessary after the abdominal operation was finished.

CLOSURE AND DRAINAGE

Despite the risk of sepsis, which was to some extent reduced by the employment of penicillin in the later stages of the war, laparotomy wounds were usually closed primarily, and in three layers. All surgeons of experience took the greatest care to suture the peritoneal layer securely, some using interrupted mattress sutures, followed by a continuous stitch; others employed a continuous method with interlocking stitches. Drainage of the peritoneal cavity and exteriorisation of bowel were never made through the laparotomy incision; separate incisions were made for both purposes by most surgeons.

The fascial or muscle layers were usually closed by interrupted stitches; drainage of the muscle layer was advisable, especially if there had been soiling of the tissues by intestinal contents.

Most operators repaired the skin completely, allowing only for drainage of the muscle layer. Some found it safer, however, to leave the skin incision open, and to allow the wound to granulate—which it did surprisingly quickly if the musculo-fascial layer was closely repaired. Others left interrupted stitches in the skin untied, tying them on the third or fourth day.

It was a common practice in the earlier period of the war to put one of the sulpha drugs in powder form in the muscle layer; later, a powder consisting of penicillin (1 part) and sulphathiazole (2 parts) was used. Since the infection was often due to the colon bacillus, local penicillin was not always of great value, and sepsis continued to appear in a percentage of the wounds, often not being observed until the patient arrived at a base hospital.

Dehiscence of the wound, sometimes as late as the tenth day, occurred with varying degrees of frequency; but one surgeon who had operated on, or in some way or other cared for 250 abdominal wounds during 1944–5, had not seen a single case.

*Drainage of the peritoneal cavity seemed to grow less and less popular as the war went on, for surgeons began to realise that drainage of the whole cavity was impracticable through any one incision. If the operation were performed within eight to ten hours, even faecal contamination of the peritoneum did not necessitate drainage, and only late cases with considerable soiling were drained, a tube going down to the pouch of Douglas and another to the point of suture, particularly if this was in the colon itself. Drainage was always required, however, if a retroperitoneal space had been opened up, the drain being brought through a separate stab wound or alongside the bowel when exteriorisation had been necessary. Wounds affecting the liver, the extrahepatic biliary tract, or the pancreas were also drained, as was the cave of Retzius in injury of the urinary bladder.

The wound caused by the missile, and tracks along the parietes were, of course, always drained in accordance with the general principles of wound treatment.

Corrugated rubber rolled to form a tube was found to be the most convenient way of securing good drainage.

POST-OPERATIVE TREATMENT OF ABDOMINAL CASUALTIES

GENERAL MEASURES

Adequate and skilful post-operative treatment is of paramount importance in the care of abdominal casualties; and the need for it is even more pronounced in service than in civilian abdominal surgery. Much labour and judgment are required, for apart from the greater likelihood

* Nevertheless the more experienced the surgeon, the more often did he drain (G. G-T.).

of post-operative shock there is the almost constant sequel of some degree of ileus, often severe. No matter how many layers of stitches are inserted, sutured wounds and anastomoses of the bowel will disrupt if distension of any magnitude is allowed to occur, and the general deleterious pressure effects of the distension also require consideration. Again, intestinal contents have often been spilled over the peritoneal cavity and the patient's resistance to resultant infection must be kept at the highest possible level.

Post-operative treatment therefore is mainly concerned with the risks and dangers of *shock*, *ileus*, and *peritonitis*. The following conclusions represent the treatment advised as the result of experience in the war.

The patient is kept flat in bed until he is thoroughly recovered from the anaesthetic; this may occasionally take as long as twelve hours, and there should be little hurry to sit him up or to make him adopt the Fowler position, since this may add further strain to a depressed circulation. Repeated blood-pressure readings will give some indication of the recovery from shock and a gradual raising with the aid of pillows will in most cases be the best procedure. Whether or not the Fowler position will eventually be insisted upon is a matter for the judgment of the individual surgeon. The majority of patients prefer some degree of the sitting position as soon as they feel fit for it.

Morphine, usually administered as a hypodermic injection of one-sixth of a grain, is advised and given by many surgeons four-hourly for the first forty-eight or more hours, but must not be started until the patient is thoroughly recovered from the anaesthetic. Apart from keeping the patient quiet and alleviating his pain, morphine is considered to exercise a tonic effect on the bowel, antagonising the liability to distension. It is wiser under field conditions to order nurses or orderlies to give it as a routine at the proper times and not to withhold it, even if the patient be comfortable or asleep.

Oxygen-therapy may be used with advantage on patients whose post-operative condition is poor; some medical officers prefer to give it through nasal catheters with or without the Tudor Edwards' spectacle frame, rather than by the B.L.B. mask. In casualties whose condition is obviously worsening quickly, intravenous adrenalin hydrochloride, 1 in 100,000 may be employed; ½ to 1 c.cm. of this preparation of adrenalin is added to a pint of physiological saline, the transfusion being given slowly. Sometimes the general condition seems to improve with this therapy, which may be repeated in eight or twelve hours. The rate of flow may be determined by blood-pressure readings; adrenalin tends to make patients restless and if this occur, the rate of flow requires to be lessened.

GASTRIC AND INTESTINAL SUCTION

Ileus and distension of the bowel occur in some degree in all penetrating wounds of the abdomen. Generally speaking, haemorrhage and shock may be said to account for the early deaths, ileus for the intermediate ones, peritonitis for the later ones. Ileus follows upon wounds of the solid as well as upon those of the hollow viscera, and if allowed to develop to a severe degree, quickly saps the patient's vitality, since it causes extreme abdominal discomfort, produces repeated, unpleasant vomiting and by upward pressure on the diaphragm embarrasses respiration and the circulation. At the same time, from the absence of peristalsis the secretions of the upper bowel are not passed on to the absorbing areas and much fluid loss is thereby sustained, whether vomiting occurs to remove it or not. Moreover, the thinned-out wall of distended bowel will tear itself away from any sutures which may have been inserted to close a rent.

The treatment of ileus thus entails the avoidance of bowel distension until peristaltic movements return. It is not enough to wait until the condition is well-established before instituting treatment; preventive measures must be initiated from the outset. The problem involved is the removal of fluid and gas from the stomach, duodenum, and upper reaches of the small bowel, thereby preventing the gaseous distension of the bowel lower down. At first sight it might appear that such removal could only be effected by a drainage system passing down to the small bowel, such as by a Miller-Abbot tube; but in actual practice it is found that drainage of the stomach alone usually suffices, the pyloric sphincter almost invariably relaxing and the secretions beyond welling back into the stomach. This is indeed a fortunate happening, since the introduction of an indwelling intestinal tube may be difficult, and the different postures that may have to be adopted by the patient to help its passage through the pyloric canal, as well as the repeated radiological control, throw an added strain on a seriously ill patient.

The usual procedure, therefore, is drainage of the stomach by suction through an indwelling tube. A Ryle's tube, or, as some prefer, one of the same pattern with a larger bore, is introduced into the stomach by the nasal route, and its proximal segment is fixed to the forehead by strapping.

The suction which is now applied through the tube may be intermittent or continuous, and in the matter of preference each type has its advocates. In the intermittent method, withdrawal of all the obtainable fluid is achieved by hourly or half-hourly aspiration through the tube by means of a 20 c.cm. syringe as the suction agent. In the continuous method the indwelling stomach catheter is connected to a simple vacuum syphon which can be easily improvised from transfusion apparatus.

Theoretically, the continuous method would seem to be the better, inasmuch as the stomach will always be kept empty; but in practice there is little between the two methods, provided each is efficiently managed. The continuous method requires nurses and orderlies to be highly trained and experienced in the use of the apparatus so that they can determine at a glance, often when engaged on other duties, whether it is working satisfactorily or not. Air-locks and kinks in the tubing, thick secretion in a narrow tube, and insufficiently tight corking in the various bottles, will all arrest the process of aspiration. In general, the continuous method needs continuous attention, and, unless the surgeon himself is able to attend to the mechanics of the continuous method of therapy, it is probably better with inexperienced orderlies to adopt the intermittent technique. An orderly is detailed, whose duty is to go from patient to patient at the appropriate interval and perform the aspirations with a syringe, the indwelling tubes being plugged with a spigot in the intervals. The intermittent method has the further advantage that the quantity withdrawn can be calculated more easily and this is of some importance, since in both methods the patient may be allowed to swallow fluids to allay the feeling of thirst. At the outset aspiration will of course remove all of this, but in two or three days it will be found that the withdrawn fluid, secreted and swallowed, is less in amount than that swallowed, shewing that some forward passage and absorption is taking place.

Indwelling suction tubes which should be inserted soon after recovery from anaesthesia, if not inserted before or during operation, must not be removed until peristalsis has unmistakably re-commenced. Peristaltic sounds heard on auscultation and the spontaneous passage of flatus announce the desirable event, but even with their forthcoming the tube should not be abruptly withdrawn, since relapse may yet occur. If the swallowed fluids as calculated by aspiration are being well retained, or if the indwelling tube is clamped without ill event for some hours, then, in the presence of peristaltic sounds and the passage of flatus, the tube may be withdrawn. The patient, invariably gratified at the event, should be warned that re-introduction may be necessary and should be told that over-indulgence in swallowed fluids will be the chief contributory cause to the need for re-intubation.

POST-OPERATIVE FLUID AND CHLORIDE REPLACEMENT

Any fluids given by mouth in the immediate post-operative period will only add to the stagnant fluid in the stomach and upper small bowel and so increase distension; accordingly, the giving of fluids by mouth is only permitted when suction apparatus is in action. The reasons for this limited oral fluid administration are partly to keep the mouth, tongue and pharynx moist and thus add to the patient's comfort, partly to keep the early thick secretions more fluid and therefore easier of aspiration, and partly to act as a psychological tonic.

The fluid and chlorides lost to the circulation and to the body from shock, by vomiting, by the kidneys, by sweating and by the secretions poured into the inert upper bowel must be replaced, and further blood transfusion will be required in the more severely shocked cases. Apart from this, while suction is being maintained, there is needed in temperate climates a daily drip transfusion of some five or six pints of saline, with an additional pint of plasma to prevent oedema. In very hot climates, such as India and Burma, the daily total necessity is nearer twelve pints, and some difficulty may be experienced in introducing such a large quantity.

Sufficient saline must be given to prevent the patient becoming dehydrated and the condition of the tongue is much the most valuable guide. It is essential that a medical officer should inspect the patient twice a day in order to ensure the adequacy of the amount of saline given; in severe conditions the appearance of the face is characteristic, and the cheeks of the patient are drawn in. If the patient develops râles at the base of the chest, the saline must be reduced or discontinued; in a temperate climate some patients, especially with concomitant chest injuries, may show such complications with amounts of from five to six pints a day.

The saline used contains 0·3 per cent. sodium chloride and 3·3 per cent. glucose. A large percentage of sodium chloride will commonly cause oedema some three or four days after the start of the transfusion; but in very hot climates an increase in the salt content is necessary, because of the increased amount lost by sweating.

These fluids are given by the intravenous slow drip method; their administration requires careful supervision and, not infrequently, it is necessary to change the receiving vein more than once in the four or more days during which the drip has to be maintained.

If after the third day there is difficulty with the intravenous transfusion and the patient is proceeding satisfactorily, saline may be given by the rectum, provided the intra-abdominal lesion is not colonic.

CHEMOTHERAPY

Post-operative chemotherapy is directed towards minimising systemic infection and local infections in the peritoneal cavity and abdominal wall. The efficacy of the sulphonamide group of drugs and of penicillin is mainly in respect of the gram-positive organisms. Only sulphathiazole, sulphadiazine and sulphathalidine are regarded as possessed of any powers against the gram-negative group, and one of the first two aforementioned preparations was employed by most surgeons for colonic wound cases and where severe peritonitis was present or expected. The drug was given intravenously, 1 g. four-hourly for some four days; and if benefit did not seem to be obtained from the use of one, a change was made to the other.

In the later campaigns of the war, penicillin was freely available and with its routine use abdominal wounds were found generally to heal earlier, more soundly and with much less tendency to local infection, while post-operative chest complications seemed to be fewer. The claim that its use in the North-western Europe campaign led to a lower incidence of residual intraperitoneal abscesses, subphrenic and pelvic, than in the Middle East would seem to be less securely founded; the time-lag before operation due to distances and the relative paucity of medical units was generally much greater in the African theatre of operations.

The sodium salt of penicillin was given intramuscularly either intermittently, at three-hour intervals, or continuously; if the former, 15,000 units were given at each injection; if the latter, 100,000 units in a pint of saline as a slow drip every twenty-four hours. Administration was continued for three or more days and larger doses were given if indicated. Where the continuous method was applied, the position of the needle in the anterior or lateral aspects of the thigh was changed every forty-eight hours.

The possibility of the supervention of gas gangrene had always to be remembered where there was associated gross soft tissue damage, as might occur particularly in the buttocks and back. Prophylactic administration of anti-gas-gangrene serum was then required.

INJURIES OF THE ABDOMINAL WALL

Unusual types of injury to the abdominal wall have long been known to occur. The fortunate course pursued by a missile which might track round the trunk from back to front, travelling in the subcutaneous layer or traversing the intermuscular tissue planes, was familiar to the surgeons in the Napoleonic Wars and was often noted in the War of 1939–45.

Moreover, that type of contusion of the belly wall in which, though the skin and superficial tissues remained intact, the peritoneum and musculo-aponeurotic structures were torn and led to the formation of a traumatic hernia, was described long ago by Larrey and Guthrie, and at a later date by Haberer.

Immunity of Viscera. Surgical exploration of the abdomen in the War of 1914–18 proved beyond refutation the occasional immunity of viscera in penetrating wounds of the belly, even when implicating the intestinal area. This immunity-belief promulgated by Makins and Cheatle in the South African War and confirmed in the War of 1914–18 was also known to surgeons centuries ago; thus Ambroise Paré wrote: 'Yet I have dressed many who by God's assistance and favour have recovered from wounds passing through their bodies'.

E. G. Guthrie, John Thomson, Hennen and Baron Larrey, all writing of the Napoleonic Wars of the beginning of the nineteenth century, were aware of this fortunate phenomenon. The first-mentioned surgeon described a successful case where a soldier received a perforating wound of the abdomen produced by a ramrod which entered near the navel, transfixed the body of the 3rd lumbar vertebra, and projected about $1\frac{1}{8}$

in. beyond the skin of the back. Guthrie regarded it as still more remarkable that a bullet or even a sword might do the same thing, remarking that Wiseman, Ravaton, Lamotte, etc., had also commented on the phenomenon.

Larrey also quotes the case of a fusilier who received a sabre wound two fingers breadth above the navel and to the right of the middle line; surgical exploration revealed that the track went between the stomach and transverse colon; the man recovered.

The possibility of spontaneous recovery from a proven wound of the stomach was demonstrated by Makins, Cuthbert Wallace, Green-Armytage, by Elliott and Henry and others in the First World War.

During the air-bombardment of Britain, casualties were met with where fragments of bomb-casing or pieces of glass which had damaged the bowel were voided *per vias naturales*, the injured bowel recovering without surgery.

Case : A patient was admitted with an entry-wound in the left loin, and X-rays demonstrated a fragment of bomb to the left of the body of the 2nd lumbar vertebra. For a day or two the urine was deeply blood-stained, and left-sided abdominal pain very severe. Ten days after the 'incident' he passed a fragment of metal from the rectum ; further X-rays showed that the foreign body originally demonstrated had disappeared. The urine became clear ; recovery was uninterrupted.

Case : Through-and-through revolver bullet wound ; entry-wound just below right costal arch over the linea semilunaris ; wound of exit immediately to the right of 2nd lumbar spinous process. On laparotomy, the bullet was found to have passed 1 in. below the inferior border of the liver and to have pierced the transverse mesocolon ½ in. from the gut, no blood-vessel being damaged. The track then passed through the angle situated between the lower pole of the right kidney, duodenum and inferior vena cava ; subsequently it traversed the medial portion of the psoas muscle, emerging between the 2nd and 3rd lumbar transverse processes. Recovery was uneventful.

Sub-minimal Injuries. These were of infinite variety, including such lesions as wound of a single appendix epiploica, a through-and-through wound of the falciform ligament of the liver with a resultant intraligamentous haematoma, or a small haemoperitoneum trickling through into the coelom from a more extensive retroperitoneal extravasation (D. H. Patey). Fortunate was the 'Wren' who sustained only a neat tunnelled wound to the lower part of the liver, the bullet emerging through the quadrate lobe; no other viscus was damaged and the girl made a good recovery. (H. L. Gervis' case).

WOUNDS OF THE STOMACH

Ambroise Paré in the sixteenth century regarded injuries of the stomach as 'deadly', but wounds of that organ have certainly healed spontaneously in the past, as for example in an ancestor of Sir Walter Scott. 'This gentleman had joined the Pretender, and, with his brother, was engaged in that unfortunate adventure which ended in a skirmish and captivity at Preston, 1715. It was the fashion of those times for all persons of the rank of gentlemen to wear scarlet waistcoats. A ball had struck one of the brothers, and carried part of this dress into his body, and in this condition he was taken prisoner with a number of his companions, and stripped, as was too often the practice in those remorseless wars. Thus wounded, and nearly naked, having only a shirt on, and an old sack about him, the ancestor of the great Poet was sitting, along with his brother and one hundred and fifty unfortunate gentlemen, in a granary at Preston. The wounded man fell sick, as the story goes, and vomited the scarlet cloth which the ball had passed into the wound. "O man, Wattie," cried his brother, "if you have a wardrobe in your wame, I wish you would vomit me a pair o' breeks".'

Larrey in his Memoirs refers to knives successfully removed from the stomach by Dr. Kruger, a Polish surgeon in 1613, and by Professor Frizac of Toulouse, but these operations were deliberately undertaken apart from the tumult of war. Larrey, Guthrie and Thomson make no enthusiastic comments on the surgery of this organ, although Larrey specifically mentions one case where a wound of the stomach recovered through the kindly influence of nature without gastric suture. A big sabre wound penetrated the chest between the seventh and eighth ribs, and implicated the diaphragm and stomach of a soldier of the Guard; the man recovered; the direction of the wound, the escape of food swallowed by the mouth and haematemesis all confirmed the diagnosis of a stomach injury.

Baron Percy, the French military surgeon, estimated that 20 to 30 per cent. of stomach wounds recovered in the Peninsular War, but Guthrie thought that a figure of about 10 per cent. would be much nearer the truth, and that the injury was a very fatal one. Guthrie mentions, however, the successful case of General Sir John Ellery who was wounded in the stomach by a sabre in the last charge of the heavy cavalry at Waterloo. Thomson writing of his experiences after Waterloo saw only two patients recovering from wounds of the stomach, one inflicted by a lance, the other the result of a musket-ball.

INCIDENCE OF WOUNDS OF THE STOMACH

Stomach wounds accounted for some 5–7 per cent. of all abdominal injuries in the War of 1939–45 and carried the relatively high mortality of between 25–50 per cent. (B.L.A. 39 per cent.), the mortality resulting largely from accompanying injuries to neighbouring important viscera and also varying with the quantity and composition of the gastric contents at the time of injury.

In Sir Cuthbert Wallace's analysis of 965 operations for penetrating wounds of the abdomen in the War of 1914–18, the intestine was implicated nearly eight times as frequently as the stomach. The relative incidence was not very dissimilar in the War of 1939–45, e.g., Parker 6:1; Giblin 8:1; Duncan Stout (New Zealand) 10:1; Sperling *et al.* (U.S.A.) 9:1; Beaton (Canada) 6:1; C.M.F. statistics 15:1; B.L.A. 9:1.

In contrast to the findings in the War of 1914–18 that in two-thirds of the patients in whom the stomach was damaged the latter was the only viscus injured, the B.L.A. figures for abdomino-thoracic injuries suggest that in only one-seventh of the casualties coming to surgery was the stomach injured alone, and in another series from the B.L.A. in only one-fifth was the stomach the solitary viscus damaged, a percentage far more consonant with my own impressions of the frequency of associated injury with gastric wounding.

The upper jejunum and the transverse colon are those portions of the alimentary canal most liable to be damaged in association with gastric injury: of solid organs, the liver is that most likely to be implicated, but kidney, pancreas, spleen and the thoracic organs have all been damaged concomitantly.

Wounds of the stomach itself were of infinite variety, depending on the size, shape and velocity of the missile, the direction of its flight, and the state of the stomach in respect of repletion or emptiness. In some cases the wounds were wide and gaping; in others the wound was small and there was no attempt at eversion of the mucosa. There might be a marked difference between the wounds of entry and exit, the former small, edges tending to adhere and capable of spontaneous closure, the latter of considerable dimensions, with mucosa extruded. Eversion of the inner tunics of the stomach was perhaps most marked at the curvatures, and in wounds where the direction of the missile had produced a wound on the surface of the stomach of considerable length. One variety of linear wound has been referred to as 'the note of exclamation' wound (Cuthbert Wallace).

The possibility of a through-and-through wound or of a solitary posterior wound had always to be borne in mind; these were very easy to miss at operation: Major T. J. Brownlee recommended examination for wounds of the posterior wall of the stomach by means of a finger introduced through the anterior gastric laceration. Posterior wounds necessitated mobilisation of the stomach, which was generally carried out through the lesser sac; gastric wounds situated high up under the costal arch were approached with greater ease if a limited resection of the costal margin was performed.

All stomach wounds were sutured in two layers; there was ample tissue available and the closure was thereby rendered so much the more secure. The majority of surgeons seem to have employed strong chromicised catgut in this area. The possibility of a foreign body having come to rest within the cavity of the stomach had to be remembered.

In view of the rich vascular supply of the stomach, it is scarcely a matter of wonderment that gastric wounds are prone to be associated with severe bleeding, either into the cavity of the organ or into the peritoneal cavity. The vascular arcades along the curvatures may bleed severely, as may the vessels coursing in the walls of the stomach itself.

Cases A W.A.A.F., while engaged in getting a barrage balloon into the air during a raid was struck by a fragment of bomb casing, measuring 2 in. × ½ in., which divided the left gastro-epiploic artery and produced a rent in the anterior wall of the stomach; she made a good recovery. (Mr. J. A. McLaughlan's case.)

Another remarkable wound was that sustained by a woman admitted to Dover Hospital on September 25, 1944 as a casualty from enemy shelling; she had multi-visceral injuries, including a curious laceration of the stomach which was rent from near the cardia to the pylorus for a length of at least 6 in., the viscus being turned inside out. This gastric laceration was responsible for most of the bleeding which had already taken place and was continuing at the time of operation. The woman recovered (Gordon-Taylor).

DELAYED OPERATION ON WOUNDS OF STOMACH

A man who had received a bullet wound in the lower left chest eight days before, came under the care of Lt. Colonel R. S. Handley. The patient had appeared so fit that the 'forward surgeons', who were heavily pressed at the time by Rundstedt's 'break through' in the Ardennes at the end of 1944, had not operated. A slight rise of temperature called for an X-ray examination; this showed a bullet in the left hypochondrium and a small left pleural effusion. At operation a collection of mucus was found sealed off from the peritoneal cavity; on mopping this out and separating some adhesions, a rent three inches long was found in the anterior wall of the stomach which had sealed itself by adhesions to the back of the anterior abdominal wall. The rent was sutured, and the bullet removed from the great omentum. An uninterrupted recovery took place.

PERFORATION OF PEPTIC ULCER 'IN THE FIELD'

The problem of peptic ulcer in the Services has been the subject of many communications: D. N. Stewart and D. M. de R. Winser drew attention to the increased incidence of perforation of peptic ulcer in association with heavy air raids on Britain.

The circumstances under which perforation of a peptic ulcer may occur and operation be undertaken for its repair may invest a mundane occurrence and a banal surgical procedure with a dramatic colour. More than one perforated ulcer received successful treatment on the Dunkirk beach in 1940.

Case: Driver H, 30, had suffered from indigestion for 6 months and, following perforation of a peptic ulcer, was operated upon in a French Field Ambulance in a wood near Dunkirk. He was conveyed partly by cart, partly by stretcher to the beach, evacuated in one of H.M. destroyers and arrived in England in excellent condition. Many, in addition to the strong arm of the Royal Navy, must have contributed to this man's recovery.

Case A private whose peptic ulcer perforated upon the beach at Dunkirk, was after various vicissitudes of fortune and exciting and exhausting transportation, operated on in Britain six days after perforation for general peritonitis. The perforation was sutured, and the abdomen closed without drainage. After a stormy convalescence the man recovered.

Sudden acute dilatation of the stomach may take place as the result of contusions of the chest. A motor cyclist was admitted to hospital and, when first seen, was coughing up a small amount of frothy blood; shock was profound; the pulse ranged between 130 and 140 and there was considerable cyanosis; the abdominal muscles were rigid. An X-ray revealed gross dilatation of the stomach and a patchy mottling of the middle and upper zones of the left chest; there were no fractured ribs. Six hours later the man vomited, bringing up quantities of gas and relieving his dyspnoea. Complete recovery ensued.

INJURIES OF THE INTESTINES

WOUNDS AND INJURIES OF THE DUODENUM

The sinister reputation which attached to wounds of the duodenum during the War of 1914–18 was amply confirmed in the Spanish War and in the Second World War. In none of the statistical tables relating to the War of 1939–45 is the duodenum specifically dealt with, but perusal of the reports of individual surgeons serving oversea and information obtained by personal inquiry from other operators, leave one in no doubt as to the fatal nature of injuries of this first segment of the intestinal tract. Gunshot wounds of the duodenum were likely to be complicated by wounds of other viscera, including the pancreas, while the neighbouring spine, the propinquity of the large blood vessels, the liability of a retroperitoneal tear to be overlooked, and the surgical inconvenience of the anatomical area demanding repair, combined with the disadvantageous environment of forward surgery, were all factors which invested wounds of the duodenum with their grave reputation. Colonel Duncan Stout, C.B.E., D.S.O. considered it 'an extremely serious injury', and thought that his New Zealand surgeons were fortunate to save two out of five patients; Lt. Colonel Geoffrey Parker, D.S.O. remarked on the disappointing results that attended the surgery of their repair; Lt. Colonel Cedric Tuckett (of Tonbridge) alone seems to have had more than his share of good fortune.

The proximity of the duodenum to vital structures doubtless explains the infrequency with which surgeons were confronted with its wounds; thus, many Army operators never encountered a wound of this portion of the gastro-intestinal tract, and Major Geoffrey Wooler operated on only one such patient, an Italian girl of 10 years who had two small holes through the anterior and posterior walls of the second part which were sutured, but there were many other injuries and the patient only survived a few hours. Lt. Colonel Andrew Lowdon saw two patients with duodenal wounds and saved both; (a) one patient had sustained wounds of the duodenum, hepatic flexure of the colon and right kidney, and (b) the other had wounds of the duodenum and transverse colon. Lt. Colonel Guy Blackburn had three cases and obtained a successful result in two, one of the successful cases requiring a simultaneous cholecystectomy, the other a nephrectomy: in each of his patients forty-eight hours had elapsed since the infliction of the wound.

Success has also followed operative interference in the case of casualties operated on in this country. In Colonel Hedley Atkins's successful case a soldier was wounded in the loin by a machine-gun bullet while lying face downwards on the deck of one of H.M. Destroyers during the Dunkirk evacuation of 1940; he had sustained a perforating wound of the duodenum and a wound of the liver, and there was considerable haemoperitoneum.

Surgeon Commander Rex Williams's successful case had the second part of his duodenum almost completely torn across, and had also received wounds of the transverse colon and jejunum. Lt. Colonel Henry R. Thompson saved two cases of wounding of the duodenum during the London 'blitz': a boy of 6 years sustained a perforation of the first part of the duodenum and also one of the stomach: these were sutured and recovery ensued. In Thompson's second successful case the man had sustained a complete rupture of his duodenum as the result of 'blast'; the proximal and distal ends of the torn duodenum were sutured and a gastro-jejunostomy performed. Success attended the case operated on by T. J. Cobbe of Dover; the victim was a mate in a ship in mid-channel and had been hit by bomb fragments which damaged the duodenum, colon and both walls of the stomach. Equally successful was W. H. L. Molesworth in dealing with a duodenal injury in a right-sided thoraco-abdominal wound from an anti-aircraft shell.

The *treatment* of wounds of the duodenum was suture in two layers, when possible, and drainage; local sulphadiazine to the site was applied as a routine and drainage was instituted, either through a separate stab incision anteriorly, or of the retroperitoneal area by a tube inserted over the right kidney beneath the 12th right rib. Mobilisation of the duodenum and of the hepatic flexure is required adequately to expose the second and commencement of the third portions of the duodenum. The presence of a retroperitoneal haematoma should remind the surgeon of the possibility of a tear of the posterior wall of the duodenum, and such a perforation should be repaired by a two or even three layer closure of silk or thread.

Lt. Colonel Aylett was of the opinion that wounds of the second and third parts of the duodenum were prone to break down after suture of the laceration; Major Wooler mentions a patient seen by him at the base in whom in the forward area two lacerations of the second part of the duodenum had been sutured with thread in two layers and drainage instituted retroperitoneally through the loin. When the patient arrived at the base, the wound had broken down and was discharging duodenal contents; the surrounding skin became excoriated and the man rapidly wasted. A jejunostomy was performed, and in addition a split piece of rubber tubing was sutured into the second part of the duodenum, the split facing the postero-internal wall. The duodenal wall was sutured as well as possible over this tube. This device worked remarkably well, and after a month the wound had almost healed, but X-ray showed that the rubber tubing was still in the duodenum. He was evacuated to the United Kingdom in this condition.

Aylett counselled a simultaneous gastro-jejunostomy for duodenal lacerations, but the great majority of surgeons (Tovee, etc.), were of the opinion that this should be reserved for very severe duodenal lacerations, for cases where suture had produced obvious stenosis, and for patients with a trans-section of the duodenum, where the two ends were separately closed and a gastro-enterostomy manifestly had to be done.

It was rare to meet with patients suffering from a duodenal wound alone, and when other major injuries complicated the picture, the addition of a gastrojejunostomy to the operative work required was not felt to be justified.

Michael Oldfield and Handley had a successful case, where a splinter entering through the right flank was found sticking corkwise into the descending part of the duodenum opposite the biliary ostium.

Prognosis. Wounds of the duodenum formed only 2 per cent. of all abdominal injuries, but carried the sinister mortality figure of 50 per cent. due to (*a*) the frequency of severe associated visceral injuries; (*b*) the fact that the duodenum is partially retroperitoneal and that in this area, particularly in the presence of the frequently accompanying large retroperitoneal haematoma, the liability to infection was high; (*c*) the inaccessibility of a large part of this portion of the intestinal tract and therefore the likelihood of missing minor injuries.

The dramatic story of a patient under the care of Lt. Colonel J. H. Baty is placed on record:

Case Corporal R. reached a mobile surgical unit in Arakan on March 4, 1944, eleven hours after sustaining a through-and-through bullet wound, the wound of entry being situated above and to the left of the umbilicus, the exit over the posterior portion of the 10th right rib. At laparotomy there were quantities of blood, bile and gas in the coelom, but the blood pressure registered 140/90, and the pulse rate was only 100. *A double perforation of the second part of the duodenum* necessitated mobilisation of this part of the alimentary tube and double-layer closure. Other injuries included two lacerations of the jejunum, a wound of the anterior wall of the pyloric antrum, the embedding of flakes of metal in the posterior wall of the stomach, a radiating fissure of the liver, a laceration of Hartmann's pouch of the gall-bladder (sutured) and a haemorrhagic effusion between the layers of the mesentery and in the retroperitoneal tissues.

Despite a crisis evacuation on the third post-operative day and an appalling journey back to the C.C.S. on which he was accompanied by the transfusion officer supervising the intravenous drip and the gastric suction, and after some critical days at his new stopping place the corporal made a good recovery.

Thoraco-Abdominal Wound and Laceration of Duodenum.

A private was admitted to a M.D.S. in Burma on August 7, 1943 within an hour of being wounded by aircraft machine-gun fire; he had an open pneumothorax on the right side, with shattering of 3rd, 4th and 5th ribs. Wound excised and thoracotomy under regional anaesthesia. A subcostal novocaine block enabled the upper part of the abdomen to be inspected; a wound of the liver was found and a laceration of the second portion of the duodenum from which the contents were escaping; after mobilisation of the duodenum, a two-layer repair was carried out. Ultimately recovery was complete. (Case of Lt. Colonel J. H. Baty.)

WOUNDS OF THE JEJUNUM AND ILEUM

A. General. Wounds of the small intestine accounted for 25–30 per cent. of all abdominal injuries and were found to carry a mortality of

25–50 per cent., varying with the presence of associated major lesions and with the method of treatment required in each individual case. In general, individual suture of separate wounds of the small gut produced a mortality around 20 per cent. and those requiring resection and anastomosis a death rate of about 50 per cent.

A systematic examination of the whole length of the small intestine from duodeno-jejunal flexure to ileo-caecal junction, through an adequate incision, was essential: usually the examination was carried out in the reverse direction, i.e. caecum to duodenum and in the course of this inspection the lesions, which were more frequently multiple than single and sometimes involved twenty or more separate apertures, were either sutured as they were discovered or marked *en passant* by the attachment of a pair of light forceps (e.g. Allis) and dealt with after the full examination was completed. The former method was preferred, a short length of gut being withdrawn with the immediate suture of any perforation and the performance repeated along the whole small intestine. Although this technique obviously avoided further soiling, and did not inflict the shock which generous surgical evisceration of much intestine inflicts upon a man already severely injured, it occasionally led to involuntary waste of time, since ultimately a length of cobbled small intestine on which multiple closures had been performed required resection. However, the general principle that suture was preferable to anastomosis, if an option existed, a principle that had been so firmly established by the vast experience of the surgeons of the casualty clearing zone in the War of 1914–18, became accepted early in the Second World War and was not thereafter seriously shaken.

B. Suture. For a solitary hole, i.e. perforating bullet wounds, a purse-string suture afforded rapid and secure closure; in the case of jagged rents from fragments of shell, bomb, etc. a transverse closure, where possible, was advisable to avoid stenosis, but in view of the fluidity of the small intestinal contents, some narrowing as a result of suture was of little import. Clamps were not required for these procedures, and if time was a matter of consequence, and it generally was, a single layer of suture proved adequate, particularly if care was taken to see that the mucosal edges were well inverted. In isolated lesions a second layer of Lembert sutures, provided this did not produce marked narrowing of the lumen, or an omental patch was undoubtedly a safeguard; but as in the War of 1914–18, fatal cases examined post-mortem showed that it was most exceptional to find a leak from the site of a sutured perforation.

The number of perforations of the gut due to missile-injury varied enormously: the gravity of the prognosis in small-bowel injuries was not unnaturally increased by multiplicity of perforations because of the added bleeding, the greater risk of contamination and the more prolonged time involved in their surgical repair. Recovery, however, followed suture of more than twenty perforations in one patient: Tovee in the field successfully sutured 20 and in addition performed a double resection in the same patient: S. E. Duff, of Grimsby, saved a patient injured during an air raid in this country who required the suture of 20 perforations, and A. L. Ledingham successfully dealt with 16 lacerations of the jejuno-ileum in one patient injured during the air bombardments of London in 1941. Major Gavin Cleland sutured 24 perforations in a boy of nine wounded by a hand-grenade in Sicily; the boy recovered. The accuracy of the number was vouched for by the Roman Catholic padre.

C. *Indications for Resection of Small Intestine.* The enormous experience of both methods of treatment of wounds of the small intestine in two world wars strongly favours the adoption of the simple suture except under the following circumstances:

(*a*) The separation of the intestine from its mesentery for a length of more than $\frac{3}{4}$ inch.* In the event of contusion or laceration of the implicated segment of bowel, any mesenteric detachment must be viewed with a more critical and less complacent look.
(*b*) Where proximity of multiple wounds is likely to render the result of their individual suture a mosaic of threads or a mis-shapen patchwork, probably resulting in interference with the mechanics of the bowel.
(*c*) When the weight of the missile has crushed the life out of the damaged intestinal coil.
(*d*) Where the bowel has been scorched or burnt by incendiary bullets etc.
(*e*) In cases of intestinal infarction.
(*f*) Where lacerations of the bowel are so numerous, especially if they are also extensive, that it may be less time-consuming to include a great number of lesions in one segment of intestine ablated.
(*g*) In cases of extensive rupture of the muscular and serous tunics of the bowel, especially if the tear almost encircles it; such cases are encountered in contusions of the abdomen and in blast effects.
(*h*) In some wounds along the mesenteric border of the intestine, where vascular damage or blood extravasation arouses anxiety about the success of suture.

D. *Methods of Anastomosis.* Either end-to-end or side-to-side union after resection proved equally good. In most hands the former was slightly the quicker and became the method of choice. It was found that as a surgeon's experience increased, he 'graduated' from side-to-side to routine end-to-end anastomosis, employing a continuous suture of

* This understates the figure given by several writers on military abdominal surgery.

catgut, silk or thread in two layers, the junction where possible being reinforced by a few interrupted sero-muscular (Lembert) sutures. One of the many well-known methods for dealing with the mesenteric ('dangerous') angle was employed; however the old bogey of the 'dangerous mesenteric angle' had been dispelled thirty years before during the First World War, and nothing emerged from the experience of surgeons in the Second War to resurrect it.

As a means of safeguarding the blood supply of the anastomosis, it is advisable to pick up the edges of the resected mesentery in pairs of light artery forceps placed opposite each other and to ligate these rather than to sew up the rent with needle and suture.

Mention may be made of a method of anastomosis which enjoyed a limited vogue and mostly proved adequate, although a little time-consuming. This is the so-called 'pull-through (invagination) method' of Pringle.* This was an attempt to overcome the imagined risks of the mesenteric angle and consisted of denuding of its mesentery one inch of the proximal end of the gut after resection and by means of three stay sutures through all layers of the distal gut telescoping this denuded portion into the distal portion; the free end of the distal segment was then sutured (by interrupted sutures) to the serous and muscular coats of the proximal segment. The denuded proximal end ultimately sloughed off inside the bowel.

This operation suggested by Pringle is closely akin to that successfully employed by a German surgeon, Ramdohr, in the beginning of the eighteenth century, and improved by Zina Pilcher of the United States Army in 1842. Few of the contributions from surgeons of the Second World War make much comment on it: Tuckett, however, was enthusiastic and thought it time-saving: Eaton thought it no quicker and to have no advantages; Tovee who employed it occasionally lost a case on the tenth day after operation from intestinal obstruction due to oedema and occlusion at the site of anastomosis.†

E. Prognosis of Wounds of the Small Intestine. The prognosis depended largely upon factors which apply to wounds in general, such as delay in treatment, contamination, blood loss, and associated injuries; but in the small gut the gravity of the prognosis also increased with the number of perforations, because of the bleeding and contamination which they produced, and the more difficult surgical repair involving either multiple suture or resection. In general, however, the more proximal wounds carried the higher mortality, probably because of the association of jejunal wounds with damage to major vessels and injury to other important viscera (liver, spleen, stomach, kidney).

* Major J. S. M. Pringle.
† A few novices seem to have employed an end-to-side junction.

Recovery-Rate of all Cases of Penetrating Wounds of Small Gut Associated or Not with other Injuries

	Per cent.
Central Mediterranean Force (C.M.F.) .	42
Bradshaw Lecture Series (Largely air raid casualties in Britain in 1940–1) (Gordon-Taylor)	47·3
British Liberation Army (B.L.A.) (1944–5) .	52
Western Desert (1942–3) (Sir Heneage Ogilvie)	62
Hunterian Lecture Series (1944) (Air raid casualties in Britain, abdominal injuries and wounds incidental to troops in training, V1 and V2 casualties, etc.) (Gordon-Taylor)	63

Recovery-Rate when Injury was confined to Small Intestine

	Per cent.
Middle East (1942–3) (Sir Heneage Ogilvie) . . .	63
Bradshaw Lecture Series (1940–1) (Gordon-Taylor)	64
Central Mediterranean Force (C.M.F.) .	65
Hunterian Lecture Series (1944) . . (Gordon-Taylor)	70
British Liberation Army (B.L.A.) (1944–5)	76

In contrast. Recovery-rate of all wounds of small intestine ('associated' or 'non-associated') in the War of 1914–18 was about 27 to 30 per cent. (Sir Cuthbert Wallace); where injury was confined to small intestine, recovery-rate was 34 per cent.

Many cases were recorded in which surgeons resected either a considerable length of the small intestine or performed multiple resections (two, three and even four) on the same patient. Both these procedures inevitably carried a heavy mortality—the multiple resections in the early post-operative stage and the long resections at a later period.

LENGTHY RESECTIONS OF INTESTINE

The longest segment of bowel successfully resected in the Second World War was that operated on by Major R. B. Eaton, R.C.A.M.C.; the segment resected measured 7½ ft., and the patient had also sustained perforations of the caecum, descending colon and pelvi-rectal junction.

A man successfully operated upon by Wing Commander J. B. Kinmonth, R.A.F.V.R., received frightful abdominal injuries in London from an explosive-incendiary which landed in the bed in which he was trying to rest; he was admitted to Hospital with an enormous prolapse of shattered bowel. At least 6 ft. of small intestine were resected; the man's condition was so desperate that the two ends of the gut were brought to the surface and the continuity of the intestinal canal was not restored until two days later.

Surgeon-Captain T. N. D'Arcy R.N., saved a patient following a 6-ft. resection of small intestine which contained twenty perforations and was severely scorched in many places by an incendiary bullet from an enemy plane: a wound of the pelvic colon was also sutured (Plate VI).

Major R. B. Eaton saved five other patients requiring resections of 5 ft. of bowel; Surgeon-Commander B. G. Murless, R.N.V.R., also operated successfully on a naval casualty requiring a resection of 5 ft. of gut. Lt. Colonel Bentley and Major E. D. Tovee each had successful 4-ft. resections.

MULTIPLE RESECTIONS OF BOWEL FOR GUNSHOT INJURY

Multiple resections of bowel for gunshot injury and for the extensions of malignant disease have always provided an interest for the writer. Although in the War of 1914–18 he had obtained a successful result in 11 out of the 22 cases of double resection of intestine which the ravages of war seemed to demand, the writer had no successful triple resection of gut, nor is he aware that any such resection survived in the First World War.

Only the briefest reference to multiple bowel resections is to be found in the various communications on the abdominal surgery of the Second World War, and such information as is forthcoming here has only been elicited by much cross-questioning of laconic surgeons or extracted by hard endeavour from the few published articles that have deigned to mention the subject.

During the War of 1939–45 success not only attended double resections of intestine, but even quadruple resections of small bowel; thus, Meyrick Thomas successfully performed a quadruple resection on a youth who had also sustained a wound of his bladder: H. W. L. Molesworth also had a successful result from a quadruple resection of small gut, each segment removed measuring 10–12 in. long. Major R. B. Eaton, R.C.A.M.C., had two successful triple resections and no fewer than four recoveries from double resections; some of these successful cases were associated with lacerations of the colon or solid abdominal viscera.

The intrepid Eaton lost a patient after a quadruple resection of gut, 'in the field', and Sol Cohen failed to save a civilian who required a triple resection of bowel for an injury caused by air bombardment over Britain.

J. W. D. Buttery, of Folkestone, and E. K. McLean of Shoreham each performed successful double resections on patients injured in this country or who were brought ashore from ships attacked by enemy aircraft.

Case: A private sustained a bullet wound in the left flank on January 26, 1944, 7 hours before admission to a M.S.U. in Arakan. Severe injuries to the jejunum necessitated a resection of bowel; there were lacerations of the ascending colon and proximal portion of the transverse colon; a big sub-serous haematoma of the caecum and an extensive tense retroperitoneal haematoma provided an added reason for radical measures and a right-sided colectomy was also performed. The man made a good recovery from his double resection. (Lt. Colonel J. H. Baty's case.)

WOUNDS OF THE LARGE INTESTINE

General Remarks: The incidence here, as in the case of wounds of the small intestine, was between 25 and 30 per cent. of all abdominal wounds; therefore, injury to the intestine as a whole, large and small, accounted for something between a half and two-thirds of all wounds of the belly. The percentage mortality in wounds of the large intestine fluctuated widely between 10 per cent. for small solitary puncture wounds to 70 per cent. for large or multiple wounds, especially those associated with other major injuries. The wound-operation interval and the amount of soiling of both the peritoneum and the extra-peritoneal tissues were also very important factors influencing the prognosis. Although the following figures are only approximate averages, they serve to show a very marked improvement in results in this war as compared with the last.

Recovery-Rate from all Injuries of the Large Intestine associated or not with other Injuries

	Per cent.
Bradshaw Lecture Series (1940–1) largely injuries due to air bombardment of Britain (Gordon-Taylor)	40
B.L.A. (1945)	48
C.M.F. (1945)	50
Hunterian Lecture Series (1944) (Gordon-Taylor)	56
New Zealand Expeditionary Force (1945) (Duncan Stout)	58·2
Middle East (Western Desert) (1942–3) (Sir Heneage Ogilvie)	61

In contrast, the recovery-rate for *all* injuries of colon submitted to operation during the War of 1914–18 (Cuthbert Wallace) was only about 41 or 42 per cent.

Recovery from Operations where the Colon alone was injured

	Per cent.
Bradshaw Lecture Series (1940–1) (Gordon-Taylor)	45
C.M.F. (1945)	57
M.E.F. (1943) (Sir Heneage Ogilvie)	60
Hunterian Lecture Series (1944) (Gordon-Taylor)	62·8
New Zealand Expeditionary Force (1945) (Duncan Stout)	70
B.L.A. (1945)	72

VARIOUS CONSIDERATIONS DETERMINING THE SERIOUS CHARACTER OF INJURIES OF THE COLON

(i) The frequent retroperitoneal situation of one or more of the wounds of this portion of the intestinal tract increases (but does not condone) their liability to be overlooked by operators.

(ii) The vulnerability of the retroperitoneal tissues to infection, more especially to anaerobic invasion, increases the gravity of wounds of the large bowel.

(iii) Bruising of the large gut is often considerable and may spread some distance from the actual margin of the laceration. In the case of penetrating wounds this phenomenon is encountered more frequently in the colon than in the jejuno-ileum; satisfactory suture of a wound of the colon is thus rendered less certain. Ecchymoses of varying degree, especially in the ileo-caecal area, are very characteristic of immersion blast and are more fully described elsewhere. Futhermore, the frequent deposit of fat in the wall of the colon demands special watchfulness on the part of the surgeon: *dégraissement* has no place in war surgery; effused blood in the intestinal tunics of the obese engenders still greater uncertainty and anxiety lest a subsequent perforation should occur, and constitutes a powerful argument for exteriorisation.

(iv) The outer coats of the colon are sometimes ruptured and stripped back from the underlying intact mucosa: this phenomenon is occasionally encountered in intestine situated in close proximity to the track of a missile, and at other times may be some little distance away. Such lesions demand exteriorisation.

(v) The more fixed portions of the colon contrast with the small intestine in surgical accessibility; the exposure of a retroperitoneal wound of the flexures or of the vertical segments of the large bowel through a mid-line abdominal incision may be fraught with technical difficulty.

(vi) The early escape of fluid faecal material from the lumen of the injured colon is indubitably more frequent than from the small gut, and even in these days of the sulphonamides and antibiotics, weighs against the patient's recovery. If the peritoneal cavity at the time of operation is already inundated with a flood of highly infective stercoral fluid from the intestine, or if the extraperitoneal tissues or psoas muscle be soaked, sodden or bespattered with bowel contents, efforts to save the patient are likely to be fruitless. Major Gordon Johnston, R.C.A.M.C. pointed out that the amount and nature of the contents of the large intestine at the time of wounding played no inconsiderable part in determining the prognosis:

(*a*) When the bowel contents are bulky, moist or semi-solid, as they were in the wounded civilians who were encountered, they pour out of the defect and lavishly inoculate the peritoneum with virulent toxins and bacteria. Death is not usually long delayed.

(*b*) The soldier on the other hand, when fighting, partakes infrequently of a concentrated diet. As a result, his colon was observed to contain only a small amount of desiccated faeces. Some wounds were seen where *no* faecal material had escaped from the bowel at all; in others a few hardened particles lay free on the adjacent peritoneum and could be lifted out, and these cases occasioned little concern.

(vii) Regarding the special proclivity of the large gut to suffer secondary perforation in lesions due to immersion blast, it is doubtless not without some import that the large intestine has not the uniformly disposed musculature that characterises the jejuno-ileum.

(viii) Infarction is more often met with in missile wounds of the large intestine than in the case of the small bowel; such cases cogently demand exteriorisation.

The treatment of these wounds did in one instance define a marked advance in war surgery—the policy of routine exteriorisation of wounds of the large gut. Increasing experience gave ample proof of the necessity of grouping with actual surgical wounds those cases in which the colon had simply been contused or in which there was a marked extravasation of blood into its walls. So serious was the significance of such cases, that they were considered to merit identical treatment with an actual perforation. Perhaps even more than in the case of wounds of the small intestine, adequate exposure allowing thorough systematic examination of the whole colon was of prime importance, and in the treatment of wounds of this portion of the alimentary tract the ever-present possibility of extraperitoneal wounds, either alone or combined with intraperitoneal lesions, had always to be remembered.

Inasmuch as a systematic examination needed to be carried out from caecum to pelvic colon, and such inspection took second place only to the control of massive haemorrhage, individual lesions were cobbled as they were discovered to prevent any continuation of peritoneal or extra-peritoneal soiling.

TECHNIQUE: The following methods were available for treatment of colonic injuries:

a. Resection.
b. Exteriorisation.
c. Suture and proximal colostomy.
d. Suture alone (with or without drainage).

a. Resection: Resection was avoided whenever possible, since it carried a consistently high mortality, somewhere in the neighbourhood of 65 per cent. Its chief use was in massive wounds of the caecal region, in which case the continuity of the bowel was restored by an ileo-transverse junction. Some thought it a valuable safeguard, if the proximal end of the transverse colon was left open and brought to the surface temporarily, but there was no unanimity about this, and there is no anastomosis so satisfactory, safe and rapid as the end-to-end variety.

b. Exteriorisation: As has been stated, this was the routine method of treatment and has rightly been described as one of the definite advances of the surgery of this war. It was universally accepted as a primary treatment on all fronts and deviation from such a course was only permitted in wounds with special characteristics (*vide* page 135.) or to surgeons of wide and long experience.

Thanks to the vision and enthusiasm of Major General Sir Heneage Ogilvie, the practice of exteriorisation of the colon for its injuries remained almost unchallenged as the premier treatment of wounds of the large gut throughout the long years of the war; the influence and teaching of this great surgeon and the ready response of those who manned the forward surgical units and casualty clearing stations in the different theatres of war to his sustained and unswerving advocacy of the exteriorisation technique, saved the lives of thousands of wounded men. It was better that exteriorisation should be performed without primary resection, i.e. that the damaged loop of colon, mobilised, if and as necessary, should be brought out *in toto* and the wound allowed to act as a colostomy; resection of the loop could then be done with safety some 48 hours later. Wherever possible, the exteriorisation was done through a separate stab incision and not through part of the laparotomy wound; and furthermore, the stab incision was preferably through muscle, e.g., for a wound in the transverse colon the loop was brought through the rectus abdominis.

Wherever possible, a 'spur' was formed by suturing the two limbs of the loop with interrupted sutures on their anti-mesocolic borders: this involved some rotation of the segments to ensure good apposition of serous surfaces: the optimum length for a spur was at least two inches. Although mobilisation of the more fixed portions of the colon was not a particularly difficult manoeuvre, especially in those cases where a retroperitoneal haematoma, so frequent an accompaniment of colon wounds, provided a well marked line of cleavage, the formation of a spur was sometimes difficult to accomplish without tension.

Even before the termination of the war and in more recent years, experience has provided ample proof that spur-formation is not so essential as was originally thought. With the use of the non-absorbable sulphonamides, e.g. sulphaguanidine, sulphasuxidine and sulphathalidine, the closure of a colostomy has become a much safer procedure, so much so that excision of the colostomy with end-to-end suture and intraperitoneal replacement of the re-united gut is to-day accepted as the method of choice. Hence the preliminary formation of a spur, the object of which was to secure extraperitoneal closure by crushing, has become far less important.

This technical advance is not without considerable practical value in the primary treatment of these wounds, since mobilisation of the fixed colon, a greater degree of which was obviously necessary for the formation of an efficient spur, was in itself productive of shock, especially if carried out in the upper part of the posterior abdominal wall. Furthermore, spur-formation often led to the increasing size of the retroperitoneal 'dead-space' which, though as a routine it should be treated locally and drained, provided an area widely exposed to the risk of infection.

There was no harm in suturing the exteriorised loop to the peritoneum, but this step was not really necessary; indeed valuable time was saved by simply anchoring it with a glass-rod, a piece of strong rubber tubing or a tube of catgut, inserted through the mesocolon at skin level. In a large series of cases the mortality of this procedure averaged between 20 and 30 per cent.

c. Suture and Colostomy: There was a limited field for this technique, the indications for which may be summarised as follows :

(i) In minor wounds of the right colon and caecum.
(ii) In wounds of the lower pelvic colon and rectum, though it should be pointed out that wounds of the lower segment of the pelvic colon were all too frequently inaccessible to suture. In such cases simple drainage combined with proximal colostomy was indicated.

The site of suture was always drained for a few days and some 10 g. of sulphadiazine applied locally. Colostomies made in connexion with such lesions as those mentioned above were placed as near the laceration as was practicable, were formed with a good spur and were opened at once. The average mortality of 33 per cent. in cases treated by such methods showed that the procedure should only be used as a necessary substitute for exteriorisation where mechanical and other considerations made the latter difficult or impossible.

d. Suture Alone (with drainage): In the selection of cases for treatment by suture alone, considerable experience and very careful judgment were required. Such a method could only reasonably be used for minor wounds, particularly those of the right colon where the risk of bacterial contamination from bowel contents was relatively less. The suture was in two layers and, where possible, reinforced with omentum. Only in very exceptional instances could drainage to the site of suture be dispensed with, and in all cases the local application of sulphadiazine was carried out. The low mortality of 20 per cent. shown by a series of such cases was due to the fact that the wounds were specially selected and in general of a minor nature.

The following series of colon wounds treated by suture or exteriorisation is an index of the surgical judgment of two experienced officers:

Wounds of Large Intestine

(With or without associated visceral or other injuries.)

(Blackburn and Rob)

73 cases: mortality = 42·4 per cent.

	Alive	Dead	Mortality
			per cent.
Suture . .	11	5	31·2
Exteriorisation .	31	26	45·8
Totals	42	31	42·4

Caecum and Right Colon: From the above paragraphs it will be obvious that in certain respects this portion of the large intestine presented a rather different problem from the rest of the large gut, and many thoughtful surgeons towards the end of the war felt that the routine exteriorisation, practised for injuries in the middle and left-sided colon, often proved disadvantageous to patients wounded in the right-sided colon, especially the caecum. This was particularly apparent in the subsequent dehydration and skin excoriation which ensued owing to the fluidity of the faeces at this level (Plate II).

Therefore, the right-sided colon and caecum became in carefully selected cases the chief site for the employment of conservative methods. Even in those cases in which exteriorisation seemed the wisest course, several experienced surgeons (Aylett and others) considered an accompanying ileo-transverse colostomy was a thoroughly justifiable procedure, when the extra time involved in making the anastomosis was not primarily a risk to life. By such a side tracking, it was estimated that some two-thirds of the faeces proceeded by the normal route to the rectum.

The spirit of revolt against routine exteriorisation of the caecum and also the ascending colon first flared up in the Central Mediterranean area: men like Geoffrey Estcourt, Guy Blackburn, Benison, Dill Russell and others may have been the more diligent with their pens on this subject, but many of the veteran F.S.U. surgeons became very critical of exteriorisation for wounds of the caecum.

Some of the older generation of surgeons who had frequently in the past witnessed the distress, dehydration and sometimes death that followed right-sided exteriorisation, used for resection of the large gut for malignant disease, had persistently warned against exteriorisation of the caecum, and may have been silently surprised at directives issued to the F.S.U. surgeons even late in the war enjoining exteriorisation for all and sundry injuries of the large gut, regardless of their situation. It was therefore without wonder, but with dismay that they witnessed the post-operative state of those wounded in the right iliac fossa and evacuated to Britain in the early days of the Normandy landing. Still more distressing was the state of this particular group of abdominal casualties when the innominate bone was damaged as well as the caecum. The exteriorisation procedure for wounds of the caecum has always been anathema to the writer, but for the hapless wretch, perhaps wounded in many parts, it was a grievous burden scarcely to be borne.

As the months of the B.L.A. campaign passed by, the surgical tyro became an experienced veteran, and protests against exteriorisation of the caecum waxed more vigorous. Long before, during the Eighth Army Desert campaign, Andrew Lowdon had written 'the caecum should not be exteriorised: most of the wounds I encountered were successfully treated by repair and caecostomy': Handley, as far back as 1940, had commanded success by merely sewing a catheter into a perforation in the right colon and caecum, and even by simple suture without any decompression. E. B. Tovee, writing of severe wounds of the right-sided colon, said that exteriorisation was a matter of necessity rather than choice; Strang, with all his experience, developed a preference for suture of small wounds of the large bowel, especially in the right-half, followed invariably by the establishment of a valvular caecostomy.

Major S. D. McKinnon, R.C.A.M.C. confessed to sore temptation to disobey instructions, when confronted with minimal wounds of the large intestine, especially on the right-side. Lt. Colonel Cecil Murray wrote 'Wounds of the caecum, and especially those involving the region of the ileo-caecal valve, were unsatisfactory when exteriorised and difficult to close later, owing to skin excoriation and infection, and prolapse of the ileo-caecal valve'. Murray treated four cases of this type in the forward areas by primary suture of the caecum in two layers combined with an ileo-transverse anastomosis, with good results: and thought that this line of treatment had a definite place in this type of case.

Most forward surgeons, at some time or other, performed the operation of right hemicolectomy for cases in which there was 'fragmentation' of the right-half of the colon resulting from multiple wounds, but Murray found this proved to be a most lethal operation for 'battle abdomens'. This type of case was always serious, and the best chance of success appeared to lie in excision of the damaged segment of bowel followed by exteriorisation of the ends, and associated with an ileo-colostomy; the provision of adequate drainage of the retroperitoneal space was absolutely essential.

Multiple Colon Wounds. Ingram met with this in no fewer than 20 per cent. of colon wounds. Lowdon says: 'Multiple lesions of colon are not infrequently encountered: I had 4 such cases in 64 cases of abdominal wound. The obvious operative solution by repair or resection of the distal area and exteriorisation of the proximal area does not meet all cases. For example, one of my cases had large tears and extensive bruising of the transverse colon and a small clean wound of the ascending colon, and I thought it best to exteriorise the transverse colon and repair the ascending colon with a caecostomy. I have not found it necessary to make two colostomies, but I have seen Major S. Wilson (N.Z.M.C.), in a case with extensive areas of damage in both transverse and descending colon, exteriorise both lesions rapidly and successfully, preferring this course largely because the patient appeared too ill for the delay that resection and anastomosis of the descending colon would have involved.'

Secondary Haemorrhage after colon injury. This is rare but may occur.

Case: G. R., a German S.S. paratrooper, had a left-sided thoraco-abdominal wound involving lung, spleen and splenic flexure of the colon. To save time a proximal transverse colostomy was performed. The patient had two violent secondary haemorrhages evidenced as melaena on the fifth and eighth day after operation, necessitating the transfusion of 5 and 8 pints respectively.

WOUNDS OF THE RECTUM AND ANAL CANAL

Incidence. The percentage of missile injuries of the rectum among abdominal casualties, as judged from Brigadier Sir Arthur Porritt's large collected series (7·05 per cent.) and from the strikingly corresponding percentage from the C.M.F. (7·1 per cent.), would seem to suggest a relatively greater frequency of rectal injuries in the Second World War than in its predecessor, in which the rectum was wounded in only 2·2 per cent. of abdominal casualties (Sir Cuthbert Wallace). Incidence percentages, however, varied in the different campaigns of the 1939–45 conflict; thus, among the abdominal casualties from the Western Desert, Ogilvie found the rectum involved in 17 per cent. of abdominal battle casualties.

The divergent experience of individual operators, based on much smaller series of cases, may be gauged from the perusal of such incidence-percentages among abdominal casualties as 1 per cent. (Michie), 3 per cent. (Sperling and his American colleagues), 4·7 per cent. (Stout's New Zealand series), 6·6 per cent. (Giblin), 7·4 per cent. (Geoffrey Parker), 11 per cent. (Eaton) and 12 per cent. (Lowdon), percentages which were all in excess, sometimes greatly so, of the 2·2 per cent. of the War of 1914–18.

WOUNDS OF THE RECTUM

The anatomical relations of the rectum determine the possibility of three varieties of rectal wound (*a*) extra-peritoneal (*b*) intra-peritoneal (*c*) intra- and extra-peritoneal. In some perforating wounds the direction of the wound-track indicates with certainty the portion of the rectum implicated, and radiography may perform a similar service in the case of penetrating injuries; in other cases, especially those with semi-vertical wounds of pelvis and perineum, both 'pelvic' and 'perineal rectum' may be damaged. The possibility of rectal laceration should not be forgotten in any wound of the buttock, sacral area, upper thigh, hip or perineum.

(*d*) A fourth type of injury, the explosive wound of the perineum, was as familiar to forward surgeons in the War of 1939–45 as it was to their forebears in the First World conflict; in this the anal orifice and anal sphincters are torn away from their normal anchorage in the perineum, perhaps surrounded by a peri-anal frill of skin, and perchance retracted into the depths of the wound. It has been suggested that at the time of impact the levatores ani and the sphincters contract violently, and hold tight while the concussion of the missile traversing the loose tissues bursts the skin of the perineum in a manner comparable to 'the popping of a closed paper bag'.

Less was heard in the War of 1939–45 of the gangrenous ulceration of the gut associated with injuries to the sacrum in which the missile track did not traverse the rectal wall, a lesion to which attention was drawn by Hamilton Drummond and Shaw Dunn in the War of 1914–18. The rapidity with which the mucosa ulcerates after losing its blood supply by reason of rupture of the muscularis of the bowel wall is very remarkable.

Lengthy Missile Tracks Involving the Rectum. Brigadier C. Naunton Morgan recorded the case of a man who had sustained a bullet wound through the great trochanter, and in whom a wound of the rectum was not suspected until the patient 'passed wind through the great trochanter with a high musical note'.

Lt. Colonel R. S. Handley had under his care an Italian officer wounded by a bullet just above the popliteal fossa, the missile escaping from the opposite buttock. Shortly after his arrival at the base he passed flatus and a small motion from the popliteal fossa. Subsequent operation showed that the bullet had nicked the anal canal, as it crossed the mid-line without 'surfacing', and the bowel contents had escaped from the rectum into the long track down the thigh. After appropriate surgery he made a good recovery.

Case: Private A. of the R.A.C. was admitted to the C.C.S. in November 1942, 17 hours after being wounded by a shell splinter. Faeces were leaking through a large wound of the left hip joint. At operation it was found that the peritoneum had been spared but there was a big wound of the rectum for which colostomy was performed. The man was seen at a base hospital one month later, and was slowly improving. (Lt. Colonel Bernard Williams' case.)

Comment. This case shows remarkable survival following an extensive and grossly contaminated wound. The early diversion of the faecal stream was doubtless an important factor.

The circumstances of buttock wounding were multifarious; members of each Service sustained wounds of the bottom with 'their pants down'.

Case: A stoker in one of H.M. ships was at the 'heads' when the ship struck a mine; he was flung upwards and came down on a broken seat, receiving a wound traversing the ischiorectal fossa, dividing the levator ani and exposing the peritoneum in the depths of the wound.

Case: In November, 1942 Pte. F. of the Australian Imperial Forces was engaged in opening his bowels in the squatting position. This act was rudely interrupted by the explosion behind him of a shell and by the sensation of 'being kicked in the "date" by a horse'. Examination at the C.C.S. showed an entry wound of the left buttock 1 in. in diameter, and a large foreign body was palpable under the skin of the right thigh just above the adductor tubercle! A trickle of blood from the anus was observed, and digital examination showed the absence of the rectal ampulla and all the anal canal except the outer skin. At operation the peritoneum was found to have escaped injury. Colostomy was done and the wounds excised as far as possible. The foreign body was a shell splinter measuring 4½ in. by ½ in. by ½ in. Convalescence was surprisingly smooth. (Lt. Colonel Bernard Williams' case.)

In cases where injury has been produced by a large fragment, the degree of damage to the gluteal region and sacrum may be frightful, and anus and perineal rectum may be completely avulsed. The lessened fatality of wounds of the sacrum in the last conflict in comparison with the War of 1914–18 could not but impress an older generation of surgeons with the inestimable value of antibiotic therapy as an adjuvant to wound excision.

On occasion a fragment of high explosive, felt projecting into the postero-lateral wall of the rectum, has been removed.

Apart from wounds inflicted by enemy missiles, spicules of bone, etc., the rectum was wounded in other ways. During the 'Battle of Britain' an officer of the R.A.F. at the termination of an enforced parachute descent landed in the fork of a tree and sustained a laceration of the rectum, a branch of the tree also disrupting the pararectal tissues right up to the iliac fossa: happily the peritoneum was untorn. The injured man then fell to the ground, sustaining a severe fracture of the pelvic girdle; there 'was a wide separation of the symphysis and a disruption of the sacro-iliac synchondrosis'.

An artilleryman was standing on a pyramid of petrol tins in order to hang his towel on some hot pipes meanwhile supporting himself on a broom-handle. The pyramid collapsed and the handle of the broom entered the anus, producing a rent in the anterior wall of the rectum and base of the bladder. The wound in the bladder was successfully sutured by H. W. L. Molesworth by a transvesical approach and a transverse colostomy was performed, which was subsequently closed.

Severe Secondary Haemorrhage may occur in Connexion with Missile Wounds of the Rectum

Case: Private W., infantryman, sustained a shell wound of the sacral region in March 1943. Rectal examination revealed a crepitant haematoma, and there was blood on the examining finger. Exploration of the abdomen showed no intraperitoneal lesion ; colostomy was performed and the sacral wound trimmed and drained. On the tenth day he had severe secondary haemorrhage from the sacral wound, for which the internal iliac artery was tied. There were further haemorrhages in spite of this measure, but with adequate blood transfusion the man survived. (Case under the care of Lt. Colonel Bernard Williams.)

Comment. A finger in the rectum is sometimes as important in war as in peace!

Case: An infantryman of the Leicester Regiment received a through-and-through shell wound of the abdomen, as well as multiple injuries of other regions of the body, including a traumatic amputation of one leg. His sacrum and rectum were shattered; a coil of small gut had herniated through the anterior belly wound; numerous lacerations of the small intestine were sutured and a colostomy was performed. An infection of the injured remaining knee-joint with *B. pyocyaneus* responded dramatically to treatment by sulphathiazole and flavine, but recurrent haemorrhages of a torrential character from the rectum and sacral wound punctuated his passage to recovery, and in the many weeks of hospitalisation several times gravely jeopardised his life. The most severe haemorrhage of all, in which some five pints of blood were lost literally in a few seconds, was perforce treated by division of the ano-rectal musculature and the blind application of long artery forceps to the source of bleeding some 4 in. up the bowel on its posterior surface; these were left *in situ* several days; the haemorrhage was arrested and happily did not recur. Nearly 100 pints in all were employed during the man's lengthy convalescence. No repair has been possible for the divided anal sphincter, but the man leads a useful life. (Case of C. K. Warrick.)

On this exceptional occasion the sacrifice of the anal musculature was the price to be paid for the preservation of life in rectal injury of gunshot origin.

TREATMENT OF WOUNDS OF THE RECTUM AND ANAL CANAL

It must be remembered that a *colostomy is an essential procedure in all wounds of the rectum.* Apart from this the general lines of treatment are as follows:—

(*a*) *Intraperitoneal Wounds.* Every effort must be made to close an intraperitoneal wound of the rectum. This can usually be accomplished after good exposure, but a wound in the depth of the pelvis associated with wide-spread damage of the rectal wall, may be impossible to suture. In such a case free drainage, local chemotherapy by daily instillation of a sulphonamide down a catheter inserted into the wound, and the judicious use of the omentum as a protective, will help to control infection and shut off the area from the general peritoneal cavity. All intraperitoneal wounds should be drained; the Coffey drain is of value in such cases.

(*b*) *Extraperitoneal Wounds.* It is rarely wise or possible to close an extraperitoneal wound of the rectum, but good drainage of the perirectal tissues must be obtained, especially when there is a wide-spread haematoma or extensive damage to the rectal wall.

Although good drainage of the pelvic cellular tissue planes is difficult to establish, an external wound near the lateral border of the sacrum may be extended vertically along the side of the coccyx and sacrum for free drainage. However, the most satisfactory method of draining the perirectal tissues is by excision of the coccyx, division of the fascia of Waldeyer, and the opening up of this area by finger dissection. The patient need not be turned on the table to do this; elevation of the sacrum on a sandbag with the legs in the lithotomy position will suffice.

Drainage of the lumen of the rectum must not be forgotten, and at the end of the operation the anal canal should be dilated and a large rubber tube stitched in position to the anal verge. *There is never any* *justification* for division of the ano-rectal musculature in order to provide drainage.

(*c*) *Explosive or Bursting Wounds of the Perineum.* After wound toilet, it is usually unwise to attempt primary repair, but delayed primary suture is of great value in these cases and, when the urethra is damaged, should always be carried out. The ano-rectal musculature should not be widely excised.

INDICATIONS FOR COLOSTOMY IN WOUNDS OF OR NEAR THE RECTUM

1. As stated above, Colostomy is an essential procedure in all wounds of the rectum.
2. Colostomy may also be desirable in large wounds of the buttock, especially where situated near the anus; nursing is thereby made easier.
3. Colostomy is advisable in cases of extensive perirectal trauma with haematoma formation, even without demonstrable injury of the bowel. The indication is still more cogent in those cases where infection, spreading from a buttock wound through the fascia of Waldeyer, may result in secondary involvement of the bruised and devitalised rectal wall and initiate pelvic cellulitis.

The Indications for drainage of circumrectal tissues in wounds of or near the rectum are as follows:

(*a*) Any laceration of extraperitoneal ('perineal') rectum, whether it has been repaired or not.

(*b*) Any injury of the 'pelvic' rectum, where its non-peritoneal surface is actually or potentially damaged, more especially if there is extraperitoneal extravasation or a haematoma, of any size.

(*c*) Where infection of the retroperitoneal or pararectal tissue is already established.

TECHNIQUE OF COLOSTOMY FOR WOUNDS OF THE RECTUM

The colostomy should be made as near to the rectal or colonic lesion as possible. A long loop with suture of its limbs and the formation of a good spur will make subsequent closure much easier. For a wound of the rectum the middle of the sigmoid loop is generally the best site for a temporary colostomy. The two limbs of the colon are sutured together along their anti-mesenteric borders for several inches, the suture being commenced from within the abdominal cavity and uniting longitudinal bands. The colostomy should be established through a separate stab wound, but in a desperate case colostomy through the exploratory wound is justifiable. A glass rod, a glass catgut-tube or a piece of stout rubber tubing may be used to hold the colon in position; suture to the abdominal parietes is unnecessary. At the end of the operation the colostomy is opened and a finger passed into each stoma.

When extensive laceration of the rectum or the sigmoid colon has occurred, and in view of the future reconstructive operations, a defunctioning colostomy in the transverse colon will leave the area of damage free for future manipulations. However, it must be remembered that the primary object of a colostomy is to save life and that it can always be closed.

TREATMENT AT THE BASE

Operations for the repair of wounds of the pelvic organs are usually long and difficult procedures, and therefore must not be undertaken until the patient's general condition is satisfactory and sepsis under control.

Delayed primary suture is of the greatest value for wounds of the perineum when the urethra and anorectal region are involved, because the fibrosis and distortion which accompany healing by granulation tissue make repair much more difficult.

Before a rectal wound can be repaired, it is essential that the colostomy should completely exclude the distal gut from contamination. Intraperitoneal wounds usually close spontaneously when drainage is free, but in some cases operation is necessary, and repair will require mobilisation of the sigmoid colon and rectosigmoid from the front of the sacrum.

Extraperitoneal wounds adherent to the sacrum are troublesome and complete mobilisation of the gut must be carried out before suture. Skin closure should be obtained as soon as possible so that, even if the wound in the rectal wall breaks down following suture, the resulting internal fistula will not be of any inconvenience to the patient.

Sulphasuxidine, twenty grammes in six ounces of half strength mucilage, instilled daily into the distal colostomy loop ten to fourteen days before operation, and the use of parenteral and local penicillin, make repair more certain.

The colostomy must not be closed until all wounds, especially of the skin and anal muscles, are soundly healed.

PROGNOSIS OF WOUNDS OF THE RECTUM

Accounts of former wars record the occasional spontaneous recovery of patients with rectal wounds, as in the two cases recounted by Guthrie; the first concerned a naval officer wounded by a ball which damaged his rectum and emerged at the side of the sacrum, faecal matter escaping from the wound; he ultimately returned to sea to command his ship. The second was a French prisoner wounded at Salamanca, who received a penetrating wound at the side of the sacrum and on the sixth day passed the ball per anum and quickly recovered.

The main features of missile-wounds of the rectum have not differed in the two Great Wars, but modern ancillary methods of treatment, as well as the routine performance of colostomy and a more thorough opening up of the circumrectal tissues to ensure satisfactory drainage, have yielded results in the War of 1939–45 which definitely surpass those of the War of 1914–18.

Perhaps the mortality figures of injuries of the rectum, which amount to 30 and 36 per cent. in two series from the B.L.A., approximate most nearly to the truth; when the rectal lesion was associated with other wounds, the mortality rose to 50 per cent.

The mortality from wounds of the rectum in the C.M.F. amounted to 47·5 per cent. (Harold Edwards and Stead), and from the Western Desert (Ogilvie) reached 52 per cent.

No individual surgeon met with large numbers of wounds of the rectum; indeed, one or two failed to encounter a single case, and from the limited experience that any one surgeon can have had and the variable attendant circumstances in which operation was performed, no worthwhile information as to fatality was to be expected from individual records. On the whole, the results attending the efforts of individuals were considerably better than those recorded by surgeons of the War of 1914–18; thus, Stout and his New Zealand colleagues had a recovery-rate of over 53 per cent., a figure very closely approximating the 52 per cent. recorded by Gordon-Taylor in his Bradshaw Lecture, which largely dealt with abdominal casualties on the 'home-front'.

CLOSURE OF COLOSTOMIES

For the closure of colostomies in the latter period of the war, centres were established to which such patients were sent: thus, there were two 'colostomy centres' in the C.M.F., one of which was under the care of Lt. Colonel Cecil Murray at 100 General Hospital, C.M.F. (whose account is made use of in this note); there were also two Canadian 'colostomy centres' in Britain. During the period in which the scheme was in operation its advantages became manifest:

(*a*) Delay in the closure of colostomies was very much reduced; this was especially noticeable in Italy, where previously these patients had tended to be evacuated from hospital to hospital, eventually being transferred to the United Kingdom, where again more time was lost, so that it was not unusual for six months to elapse before a start was made to restore the normal functioning of the large bowel. In the later cases of the series treated in the colostomy centres in the C.M.F. it was found possible to start the process of closure within about a month of the initial injury.

(*b*) All cases with a colostomy were segregated into one ward kept exclusively for this type of case. The isolated colostomy patient who finds himself in a general ward feels self-conscious and readily gets the idea, almost always wrongly, that his fellow-patients look on him as 'dirty' and the staff regard him as a nuisance. Nothing does more to encourage these patients or restore their confidence quickly than to find themselves in a ward with men who have just had their colostomy successfully closed.

(c) It enables the nursing staff to be trained in the appropriate pre-operative and post-operative routine, and especially in the giving of efficient wash-outs.

After admission nothing in the way of investigation was done for forty-eight to seventy-two hours: this interval of 'peace' was of some importance as most of these men had done a great deal of travelling with its inevitable evils of discomfort, loss of sleep, irregular meals and decreased fluid intake. A good sleep, a shave, a blanket bath, appetising food and copious fluids worked wonders; and the respite also gave the man time to get to know his fellow patients.

Routine investigation consisted of a complete clinical examination and a careful review of the patient's other wounds, followed by any necessary X-ray examination. A routine blood count and plasma-protein estimation was done on all cases. Then followed an examination of the colostomy in the theatre under pentothal anaesthesia to determine the type and condition of the 'spur' and plan the closure.

COMPLICATIONS ON ADMISSION TO COLOSTOMY CENTRE

In view of the severity and multiplicity of the wounds in many of these cases, serious complications on arrival at the base were remarkably few and, apart from one patient with an incisional hernia of some size through his colostomy wound, were all due to sepsis, and are set forth in the table below:

Subphrenic abscess	Pelvic abscess	Abdominal wall infection (severe)	Empyema	Faecal fistula	Osteo-myelitis of ilium	Ventral hernia
3	1	2	1	1*	1*	1

* In the same patient.

Of the three cases of subphrenic abscess, two were in patients who had been treated by a primary suture of a solitary wound in the splenic flexure of the colon. The two cases of severe abdominal-wall infection were both due to partial retraction of the colostomy. Minor degrees of abdominal-wall sepsis were present in about a third of the cases and were noticeably more frequent in those cases in which the colostomy had been brought out through the laparotomy wound.

Spurs. Two of Lt. Colonel Murray's series of colostomy cases for closure had no 'spur'; both had received small single wounds of the transverse colon which had been exteriorised as a 'spurless' colostomy. On admission to the colostomy centre these two patients had small fistulae showing no signs of spontaneous closure: both patients were

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passing normal stools per rectum and both fistulae were closed with the greatest of ease. This type of 'colostomy' would appear to have a definite place in the initial treatment of small single wounds of the colon, and to Murray this seems a much sounder surgical proposition than primary suture without colostomy, which at the best is a hazardous undertaking and may be disastrous. The remaining cases all had 'spurs', ranging from the ideal to others falling very far short of this standard, although in no case were the main vessels found in the 'spur'. Most trouble was encountered with the rather short, fat, divergent type of spur, to which the application of a crushing clamp was difficult or even dangerous, and in two of these cases it was found necessary to resect the whole colostomy and restore the continuity of the bowel by end-to-end anastomosis.

Faecal impaction in the distal segment. All patients admitted with colostomies were found to have inspissated faecal material in the distal colonic segment. This was most marked in cases with poor spurs, but was also found in those in whom the spur was in every way ideal; this condition appears to be inevitable under war conditions and is of no great moment provided that the condition is recognised, and the distal segment cleared before any attempt is made to close the colostomy.

The pre-operative preparation of the bowel is most important and the routine adopted in these cases was to give daily washouts until the bowel was clear, after which the washouts were given every third day. Daily washouts of the proximal segment were given every morning throughout.

Prolapse of the Mucosa. This condition was present in the majority of the cases, and an attempt was always made to reduce it as much as possible when the colostomy was first examined under an anaesthetic, and, if successful, reduction was repeated daily after the washout and a firm dressing applied. By this means it was found possible to reduce the chronic oedema of the bowel ends, greatly facilitating the subsequent closure.

IMMEDIATE PRE-OPERATIVE TREATMENT

Once the 'spur' was satisfactorily crushed, an interval of ten to twelve days was allowed to elapse before the final operation. About a week was the minimum time taken for the oedema and reaction in the bowel ends to subside after the clamp came off; some prolongation of the interval before final closure appeared to be no disadvantage.

During this interval the patient was put on a high protein, low residue diet and the blood picture, if not already normal, was restored by transfusion, and, on the fourth day preceding operation, a course of sulphasuxidine—20 g. daily, was started. Daily proximal and distal washouts were given from the third pre-operative day up to and including the morning of operation.

Sulphasuxidine. In the 'colostomy centres' it was found that after four days with a dose of 20 g. of sulphasuxidine a day, given as 10 g. night and morning, *B. coli* disappeared entirely or only a few colonies were present in high dilution cultures after four days. This inhibition of the *B. coli* was maintained for as long as the administration of the sulphasuxidine was continued.

The behaviour of the *enterococci* was somewhat different: the colony counts dropped more slowly and reached their lowest levels in four to five days, but complete absence of the *enterococci* seldom occurred. This phase lasted for five to six days, after which, an 'escape phenomenon' seemed to occur so that in a further three to four days the organisms had reached their normal pre-drug level, and further administration of the sulphasuxidine caused no further change, although the *B. coli* still continued to be inhibited.

To obtain the maximum effect at the time of operation and in the immediate post-operative period, sulphasuxidine should be administered in a dose of 20 g. a day, commencing four days before operation and continuing for seven to eight days after.

OPERATION

This was carried out along orthodox lines with slight variations to overcome individual problems in each case. The type of operation carried out by Lt. Colonel Cecil Murray in 23 colostomies submitted to closure is set forth in the subjacent table.

In nine cases the peritoneum was deliberately opened to facilitate closure: in all these cases the colostomy had originally been brought out through the laparotomy incision.

In all cases the bowel was sutured in two layers and the abdominal wall reconstituted in layers over penicillin-sulphathiazole powder. A small corrugated stab drain, inserted down to the region of the bowel suture line in each case, was removed after seventy-two hours. Sulphasuxidine was continued for six to seven days post-operatively.

Method of closure	Cases	Deaths
Extraperitoneal closure after crushing spur . . .	9	1
Extraperitoneal closure, no spur crushing necessary .	5*	Nil
Intraperitoneal closure after crushing spur . . .	7	Nil
Resection with end-to-end anastomosis and temporary valvular caecostomy . .	2	Nil
Total cases closed	23	1

* Includes 3 caecostomies.

In two cases resection of the colostomy and an intraperitoneal end-to-end anastomosis were performed, and in both a temporary valvular caecostomy was done as a safety valve; in each case the caecostomy closed spontaneously after removal of the catheter ten days after operation.

RESULTS

In this series of 23 patients submitted to operation there was one death which followed the extraperitoneal closure of a left inguinal colostomy and resulted from a post-operative chest complication, confirmed at autopsy, at which the colostomy closure was found to be sound and the peritoneal cavity clean. The remaining 22 patients made uninterrupted recoveries and in no case did any leak take place from the suture line.

Cases of colostomy should be sent to special centres at the base for closure as soon as possible after they are fit to travel. Normally the aim should be to commence closure of the colostomy within three or four weeks after the initial surgery.

The risk of operation for closure of the colostomy can be minimised by a carefully planned pre-operative routine which includes the following:

(*a*) The restoration of the blood picture to normal by a high protein diet and, if necessary, transfusion.
(*b*) Reduction of the risk of sepsis by delayed suture of any co-existing unhealed flesh wounds.
(*c*) Careful bowel preparation by efficient washouts.
(*d*) The administration of sulphasuxidine before operation and during the first post-operative week.

INJURIES OF THE LIVER

The incidence of wounds of the liver approximated 10 per cent. of all abdominal injuries, and such wounds carried a widely varying mortality (20–60 per cent.), according to the occurrence of associated lesions and also the method of treatment necessary, i.e. the severity of the local injury.

Surgical opinion upon the gravity of liver injuries due to enemy action has changed since the days of Ambroise Paré, who wrote that wounds of the organ were deadly, for this part is 'the workhouse of the blood, wherefore necessary for life'. On the other hand, centuries before the time of Paré, Paulus Aegineta had written that 'the lobe of the liver may be cut away without the consequences of death'. British surgeons of the Napoleonic era as a result of their experience in the Peninsula and after Waterloo, and Baron Larrey from his still wider knowledge, gained in every country of Europe as well as in Africa, were well aware that some patients with wounds of the liver recovered completely, while other survivors might suffer more or less permanent disability, the latter being more often related to the effects of concomitant damage to the thoracic framework than to the injured liver. There is at least one great therapeutic difference in the fashion of to-day from that obtaining in the early years of the nineteenth century; whereas in recent campaigns the transfusion of blood is utilised in generous fashion to render succour to those wounded in the belly, surgeons like Larrey, Guthrie, Thomson and Hennen placed their trust in blood-letting.

In Guthrie's *Wounds and Injuries of the Abdomen and the Pelvis* one may read of the vampire methods used in the treatment of Lt. General Sir S. Burns, who at Salamanca received a through-and-through wound involving his liver, and who nevertheless was certainly alive in 1819: of Lt. Colonel H. who recovered after repeated bleedings from a right-sided thoraco-abdominal wound involving the liver, sustained at Quatre Bras; of Corporal Macdonald, of the 79th Regiment, who also recovered from a wound of the liver received at Quatre Bras; and numerous others. Surgeon Thomson saw twelve through-and-through wounds of the liver recovering after Waterloo.

Experience in the First Great War impressed on the military surgeon of the second decade of this century that, if injury to other viscera could be excluded, surgical abstention in the treatment of liver wounds was the best policy, except under the following conditions: (*a*) gross haemorrhage; (*b*) the probable association of some other abdominal or thoracic lesion which demanded exploration; (*c*) retention of a large fragment in an accessible position in the liver.

In relation to the need for urgent surgery to arrest severe haemorrhage from missile injury, so distinguished a forward surgeon as Lt. Colonel (now Professor) C. G. Rob found that in only one out of 34 cases of penetrating wound of the liver was surgery necessary for the control of bleeding. No observer did more than Rob to stress the importance of careful clinical examination, especially where X-ray facilities were lacking, emphasising the inestimable value of repeated auscultation of the abdomen. In no case where the liver was the sole visceral lesion was peristalsis absent, although in several patients a large, diffuse peritoneal effusion of blood, bile etc. was present.

Pathology. Lesions of the liver due to missile injury may present themselves as a perforation, possibly with cracks or fissures radiating therefrom, a superficial score or 'gutter', a ragged wound or a crateriform cavity. The lower border of the right lobe, two or three inches or even a hands-breadth in depth, has on occasion been torn off by a fragment of high explosive (Tanton) or has only awaited the surgeon's scissors to effect the final separation. Considerable portions of the right lobe (John Anderson) or even three quarters of the left (Quenu, Tovee, etc.) may be shot away and lie loose in their raggedness within the peritoneal cavity, and yet the patient may recover from so devastating an injury. The liver is damaged in practically every thoraco-abdominal wound on the right side, and may be badly shattered in tangential injuries involving the lower portion of the thoracic framework. The whole organ may be completely disrupted even by a bullet wound, and the degree of hepatic destruction may be amazingly disproportionate to the size of the wounds of entry and exit.

Examination of museum material reveals injuries of the liver for which surgery would be futile; an operator's prowess alone cannot prevent infection throughout a long ragged tunnel running from one lateral surface of the organ to the extreme hepatic pole on the other side of the body, and surgical zeal would be entirely misplaced and probably harmful; chemotherapy promises more than surgical enterprise (Plate V).

A. P. Prior, from his autopsy material, described missile wounds of the liver as exhibiting a central ragged track surrounded by an area of necrosis, and this in turn by an area of white condensed fibrotic tissue. The extent of the fibrotic reaction and of hyperaemia in the zone outside the fibrotic area depended on the age of the wound; the most recent wounds of the liver showed least central necrosis and a less degree of fibrosis. Prior emphasised the large size of liver wound which might exist without proving lethal.

In the National War Collection (N.C. 361) is a specimen exhibiting an area of ischaemic necrosis of the liver in relation to a large internal rupture of the organ. The man had been struck on the back by an aeroplane landing on a runway; laparotomy revealed no external evidence of hepatic rupture; a tear of the duodenum was satisfactorily sutured and played no part in causing the patient's death, which did not occur till eleven days after the accident (Wing Commander E. S. Cato's case).

Among things curious in the War Museums (N.C.15) is a ruptured traumatic aneurysm of the hepatic artery consequent on a wound in the back during the War of 1914–18. No glamour of the field of battle attended the aneurysmal rupture, for it occurred during the course of a barium-meal investigation. A fragment of high explosive was found embedded in scar tissue under the left cupola of the diaphragm (Dr. L. R. Janes' specimen).

Another specimen in the War Collection (C.M.F.375) shows an aneurysm of a branch of the hepatic artery, which had produced a fatal haemorrhage in a soldier who had sustained a right-sided thoraco-abdominal bullet wound: the bleeding came from a small aneurysm projecting from the wall of an abscess cavity in the liver (Lt. Colonel C. J. Cunningham's specimen).

In casualties due to air-bombardment the majority of the injuries are not the primary effects of the explosion—i..e. are not produced by splinters or the direct impact of a blast-wave. Most are due to the secondary and tertiary effects of the bomb detonation. Those effects are said to be *secondary* where the casualty is directly exposed to the bomb, and where the injuries are due to the patient being thrown over either by the blast-wave or as a result of some splinter wound of another region. *Tertiary* effects are due to the impact of dislodged masonry, fragments of wood or other missiles, the collapse of houses, shelters, etc.

Sub-parietal or non-penetrating injuries of the liver may be produced by each of these agencies. Although injury to the spleen was the most frequent form of abdominal damage found in fatal cases in the mortuaries during the London Blitz of 1941, the liver sometimes suffered a primary blast-injury, and this was also occasionally encountered in cases of 'immersion blast'.

An extraordinary case of blast-injury, terminating fatally, came under the care of Major Wooler; at post-mortem the man was found to have a congenital diaphragmatic hernia which contained part of the injured left lobe of the liver herniating into the chest.

The degree of damage to the liver in recipients of a non-penetrating injury varies from an infracapsular haematoma, a central rupture or severe disruption, and even complete separation of a fragment of the organ.

THE FATE OF MISSILES IN THE LIVER

Inquiries at Pensions hospitals in Britain show no evidence of late operations for the drainage of abscesses round retained fragments in the liver, and confirm the view that small fragments remain innocuously in the organ. Nevertheless the evidence of War Museums indicates that retained foreign bodies, even of small size, may determine the formation of an intrahepatic abscess (Plate IV), but in the majority of cases an optimistic attitude may confidently be adopted, remembering that the consequence of a retained foreign body may not be worse than the trauma associated with blind attempts at its removal. If smaller fragments are destined to cause trouble, complications occur early; elevation of temperature and pulse made Geoffrey Wooler re-dress 5 cases between the fifth and seventh day after the original operation, and he was impressed with the necrosis of the liver that had taken place, large sloughs of liver lying in the abscess cavity.

Sometimes missiles may lead to unexpected and disastrous consequences; thus a missile which produced a tunnelled track through the liver also produced a laceration of the inferior vena cava, and the shell fragment concerned was carried to the right ventricle of the heart.

A dire misfortune befell a bombardier who had sustained a right-sided thoraco-abdominal injury; the wound of entry was in the 8th right interspace without any rib fracture. Laparotomy rapidly performed disclosed the presence of two pints of blood in the coelom and a lacerated right dome of the liver. Twenty-four hours after operation the patient suddenly and most unexpectedly succumbed, and at the autopsy a fragment of metal ¼ in. by ½ in. by ¼ in. was found to have traversed the liver, diaphragm and the antero-inferior aspect of the right auricle and had become lodged in a *sinus of Valsalva.* No effusion of blood was present in the pericardium; the small clot adherent to the wound of entry in the right auricle had effectively sealed the aperture.

TREATMENT OF PENETRATING WOUNDS OF THE LIVER

Some cases of penetrating injury of the liver manifestly require no operative interference; it is obvious from the missile-track that other viscera have not been damaged and the patient's condition remains good.

As the war progressed, a steadily increasing tendency to treat liver wounds conservatively became more obvious, and in the later period whenever diagnosis pointed to an exclusive injury of that organ, emergency operation was avoided. This was particularly the case where the entry wound was in the thoracic region. The size of a fragment of high explosive cannot be accurately gauged in the absence of X-ray equipment far forward; severe damage to the thoracic wall will constitute an indication for surgical débridement and a large metallic fragment may be felt through the diaphragm and readily removed. Tweddell remarked that the less the liver was traumatised by surgeons the better the prognosis; Blackburn was doubtful whether packing and suture did not do more harm than good. F.S.U. surgeons like Railton, Dill-Russell and A. S. Bullough (10 F.S.U.) were of the opinion that when the liver alone was thought to be injured the best course was to do nothing. If laparotomy were performed, most bleeding could be controlled by hot saline packs; where actual packing was required, the prognosis was very grave. There were three methods of operative treatment available—suture, packing, or simple drainage; these three methods carried approximate average mortalities of 50 per cent., 60 per cent., and 20 per cent. respectively.

SUTURE. Liver suture is notoriously difficult; there is a very great tendency for sutures to cut out. The best method was the use of wide mattress sutures of No. 2 catgut inserted by a large round-bodied needle, preferably through a chain of interlocking sutures along the sides of the cleft, according to the method of Grey Turner. Both omental grafts and free muscle grafts from the rectus abdominis (Geoffrey Parker) were frequently employed to reinforce the suture line.

PACKING. On the whole this method was probably more efficient than suturing, but inasmuch as it was used principally in the most severe cases its recorded mortality was correspondingly higher. Gauze (rolls) was the chief material employed for packing, but several surgeons relied solely on the omentum, turning up the whole flap into the liver rent as a 'blanket graft' (Tuckett). As a variant the rent was lined with omentum and into this gauze was packed (Ogilvie).

As an adjuvant, 'fibrin foam' was found to have a definite field of usefulness, but was of limited value where haemorrhage was at all

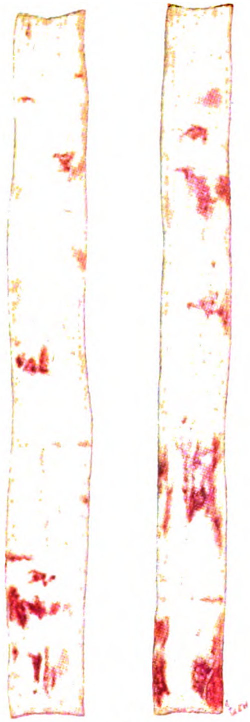

PLATE I. Goat intestine, showing changes produced by exposure to 'immersion blast'.

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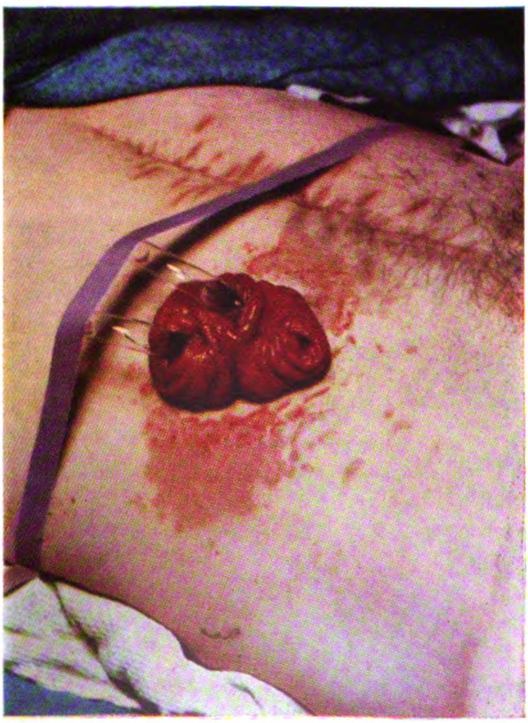

PLATE II. Gunshot wound of abdomen: exteriorised right-sided colon: the excoriation of the skin which is often so distressing a feature of right-sided exteriorisations is well shown.

PLATE III. Kidney : Thoracico-abdominal bullet wound necessitating splenectomy. Death two months later ; bullet had passed through upper pole of kidney cutting off blood supply, so that it has the appearance of an old white infarct.

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PLATE IV. Right lobe of liver riddled with multiple thick-walled abscesses. Death occurred several months after wounding, and in the interval the man had appeared well.

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PLATE V. Liver showing track of bullet from 'Tommy' gun : thoracico-abdominal wound. Death two days after injury.

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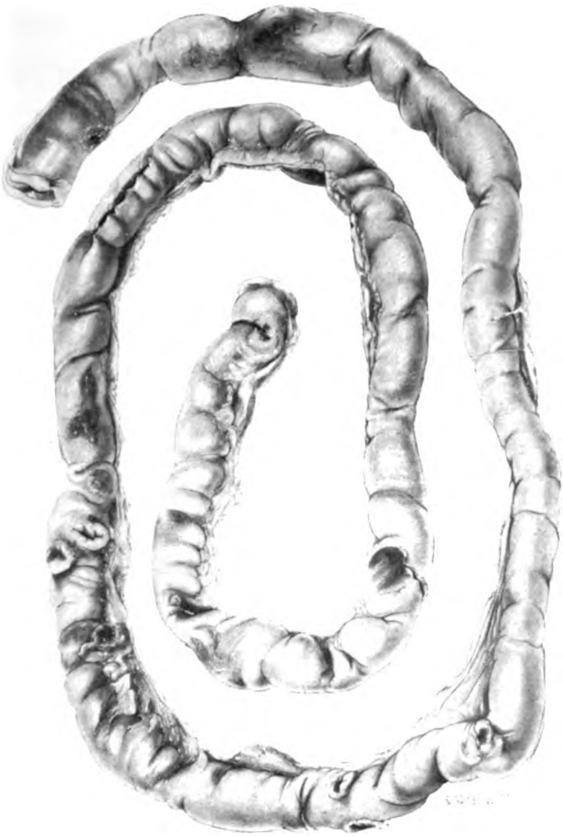

Plate VI. Surgeon Commander T. N. D'Arcy's case of successful resection of 6 ft. of bowel.

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Plate VII. Small fragments of bomb casing which entered buttock and produced many wounds of small intestine.

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PLATE VIII. Severe shell-fragment wound of perineum.

PLATE IX. Same case. Wound of perineum in process of repair: the reconstructed vaginal and anal orifices are reasonably well shown.

excessive. The chief advance, only employed in the final stages of the war, was the use of oxidised cellulose, which, being absorbable, could be packed firmly into the liver wound and left *in situ*.

DRAINAGE. In all cases which were operated upon for liver damage, drainage was considered essential to deal with subsequent effusions of bile rather than possible collections of blood; in many cases drainage tubes could be removed within 48 hours of operation.

TREATMENT OF NON-PENETRATING INJURIES OF THE LIVER

Minor degrees of liver damage recover spontaneously; the more severe type demands instant surgery, if life is to be saved; probably 60 to 80 per cent. of those with injuries to the liver of such severity as to necessitate immediate operation do not recover.

The time-honoured and valuable advice of Hogarth Pringle to grasp the structures in the free edge of the gastro-hepatic omentum as a temporary measure in quelling massive bleeding from a damaged liver has of course often been employed in the past by surgeons everywhere, but probably owed its usage in the War of 1939–45 to the oft-repeated advocacy of that master surgeon, Grey Turner. The latter also often warned surgeons that hepatic haemorrhage is partly controlled by the contraction of the abdominal muscles, and that as soon as this is relaxed under anaesthesia and after the abdominal cavity has been opened, the edges of the torn liver tend to 'sag apart' and bleeding which had already almost ceased may be re-started, and may even be torrential.

INJURIES OF THE GALL-BLADDER

Former military surgeons like Baron Larrey and Guthrie regarded wounds of the gall bladder as mortal, the effusion of bile into the coelomic cavity being in their experience a fatal 'issue'; the 'forward' surgeons of the recent war were no less cognisant of the lethal import of biliary peritonitis, and counselled abdominal drainage where there was leakage or possible seepage of bile into the peritoneal cavity.

The gall-bladder is rarely injured, and, if injured, rarely suffers damage alone. Andrew Lowdon reported no injury to the gall-bladder in a series of 64 abdominal cases: Duncan Stout found only 3 in his collected series of 318 New Zealand abdominal casualties: Giblin of Hobart had but 2 in 76 abdominal wounded; Eaton, the Canadian surgeon, found the gall-bladder injured 7 times among 209 battle casualties where laparotomy was performed.

The viscus does not figure in statistical tables, except in one compiled by Sir Heneage Ogilvie from the Middle East, where the number of times the gall-bladder was reported as injured was in keeping with that recorded in the figures reported above.

Careful inspection and examination of the organ at operation will naturally be invited by the discovery of bile in the abdominal cavity;

laceration of the viscus may be associated with damage to the liver, and may be at once apparent or only recognised by very careful scrutiny. Lt. Colonel J. E. Andrew, R.C.A.M.C., suggests that a possible perforation of the gall-bladder should be borne in mind when a laceration of the liver extends behind the gall-bladder, and confesses to overlooking a small tear of the deep surface of the gall-bladder, which unfortunately caused biliary peritonitis.

The organ seems to have borne a charmed existence during the periods of air-bombardment of Britain, and in one series of 600 abdominal casualties recorded by Gordon-Taylor in his Bradshaw Lecture (1942) there were records of only two cases of gall-bladder injury. One of these two victims succumbed from severe associated injuries: the other also suffered from multivisceral damage, but was successfully operated on by Miss E. M. Hall, who drained an injured gall-bladder.

Many have recommended routine cholecystectomy for injuries of the gall-bladder; this may sometimes be appropriate and of easy execution, but certain experienced forward surgeons counselled repair and drainage; Major Eaton, who could perhaps boast the most astounding record of success in the abdominal surgery of this last war, advised suture of the gall-bladder and drainage of the peritoneum. So also wrote Eaton's fellow-Canadians, Bastedo and Johnston: 'gall-bladder wounds should be repaired, cholecystectomy is rarely indicated'. Giblin, of Tasmania, performed cholecystostomy and drained Rutherford Morison's pouch in each of his two successful cases of gall-bladder injury. Humphrey Nockolds successfully dealt with a woman injured in London by a 'flying bomb' in whom a fragment of glass had damaged diaphragm, liver and gall-bladder; the wounds of the gall-bladder were sutured, and cholecystostomy performed. The American surgeon, Bogle, also advised cholecystostomy, as being simpler and quicker.

H. W. S. Wright dealt successfully with an air-raid casualty, a female, who sustained a right-sided thoraco-abdominal injury, while lying prone in a Morrison shelter (steel table). After dealing with diaphragm and the liver transpleurally, the abdomen was opened by a right paramedian incision; there was a little free bile in Morison's pouch. The shell fragment had penetrated the liver, made a tear in the gall-bladder, and was found between the gall-bladder and the duodenum. A tube was put through the tear in the gall-bladder, which was near the fundus, and fixed with a purse-string suture. The patient made an uneventful recovery.

The hazards of cholecystectomy in an area traumatised by enemy missiles, and a lively memory of the variations in the extrahepatic biliary apparatus and in the blood supply of the area, doubtless reminded experienced surgeons that discretion is the better part of valour.

There was only one specimen of a penetrating wound of the gall-bladder in the War Collection of the War of 1914–18: its loss in 1941 has been replaced by another which was figured in an article on the 1939–45 National War Collection (see B.J.S., 1949, 37, 141). This later War Collection also contains a specimen obtained from a sailor fatally injured during air attack on his ship; the fragment of bomb had produced a vertical fracture of the liver, and perforated the gall-bladder.

It is recorded by Guthrie that a soldier (who was under the care of M. Huttier of Chalons-Sur-Marne) was hit in the right side of the abdomen by a musket ball which was retained in the body: when the patient died two years later the bullet was found at autopsy within the gall bladder.

INJURIES OF THE COMMON HEPATIC AND BILE DUCTS

It has been affirmed that in penetrating wounds of the abdomen involving the main bile ducts, success has attended suture of the injured duct and drainage of Morison's pouch, but the literature contains few reports of such cases; doubtless the proximity of the large blood vessels explains the paucity of such cases coming into surgical hands. Lambert Hurt's patient received a right-sided thoraco-abdominal wound, with a resultant broncho-biliary fistula; the bronchial fistula was first surgically closed, and the patient was now left with a biliary fistula only. The migration downwards of the metallic fragment into the common bile duct below the insertion of the cystic duct produced symptoms suggestive of cholelithiasis, and a piece of metal ½ in. × ¼ in. × ¼ in. was ultimately successfully removed from the duct, and the patient cured.

A somewhat similar case to that recorded by Hurt was that of a distinguished general who received a right-sided thoraco-abdominal wound in Tripoli. The bullet, shot from an aeroplane in air-combat at many thousand feet, struck the officer in the right infraclavicular region and emerged at the right buttock, dropping on the foot of the D.D.M.S. of his corps who was beside him. At laparotomy the liver and right kidney were found to be wounded; after an eventful post-operative history the general returned to full duty and took an active part in the B.L.A. Campaign. Six years after his wound he developed jaundice, and Professor John Morley removed from his common bile duct a calculus which contained material from his khaki shirt.

The proclivity of foreign bodies left in the peritoneal cavity gradually to find their way into the lumen of the intestinal tract seems parallelled by the behaviour of foreign bodies in the vicinity of the biliary channels.

A patient of Sir James Walton had received multiple wounds, and after laparotomy was left with a suprapubic fistula discharging quantities of bile; the common bile duct at a subsequent operation was found to be replaced by a fibrous band. A reconstruction procedure employing a rubber tube, successfully attached the common hepatic duct to the stomach.

Major Harold Park's patient was a marine who had beeen wounded on the return journey from the Dieppe Raid on August 19, 1942. On admission to a Brighton hospital he was in a severe state of shock, and blood and bile were flowing from his wound; the hepatic duct was completely divided and a large unidentified artery, bleeding vigorously, was ligated. The main bile channel was subsequently restored by end-to-end suture by Park and Gordon-Taylor. Some four years later the patient died from recurrent gastric haemorrhages; the autopsy showed the bile channel to be satisfactory, but the liver exhibited marked cirrhosis, probably due to derangements of its blood supply resulting from the injury from the fragment of bomb.

Estcourt and his colleagues working at Anzio had two patients with injury to the common bile duct, one of whom succumbed, his belly being full of blood and bile: there was gross damage in the region of the foramen of Winslow, and the man's desperate condition precluded any prolonged effort to introduce a tube in the divided duct: death ensued 24 hours after. The successful case was treated by drainage of a retroperitoneal collection of bile extending up and down behind the first part of the duodenum and between the layers of the lesser omentum. The man was evacuated in splendid condition a fortnight later, bile still continuing to escape along the drainage track.

INJURIES OF THE PANCREAS

In the War of 1939–45, as in that of 1914–18, injuries of the pancreas were less frequent or at any rate less often recognised than those of any other abdominal viscus; experienced 'forward' surgeons like Geoffrey Parker (24 F.S.U.), T. N. Tweddell (11 Canadian F.S.U.) and Major Railton never saw a case, and although it has been asserted that pancreatic wounds account for about 2 to 3 per cent. of all abdominal injuries, Brigadier Sir Arthur Porritt, from an analysis of the considerable series of abdominal casualties of 21 Army Group, estimated wounds of the pancreas at a lower figure (1·29 per cent.) and found that 95 per cent. of its wounds were associated with other injuries.

Operations for missile wounds of the pancreas in the War of 1939–45 were said to carry a mortality of 40 per cent., but indubitably many wounds of the pancreas never reached an abdominal centre; the intimate anatomical relations of the gland to the large blood vessels are such that a wound of the organ is fraught with the gravest danger of an immediate severe and probably fatal haemorrhage.

The sinister reputation of wounds of the pancreas is also not unrelated to the irritative nature of the pancreatic secretion: Lt. Colonel Andrew Lowdon considered that a wound involving the head of the pancreas presented the most 'harassing problem' that he encountered: 'the tissues are digested and excessively friable so that every manipulation increases the haemorrhage'.

Lt. Colonel R. S. Handley commented on the curious way in which patients with wounds of the pancreas seem to die without obvious cause, the fatality of wounds of the organ appearing to be out of proportion to the anatomical changes disclosed. In two autopsies in which there was little haemorrhage, fat necrosis or peritonitis, only a few minute fragments of metal were found in the pancreas.

Most operators thought that little could be done except drainage (Lowdon, Aylett, Railton, etc.) in the hope that cyst formation might be thereby prevented, and the drainage track would ultimately heal.

In a patient under the care of Lt. Colonel Stanley Aylett, where a wound of the middle of the body of the pancreas treated by suture terminated fatally, autopsy showed that the part of the pancreas to the left of the injury was completely necrotic; there was fat necrosis and apparently commencing digestion of the surrounding tissues, especially of the posterior wall of the stomach. This experience was profitably utilised by Arthur Gild of Adelaide, who resected the left half of the pancreas distal to the site of a gunshot injury of the body of the organ, closing the cut end with thread. The lesser sac was drained, and recovery was uninterrupted. Lt. Colonel Blackburn had a successful case of removal of the tail of the pancreas, associated with a left nephrectomy.

In some cases of wounding of the pancreas it was found possible to remove the metal fragment, and this was sometimes followed by suture and always by drainage.

A missile-wound of the pancreas may be followed by an abscess of the organ; the former War Collection in the Royal College of Surgeons contained a specimen obtained from a patient dying some fourteen or fifteen days after wounding, where a slight wound of the left kidney with a perinephric haematoma was complicated by an abscess in the body of the pancreas containing a fragment of high explosive.

The writer has no knowledge of traumatic pseudo-pancreatic cysts consequent on penetrating wounds in the War of 1939–45, akin to those which follow contusions of the belly received under civil or military conditions, including immersion-blast; but thirty years ago Professor John Morley recorded one such case, where a man hit by a fragment of shell during the Somme Offensive in July 1916, and admitted into a Manchester hospital three weeks later, was found to have a pseudo-cyst containing pancreatic ferments and a fragment of the copper band of a shell 1 in. in length; the cyst was drained through an incision in the left loin just below the twelfth rib, the patient making a good recovery. Morley, while commenting on the rarity of this variety of pseudo-pancreatic cyst due to penetrating wounds, mentioned a comparable case from the Hungarian literature, reported by E. Holzwarth.

Another complication of a penetrating wound of the pancreas has been secondary haemorrhage. Brigadier Harold Edwards quotes a mortal thoraco-abdominal case, in which the patient died on the 10th day after being wounded. At the primary laparotomy, the left gastric artery had required a ligature; fatal secondary haemorrhage took place from the splenic artery which had been injured in association with the pancreas.

Still more curious was the case of a pancreatic cyst which had been impaled by a fragment of glass in one of London's air raid 'incidents'. The woman had previously undergone a laparotomy for an abdominal condition and had been discharged from another hospital with the diagnosis of inoperable cancer. She was admitted to another hospital as an air raid casualty: a sliver of glass had perforated the scar of the previous coeliotomy. From the epigastric wound there now flowed a discharge of slightly green, watery fluid of alkaline reaction; at this second operation fragments of plate glass were found in a large pancreatic cyst. The glass was removed and the cyst marsupialised, the patient making a complete recovery. (Brigadier C. Naunton Morgan's case.)

SUB-PARIETAL OR NON-PENETRATING INJURIES OF THE PANCREAS

Mocquot and Constantini (1923) collected from the literature 30 examples of non-penetrating injury affecting the pancreas alone: of this group 21 patients were treated by operation, 16 surviving; of the 9 patients unoperated upon all succumbed. Treatment must therefore be surgical. The common sequelae of an injury to the pancreas are (*a*) the formation of a pseudo-pancreatic cyst (*b*) a persistent pancreatic fistula.

Air Vice-Marshal Geoffrey Keynes records the case of a Flight-Sergeant cycling in the 'blackout' in Malta who ruptured his pancreas, his life being saved by Major Shucksmith, R.A.M.C.; the man subsequently developed a pseudo-cyst which was drained, a permanent pancreatic fistula resulting. Keynes had to decide between excising the body of the pancreas to the left of the rupture and an attempt to implant the fistula into the alimentary canal. Success has often followed pancreato-gastrostomy but Keynes had a brilliant result by anastomosing the fistulous track to the jejunum.

Keynes also recorded the formation of a pseudo-pancreatic cyst in a survivor from a Sunderland flying-boat which was shot down at the moment that it sank an enemy submarine; he was exposed, when in the sea, at 400 yards distance, to the explosion of depth charges.

A tragic case was that of a soldier who was struck in the belly by the steering wheel of the vehicle which he was driving and which was involved in a car smash. His pancreas was torn right across and the third part of his duodenum ruptured. He died.

J. F. Curr successfully dealt with a complete rupture of the pancreas by closing each end of the trans-sected organ.

Case: An R.E. private driving a heavy tractor was trapped between the caterpillar track and the driving wheel guard, his pelvis, abdomen and chest on the left side being crushed into a space just under 4 in. wide. The pelvis had been completely crushed, with dislocation of the symphysis pubis and both sacro-iliac joints. The skin of the trunk in front and at the back of the left side was so excoriated that on first sight it appeared to have been stripped from his body. At operation the body of the pancreas just to the left of the midline was found completely severed with the pancreatic vessels bleeding freely into the peritoneal cavity. Other intra-peritoneal damage consisted of tears in the sero-muscular coat of the stomach, the colon and five loops of small intestine; there was also a tear of the mesentery. All these serous and sero-muscular rents were repaired with simple catgut sutures. There was much retro-peritoneal bruising, but no damage to the spleen or urinary apparatus. Many ribs were fractured and subsequent X-rays showed the lung to be contused. The man made a recovery surprisingly satisfactory, considering that treatment had to be directed towards restoring the alimentary function, draining the pancreatic fluid, preventing digestion of the excoriated abdominal wall, and applying traction and fixation to the comminuted pelvis, apart from the treatment of his injured left chest. (Lt. Colonel Alan Hunt's case.)

Time for Formation of Pseudo-pancreatic Cyst

A pseudo-cyst formed in five weeks in a woman of 28 years, who had been buried under a collapsed house during one of the air raids on London in 1941 (Mr. Guthrie Clothier's case). In Major Shucksmith's case (*vide supra*) a pseudo-cyst had formed in ten days.

WOUNDS AND INJURIES OF THE SPLEEN

The surgery of the spleen has advanced far since the days of Ambroise Paré, who thought wounds of the spleen to be 'commonly deadly but always ill'. Guthrie and the military surgeons of the Peninsular Wars and the Waterloo Campaign found little encouragement in their experience of injuries to the spleen, whether due to gunshot wounds, stabs, contusion or crushing force. After Waterloo, Thomson himself saw no wounds of the spleen, but had heard of two fatal cases, one of whom died from haemorrhage from an external wound, the other from intra-abdominal bleeding. Guthrie confesses to have seen cases recover from stabs or musket-balls which ought to have wounded the spleen, and he had also observed at autopsy cicatrices in the spleen corresponding to external marks indicative of previous wounding, demonstrating thereby the possibility of a natural cure.

The prodigious fatality of prolapse of the spleen, through the wound of entry or exit in thoracic or abdominal parietes, was well-known to Guthrie, who, however, was aware of two patients who suffered from prolapse of the organ nearly a century before Waterloo in whom recovery ensued: (*a*) After the Battle of Dettingen, 1743, a spleen covered with dirt was cut away from a patient and the man recovered. (*b*) In another patient in 1737 the spleen which was found outside the wound at the end of 24 hours was 'cold, black and mortified'; three inches and a half of the spleen were removed and the remaining portion of the viscus was returned to the abdominal cavity, and the patient got well.

A similar case from the Second World War was communicated to me by Lt. Colonel B. G. A. Lilwall, D.S.O., who successfully operated upon a private of the K.O.S.B. under somewhat dramatic conditions on the Arakan Front.

Case: The patient was brought into the mobile surgical unit with a bullet wound of entry in the left chest and bleeding severely from the spleen which was lying in the open exit wound between the shattered 11th and 12th ribs. At that time the M.S.U. was only a skeleton affair, since the previous night the unit had been driven out of the position with the loss of most of its equipment. The spleen was removed and a drain put down to the pedicle, no exploration of the abdomen being possible. The patient made an uninterrupted recovery.

On the other hand, a fatal result occurred in the case of a woman who had undergone an arthrodesis of the hip in a London hospital that had borne more than its share of damage from enemy aircraft and pilotless missiles and who, after being transferred to St. Bartholomew's Hospital in a state of profound shock, presented herself with a large wound through which spleen and fat protruded.

Incidence of Injury to the Spleen. Apart from thoraco-abdominal injuries, laparotomy has shown that the spleen is infrequently injured. In the War of 1914–18 the spleen was wounded in 4·16 per cent. of abdominal casualties, a figure closely approximating that furnished by Ogilvie from one series of cases from the Western Desert (4·9 per cent.) and not very dissimilar to that emanating from the C.M.F. (3·2 per cent.). In the B.L.A., however, the injury constituted only 1·67 per cent. of one series of abdominal operations for missile injury.

The experience of an individual is often capricious, for whereas Andrew Lowdon saw only one case of injured spleen in 64 laparotomies —and that a subparietal injury—Giblin encountered a wound of the spleen in 4 per cent.; Bogle, the U.S. Army Surgeon in 4·3 per cent.; Geoffrey Parker, in about 10 per cent., and Major Eaton, R.C.A.M.C., in 14·6 per cent. of his series of laparotomies.

When injured by enemy missile, the spleen most frequently suffers alone among abdominal viscera: in the War of 1914–18 in nearly 60 per cent. of the cases submitted to surgery; in one series collected by Ogilvie from the Western Desert it was injured *alone* in 75 per cent., in a series from the B.L.A. in 55 per cent., in a series from the C.M.F. in 66 per cent., but in 208 thoraco-abdominal casualties from North-west Europe splenic injury was more frequently (60 per cent.) associated with concomitant visceral damage. The shelves of a museum lend visible and tangible support to statistical evidence of the frequently univisceral character of gunshot injuries damaging the spleen, to which attention has already been drawn. The plethora of spleens resting in their bottles in solitude is a reminder that the organ is most frequently injured alone.

Pathology. The nature of the splenic injuries of gunshot origin varies considerably; there may rarely be a mere tear of the capsule, or a round or stellate perforation of the organ; a greater or lesser amount of either pole of the spleen may be torn off, and some casualties have had the lower pole of the spleen and upper pole of the left kidney avulsed by the same missile.

Sometimes the spleen is split into three or even more fragments or may be completely disrupted; the pulp of the organ may be the seat of extensive blood extravasation, whereby the size of the organ may be greatly augmented. The blood-vessels in the hilum of the spleen may be damaged, necessitating early surgery. The former War Collection contained the specimen of a spleen from a fatal case of wounding which on section exhibited four irregular pale yellow areas of infarction, each surrounded by a narrow hyperaemic zone; the main splenic vessels were not damaged.

Molesworth had a successful case of rupture of the spleen produced by the collapse of a house on to a patient as a result of a 'V' bomb; on the other hand, the manipulation of the radiologist has been known to rupture a spleen.

The spleen has been ruptured under such bizarre circumstances as the falling of weary sleepy men and women out of upper-tier bunks in the 'shelters'; another warrior ruptured his spleen by falling on his gas respirator. A specimen in the War Collection of a ruptured malarial spleen, the result of a soldier's unlucky fall over a tent-rope on to a tent-peg, is a reminder that such an accident may not have been rare in a war waged in so many parts of the world; this spleen weighed 630 g. and measured $6\frac{1}{4} \times 4\frac{1}{4} \times 1\frac{3}{4}$ in. (Lt. Colonel Michael Oldfield).

Case: The detonation of a mine blew the Captain from the port wing of the bridge of one of H.M. ships on to the aft-gun on the boat deck, a distance of some 30 ft.; a second explosion blew the officer into the sea. He was rescued from the sea by Surgeon Lt. Commander John Ferguson, M.B.E., R.N.V.R., who not only landed his fellow-officer in Sardinia, but found a laparotomy cogently demanded. At operation he found the spleen completely disrupted and the abdomen full of blood, and performed a splenectomy. The officer's recovery from the operation performed under disadvantageous conditions seemed assured, but unfortunately circumstances necessitated the surgeon proceeding to sea on operational duties, leaving his patient on a foreign shore under the supervision of those who were too little cognisant of the value or the technique of gastric suction and other modern post-operative methods; a promising case thus ended sadly.

Case: The spleen has been injured by *secondary and tertiary missiles*, as in the following case. A lance-cpl., Dragoon Guards, whose Sherman tank was hit by an armour-piercing shell, sustained penetrating wounds of the left lower chest posteriorly. The shell knocked off the tank a strip of metal which had then picked up and driven a piece of screened electric cable in front of it. At the first operation a piece of metal 4 in. long was removed.

At a second operation performed five days after initial injury an infected wound was excised with removal of fragments of left 11th rib. The pleura was infected and there was a hole through the diaphragm into the abdomen through which a piece of screened electric cable could be felt lying within the substance of the spleen. The fragment was removed transpleurally without in any way interfering with the adhesions which had formed around the rent in the spleen. The pleura was closed above the 11th rib, and the cavity in the spleen drained through the wound.

Convalescence was satisfactory. (Lt. Colonel Alan Hunt.)

There has been a greater bias towards splenectomy for missile-injury of the spleen in the War of 1939–45 than in its predecessor; Ogilvie with his great experience consistently advised it; Wooler removed all the injured spleens that he encountered; Geoffrey Parker never saw a case where the injury to the splenic pulp was of so minor a degree that something less than splenectomy might have been considered; complete explosive disruption of the spleen was the only condition seen, except in those cases where the vascular pedicle was alone damaged, of course demanding splenectomy. Major Beaton, the Canadian, and Bogle, the American, saw very few cases where any procedure less heroic was possible: Lt. Colonel Andrew also agreed that for the majority of cases splenectomy was required, but mentioned the difficulty of the removal of the organ in Italian prisoners-of-war with greatly enlarged spleens and perisplenitis.

In the occasional minute wounds of the spleen, less drastic methods are desirable; the splenic pulp usually ceases to bleed in about ten hours, and in small wounds if haemorrhage has stopped, they may be left alone advisedly, or a couple of stitches may be required (Col. Duncan Stout), or the rent may be sutured over a free omental graft (Lt. Colonel T. Giblin). In one case where the haemorrhage came from the vasa brevia gastrica, the spleen was conserved.

There is, of course, always the menace of restarting haemorrhage by manipulating or suturing the injured organ; despite this risk circumstances may determine the surgeon to adopt a conservative attitude: thus Estcourt had under his care two patients in the treatment of whose wounds discretion proved the better part of valour.

(i) The first had a large wound of the hepatic flexure and a small penetrating wound of the spleen which had caused little bleeding; by the time his colon had been mobilised and exteriorised the man's condition was so serious that it was decided to risk leaving his spleen. (ii) The second casualty had sustained multiple injuries, including a traumatic amputation of one leg and extensive muscle wounds in both thighs. The man did not respond satisfactorily to resuscitation and was therefore operated on as quickly as possible as a very bad surgical risk. The last wound to be excised, a small one over the left lower ribs, was unexpectedly found to lead to a hole in the spleen large enough to admit two fingers, but by this time the patient was almost pulseless and the anaesthetist insisted on the operation being terminated. A course of penicillin was given and the man made an uninterrupted recovery. Both cases reached the United Kingdom in good health. Such cases are perhaps very rare. If a damaged spleen is left *in situ*, the *patient should not be evacuated for at least fourteen days.*

Where other serious visceral injuries were associated with damage to the spleen, the mortality might rise as high as 60 per cent., but the rediscovered advantages of a trans-thoracic approach to the spleen, well known to the surgeons in the War of 1914–18, became more and more appreciated as the war progressed; the ease with which a trans-pleural splenectomy can be carried out was almost incredible until it had been experienced. The trans-thoracic approach was usually made by an oblique left thoracic incision with resection of the 9th rib.

As indicated above, the accepted routine treatment of splenectomy for all splenic injuries became slightly modified during the last year or two of the war, when a more conservative attitude was frequently adopted in cases where the patient's general condition was poor, where the splenic wound was of a minor nature or where only the vasa brevia gastrica were injured. The results of such conservatism were on the whole satisfactory.

The recovery-rate of wounds of the spleen for which surgical treatment was employed was about 50 per cent. in the War of 1914–18, but during the World War of 1939–45 transfusion facilities, expert anaesthesia, the availability of limitless sulphonamide drugs and penicillin, standardisation of post-operative treatment under skilled medical officers and nurses, all contributed to lowering the mortality of splenectomy, and transpleural removal of the organ for injury and associated thoracic wounds reached the flattering figure of 15 per cent.; while for wounds of the spleen associated with lesions of other abdominal viscera treated by an abdominal approach splenectomy only carried a 25 per cent. mortality.

PROLAPSE OF THE VISCERA OR ABDOMINAL EVISCERATION

Evisceration has been defined as the protusion of an abdominal viscus or abdominal viscera through a missile-track which has interrupted the continuity of all the layers of the abdominal wall.

The frequency with which herniation of an organ takes place through a gunshot wound is dependent on the motility of that organ, its volume and also its relation to the site and size of the missile-track. Herniation occurs more frequently through the wound of exit than at the entry wound.

Nature of the Missile and Herniation of abdominal contents. In more than half the cases of visceral herniation a fragment of shell was responsible for the wound; then, in order of causal frequency, followed small arms ammunition, and lastly mortar, bomb, grenade, and mine injuries.

Site of Wound permitting Evisceration. This occurred with almost equal frequency in the upper and lower abdomen, much more rarely in the flanks, and still more uncommonly in the thorax. Herniation on one occasion took place through a wound in the sacral region, and once through a wound in the left buttock of a child.

In contrast to the more optimistic view of bowel protrusion entertained by a minority of surgeons, such as Wheeler, Blackburn, Bleasdale* etc., most British operators regarded the condition in a far more serious light, (Estcourt, Ross, Clarke, Tovee, McKinnon, Gordon Johnston, Strang, etc.): indeed Major Gordon C. Johnston, R.C.A.M.C.,, said that 66 per cent. of those with prolapsed bowel died, and pointed out that visceral damage was usually great in these cases and soiling of the peritoneum a marked feature: the extruded bowel might be small or very considerable in amount and was almost invariably grossly contaminated with dirt, grass etc.

* Bleasdale had a successful resection of 2½ ft. of herniated small intestine, and Blackburn saved no fewer than five out of seven resections for prolapsed intestine through wounds due to enemy missiles.

The heavy mortality of cases of evisceration encountered 'on the field' only too surely confirmed the sinister experience of surgeons in London and throughout Britain during the air-bombardments of this island.

Although the first successful intestinal operation in the First Great War, performed by the late Colonel Owen Richards, on March 18, 1915, concerned a young Canadian who returned from a trench-raid holding in his hands his prolapsed bowel, six feet of which required resection, the surgeons of the War of 1914–18 always regarded cases of evisceration as 'bad surgical risks'.

Gordon-Taylor, investigating abdominal air-raid casualties in Britain in 1940–2, found that the mortality rate for prolapsed non-perforated small intestine was 50 per cent., but that when the small gut was not only extruded but also lacerated, the mortality was about 80 per cent. The mortality was highest in casualties with herniation of the colon, either alone or with other viscera.

Bradford and his colleagues of the United States Army lost 10 out of 16 abdominal casualties with evisceration (63·8 per cent.) and of the 6 who recovered 3 had only omentum extruded; excluding these last three, the mortality rate was 76·9 per cent.

On the other hand, Sperling and his associates saved 75 per cent. of their 8 cases of extrusion, both the fatal cases having frightful wounds, one with the loss of abdominal wall amounting to 10 cm. × 8 cm.

Prolapse of Omentum. The treatment of omentum herniated through a penetrating wound of the belly has varied in the hands of different surgeons, and from century to century. Whereas Hippocrates believed that the omentum would necessarily putrefy, if left outside the belly for any length of time, Sabatier and Larrey in the eighteenth century preferred to leave that structure outside the belly-wall, knowing that it would gradually recede within the abdomen. If the protruded omentum were already gangrenous Larrey and also Guthrie unhesitatingly removed the dead portion and replaced the healthy part within the lips of the wound in the parietal peritoneum. Ambroise Paré in the sixteenth century was more modern than many of his successors, since he gently cleansed the omentum and replaced it inside the belly. Prolapse of the omentum has nowadays a diagnostic rather than a prognostic value, the latter depending upon the associated damage to abdominal viscera; nevertheless there was a mortality of no less than 37·2 per cent. in Child's American series when the omentum alone was herniated.

The considerable series of cases of visceral herniation or extrusion analysed by Colonel Child, M.C., U.S.A., constituting 10 per cent. of the 3,154 abdominal and thoraco-abdominal American casualties operated on in the Central Mediterranean area, Southern France and Central Europe, showed a 40·3 per cent. mortality—nearly double that of the total series (24·2 per cent.).

Prolapse of Intestine. It seems that evisceration only very rarely occurs without concomitant abdominal visceral damage; but, in Child's series of cases of prolapse without perforation of the lumen of the gut, 80 per cent. recovered; none of these exhibited any evidence of clinical shock.

In one third of the cases of small bowel herniation, it was the sole organ involved, and in each of these victims the gut was wounded; the *mortality* (24·2 per cent.). was much higher than that in wounded non-prolapsed bowel (13·9 per cent.).

The civilian as well as the soldier in the field suffered eviscerating injury:

Case: A member of a bomb-disposal squad was standing in a South-eastern county of Britain in the open, about 10 yds. away from an aerial bomb when it exploded and tore most of his clothes off, leaving his intestines 'lying in the grass': there was a huge wound in the right iliac fossa measuring about 4 in. in every diameter. Lacerations of the extruded intestine and its mesentery demanded a limited resection of bowel. Recovery followed. (Lt. Colonel Geoffrey Parker.)

Case: Another patient with evisceration resulting from enemy air raids over London was a patient successfully dealt with by O. V. Lloyd-Davies: the man had received a huge bomb wound of the lower right quadrant of the abdomen, through which caecum, transverse colon and about two-thirds of the small intestine were extruded and were lying in his trousers. Shock was profound, but the man was conscious. The abdominal wall and the huge evisceration were covered with fragments of stone, mud, mortar, etc.; much ingenuity was required to close the gap in the abdominal wall.

Case: Another air-raid casualty with evisceration was Joyce H., 15 years of age, who was travelling in a trolley-bus which received a direct hit from a bomb: through an appalling rent in the left hypochondrium there protruded a gigantically distended stomach, the splenic flexure of the colon and a lacerated spleen: these viscera were smothered with dirt from the roadway of a London suburb. The spleen was ablated, stomach and colon cleansed and returned within the abdomen; a pulped left kidney bleeding furiously was also removed, as were several shattered ribs. Recovery followed (J. Scholefield's case).

Case: A man in a Liverpool street was wounded in the left loin by a bomb-splinter; through the rent was extruded a damaged descending colon from which faeces were escaping. The prolapsed lacerated bowel was excised, and a side-to-side junction completed between transverse and pelvic colon. The parietal peritoneum was completely closed, but part of the flank incision was left unsutured: a prophylactic caecostomy was performed. The man recovered. (F. J. S. Heaney's case.)

BURST ABDOMEN

To an older generation of military surgeons one of the most striking features of the abdominal surgery of the War of 1939–45 was the wonderful healing of the laparotomy incision: the many factors that contributed towards this have been frequently mentioned, but the superb nutrition and health of the fighting troops doubtless proved a valuable asset and a compensating insurance against this post-operative catastrophe. To one who has had the privilege of reading the many personal acccounts of experience in military abdominal surgery the paucity of reference to dehiscence of the wound is remarkable. When it is remembered that in one series of 200 laparotomies undertaken in civil life the wound was said to have burst in 0·5 per cent., the rupture occurring usually between the 6th and 9th post-operative day, with some part of the peritoneal contents becoming visible, it might have been thought that the circumstances attending the infliction or repair of abdominal wounds in soldiers would lead to frequent wound dehiscence.

Forward surgeons like W. A. Law, Guy Blackburn, Stanley Aylett, Stanley Raw and John Fairbank never saw a case of 'burst abdomen'; Lowdon had no case of his own where disruption of the laparotomy incision took place, although it fell to his lot to treat 3 cases of 'burst abdomen' occurring within 10 days after operations performed by other surgeons. Peter Ingram, Geoffrey Parker, Dill-Russell and Tuckwell each saw only one burst abdomen, and Estcourt* and his colleagues during their period of work on the Anzio beach-head had only one broken-down laparotomy wound among 195 abdominal casualties; Major R. B. Eaton, R.C.A.M.C., to whose brilliant results in abdominal surgery of the B.L.A. reference has already been made, had 2 ruptured incisions; these were consecutive cases which burst on the fifth and seventh post-operative day respectively, and were perhaps not unfairly attributed by the operator to defective catgut or some flaw in technique.

The chief causes of burst abdominal scar were inadequate suturing of the peritoneum and sepsis, although doubtless there were in some cases other factors—low blood-protein associated with anaemia, the strain caused by chest complications and perhaps in certain cases a deficiency of vitamin. Lowdon was of the opinion that in the three cases, operated on by other surgeons than himself, the occurrence of this complication was attributable neither to wound-infection nor technique of suture, but to a greater or less degree of vitamin deficiency in the wounded man, brought to light only when the extra demands of the injury were thrown on the constitution. In all three there was no unusual degree of inflammation, but evident absence of tissue repair both in the laparotomy incision and in the actual wounds. There is much evidence to show that such a state of affairs was to be attributed to vitamin-C deficiency: all three cases occurred in the desert where the men had been subsisting on a diet low in vitamin-C-containing foods and had, as they admitted, failed to take the ascorbic-acid tablets provided. One of these three casualties was particularly interesting in that there appeared in his case to be clear evidence of deficiency of vitamins B, C and protein:

> He was apparently healthy when wounded: Major F. M. Hanna operated on him thirty-one hours after injury, repaired three tears of the small intestine through a paramedian incision, left 10 g. of sulphadiazine in suspension in the peritoneal cavity and drained the pelvis. The patient made satisfactory progress for three days, and when Lowdon took over the care of the case at the same location, there was evidence of intestinal peristalsis and very little distention of the abdomen. After the third day he became cyanosed and mentally confused, appeared toxic, but was completely apyrexial. There was oedema of trunk and limbs which became steadily worse and his gums began to bleed.

* Estcourt throughout his long experience in the Forward Area in the C.M.F. had 4 burst abdomens, of whom 2 died.

A blood-count six days after operation showed Hb. 90 per cent. and W.B.C. 26,000 with 95 per cent. polymorphonuclears. He was slightly jaundiced. The urine was about 50 oz. daily and normal in character. On the eighth day the laparotomy wound burst and was resutured: the whole wound was a slough without spreading inflammation. There was no tissue reaction in this or the other wounds on his body and he was still apyrexial. Vitamins B and C had been given by mouth since the fifth day and he had received 2 pints of plasma intravenously. No improvement was seen till the tenth day when a diuresis started and continued for six days with a daily average of 160 oz. From the tenth day he improved rapidly: cyanosis, jaundice and oedema passed off and he became mentally normal. On the thirteenth day he was feverish for the first time. On the sixteenth day he relapsed with abdominal distension and some vomiting, and again his life was despaired of, but on the advice of Major W. B. Hamilton he was fed on raw eggs and improved slowly. Finally a complete recovery resulted and the man returned to duty.

Lowdon had seen another very similar case in an officer with severe limb wounds: there was cyanosis, oedema, mental confusion, complete absence of pyrexia and no tissue reaction in the wounds: his haemoglobin was only 30 per cent. but he had a leucocytosis of 48,000. The officer also had been living in the desert on hard rations for many weeks, and had failed to take the ascorbic-acid tablets; he recovered after infusion of blood, and the administration of vitamins B and C by mouth.

There is little doubt that this complication became much less frequent towards the end of the war, and that among the various possible causes for the improvement, intravenous penicillin was predominant.

Tension stitches through muscle and skin were in common use, but many surgeons of experience did not approve of them and thought that their value was over-rated. Neither patient nor surgeon, however, readily forgets the sight of intestines in the bedclothes. *Verb. sap.*

Healing of Laparotomy Incisions. Some recent laparotomy incisions withstood unusual and premature strains extremely well, and especially in the post-penicillin period of the war, created pleasurable surprise, contrasting most favourably with those seen at the base in the War of 1914–18. Lengthy abdominal scars were even known to withstand the strain of shipwreck and immersion in the sea fifteen days after wounding.

Case: A R.E.M.E. sergeant attached to the Guards Armoured Divison was blown up in a tank that had gone over a mine, and received a large superficial abrasion over the lower right ribs. He was in great distress. Operation revealed a huge haemoperitoneum due to a tear in the liver; he made a good recovery and was evacuated to U.K. on the fifteenth day on the ill-fated hospital ship 'Amsterdam' as a stretcher case, never having been out of bed. When the ship struck the mine the patient got up on deck and slid down the ship's side into the sea and swam quite a fair distance to a destroyer, in which a 'tot of Navy rum put him right'. (Major Philip Bleasdale.)

Havildar, ——, 1/11th Sikhs was wounded in the abdomen by fragments from a Japanese grenade. At laparotomy in the M.S.U. several perforations of the ileum were repaired and the abdomen closed. Twelve hours later the M.S.U. was overrun by the Japanese and the wounded were taken prisoner, but on the following day the Havildar crawled out of his bed and escaped into the jungle. To reach our lines he had finally to cross 40 yd. of open paddy; he sprinted across the open to fall a few yards short of our lines with a bullet in his leg, but managed to crawl in. He made a rapid recovery from his abdominal and leg injuries. (Case under the care of Lt. Colonel B. G. A. Lilwall.)

WOUNDS OF THE KIDNEY

INCIDENCE OF KIDNEY WOUNDS

In contrast to Sir Cuthbert Wallace's findings in the First Great War which showed an incidence of 7·5 per cent. kidney wounds, the B.L.A. series (1944–5) showed only half that frequency (3·75 per cent.).

Some individual operators in the forward zone seem to have had more than the average percentage of missile injuries of the kidney, e.g. Lowdon, 11 per cent.; Eaton, 13·4 per cent., Geoffrey Parker, 18 per cent. of the abdominal cases submitted to surgery.

Whereas in the War of 1914–18 Sir Cuthbert Wallace found the kidney wounded alone of the abdominal viscera in half the cases, in the B.L.A. series it was wounded alone in less than a third.

TREATMENT OF RENAL WOUNDS

As the war progressed, a conservative attitude towards the treatment of renal wounds became more and more pronounced. Where possible, operation was avoided altogether, simple drainage being used where necessary; suture of the renal parenchyma was found to be quite satisfactory in localised wounds and *partial nephrectomy* (i.e. of one pole) proved itself a practicable operation, leaving a kidney which still functioned adequately.

Complete nephrectomy was however still adopted, if either the vascular pedicle or the renal pelvis was severely damaged; if there was excessive parenchymatous destruction, i.e. more than half the renal substance; if the upper ureter was completely torn across; if after a conservative attitude had been adopted, macroscopic haematuria persisted and the patient showed signs of deterioration; as a routine if the renal wound also involved a part of the adjacent colon; and occasionally if some pathological change was already existent in the wounded organ, of which the following case was an example:

Case: A Maltese greaser in a merchant navy ship in Brindisi harbour, while out drinking became involved in a fracas and was stabbed between the 8th and 9th ribs in the left anterior axillary line. He was brought into the C.C.S. bleeding fairly profusely from this small wound of entry; there was a little tenderness in the abdomen and no evidence of injury to the left pleural cavity, but a catheter passed, since he was unable to produce a specimen of urine, provided blood-stained urine from the bladder. The left loin was, therefore, explored and the stab wound was found to have pierced the kidney, which, on further exploration was seen to be grossly hydronephrotic. Nephrectomy was, therefore, carried out and the specimen showed a kidney which was the seat of a so-called congenital type of hydronephrosis, and would very likely have required planned surgical intervention at a later date. (Case of Lt. Colonel Robert Cox.)

Though, as stated above, wounds of the kidney can often be treated conservatively, a kidney that goes on bleeding for longer than twenty-four hours must be viewed with the gravest suspicion, should be explored, and will usually require removal. If left alone, the haemorrhage may stop only to start again when the patient is moved or when his blood pressure recovers, and it may recur with such severity as to endanger life. Above all, such a case should not be evacuated, or death from a brisk reactionary haemorrhage is only too likely to occur.

In lesions of the kidney alone mortality was relatively low—in the neighbourhood of 10 per cent.—but this figure rose quickly in association with other injuries to as much as 45 per cent.

The greatly increased mortality in complicated renal injuries is well known, and it is interesting that the mortality-percentage in the complicated group exhibits an extraordinary similarity—56 per cent.—in the two world conflicts (Plate III).

Wooler was compelled to perform abdominal nephrectomy on only two occasions; but both died of anuria a week later. Lowdon lost 62 per cent. and Giblin 40 per cent. of cases of nephrectomy; on the other hand, Geoffrey Parker found no fewer than 14 out of his 17 renal injuries to be complicated, but only lost 3 of these, while Sperling saved 84 per cent.

SURGICAL APPROACH TO THE KIDNEY

In war wounds the kidney was generally approached transperitoneally, since laparotomy had been indicated for concomitant visceral injury. In some cases a large rent of the peritoneum medial to the ascending or descending colon dictated the route; in others, the peritoneum was incised along the lateral paracolic gutter and after mobilising and retracting the colon towards the middle line nephrectomy could be carried out easily. During the manipulations to mobilise and deliver the kidney, haemorrhage could be controlled by digital pressure on the vascular pedicle. Mobilisation and delivery of the damaged kidney from its surrounding fibro-fatty envelope were aided to a considerable degree by first clamping and cutting the ureter; the vessels could then be dealt with relatively simply (Aylett, Wooler, etc.). In the less frequent cases where exposure from the loin was indicated, there was no hesitation in removing the 12th rib—particularly if this structure was also damaged; exposure was thereby considerably improved and the risk of subsequent chronic sepsis probably lessened.

INJURIES OF THE URETER

Injuries of the ureter apart from its junction with the renal pelvis were rarely encountered by 'forward' operators, and were said to constitute only 1 per cent of abdominal injuries. The comparatively protected and inaccessible course of the ureter probably led to the injury being frequently overlooked in a routine examination, and possibly this fact together with the likelihood of severe concomitant injuries, accounted for their high mortality of 50 per cent. Ureteral wounds occurred equally in the loin and the pelvis, their existence usually becoming clinically obvious either by a spreading retro-peritoneal infection or by a urinary fistula. If at the time of operation the injury was recognised, some surgeons sutured the ureteric wall, employing usually one layer of interrupted fine catgut sutures; others left the wound unsutured, but drainage of the surrounding extraperitoneal tissues was considered of paramount importance.

One patient, whose many lacerations of small and large bowel Major Geoffrey Wooler had successfully dealt with, developed a ureteral fistula, which necessitated a subsequent nephrectomy at the base. In another patient, Guy Blackburn recognised a large haematoma in the ureteral wall; this was not interfered with, and a successful result followed, while another partial tear of the ureter followed by a ureteral fistula, which was also not interfered with, healed spontaneously, no appreciable hydronephrosis resulting.

Lt. Colonel Tovee, R.C.A.M.C., found no lesion of the ureter among the cases of abdominal injury on which he operated, although the vermicular contraction of that tube was simulated in one case by an ascaris which had escaped from a perforation in the wall of the large intestine; a torn ureter was also encountered by Lt. Colonel J. E. Andrew, R.C.A.M.C., a successful result ensuing.

WOUNDS OF THE BLADDER

HISTORICAL

Hippocrates and Ambroise Paré regarded a wound of the bladder as 'deadly'. Baron Larrey wrote a memoir on wounds of the bladder, emphasising three clinical stages in the progress of a bladder wound: (*a*) at first urine continues to escape or trickle away from the one (or two) wounds, (*b*) little or no urine escapes through the wound, but is passed *per vias naturales*; the inflammatory swelling of the walls of the wound-track impeding the escape of urine along the route of the missile, (*c*) more urine again escapes from the wound, since after the separation of sloughs the track is rendered more patent.

From his experience in the Peninsula, America and Waterloo, Guthrie emphasised the frightful mortality of wounds involving the peritoneal coat of the bladder and the escape of urine into the coelom, but it was also well known to Larrey, Guthrie, Thomson and Hennen that when the bladder is wounded below the peritoneal reflexion, persons often recover by the almost unaided efforts of nature; thus Larrey had under his care an officer wounded at Hanau, whose right spermatic cord, inferior pubic ramus and urethra were damaged by the missile. The base of the bladder had been traversed from front backwards and to the left; there was a through-and-through wound of the rectum; the wound of exit was in the left buttock near the anus. The wounded man was removed to Mayence, where the scrotum was found to be gangrenous, presumably from urinary extravasation. *Débridement* was performed, the right testicle was removed, a catheter was tied in the bladder, and in two months the man was cured.

INCIDENCE OF MISSILE WOUNDS OF THE BLADDER

Sir Cuthbert Wallace in 1918 found the bladder injured in 4·06 per cent. of abdominal cases. In the C.M.F. the percentage of bladder wounds was 3·2 per cent.; Major Eaton had 3·3 per cent. in 209 battle casualties. Lt. Colonel Giblin had 5 cases of bladder injury in 90 operations for abdominal injury, i.e. 5·5 per cent.; Sperling, Bosher and Zinnerme, 6 per cent. Brigadier Sir Arthur Porritt in an investigation of 1,038 laparotomies performed in 21 Army Group found the bladder injured in 6·15 per cent.

It was rare to find an uncomplicated bladder wound, but where this occurred, mortality figures averaged about 20 per cent. The overall mortality figure, varying between 25 per cent. and 35 per cent., rose as high as 45 per cent. in some series where wounds of the pelvic colon and rectum, and of the pelvic bones and major vessels complicated the picture. In its simplest form treatment was by suture of the rent in the bladder wall and drainage of the bladder itself, and of surrounding tissues and peritoneum where necesssary.

TREATMENT OF WOUNDS OF BLADDER

Suture. The possibilities of suture varied greatly with the site of the wound. In intraperitoneal wounds and wounds of the fundus the procedure was usually easy, and closure in two layers was systematically carried out. Extraperitoneal wounds and those of the base were correspondingly difficult. Even to obtain one layer of sutures was far from easy, and in the field intra-vesical suturing was seldom satisfactory. Such cases could only be properly dealt with by the use of specialised instruments with full surgical and anaesthetic facilities available, i.e. it was a treatment which was reserved for the base hospital. In such difficult cases inaccessible to suture, forward emergency treatment consisted simply of adequate drainage of all areas concerned, combined with control of haemorrhage.

Drainage. The bladder was drained by a cystostomy tube, never by an in-dwelling catheter, and this tube was brought out through a separate incision, not the wound site, placed as high on the fundus as feasible, and was anchored with chromic catgut. Wherever possible, continuous suction-drainage was instituted, its employment not only preventing many post-operative complications, but also greatly accelerating convalescence.

It was surprising that infection of extravasated urine did not prove a frequent accompaniment of bladder wounds, but as a preventive measure wide drainage of the cave of Retzius for some 48 hours was carried out as a routine. Similarly if the peritoneal cavity was involved in the wound, intra-peritoneal drainage for a short period was always considered a wise measure.

The proclivity of missiles to lodge within the cavity of the bladder, emphasised by writers of the War of 1914–18 and re-affirmed by surgeons in the conflict of 1939–45, was not unknown in the campaigns of previous centuries; surgeons such as Bartholin, Seger, Hildanus, Duverger, Binninger, Covillard, Burgowen, Garengeot, Petit and Morand are mentioned by Guthrie as having met with this experience, which was also well-known to Percy, Cline, Crampton and those of the 'Larrey era'. Larrey in 1812 was perhaps the first to perform perineal lithotomy for the extraction of a bullet from the bladder of a young lieutenant who had been wounded at Witepsk only four days before. The extreme pain of the injured man and the certainty of the diagnosis determined this early operation; the bullet was removed in two minutes, and the success of the surgical incursion so impressed another man in the ward, a sergeant-major of the 20th regiment of the line, that he at once demanded to be rid of a calculus which had been in his bladder for some time.

Only a year or two later Guthrie had under his care a soldier of the King's German Legion, who had been hit at Waterloo by a musket-ball; vesical symptoms made the surgeon pass a sound and a ball was found lying loose in the bladder. The casualty was transferred from Brussels to the York Hospital, London, and became, along with the French soldier whose thigh Guthrie had amputated at the hip joint, an object of great interest and attention. Guthrie operated in the presence of a large concourse of military and medical men; the operation of extraction of the ball was completed in less than two minutes. The calculous incrustation composed of triple phosphates which had formed round the ball broke and the pieces were removed separately: the ball being heavy fell below the neck of the bladder, and the bladder wall being healthy allowed it to sink on the rectum. Guthrie in the twinkling of an eye introduced a finger into the rectum, raised the ball up and caught hold of it at once, to the great satisfaction of all present.

Subsequently the patient passed a ring of calcareous matter which had formed round the orifice of the bladder—and the patient took this memento of his experiences back to Hanover, while Guthrie kept the ball with the pieces of calculus which were extracted with it. These surgical trophies he showed annually at his lectures, but alas! the craving for the treasures belonging to others appears to have been no less marked a century ago, and Guthrie adds the polite, but pathetic note: 'some gentleman had borrowed it' (the ball).

F. E. Feilden's recent case of a vesical calculus containing a bullet, which hit its owner during the War of 1914–18, is a reminder that such cases were also known in the beginning of the nineteenth century.

WOUNDS OF THE URETHRA

Urethral wounds had an occurrence-rate and mortality-rate very similar to those of the ureter, viz., 1 per cent. and 50 per cent. respectively.

From their anatomical site obviously they were seldom uncomplicated. Treatment consisted essentially in providing suprapubic drainage as soon as possible to minimise the inevitable fibrosis that follows suturing of the rent.

Three varieties of urethral injury were usually described—penile, bulbous and posterior, which accounted respectively for 20 per cent., 50 per cent., and 30 per cent. of urethral injuries. In the first two groups suture was done over a catheter, which was removed after operation; in the posterior urethral wounds after suture the catheter was left *in situ* as a splint. In all cases suprapubic drainage was instituted.

The penile urethra. These wounds were often complicated by severe damage to the penis and needed to be covered with skin as soon as possible, not only to render urethral repair easier, but to avoid contraction of the remaining portion of this organ.

Penicillin, given by intramuscular injection and by local irrigation of the urethra, allowed early closure of perineal wounds which otherwise would have been left to granulate, and as a result there was less scar tissue and stricture formation.

As soon as the condition of the operation area permitted, plastic repair of the anterior urethra was carried out, but an indwelling catheter was not employed after operation.

Missile wounds of the posterior urethra. A catheter can seldom be passed in these cases, but apparently complete loss of continuity only occurs in a few. The posterior dislocation of the prostate on the urogenital diaphragm, seen in crush injuries of the pelvis, rarely occurs as a result of a missile. The rectum may be wounded in addition to this portion of the urethra and recto-prostatic fistula may be produced.

Owing to the difficulty of estimating the site and degree of injury in this portion of the urinary tract, the use of an *indwelling catheter as a splint* is advisable. Retrograde catheterisation and manipulation of a rubber catheter through both portions of the ruptured urethra will often avoid perineal exploration.

A small indwelling catheter should be employed to allow drainage of the urethral lumen and it should be fixed in some manner to the abdominal wall alongside the suprapubic tube. This catheter is not to be used for bladder drainage, but merely as a splint and for irrigation with penicillin. Lateral holes are cut in the catheter for this purpose and its end occluded by ligature.

After-care is of the first importance and the suprapubic tube should be washed out daily and kept clear of obstruction. The tube must not be removed too early, and bladder drainage should be continued until the urethra has soundly healed and normal micturition shown to be established by temporarily obstructing the suprapubic drain.

INJURIES INVOLVING THE FEMALE GENITAL TRACT

The perineum and genital tract of women were not immune to injury from missiles and the effects of high explosive, as the following records show:

One patient succumbed from multiple injuries, including severe haemorrhage from a divided uterine artery.

A girl of 17 years happily recovered from visceral damage comprising nine perforations of the small intestine and lacerations of the right ovary and Fallopian tube as well as the right cornu of the uterus. (Case of Mr. S. H. Wass.)

A woman taking refuge in an air-raid shelter which received a direct hit had an ovarian cyst ruptured; four pints of blood-stained fluid were evacuated from the abdominal cavity and the sac of the torn tumour was removed. Recovery took place. (Case of Mr. R. L. Galloway.)

Case: A woman in a Church Army hut at Dover had a shell explode at her feet. She sustained devastating perineal injuries. An inguinal colostomy was performed and suprapubic drainage of the bladder instituted. Her recovery was despaired of in the early days after wounding, but her progress towards convalescence was greatly helped by penicillin therapy.

The bladder sphincter had fortunately escaped damage, and sphincter control of her rectum had not been completely destroyed.

My colleague, Rainsford Mowlem, effected a miracle of repair in this unfortunate woman (Plates VIII and IX). The patient conceived four years after her injury and was safely delivered of a child by Caesarean section.

ABDOMINAL INJURY IN RELATION TO PREGNANCY, PARTURITION AND PUERPERIUM

Abdominal injury in the pregnant woman proved to be of very serious import as the following incidents show:

Case: Perhaps the youngest foetus to be destroyed in the maternal womb was one of 6 cm. length—A woman in an air-raid shelter which received a direct hit was diagnosed in hospital as a blast injury to the lungs: after forty-eight hours she succumbed, and in addition to the pulmonary changes confirming the pre-operative diagnosis autopsy showed a large retroperitoneal haematoma, especially in the peri-nephric region; there was extensive infiltration of the mesentery with blood, which also encircled the bowel under its serous tunic in several annular patches. The cavity of the womb contained some blood and there was a partial separation of the placenta from the uterine wall. The foetus which measured 6 cm. in length exhibited a bruise on its anterior abdominal wall—surely the earliest living thing to receive and demonstrate a blast injury.

Case: A woman was admitted to hospital after a V.1 incident with a wound of the right loin through which about half the length of the small gut was protruding and lying in the patient's clothing. The peritoneal cavity was full of blood and faecal matter which had already escaped from a severely lacerated caecum and terminal ileum. Through a rent on the postero-lateral aspect of the womb there protruded the legs of a foetus; a fragment of metal 2 in. square was recovered from the bottom of the pelvis. Death took place fifty-six hours after operation.

Case: E. S. 20, unmarried, four months pregnant, was admitted into hospital having sustained multiple bomb injuries which included a wound of the right iliac fossa. A glass fragment, 3 in. by 1 in. was found lying loose on the caecum which was not perforated. Recovery ensued without miscarriage. (Lt. Colonel Rodney Smith's case.)

Case: A woman of 21 years, eight months pregnant, was admitted to a Birmingham hospital with a bomb-splinter wound of the left side of the abdomen, through which omentum was protruding. Several lacerations of the small gut were sutured; the haemo-peritoneum was evacuated and the belly hastily closed with through-and-through sutures. She made an eventful recovery, which was punctuated by a severe pulmonary embolism; the child was born dead on the day following the incident and operation. (Case of Lt. Colonel Guy Baines.)

Case: Rupture of the abdominal wall by blast in a nine-months' pregnant woman; extrusion of transverse colon; death of child; death of mother. Alice G. 36 years; multipara; was in the maternity department of a hospital awaiting the birth of her child. While she was actually walking along the corridor to the labour theatre a heavy bomb fell in the hospital grounds, severely damaging ceilings, windows etc. The woman collapsed and fell to the ground; a vertical wound 4 in. long, the edges clean cut and bloodless was found over the outer border of the upper part of the right rectus abdominis; the herniated transverse colon was not perforated. There was no evidence of her dressing-gown or nightdress having been torn by bomb-splinter or glass. The patient unfortunately succumbed two hours after operation. (Case of Mr. E. J. Tamblyn.)

Case: A successful laparotomy was performed on a woman whose caecum was lacerated by fragments of glass from an 'incident' at Yarmouth; only a few days had elapsed since parturition. (Case of the late Mr. Valentine Blake.)

COMMENT ON THE OCCASIONAL NEED OF A SECOND OPERATION

A second operation, especially if that operation requires performance soon after the first surgical incursion, may demand courage and judgment of a high order to ensure a successful issue. Should the first operation have been itself one of emergency, a second 'crisis intervention' will load the scales heavily against the patient's recovery.

The following three cases which ended successfully, after a second operation hot on the heels of the first, concerned air-raid casualties in London.

Case: A. W., male, was bleeding severely from a penetrating wound of the left loin, and was operated on at early dawn by Sir Ernest Rock Carling, who found the flank muscles torn and the left kidney almost divided into two fragments by a transverse laceration; a primary nephrectomy was hastily performed to save life; there was no tear discernible in the posterior peritoneum.

Seven or eight hours after this first operation the general condition of the man deteriorated, and there was now board-like rigidity of the whole abdomen. A laparotomy was performed by Mr. Stanley Lee; a bleeding point was found on the juxta-colic portion of the transverse mesocolon, and there were two large lacerations of the transverse colon, the damaged segment of which was exteriorised.

The colostomy was ultimately closed and final recovery resulted.

Case: A patient had many intestinal perforations sutured at a first emergency operation. A few days later a damaged piece of bowel perforated and was sutured at a second intervention. Recovery ensued. (Mr. T. W. Mimpriss' case.)

Case: A soldier, extinguishing an explosive incendiary, sustained a ragged penetrating wound in the right loin. The posterior aspect of the ascending colon and lower pole of the right kidney were exposed and a fragment was removed from behind these structures; no injury to the posterior peritoneum was noted.

Six hours later abdominal symptoms demanded a second operation, and on laparotomy a few ounces of blood were found in the right paracolic sulcus; there was a small laceration on the lateral aspect of the ascending colon and a small tear of the adjacent liver. No sign of any tear in the posterior parietal peritoneum could be found that had been overlooked at the first operation. Recovery. (Mr. R. Wilberforce Smith's case.)

ABDOMINAL CASUALTIES IN NAVAL SHIPS

The only specifically naval type of abdominal casualty is 'immersion blast', but except for a few such cases that were operated on by Surgeon-Commander W. G. Gill, R.N.V.R., in one of H.M. Hospital Ships, surviving patients with abdominal injuries from submarine explosion were almost entirely dealt with in shore-establishments, often by surgeons of other services.

The paucity of abdominal operations among naval casualties is explicable on account of the time-lag between wounding and operation; the nature of the missiles causing abdominal injury, which are more likely to bisect or eviscerate a man than to wound a coil or two of his intestine; the peculiar environment of the sick-bay operating room in a fighting ship; and the problem of the appropriate anaesthetic. The vicissitudes of the sea itself, which is prone to show its own hostility to any ship that has already sustained damage, also contribute to the infrequency of the survival of abdominal casualties.

John Dryden in his well-known translation of one of the odes of Horace, '*Quem mortis timuit gradum*' etc. sounds the menace of the sea apart from the missiles of a hostile flotilla:

What manner of death could him affright
Who, unconcerned, with steadfast sight
Could view the surges mounting steep,
And monsters rotting in the deep?
Could through the ranks of ruin go,
With storms above and rocks below?

And in the words of a famous admiral who commanded Arctic convoys and played no unimportant part in sending marauding *Scharnhorst* to her doom off the North Cape: 'There lives not the man who has taken part in a Fleet action at sea and who does not believe in God'.

The environment of abdominal surgery during or after an action at sea is that of the very battlefield itself or a regimental aid post; there are lacking most of those requisites customarily demanded for the successful operative treatment of abdominal casualties in Army field-dressing or casualty-clearing station. What a dim prospect for successful abdominal surgery is suggested by the lines of Lucretius:

. . . perfurit acri
Cum fremitu, saevitque minaci murmure pontus.

Moreover, any anaesthetic required for an abdominal or any other type of case must always be administered with the thought uppermost in the mind of the ever-threatening possibility of abandonment of ship, and the threat of the committal of the perhaps still unconscious casualty *ad undas Acherontis*.

The journal of the surgeon of one of H.M. ships at the time of the Norwegian campaign tells of conditions in a ship which had received enemy punishment.

When H.M.S. Pelican was about 15 miles off the Norwegian coast, she was attacked from the air and struck on the quarter deck by a bomb, 35 men being killed instantly and about 40 wounded. The quarter deck, the last forty feet of which had disappeared, was a shambles, some 25 mangled bodies strewn around and no sign of life. Further for'ard the mess decks were in complete darkness and save for a few muffled groans and the stertorous sounds of Cheyne-Stokes' breathing, there was a tomb-like silence. Most of the men not critically wounded had already been taken up to the captain's cabin and the boat deck; all but a few of those still below were beyond recovery.

Here is an extract from the journal of Surgeon Lt. Commander C. D. D. de Labillière who was subsequently lost with his ship H.M.S. *Fiji* in another action.

At 1700 on Sunday September 1, 1940, the ship was struck by an enemy torpedo. The torpedo struck the ship on the port side by the forward boiler room, causing complete wreckage of the boiler room, a large hole in the ship's side with immediate flooding of the boiler room, and killing all five occupants in that compartment. The ship was 450 miles out from Scotland in the N.W. Approaches. A heavy sea was running at the time and she immediately took on a list to port and all the lights went out.

Immediately after the explosion the staff spread out over the ship to look for casualties, as none arrived of their own accord. Several of them went down to the marines' mess-decks, the point nearest to the site of explosion, where casualties were found. These decks were in darkness and partly awash and covered in oil-fuel, and first aid had to be given with the aid of torch light only. It was 'trying' work for everyone, as in those early moments after the explosion no one knew if the ship was going to sink at once or not, or if further explosion might occur.

Surgeon Lieutenant K. W. Donald, performed a laparotomy in one of H.M. destroyers, when the naval situation was such that there was no possibility of transference of the abdominal casualty ashore or to a hospital ship for many days. Unfortunately the caecum and ascending colon proved to be gravely damaged, with extensive contamination of the peritoneal cavity with liquid faecal material; the man succumbed.

On one occasion a naval patient who ultimately reached a hospital ship thirty-seven hours after wounding, recovered from lacerations of the small intestine and peritonitis. (Case of Surgeon Lieut. Commander F. S. Gowar, R.N.V.R.)

Abdominal incursions in L.S.Ts. during the Normandy landing were frowned upon by those in charge, although one or two successful operations were in fact carried out; it sufficed that these craft evacuated safely to the 'hards' on the northern side of the English Channel abdominal casualties already dealt with on the beach-head at Arromanche, or destined for operation at the hands of surgeons at Haslar, Portsmouth and Southampton.

Abdominal operations performed by naval surgeons in shore-establishments are found interspersed throughout this narrative.

Case: A naval rating in one of H.M. destroyers sustained a penetrating left thoraco-abdominal wound. On admission to a shore establishment the splenic pedicle and spleen were found severely damaged. Recovery followed splenectomy. (Case of Surgeon Captain Claude Keating, R.N.)

Case: A delicate boy with a double aortic murmur and a strong personal and family history of epilepsy, despite 193 days' sojourn in hospital during his period of service, pluckily contrived to get aboard one of H.M. destroyers and sustained a right-sided thoraco-abdominal wound in action. The abdominal injuries comprised two tears of the small gut, a laceration of the liver and a rent of the mesentery. The patient made a good recovery. (Surgeon Captain Claude Keating's case.)

A rating was stabbed in the left flank by a sailor of an allied Navy: six feet of small gut had herniated through the wound; a small perforation of the jejunum was sutured and tear of the mesentery dealt with. Recovery followed. (Surgeon Lt. Commander O. J. Vaughan Jackson's case.)

ABDOMINAL CASUALTIES IN THE ROYAL AIR FORCE

The airman's abdomen did not appear to be so vulnerable a target as that of the soldier; at any rate there are no large numbers of laparotomies recorded for abdominal wounds in the Royal Air Force. A few, while they were engaged on ground duties, sustained wounds from missiles from hostile aircraft; one or two suffered rupture of the intestine during faulty landings in 'assault' courses, but most received their wounds in air combat, in landings after 'baling out', or even from immersion blast from depth-charges carried in sinking ships or submarines when friend and foe alike might suffer injury.

In one respect the patient suffering from an abdominal injury in the R.A.F. was fortunate; he often reached a surgical hospital within a very brief space of time.

Case: A gunner in a 'bomber' received a left-sided thoraco-abdominal injury one hour before the aircraft returned to its aerodrome. Fortunately there was no laceration of the abdominal viscera, and the man made a good recovery.

Case: A squadron leader in a 'fighter' was wounded when attacking enemy aircraft at midnight at 20,000 feet. When hit he felt 'winded'; in 30 minutes he had landed at his own aerodrome; he did not feel faint, but experienced a little difficulty in walking. Laparotomy disclosed a laceration of the transverse colon, a tear of the inferior margin of the left lobe of the liver and bleeding from the mesentery. He recovered.

Many of the injuries received by airmen involved the pelvic viscera.

Case: A flight sergeant air-gunner was shot over enemy territory by a 'night-fighter'. He was operated on five hours after being injured (Group Captain G. H. Morley). Blood could be expressed from the penile urethra; X-ray revealed a cylindrical bullet, deep in the right side of the pelvis near the right ischial spine. December 22, 1942. Operation. A urethral bougie revealed wound of urethra communicating with scrotal wound; the latter was progressively excised and explored until the scrotum widely divided revealed no injury to testicle or spermatic cord. Complete severance of the urethra was found one inch posterior to the inferior border of the pubic arch, and almost complete division of the right crus of the penis.

After suprapubic cystotomy had been performed the proximal urethra was found retracted. An extraperitoneal approach was made towards the lower end of ureter, and the foreign body, located in immediate proximity to the origin of right internal iliac artery, was exposed and removed. Retrograde catheterisation revealed the proximal end of the urethra, the posterior 'roof' of which was accurately sutured with interrupted fine catgut. Over a catheter the remainder of the urethra was similarly sutured and the catheter then removed. The fascia of the corpus cavernosum and the scrotal wound were sutured, a corrugated rubber drain inserted, the bladder closed around a de Pezzer catheter, and intermittent suction of bladder catheter instituted. The missile proved to be the hard cylindrical, sharp-pointed core of an armour-piercing bullet, the casing of which was missing presumably through hitting part of the aircraft before hitting the patient. The core was about 1 in. long by ¼ in. diameter. *Progress*: December 31—Urethral dilatation and bladder wash; January 6, 1943—Suprapubic bladder drain out. Dilatation on January 14, January 21, Febuary 8, March 6, April 5, May 12, 1943. The patient returned to operational flying with the full category A3B with the arrangement that he would come periodically for dilatation of the urethra. Five years later, in late 1949, he was encountered accidentally and reported that he was not bothered in any way by his injury, had never had the urethra dilated after May, 1943 and seemed slightly surprised that his case interested the surgeon!

Case: A sergeant in Bomber Command was admitted to an R.A.F. Hospital 7 hours after being hit over enemy territory. Laparotomy revealed numerous lacerations of ileum and a considerable wound of the posterior wall of the caecum from which faecal matter was escaping freely. A resection of ileum was carried out; the laceration of the caecum sutured and a caecostomy performed. The man returned to full flying duties, but subsequently developed an abscess round the fragment deep in the iliacus muscle. Complete recovery followed its removal.

Squadron leader W. P. Griffin, R.A.F. dealt successfully with an accidental abdominal wound in a transport in mid-ocean on April 17, 1942. Most of the small intestine, caecum and appendix and a large portion of the omentum had prolapsed through the belly wound and were lying over the pubic region and between the thighs supported only by the man's trousers. Fortunately visceral damage was minimal, but the extensive wound of the parietes demanded considerable ingenuity to effect its closure. The man was able to return to service in a coastal battery.

A lieutenant of the U.S. Air Force was hit by cannon fire from an enemy fighter over France and sustained two wounds in the right iliac fossa and two in the upper part of the right thigh. Laparotomy disclosed a 2½ in. rent of the caecum and ascending colon, and there were eight perforations of the terminal ileum. Recovery. (J. H. H. Gough's case.)

A navigating officer of the U.S. Air Force was brought down in the sea by anti-aircraft fire. Picked up by a rescue launch and admitted to a hospital on the Thames estuary, he was found to have an abdominal wound demanding laparotomy; severe damage to the mesenteric vessels necessitated a resection of small intestine. Recovery took place. (Mr. A. E. Wynne's case.)

A Polish flying officer recovered from two large lacerations of the pelvic colon and several non-perforating wounds of the small gut produced by a fragment of cannon-shell measuring 1 in. × 1½ in. (Mr. Richard Charles' case.)

Colonel Loyal Davis, of the U.S.A. Medical Service informed me of a successful result in an officer of the U.S. Air Force who had undergone a double resection of bowel for injuries sustained in air combat.

Case: A pilot officer crash-landed in Arakan on March 23, 1944, after sustaining a left-sided thoraco-abdominal-arm wound from ground rifle fire. The wound of entry over the seventh left costal cartilage lateral to the nipple line was plugged by prolapsed omentum; the freely bleeding exit wound was over the eighth right space medial to the nipple line. Operation was performed under intercostal and subcostal novocain 'block'. A tear in the left diaphragm had extended into the membranous portion, exposing extra-pericardial fat; the diaphragmatic rent was enlarged and deep bleeding laceration of the liver was repaired .The diaphragm and chest wounds were closed and the officer was evacuated by air on the seventh day. A left-sided empyema subsequently developed, but five months later the officer was in good health and about to resume flying duties. (Case of Lt. Colonel J. H. Baty.)

THORACO-ABDOMINAL and ABDOMINO-THORACIC INJURIES

THE SERIOUS NATURE OF THESE WOUNDS

The behaviour of wounds of the diaphragm received in warfare has been known to surgeons since the days of Ambroise Paré, and they were not inaccurately noted and discussed by Guthrie and by his famous French contemporary Baron Larrey, when writing of the war surgery of the Napoleonic era.

As the years of the War of 1914–18 dragged on with all their slaughter, the prognosis of thoraco-abdominal injury steadily improved. Whereas Walters, Rollinson, Jordan and Banks in reviewing their first 500 abdominal casualties of the Somme Offensive (1917) could only report 18·5 per cent. of recoveries from thoraco-abdominal injuries and mentioned that all these survivors had only sustained injuries to the solid viscera, the *rapport* of Sir Anthony Bowlby to the Surgical Congress at Val-de-Grace in November 1917 was able to boast a recovery-rate of 49 per cent., and a few months later a series collected by

Sir Cuthbert Wallace showed a recovery percentage very little less. The best series of the War of 1914–18, however, in which a recovery-rate of no less than 66·6 per cent. was attained, came from a group of surgeons of the Fourth Army in the autumn of 1918, and was reported by Gordon-Taylor in a Hunterian Lecture in 1919.

The remarkable figures of Charles Saint (subsequently Professor of Surgery, University of Cape Town) and the late John Anderson (subsequently Professor of Surgery, University of St. Andrews) are worthy of special notice. Major Saint's recovery-rate in 22 cases actually exceeded 80 per cent.: in only 2 cases, however, of his series was there injury of any hollow viscus, but some of his cases that recovered were complicated by very severe wounds of other parts. Major John Anderson had also the remarkable recovery-rate of 79·2 per cent., but in his 53 cases the number of cases associated with injury to a hollow viscus was also small.

As in the last World War, so in the War of 1914–18 the immediate prognosis of a thoraco-abdominal injury was in no small measure determined by the nature of the abdominal damage. Sir Cuthbert Wallace found that where a wound of a hollow viscus existed, only 25 per cent. were evacuated from the forward area to the base: Gask and Wilkinson saved only 3 out of 13 with hollow viscus injury, and another series showed only a 20 per cent. recovery-rate. The indefatigable and skilful Lockwood, however, saved 8 out of 20 thoraco-abdominal cases where a hollow viscus was wounded; Gordon-Taylor's thoraco-abdominal casualties (1918) with hollow viscus injury showed an even higher recovery-rate of 50 per cent.; where only solid viscera were damaged, 70 per cent. of this surgeon's patients got well.

The improved recovery-rate in thoraco-abdominal wounds was ascribed by A. L. Lockwood (of Toronto) to the operative closure of the rent in the diaphragm, but Sauerbruch held the opinion that the importance of a rent in the diaphragm in relation to cardiac and respiratory embarrassment had been exaggerated. Probably the great improvement in the recovery-rate in this group of cases was due to the better treatment of the thoracic damage and increasing familiarity with the many problems of war-surgery. Moreover, small wounds of the diaphragm alike in the Wars of 1914–18 and 1939–45 have been found to heal spontaneously, and others are at least temporarily plugged by omentum, spleen, liver, or stomach.

INCIDENCE OF THORACO-ABDOMINAL WOUNDS

In one series of cases from the War of 1914–18 (Sir Cuthbert Wallace) thoraco-abdominal cases constituted 12 per cent. of the abdominal injuries which reached the casualty clearing stations of an Army: in the Spanish Civil War the proportion of thoraco-abdominal casualties admitted to a 'hospital of first urgency' was not dissimilar, i.e. 11 per cent. (Jolly, 1940). As a result of their experience in the C.M.F. in the last Great War, Brigadier Harold Edwards, and Lt. Colonel J. R. St. G. Stead reported 78 operations for thoraco-abdominal wounds out of 640 abdominal casualties, i.e. 12 per cent.; but of 5,105 abdominal casualties in the B.L.A. there were 786 thoraco-abdominal or abdomino-thoracic wounds—15·4 per cent. of the total abdominal cases.

The percentage of abdominal casualties that were thoraco-abdominal or abdomino-thoracic in character varied widely in the experience of individual operators from 8 per cent. to 39·5 per cent., but for the most part these constituted between 14 or 15 per cent. and 24 or 25 per cent. of the total abdominal casualties as seen in Table I.

TABLE I

			Per cent.
Colonel Duncan Stout, (2 N.Z. Exped. F.)	318	26	8
Sir Gordon Gordon-Taylor (Bradshaw Lecture, 1942) (Air raids on Britain) .	600	78	13
Lt. Colonel A. S. Dill-Russell, R.A.M.C.	100	14	14
Lt. Colonel R. Strang, R.A.M.C.. .	67 (or 55 if non-penetrating wounds excluded) . .	10	15 or 18
Lt. Colonel C. I. Tuckett, R.A.M.C. .	88	14	16
Major R. B. Eaton, R.C.A.M.C. . .	209	35	16·7
Lt. Colonel A. McLachlin, R.C.A.M.C.	354 (or 287 if non-penetrating abdominal wounds excluded .	67	19 or 23
Lt. Colonel Geoffrey Estcourt, R.A.M.C. (36 F.S.U.)	139	27	19·4
Lt. Colonel S. C. Raw, R.A.M.C. (6 F.S.U.)	117	24	20
Lt. Colonel John Fairbank, R.A.M.C.	62	13	21
Major S. D. McKinnon, R.C.A.M.C.	109	32	
Lt. Colonel Geoffrey Parker, R.A.M.C.	94	20	21·3
Major S. V. Railton, R.C.A.M.C. . (6th Canadian F.S.U.)	70	15	21·5
Lt. Colonel Andrew Lowdon, R.A.M.C.	64	14	22
Lt. Colonel E. D. Tovee, R.C.A.M.C.	50	12	24
Lt. Colonel J. E. Andrew, R.C.A.M.C.	83	20	24·1
Lt. Colonel Peter Ingram, R.A.M.C. .	59	15	25·4
Lt. Colonel Estcourt, Wheeler, Ross, and Blackburn	550	144	26
Lt. Colonel Guy Blackburn, R.A.M.C.	105	32	30·5
Major Geoffrey Wooler, R.A.M.C. .	81	32	39·5

Certain American figures are comparable: thus Bradford, Battle and Gasachoff had 81 thoraco-abdominal cases in 341 abdominal casualties—23·7 per cent.

Blackburn specially comments on the greater frequency of thoraco-abdominal wounds in the War of 1939–45 than in the case of its predecessor, but the general experience of the B.L.A. with its very considerable number of casualties only showed a slightly increased relative frequency of this group of cases, and there was no difference between the percentage of Sir Cuthbert Wallace (12 per cent.) in the War of 1914–18 and that of Brigadier Harold Edwards in the C.M.F. area in the Armageddon of 1939–45. Perhaps the particular terrain over which a campaign was fought may account for the varying incidence and the increased percentage of thoraco-abdominal injuries encountered by certain surgeons; thus Italy and North Africa were hilly and mountainous compared with the plains of North-west Europe, and direct frontal attack by infantry was costly and often unsuccessful. Flanking movements, therefore, tended to replace it and these, of necessity, produce more wounds of the flank. Coincident and steadily increasing attack from the air may also have contributed capriciously to the increased frequency in certain units.

CLASSIFICATION OF THORACO-ABDOMINAL WOUNDS (TUDOR EDWARDS)

(i) The chest and abdomen may be penetrated by separate missiles, the wounded man sometimes becoming a veritable St. Sebastian, his chest and abdomen riddled by machine-gun bullets or fragments of high explosive.

(ii) Missiles may penetrate the chest and may emerge through the abdominal wall or be retained within the belly (*thoraco-abdominal injury*); on the other hand, the track of the missile may be in the reverse direction—the wound of entry in the abdomen and the bullet or fragment of high explosive retained within the thorax (*abdomino-thoracic injury*): the latter is associated with a heavier mortality.

(iii) Traversing wounds of the lower chest, especially if inflicted during expiration, may pass through the diaphragm and occasion damage to any abdominal organs lying immediately subjacent to the midriff.

(iv) Tangential wounds of the lower thorax in which considerable damage, including diaphragmatic injury and visceral perforation, is produced by the missile and/or indriven fractured ribs.

ABDOMINAL ORGANS INVOLVED IN THORACO-ABDOMINAL WOUNDS

Both C.M.F. and B.L.A. figures for thoraco-abdominal injuries show that a majority of these wounds are plurivisceral except in the case of the liver, where the B.L.A. statistics show that in about half the casualties with liver injury that organ is damaged alone: in the C.M.F. in 67 per cent. of the cases of hepatic injury, the liver alone was wounded.

Not unnaturally the upper abdominal organs were most frequently involved in thoraco-abdominal wounds and, as might be expected in view of its size, the liver heads the list. All surgeons saw more right-sided thoraco-abdominal wounds than left-sided, perhaps because the diaphragm is higher on that side, perhaps also because left-sided chest wounds were a more frequent cause of death than those on the right side on account of the liability to an injury to the heart. Next to the liver in order of frequency of wounding came the spleen and after that the left kidney. The right kidney was not often damaged because of its protection by the liver.

Of the hollow organs, the stomach was the most frequently injured, then the transverse colon and splenic flexure. Injuries to the small intestine, including the duodenum, and to the pancreas were recorded. In the reference to the B.L.A. statistical table (Brigadier Sir Arthur Porritt), the liver was wounded in no fewer than 51 per cent. of thoraco-abdominal casualties: the spleen in 27·4 per cent., stomach in 24·5 per cent, the kidney in 19 per cent., and the colon in 14·4 per cent. An injury to the liver was encountered in one third of the visceral wounds of another series of thoraco-abdominal cases: the spleen in this series was damaged in 25 per cent.

INVESTIGATION OF 208 CASES OF THORACO-ABDOMINAL AND ABDOMINO-THORACIC WOUNDS (B.L.A.)

Frequency of Involvement of Individual Viscera. In 208 cases of thoraco-abdominal and abdomino-thoracic wounding 322 viscera were found to be involved.

In the appended table naturally every grade of visceral injury is represented—from the trivial to the catastrophic. In all true thoraco-abdominal and abdomino-thoracic wounds the diaphragm is perforated and that was so in this series, but in a small number no associated visceral lesion was discovered. There may have been minor damage to the liver or lung, but the wise surgeon does not explore officiously when there is obviously no major lesion requiring surgical attention.

TABLE II

Showing liability of abdominal viscera to be damaged in thoraco-abdominal wounds

Organ	Number of Lesions	Percentage
Liver . . .	106	33
Spleen . .	64	20
Stomach . .	51	16
Kidney . .	40	12
Colon . .	31	10
Small intestine .	17	5
Diaphragm alone .	13	4
Totals	322	100

DIAPHRAGMATIC LESIONS

The injuries of the diaphragm met with in penetrating thoraco-abdominal injuries are mostly in the sloping muscular portion, and are specially frequent where this lies in contact with the chest wall. In the cases that come to operation the rent is usually small; in one series the linear tear in 50 per cent. of the cases was half an inch long or less. Many openings are mere punctures; larger irregular apertures in patients fit for surgery are seldom found to be more than one and a half to two inches in diameter.

In a case successfully operated upon by Lt. Colonel A. L. d'Abreu there was an extensive avulsion of the diaphragm from its anterior and lateral parietal attachments, and the opening into the peritoneal cavity was at least 10 in. long. The defect was repaired by suturing the torn diaphragm to the chest wall above the line of its natural attachment.

Impaired mobility of the diaphragm, which remains high long after operation in this type of wound, is a matter of common experience and should not give rise to concern in the absence of other signs and symptoms. It is also a feature of cases of simple haemothorax.

TERMINOLOGY: NATURE OF MISSILES, ETC.

The far greater gravity of wounds where the missile enters by the abdomen and travels upwards to the thorax via the diaphragm, in comparison with those where the missile-track is in the reverse direction, was universally appreciated; to the former the term 'abdomino-thoracic' was applied; the latter more frequent group was called 'thoraco-abdominal'. The preponderance of 'thoraco-abdominal' over 'abdomino-thoracic' wounds was 7:1.

In penetrating thoraco-abdominal injuries the damage to diaphragm and viscera might be caused by bullet or fragment of high explosive, but also by bone fragments which might project through on the under surface of the diaphragm, although the metallic foreign body remained on the pleural side. Blackburn had two successful thoraco-abdominal cases with involvement of the heart or pericardium, where bone, not metal fragment, produced the damage.

PENETRATING INJURIES CAUSED BY LARGE MISSILES

The injuries produced inside the abdomen by large fragments of metal or other foreign body are almost always fatal; the result is scarcely likely to be different if more than one cavity of the body is implicated. The writer has, however, figured elsewhere a piece of brass tubing, $4\frac{3}{8}$ in. long, removed from a Greek soldier who recovered after the simple extraction of the missile, which had passed from behind forwards through the right scapula and projected in the epigastrium.

Saint (quoted by Gordon-Taylor) had a successful right-sided thoraco-abdominal case, in which a fragment of shell weighing two ounces had traversed chest, diaphragm and liver and produced two perforations of the duodenum and one in the hepatic flexure of the colon.

In one of my patients, the successful result of whose case is recorded elsewhere, a missile weighing nearly four ounces produced the most grievous damage inside the belly and fractured the bony wall of the thorax (Gordon-Taylor, 1919). The diaphragm was apparently uninjured, and a strict observance of the approved nomenclature must therefore exclude this case from the category of the true 'abdomino-thoracic'.

DIAGNOSIS OF PENETRATING THORACO-ABDOMINAL WOUNDS

Diagnosis may be obvious, for example, when herniation of lung, omentum, spleen or hollow viscus has occurred. This visceral protrusion is not always a very grave prognostic sign, since it often implies a small wound of entry through which the protruded viscus or viscera cannot naturally be reduced. Blackburn recorded a successful case where a man with a high explosive wound of the left costal margin was found fifteen hours after injury to have a herniated spleen, while the upper pole of the left kidney was free in the loin. Haematuria noted on pre-operative catheterisation in this case had pointed to renal damage; this simple preliminary must never be omitted.

Doubt may be felt at first whether the gravity of the condition of a man with a thoraco-abdominal wound is due to the thoracic, to the abdominal or to other concomitant injury. Nixon (1919), who had great experience of these cases, wrote that, if there is a fair air-entry into the lungs, thoracic injury is not to be held accountable.

The anatomical site of the apertures of entry and of exit of a traversing wound of the trunk limns the track of the missile with fair accuracy. The position of the patient at the time of injury also demands consideration; the structures probably damaged can then be readily adumbrated. In no class of case is radiological investigation of greater value, especially where a fragment of metal, spicules of broken rib, or other objects, are retained; its necessity in estimating diaphragmatic movements and thoracic lesions cannot be over-emphasised

There are also clinical signs and symptoms which arrest attention and may clarify, or possibly obscure the diagnosis.

1. *Abdominal rigidity* does not of necessity betoken involvement of the subphrenic viscera. It is well known that injuries of the pleura or lung, especially if situated in proximity to the diaphragm, may occasion abdominal rigidity and may arouse suspicion of an abdominal lesion, but the following are distinguishing features: (*a*) The abdominal rigidity associated with an injury below the diaphragm is more likely to be bilateral; in the case of a thoracic wound rigidity of the belly wall is usually confined to one side. (*b*) The abdominal rigidity accompanying a chest injury tends to be intermittent, some relaxation of the rectus abdominis occurring during inspiration. (*c*) The relaxation due to morphine is more marked in thoracic lesions.

2. *Sickness and vomiting* have been known to occur in cases of lower thoracic injury, but are more frequent in abdominal lesions, as also is eructation of gas.

3. The value of auscultation of the abdomen has already been mentioned.

Diaphragmatic injury is suggested by an almost entirely thoracic type of respiration, with a catch at the end of inspiration, sometimes a definite spasm of hiccup; yet the actual respiratory rate may be little altered. In the late stages of an injury to the diaphragm there is fixed pain, exaggerated on exertion, and referred to clavicle or scapula according to the position of the injury or location of the retained missile. Pain is induced especially by lifting, coughing, or even deep respiration. The diaphragm is kept motionless on the affected side.

The diagnosis of a wound of the diaphragm is not easy in subparietal injuries; the syndrome of tension pneumothorax may be simulated by the sudden irruption of stomach or colon into the chest. Radiology and the determination of the intra-pleural pressure enable a correct diagnosis to be attained.

In the case of penetrating injuries the decision as to the time of operation, the type of surgical procedure, and the timing of the stages of the undertaking will depend upon: (*a*) the degree of shock and collapse of the patient; (*b*) the presence or absence of collapse of the opposite lung, as suggested by intense dyspnoea, cyanosis, and respiratory retraction of the chest wall on the contralateral side (in such a case the administration of an anaesthetic and a thoracotomy in the War of 1914–18 usually proved fatal); (*c*) the experience and judgment of the surgeon.

The existence of blast-contusion of the lung is now well established on clinical and X-ray evidence and by post-mortem findings, yet it may be only the index of perhaps graver changes in the organs below the diaphragm. The wounded man may have been in very close proximity to detonating bombs, and may be suffering from a dangerous and grave degree of saturation of the blood by explosive gases, such as carbon monoxide or nitric oxide. The severity of the clinical state may even be due to such lesions as myocardial trauma. Such possibilities should not be overlooked amid the circumstances of this 'total' war; their presence and the existence of other grave multiple injuries heavily load the scales against recovery.

THE TREATMENT OF PENETRATING THORACO-ABDOMINAL INJURIES

Conservative treatment was sometimes employed, especially in right-sided lesions, in which only the liver and thorax seemed to be implicated. Lt. Colonel Blackburn, recording a personal series of 49 cases of thoraco-abdominal penetrating injury, abstained from major surgery in 9: there were no deaths among this group. In 19 cases of right-sided thoraco-abdominal wounding, Lt. Colonel Rob treated 7 conservatively, all recovering; whereas of the remaining 12, 4 had an unnecessary laparotomy, since a small liver wound was the only lesion found. Rob specially stressed the importance of very careful consideration before operating, because an unnecessary laparotomy increased both the mortality and morbidity rate of these injuries.

PREPARATION FOR OPERATION

The presence of a wound in the chest presented an additional problem to the already difficult one of the resuscitation of a patient with an abdominal wound in preparation for operation. Not only might the lung be considerably damaged, but the pleura might be full of blood. To give fluid quickly and in any quantity to such patients would have the effect of adding to the respiratory and circulatory embarrassment, and the danger of pulmonary oedema would arise. It was far more important and did far more towards resuscitation if the haemothorax was slowly emptied by aspiration than if blood or plasma were administered.

Fluid only needed to be given if there were signs of blood loss, and then blood was of far more value than plasma. The blood should be given slowly, not more than 1 pint an hour, and not more than 2 or 3 pints in all. It was sometimes difficult to know whether to transfuse or not; certainly these thoraco-abdominal cases did not require a routine transfusion, particularly of plasma, before their arrival at a surgical centre.

The priority for operation was similar to that described for abdominal cases; *early*, where bleeding was severe or where resuscitation measures failed to produce an appreciable improvement in the patient's general condition. If the wound was a sucking pneumothorax, it had to be sealed off *immediately* by an adequate dressing.

ANAESTHESIA IN OPERATIONS FOR THORACO-ABDOMINAL WOUNDS

This differed little from that given for operations upon upper abdominal wounds. Most anaesthetists preferred to use an endotracheal tube, although not all considered this essential. Positive pressure could be achieved without it, provided the face-piece was air-tight and connected to a bag.

Cyclopropane was by common consent the best agent to use, but failing this, gas and oxygen with a minimum of ether. Induction was usually achieved by a small dose of pentothal (often $\frac{1}{8}$ to $\frac{1}{4}$ g.).

The need to restrict diaphragmatic movements during the operation was a powerful indication for the use of endotracheal anaesthesia with carbon-dioxide absorption.

CHOICE OF INCISION

The method of operative approach in thoraco-abdominal wounding depended in some measure on personal preference. To quote an

American consultant surgeon: 'Thoracic surgeons are thoracically-minded; general surgeons are abdominally-minded. Thus they tend to approach thoraco-abdominal injuries differently'. However, individual bias alters with increasing experience and familiarity with the problem 'in the field'.

An analysis of 115 thoraco-abdominal wounds operated upon by several forward surgeons and reaching a chest centre in the C.M.F. provides some indication of the different approaches used in forward surgery (Lt. Colonel d'Abreu). One third of the patients had been operated upon through an extension of the original wound in the chest, followed by a trans-diaphragmatic approach of the abdominal lesion. Only 4 cases had been operated upon by a large thoracotomy wound followed by a separate formal laparotomy. As is well known, this last mentioned combined procedure carried a high mortality rate and should be avoided wherever possible.

In the B.L.A. a thoracic approach was employed in 39 per cent. of operations for thoraco-abdominal wounds. The following table (Porritt) furnishes information as to the mortality rate of thoraco-abdominal cases treated by the thoracic and abdominal routes.

The information was culled from the notes on 124 cases (B.L.A.).

TABLE III

	Cases	*Percentage*
Abdominal approach . .	75	61
Thoracic approach . .	49	39

Mortality rate for each group	*Percentage*
Mortality rate for thoraco-abdominal wounds explored through abdominal incisions . .	40
Mortality rate for thoraco-abdominal wounds explored through thoracic incisions . .	26

Brigadier Harold Edwards, writing from the C.M.F. in December 1944, noted the higher recovery rate in the 17 cases in which the abdomen was approached through the thorax than in the 61 cases in which an abdominal injury was approached through the abdomen after first treating the chest wound.

On the whole, statistical evidence seems to point to a lower operative mortality in thoraco-abdominal cases dealt with by a thoracic approach, but on the other hand, there was a remarkable series of thoraco-abdominal casualties operated on by Major E. D. Tovee, R.C.A.M.C. who lost only 1 patient out of 12 who had thoraco-abdominal wounds; all were operated on by an abdominal approach and the one death in this series was due to a faulty blood-transfusion.

There are certain injuries which all agree are best dealt with by a trans-diaphragmatic thoracic approach: firstly, for the performance of splenectomy with an associated thoracic wound. A pre-operative estimation of such a combination can be made by careful study of the line of the missile track in a through-and-through wound that corresponds accurately with the splenic area. Most military surgeons towards the end of the war were strongly of the opinion that splenectomy was an easier operation when performed through the chest than by the usual abdominal approach. The second indication is provided by the right-sided thoraco-abdominal wound in which the liver only of the abdominal viscera is involved, and there is associated thoracic trauma demanding surgery. In such cases the repair of the diaphragm is impossible from below but easy from above.

The major immediate cause of death in these complicated wounds was to be found in the intra-peritoneal lesion, and if any doubt existed as to the ability of the surgeon to deal with such lesions through the chest, laparotomy was reasonably preferred.

If the wound was strictly confined to the upper quadrants of the abdomen, a surgeon with a thoracic bias would prefer the chest approach, and many survivors of wounds of the cardiac end of the stomach, the upper jejunum, the spleen and the colon were reported after such operations. The post-operative course was also a good deal easier, because the diaphragmatic tear had been well repaired, any associated haemothorax thoroughly sucked out and the wound of the chest-wall properly excised.

If the thoracic wound was too high up in the chest to enable full access to the diaphragmatic area after excision and enlargement, it was preferable to deal with the entry wound first and then carry out a formal thoracotomy in the region of the 8th and 9th rib to provide adequate access.

If a pre-operative decision had been made to carry out the main intervention through the abdomen, it was better first to deal rapidly with the minor excision and partial closure of the chest wound before carrying out the abdominal exploration. The high incidence of thoracic complications following a promising operation for the abdominal lesions in a thoraco-abdominal injury demands emphasis: any associated haemothorax required even more careful attention than in the simple thoracic wound, because this group of patients was particularly prone to develop atelectasis of the lower lobe or massive pleural clotting, and also to become the victims of empyema.

GENERAL PRINCIPLES OF THE OPERATION

I. THE ABDOMINAL APPROACH

The mid-line or paramedian incision was that most frequently used; some surgeons, however, favoured Kocher's incision on the left side, believing that in addition to enabling them to deal with the abdominal visceral injuries it provided good access for the repair of the diaphragm, often a difficult procedure when carried out from below (Blackburn).

In the case of lacerated wounds of the liver and kidney conservative treatment was the rule, the bleeding being checked where necessary by the use of impregnated cellulose ('Oxycel'), fibrin foam, gelatin foam, muscle packs and suture, or in very extensive cases by dry gauze-packing. Wounds of the spleen, however, almost invariably required splenectomy. Drainage for liver wounds was not used extensively in the British Army, though it was the rule in the American Army in Italy. It is interesting to note in this respect that right-sided subphrenic abscess in British hospitals after liver wounds was unusual and apparently less frequent than in the American Service; on the other hand, pleuro-biliary fistulae with bile empyemata were more frequent. d'Abreu had 2 cases of right-sided subphrenic abscess in his series, and 13 on the left side.

2. THE THORACIC APPROACH

After the usual wound excision had been executed, a full thoracotomy, generally associated with resection of 9 or 10 in. of the appropriate rib, was performed. After the haemothorax fluid had been sucked out, any laceration in the lung was quickly closed by a catgut suture and the lung packed aside with saline compresses. The hole in the diaphragm was then considerably enlarged and blood welling up from its abdominal aspect was usually encountered at once. This was sucked and mopped out and, if coming from the spleen, that organ was removed. A careful inspection of the abdomen for any evidence of extravasation of stomach or intestinal contents was made and any visceral opening was closed in the usual way. In the case of the stomach it was always important to inspect both the lesser and the greater curvature and the cardiac area; any colon wound found was exteriorised through a separate stab incision in the abdomen, although towards the end of the war some successful results following the suture of wounds of the anti-mesenteric border of the colon were reported. If, however, there was any evidence of oedema or haemorrhage on the mesenteric side of the large gut, exteriorisation was undoubtedly indicated. Unless the wound track led easily to a missile in the liver, it seemed wise to leave the fragment alone, since bleeding from the liver started by the effort to find the foreign body often proved difficult to control.

When the abdominal toilet had been completed the diaphragm was sutured in two layers, preferably by interrupted silk sutures. Drainage of the appropriate subphrenic space was necessary in some instances, and the tube was usually brought out just below the tip of the 12th rib. The chest was closed in layers, usually without drainage, and 100,000 units of penicillin were left in the pleura.

Crushing of the phrenic nerve should never be performed, unless it be found necessary to help in the closure of the diaphragm; the need for an active functioning diaphragm was considered imperative to prevent, as far as possible, development of post-operative atelectasis of the lower lobe.

POST-OPERATIVE TREATMENT

The possibility of both abdominal and thoracic complications was obvious and the treatment of the two sometimes conflicted. The routine post-operative management of the abdomen by continuous trans-nasal duodenal suction indicated the need for adequate venoclysis; on the other hand, excessive infusion was extremely likely to produce water-logging of the lung in this particular type of injury, where the respiratory mechanics are so impaired. Far more plasma could be given relative to saline than would be the case in a purely abdominal wound. The post-operative measures for abdominal casualties, including the customary four-hourly injection of morphine, were continued until intestinal movements could be heard on auscultation. Avoidance of cyanosis, and retention in the forward area until the patient at rest in bed was no longer dyspnoeic, were also important rules of after-treatment. Thereafter, evacuation in stages, or longer distances by air ambulance at low altitudes, was the policy that paid best dividends. Other factors of great importance were those associated with the after-care of the thoracic lesion; aspirations were required for haemothorax effusions, and everything possible was done to prevent post-operative atelectasis and to treat it energetically if it developed.

COMPLICATIONS AT THE BASE

Although the percentage mortality in thoraco-abdominal casualties who survived the initial injury and the operative surgery that seemed appropriate was not high, there was a considerable post-operative morbidity rate. The complications in a series of 74 thoraco-abdominal wounds in patients investigated by Lt. Colonel A. L. d'Abreu at a Base hospital in the C.M.F. may be seen in the subjacent table; but the figures cannot give an accurate estimation, because under modern battle conditions, the patients arrive at the advanced base at varying periods, and those who reach a chest centre are likely to be those in whom the thoracic complications predominate, and probably many patients with late abdominal complications are omitted. Nicholson, among 1,639 admissions to a thoracic centre had 164 thoraco-abdominal wounds, of whom 23 died: d'Abreu in 1,000 consecutive cases from the Adriatic Centre of the Italian fighting, where air evacuation arrangements were a good deal easier than on the other side of Italy, had 115 thoraco-abdominal cases with 5 deaths.

TABLE IV

The Most Frequent Thoracic Complications of Thoraco-abdominal Wounds (d'Abreu)

Haemothorax (uninfected)		55
Empyema		29 (7 with 'bile' empyemata)
Atelectasis		37
Lung abscess		2
Abdominal abscesses	Subphrenic	15
	Pelvic	2

Nicholson, in his series, noted the development of 21 subphrenic abscesses, 13 of which were on the right and 7 on the left, which is in direct contrast to the incidence of such complications in d'Abreu's figures of 2 on the right and 13 on the left. Nicholson also reported 6 cases of cholethorax, all of which became infected, as happened in the 7 instances in d'Abreu's series. Nicholson also reported 2 cases of broncho-biliary fistulae.

The diagnosis and treatment of complicating lesions such as haemothorax, empyema, atelectasis and lung abscess were along the usual lines.

1. *Haemothorax, Atelectasis, and Lung Abscess.* The management of the haemothorax was no different from that in a simple thoracic wound. Re-expansion of atelectatic lobes after postural drainage and MacMahon's breathing exercises was the rule, and a course of sulphadiazine was often of value in reducing pyrexia, where progress was slow. Both the lung abscesses recorded in the table above resolved without operation, and experience led surgeons to believe that a course of parenteral penicillin, such as was given to these two cases, was of the greatest value.

2. *Empyema.* Perhaps the most significant feature was the high incidence of empyema (25 per cent.), but by no means all of them were due to infection of a haemothorax. A considerable proportion followed lower lobe collapse, associated with serous effusions that became purulent. In thoraco-abdominal wounds, therefore, a constant watch was essential, and paracentesis thoracis was indicated if signs of effusion appeared clinically or radiologically. Of the 18 treated in this series all made satisfactory recoveries, except one accompanying a large diaphragmatic hernia. The co-existence of subphrenic abscess and empyema was notable, and the injection of lipiodol followed by radiography was a valuable help in diagnosis.

3. *Subphrenic Abscess.* A total of 15 occurred. The diagnosis of a subphrenic abscess was not difficult, if the possibility of its presence was constantly in mind. Since many of them co-existed with intra-thoracic infection, such as empyema or atelectasis, pyrexia was liable to be attributed to the thoracic infection and not to a subphrenic abscess. Leucocytosis was an indication that suppuration was present, but could not of course differentiate a thoracic from a subphrenic origin. Rigidity,

guarding and sometimes tenderness over the involved subphrenic space were often of value. Radiology occasionally showed an abscess cavity with a fluid level, but frequently these abscesses did not contain air or gas. A raised diaphragm was so frequent in wounds of the lower chest that too much significance could not be attached to this sign as indicating a subdiaphragmatic collection of pus. On several occasions, however, lipiodol introduced into an empyema cavity showed on the radiograph the existence of a track through the diaphragm into a subphrenic abscess. The diagnosis of subphrenic abscess was often made only in the operating theatre by means of an aspirating needle of large bore.

Operative Drainage. Most of these abscesses were in the classical spaces described by Harold Barnard, especially the left posterior subphrenic space, and were drained accordingly. In cases with a very high diaphragm transdiaphragmatic drainage after rib resection was done, care being taken, when no empyema existed, to avoid opening the pleura. Fortunately most of the abscesses were in one or other of the posterior subphrenic spaces and were drained by the Ochsner route after resection of the 12th rib. In d'Abreu's series several had an overlying 'sympathetic' pleural effusion; six had a coincident empyema, in two of which lipiodol demonstrated the existence of a communication of the two cavities by a track through the diaphragm; in the other four pus was seen to be coming up through the diaphragm during the course of operation for drainage of the empyema. In these last four cases the empyema and the subphrenic space were drained through different incisions. In some instances of anterior abscess the drainage was made through a high subcostal incision.

4. *The Diaphragmatic Wound.* It is difficult at this early period after the war to assess the incidence of traumatic diaphragmatic hernia. Probably many more diaphragmatic lacerations were sutured in this war than in the 1914–18 conflict, and as already mentioned suture from the thoracic side is easier than from below. At the chest centres special attention was always paid to the possible presence of a hernia; in Nicholson's large series six were diagnosed, five on the left side being repaired by operation: the one on the right side in which the hernia contained only liver was not operated upon, since the patient was well. In d'Abreu's series only three diaphragmatic herniae were demonstrated radiologically, of which all were on the left side, but on eight occasions a small hole was seen in the diaphragm several weeks after the primary operation during the course of operation for clot clearance, for removal of a foreign body in the lung, or in the course of an operation for empyema. These lacerations were closed by suture and observed for several months without a hernia developing. On several occasions during the operation for the removal of intra-thoracic missiles the area through which the projectile had traversed the diaphragm was examined and firm natural healing was seen to have taken place.

5. *Pleuro-biliary Fistula. Biliary Empyema.* These were usually diagnosed by the unexpected discovery of bile in the aspiration syringe during the routine aspiration of a supposed haemothorax. All were the result of hepato-pleural fistula and, despite very careful and thorough aspiration, infection developed in all, a subsequent biliary empyema requiring treatment by rib resection and drainage.* Biliary empyemata needed to be drained early, since loculation was likely to occur, if this measure were delayed. Re-expansion was rapid in all cases and disappearance of bile more rapid still. One patient had a secondary haemorrhage from his liver, but survived after re-operation. As far as is known all these fistulae closed spontaneously after drainage without developing a diaphragmatic hernia: in Nicholson's and d'Abreu's series only one patient with a biliary empyema died.

The Fate of Retained Liver Missiles. At the primary operation the foreign body was rarely seen. After two Great Wars it is still difficult to assess the ultimate prognosis of a retained missile in the liver, but even in the early days the complication of liver abscess was by no means unknown (Blackburn and d'Abreu). Occasionally an error in the localisation of a missile in the lower part of the chest in its anterior part led to a thoracic approach, and the foreign body was felt superficially in the liver just under the diaphragm; removal was simple and the convalescence uneventful.

Foreign bodies in subphrenic abscesses were extracted on a number of occasions, and once a bullet lying on the left lobe of the liver, partly embedded in the diaphragm and causing persistent referred phrenic pain in the shoulder, was removed by a thoracic approach.

PROGNOSIS OF PENETRATING THORACO-ABDOMINAL AND ABDOMINO-THORACIC WOUNDS IN THE WAR OF 1939–45

Scrutiny of thoraco-abdominal statistics completed at 'consultant level' or furnished by individual surgeons attests the increased mortality which attaches to abdomino-thoracic contrasted with thoraco-abdominal wounds, to pluri-visceral injury, to associated injuries of other parts of the body, especially when the latter were themselves of second priority degree or greater, and to left-sided lesions in contradistinction to wounds of the right side of the body.

The accompanying table furnished by Brigadier Sir Arthur Porritt, dealing with a series of thoraco-abdominal wounds of the B.L.A., is of special value because of the large numbers which form the basis of his report.

In a series of 208 patients, 80 died, a mortality rate of 38 per cent. The mortality related to visceral involvement is also shown in the table.

**Note*: The development of empyema is an interesting observation, when it is borne in mind that bile salts were once used as a form of treatment for empyema.

TABLE V

Organ	Wounded alone		Wounded in combination		Percentage mortality	
	Number	Died	Number	Died	Alone	Combined
Liver	55	8	51	29	15	57
Spleen	25	8	39	18	32	46
Stomach	7	3	44	30	43	68
Kidney	5	1	35	18	20	51
Colon	5	1	26	16	20	63
Small intestine	5	2	12	10	40	84
*Diaphragm alone	13	5	—	—	26	—

* The fact that cases recorded in the table under 'Diaphragm alone' showed a mortality rate of 26 per cent., whereas 'Liver alone' produced 15 per cent. fatal results suggests that in the former group injuries were really more extensive than appeared at operation.

Thoraco-abdominal Wounds (59 *cases: Mortality* 46 *per cent.*)
(Lt. Colonel C. G. Rob, and Lt. Colonel Guy Blackburn.)

TABLE VI

	With associated injuries†		Without associated injuries	
	Alive	Dead	Alive	Dead
Left:—				
Single viscus	1	1	4	2
Multiple viscera	3	6	4	3
Right:—				
Single viscus	8	4	4	2
Multiple viscera	1	5	7	4
Totals	13	16 (55·1 per cent.)	19	11 (36·6 per cent.)

† Associated injuries are only indicated when these injuries were themselves of second priority degree or greater.

Lt. Colonel Geoffrey Estcourt, had the excellent recovery-rate of 74 per cent. in a series of 27 thoraco-abdominal wounds, including a successful resection of jejunum by a trans-diaphragmatic approach. Estcourt dealt with the cases via the abdomen in 11 out of his 27 cases.

A communication by Captain E. S. Yegorova from a Soviet naval war hospital dealt with 63 transdiaphragmatic wounds, for which 55 operations were performed. Right-sided abdomino-thoracic wounds bore a relation of 5:4 in comparison with left-sided injuries.

Yegorova points out that in less than 12 per cent. the diaphragm was the only structure injured; the remainder of the cases were complicated by simultaneous lesions of one, two, three or even four viscera, the liver being the organ most frequently damaged, and next in frequency both liver and lung; the foreign body was not infrequently retained in the liver.

Small intestine was more likely to be implicated in left-sided wounds, and the colonic flexures were occasionally involved in wounds of their respective sides.

The material which came under the Russian observers' care must have been of a severe type; thus in a number of cases omentum was seen protruding from the wound; in others omentum and wounded stomach, omentum with wounded and unwounded small gut, and the torn upper pole of the spleen. In one instance six ribs were broken; another patient had also sustained a compound fracture of the clavicle, complicated by an injury to the subclavian artery and vein.

It is therefore not altogether surprising that the mortality of all thoraco-abdominal admissions to a Soviet forward surgical unit amounted to 70 per cent. and for those submitted to surgery 60 per cent.

Neither this writer nor his Soviet colleagues favoured transdiaphragmatic laparotomy.

TABLE VII

Prognosis in Thoraco-Abdominal Wounds

	Operations	Deaths	Percentage mortality
Lt. Colonel E. D. Tovee, R.C.A.M.C.	12	1	8·3
Major Gavin J. Cleland	19	3	15·7
Lt. Colonel C. Tuckett, (D Day to cessation of hostilities 1945)	14	3	21·0
Lt. Colonel Geoffrey Estcourt	27	7	26·0
Major S. V. Railton, R.C.A.M.C.	15	4	26·6
Lt. Colonel John Fairbank	13	4	30·8
Unknown Author	13	4	30·8
Lt. Colonel S. C. Raw (6 F.S.U.)	24	8	33·3
Surgeon Rear-Admiral Sir Gordon Gordon-Taylor (Bradshaw Lecture Series)	78	29	37·0
Major Geoffrey Wooler	32	12	37·5
Major R. B. Eaton, R.C.A.M.C.	35	14	40·0
Lt. Colonel W. Michie	32	13	40·6
Prof. Angus McLachlin, R.C.A.M.C.	67	28	42·0
Lt. Colonel C. G. Rob, and Lt. Colonel Guy Blackburn	59	27	46·0
Lt. Colonel J. E. Andrew, R.C.A.M.C. (F.S.U. in Italy)	20	10	50·0
Lt. Colonel Robert Strang	10	5	50·0
Lt. Colonel Dill-Russell	14	8	57·5
Lt. Colonel P. W. Ingram	15	9	60·0

SUMMARY OF TREATMENT RECOMMENDED FOR PENETRATING THORACO-ABDOMINAL INJURIES

1. In many traversing (through-and-through) thoraco-abdominal wounds of the right side produced by a small fragment of high explosive or bullet, no immediate active surgical treatment is required, provided that (*a*) no gross damage has been inflicted upon the thoracic or abdominal wall—fractured ribs, explosive effect, etc.; (*b*) the direction of the track of the missile does not appear to involve the general peritoneal cavity or suggest the desirability of its exploration; (*c*) the

signs of abdominal haemorrhage or of injury to a hollow viscus are clearly absent.

2. In cases of right-sided thoraco-abdominal wounds in which a small fragment is retained in an inaccessible position in the substance of the liver, an expectant line of treatment is the correct procedure; accessible fragments, unless of small dimensions, should be sought and removed.

3. When there is an open blowing thoracic wound or a severe wound of the thorax, the *chest injury must of course assume priority of treatment.*

4. If the position of the wounds of entry and exit in a left-sided thoraco-abdominal wound indicates a track implicating that fatal left subphrenic area of the abdomen, or if radiological facilities are available and demonstrate a fragment of metal retained in this region, the thorax should be dealt with first and access to the upper abdomen obtained through the diaphragm.

5. When the thoracic injury appears insignificant, but there is evidence of widespread intraperitoneal damage, especially involvement of hollow viscera, the abdomen should be explored through an appropriately placed laparotomy incision. This instruction applies to wounds of thorax and abdomen produced by the same or by separate missiles.

6. When the thoracic injury seems slight, and when the evidence of a radiograph or the direction of a missile track in a through-and-through wound suggests an extraperitoneal course of a small fragment, such a thoraco-abdominal injury may often be left alone.

If in such cases there is evidence of injury to the kidney, the parietal wound down to the kidney should be excised, the organ investigated, any foreign body removed, and the wound appropriately treated by penicillin-sulphathiazole powder, etc.

7. If a thoraco-abdominal or abdomino-thoracic injury has been approached from the abdominal aspect, it is important not to waste further time trying to complete a difficult suture of the diaphragm in a critically ill patient, unless the aperture in the midriff is so large that immediate or early herniation of the abdominal contents is certain to occur. The liver almost always prevents diaphragmatic hernia on the right side, and therefore repair of the diaphragm on that side is not a vital step.

8. An abdominal approach is necessary in thoraco-abdominal wounds where the colon is implicated; exteriorisation of the large bowel is only practicable by this route.

Suction of the peritoneal cavity, except the immediate infra-diaphragmatic regions, can only be performed efficiently through an abdominal incision. Gross soiling in wounds of small or large gut therefore render this approach advisable.

9. Trans-thoracic crushing of the phrenic nerve is not only unnecessary but undesirable, and only aggravates the insult already inflicted on the diaphragm.

10. Concomitant damage of the kidney and colon is probably best dealt with by nephrectomy, and exteriorisation of the colon.

11. As in pure abdominal wounds, gross haematuria lasting 48 hours or more demands exploration.

NON-PENETRATING INJURIES OF THE THORACO-ABDOMINAL ZONE

In contrast to the great European conflict of 1914–18, non-penetrating injuries of the thoraco-abdominal zone played a much more important part in the surgery of the War of 1939–45; the thoracic and abdominal viscera, solid and hollow, were liable to damage under a variety of circumstances in 'modern' warfare. Fragments or masses of timber, stone, or metal might be confusedly hurled with explosive force against chest and abdomen in the indiscriminate air bombardment of civilians; women and children suffered 'crush' contusions of thorax and belly from falling masonry and iron girders; visceral damage above and below the midriff resulted from the blast of detonating bombs, mines, or other high-explosive machinery in close proximity to men and women of every age, condition, and calling, for in 'total war' none can claim privilege or sanctuary. Nor did the diaphragm remain immune when chest and belly suffered violence.

Gordon-Taylor's Bradshaw Lecture series contained no account of a successful result in a patient suffering from sub-parietal injury involving chest, diaphragm and abdomen, and the inference drawn from the cases investigated in his series was that they involved such desperate or multiple injuries that death ensued: some such cases were indeed found at autopsy. The experience of the War of 1939–45 showed that thoraco-abdominal injuries due to bullets or fragments of high explosive were on the whole less grave than those due to crushing force or the effect of 'blast'.

Case: A man of 50 was admitted to hospital after having been dug out from under the débris of a fallen house which had been damaged during an air-raid incident in the London area. He showed no marks of external injury, complained of no pain and exhibited only slight shock. On the following morning he was dyspnoeic and complained of pain in the left chest, these symptoms increasing during the day. On examination he was now found to be tympanitic over the left chest up to the 3rd rib anteriorly, and his heart was displaced to the right. X-ray suggested a diagnosis of collapse of the left lung, pneumothorax and a pleural effusion: just above the fluid level were some vague shadows which were thought possibly to indicate the presence of gut in the thorax. However, on the supposition that the condition was a tension pneumothorax, a needle was inserted in the 4th interspace anteriorly, and about a litre of air was let out, with great relief to the patient. This process was repeated, and the needle was connected with a receptacle by means of rubber drainage; fluids taken by the mouth now escaped through the needle inserted in the thorax. At operation a tear was found in the diaphragm through which an enormous hernia of the stomach had taken place; a fatal issue resulted.

Thoraco-abdominal accidents associated with parachute-jumping due to early faults in parachute design have also been described by René de Gaulejac and others, but became less frequent as the war continued.

Rupture of the diaphragm may also be produced by the passage of heavy army transport vehicles obliquely across the abdomino-thoracic zone, or by the crushing force of buffer accidents. An excellent account of the injury was given by Lt. Colonel Gordon Bryan (1922), who pointed out that the lesion was not very rare in children and adolescents, whose chest-wall is more elastic and can be compressed to a considerable degree without fracture. In some cases costochondral dislocations may occur, as shown by some displacement of the chest-wall and a clicking sound on respiration; at other times the diaphragm is torn by stretching or bursting, or may be lacerated by a fractured rib. The convexity of the diaphragm is the part that usually suffers; on the rarest occasion the crus is damaged. The left side of the midriff is that most prone to rupture under such conditions of violence; the liver is more likely to bear the brunt of an injury due to compression of the right side, although the right dome of the diphragm has been torn, with a resultant haemothorax and even the escape of bile into the pleura. The diaphragmatic lesion may readily be overlooked in the presence of cataclysmic intra-peritoneal bleeding. Rupture of the diaphragm produces shock, dyspnoea, and a disordered action of the heart. The pulse is rapid and irregular; the breathing is almost entirely thoracic, but diaphragmatic respiration may be restored after a day or two by the plugging of the rent by omentum, spleen, or other viscus.

Dyspnoea and tachycardia occur with herniation of the stomach into the chest; and severe pain with rigidity of the left hypochondrium may be complained of, and also pain in the neck or shoulder, from irritation of the diaphragmatic peritoneum. Thoracic distress is produced after meals; radiological examination will readily establish the diagnosis.

Rupture of one or both crura of the diaphragm may occur as the result of a subparietal injury. Bryan (1922) records a rupture of the left crus associated with a compression fracture of the eleventh and twelfth thoracic vertebrae resulting from a fall of thirty feet on to the pavement in a sitting posture. The intraperitoneal haemorrhage, which suggested a ruptured abdominal viscus, determined a laparotomy.

Severe crushing injuries of the chest have been known to produce a *tearing lesion of the mediastinum*, even when there has been no fracture of ribs or sternum. This had been found associated with a large retroperitoneal haematoma from damaged vessels in the root of the mesentery (Sauerbruch and O'Shaughnessy, 1937). The displacement of the mediastinum may suggest the diagnosis of a tension pneumothorax; investigation of the intra-pleural pressure and the use of radiography should prevent unnecessary and harmful surgery.

The diagnosis and treatment of *subparietal injuries of the spleen* are well established and require no comment. For subparietal *hepatic injuries* thorough surgical exposure may be necessary. Subparietal or non-penetrating *injuries of the kidney* are generally isolated lesions, and most often are mere contusions of the organ without rupture of the renal capsule. In injuries of the abdomino-thoracic zone which menace life concomitant damage rather than the renal lesion demands most attention.

BAYONET WOUNDS OF THE ABDOMEN

Recoveries from bayonet injuries were rarely seen; but Surgeon Commander Long, R.N. successfully treated a bayonet wound of the transverse colon.

Many bayonet wounds of the belly occurred in soldiers impaling themselves on their own or a comrade's weapon, often on returning to a trench where a rifle with fixed bayonet uppermost had been resting against the side of the trench; fortunately most of this group were successfully treated.

The following examples of recovery from bayonet wound of the abdomen were of interest:

Case: A soldier, impaling himself, sustained a perforation of bladder and rectum; the other viscera escaped injury and the soldier recovered. (R. S. Vick's Case.)

Case: A soldier of 24 had 'fallen on his bayonet when at practice'; the wound of entry was in the left ischio-rectal fossa and the wound of exit in the left sub-costal region. The abdominal viscera were almost uninjured, an aperture at the base of the bladder communicating with the coelomic cavity being the only lesion. He recovered. (Mr. J. S. Horn's case.)

Case: A similar lesion came under the care of the writer in the War of 1914–18, where a sergeant returning to his own trench from raiding the enemy jumped on a standing rifle and bayonet and sustained injuries to the bladder, sigmoid and the common iliac artery; the artery was completely divided, the ends retracted and were not bleeding. Recovery took place. (Gordon-Taylor.)

Case: During a 'mock practice' in the County Palatine, reality was given to the proceedings by a comrade accidentally 'prodding' the 'casualty' with a bayonet and producing a right-sided thoraco-abdominal wound: lung, diaphragm and liver were injured. Fortunately the man recovered.

The only example of recovery from a bayonet thrust delivered *à chaud* and wounding abdominal viscera concerned an enemy agent who, at the time of the Dunkirk evacuation, was bayoneted through the right lower chest by a Highlander in the 'blackout'. There was a lacerated wound of entry over the ninth right rib, which was fractured; the wound of exit was situated in the right hypochondrium anteriorly; liver, diaphragm and lung were injured. The man recovered. (Major Anthony Till's case.)

Case: A fatal case of traumatic chylothorax in a German soldier due to a bayonet wound came under the notice of Lt. Colonel A. L. d'Abreu, following bayonet wounding; at the autopsy a portion of the thoracic duct was found destroyed.

ANAESTHESIA FOR ABDOMINAL WOUNDS

It was generally agreed that the skill and resource of the anaesthetist were of far greater importance than the agent which he employed or the machine that he used, and the inclusion of a skilled specialist anaesthetist as a partner in the forward team—often he commanded the unit by virtue of seniority—proved an incalculable asset. A great share of the credit for the general excellence of the results obtained was due to the work of these officers.

Full general anaesthesia, giving maximum relaxation during exploration and repair of the abdomen, was the general routine. Other forms of anaesthesia were used but rarely—and then mostly as an experiment which proved unfruitful. Spinal anaesthesia was never used; surgeons of the last war had unanimously condemned it. Paravertebral block was soon abandoned by those who experimented with it, because the movement entailed was too disturbing for the patient. Regional novocain infiltration of the abdominal wall, though sometimes a useful adjunct to inhalation anaesthesia in patients in whom relaxation was incomplete, was never used on a large scale. There were four main reasons for its lack of appeal:

(*a*) The time factor.
(*b*) It increased the risk of infection of the abdominal wall, especially if the latter were soiled by intestinal contents.
(*c*) It hampered the surgeon when full exploration was required.
(*d*) In some 30 per cent. of abdominal injuries, wounds elsewhere in the body needed attention.

Continuous pentothal was not popular because, although capable of giving adequate relaxation, it tended to cause medullary depression, and was considered especially unsafe if thoracic injuries co-existed. Furthermore, laryngeal and bronchial spasm frequently attended its use, and, finally, recovery of consciousness from it was often long delayed.

Pentothal was, however, universally popular as a means of induction, and for this purpose a small dosage, often not more than one-sixth of a gramme, was sufficient in the shocked patient.

Apparatus for the administration of inhalation anaesthesia changed as the war continued. First came Boyle's field apparatus for gas, oxygen and ether; then the Oxford vaporiser, and finally the Heidbrink apparatus. The skilled anaesthetist would obtain excellent results from each machine, but it was the general opinion that cyclopropane and the Heidbrink were the best combination of medium and method, particularly where there was an associated thoracic injury. The respirations with cyclopropane were quieter than with gas, oxygen and ether, or with ether alone; a high percentage of oxygen could be given, and recovery from anaesthesia was rapid.

Cyclopropane was, however, not available to all commands until the closing stages of the war, and then only in limited quantity. Curare, possibly the ideal agent of the future, was not used at all for forward surgery, arriving too late for trial.

Whatever agent was used, the synchronous administration of oxygen was of the utmost importance. CO_2 absorption was useful, but not essential, except when cyclopropane was used.

Opinions differed as to the value of, or the need for passing an endotracheal tube. Many anaesthetists of experience rarely found the need for it; others used it routinely when chest injury was associated, others for upper abdominal lesions only, and some in all cases. Its value in chest injuries, in order easily to 'blow out' secretion and blood from the bronchial tree, was commented on by some. Others relied upon an accurately fitting face-piece, and a completely air-tight connexion with a bag. Some advantages advanced on behalf of endotracheal administration were: (*a*) a perfect airway could always be maintained; (*b*) less anaesthetic was needed, and (*c*) the presence of the tube would free the anaesthetist for occasional help with other things—e.g. the transfusion.

Vomiting during induction was frequent and troublesome and there was no golden rule for its prevention. Some anaesthetists insisted on passing a stomach tube before operation in upper abdominal wounds, and washing out the stomach before induction; an endotracheal tube would then be passed, the stomach tube re-inserted, and the whole pharynx carefully packed off. Such a régime may have contributed to a reduction in post-operative pulmonary complications, which were not uncommon, but did not receive general commendation because of the extra burden placed on the patient before the operation started.

Many anaesthetists accepted this early vomiting as an unavoidable nuisance and dealt with it on 'common sense' lines.

FACTORS AFFECTING MORTALITY, THE COMPLICATIONS AND CAUSES OF DEATH FROM ABDOMINAL WOUNDS

Major General Sir Heneage Ogilvie mentions four main factors affecting the mortality of abdominal wounds: (*a*) luck, (*b*) time-lag, (*c*) time of evacuation, and (*d*) the nature and number of viscera involved. To these factors should be added (*e*) the co-existence of other injuries, especially 'high priority' injuries, (*f*) the time taken over operation, (*g*) the care taken over pre-operative diagnosis and the resulting avoidance of unnecessary laparotomies, (*h*) the experience and skill of the anaesthetist.

The time expended on the operation is not unrelated to the degree of intra-abdominal damage and the co-existence of other injuries, but the type of surgeon has also an influence; the surgical tortoise has no place in a casualty clearing station or field surgical unit; Brigadier Stammers wrote: 'For every five minutes beyond the hour leads to a worsening of the patient's condition '.

MORTALITY AND MULTIVISCERAL ABDOMINAL INJURIES

Like many others, Major Ingram was firmly of the opinion that multiple visceral injury had much to do with the mortality rate. Only once in his series of missile injury to the gastro-intestinal tract was a single viscus lacerated, and 10 cases had a total of 30 visceral injuries.

Lt. Colonels Bastedo and Johnston also compared the degree of abdominal visceral injuries in survivors and fatal casualties:

Total number of viscera involved	125
Total number of patients with visceral lesions	87
Average number of viscera involved by one wound	1·4
Total viscera involved in patients who died	47
Number of patients with visceral lesions who died	26
Average number of viscera involved in these cases	1·8

Lt. Colonel Andrew Lowdon also presented figures showing the relationship of mortality and multivisceral injury:

Mortality related to Viscera Injured

No. of viscera injured	*No. of Cases*	*Deaths*	*Mortality per cent.*
0	6	0	0
1	30	10	33·3
2	21	13	61·9
3	7	5	71·4

The existence of other extra-abdominal wounds has a marked influence on the mortality of the surgical treatment of the abdominal injuries of war: thus in one series published by Lt. Colonels C. G. Rob and Guy Blackburn from the Italian Front the mortality for abdominal wounds without other first or second priority wounds was 25 per cent., but when other wounds were associated, the mortality was 42 per cent. The importance of avoiding an unnecessary laparotomy in battle casualties is therefore imperative; and the attitude of 'let's look and see' has no place in field surgery until a full clinical examination has been made, and a sound diagnosis has cogently dictated the necessity of an abdominal section.

The chief complications which led to the death of the patient either before or after operation were shock, haemorrhage and peritonitis. Death might result from severe shock, and more often from haemorrhage, before the patient could be submitted to operation, and when there was greater delay in treatment, peritonitis was sometimes the cause of death.

After operation, shock and haemorrhage still remained the most common cause of death.

Lt. Colonel Strang found that 60 per cent. of those who succumbed died within the first 24 hours after operation from haemorrhage and shock, which was not 'post-operative collapse', but failure to maintain the pre-operative improvement through the additional stress of the operation. Many operations lasted up to 1½ or 2 hours and might have a successful outcome if anaesthetist and surgeon took all precautions to avoid aggravating existing shock. But this was not always possible if lesions were severe and not ready of access.

Later complications which might prove fatal, but from which recovery was frequent were:

(i) Ileus—especially in cases of retroperitoneal injury.
(ii) Peritonitis.
(iii) Broncho-pneumonia.
(iv) Burst abdomen—this should not occur and is due to faulty technique of surgeon or anaesthetist or both.
(v) Wound infection.
(vi) Anuria—especially in retroperitoneal haematomata in which post-mortem findings of 'crush syndrome' were found in the kidneys.
(vii) Intestinal obstruction (mechanical).

Mention should be made of the incrimination and subsequent exoneration of intraperitoneal sulphadiazine as a cause. The gross haemoperitoneum and multiple bowel lacerations resulting from the passage of a missile through the abdominal cavity were sufficient potential causes of intestinal obstruction, without looking for other causes.

(viii) Moving the patient too soon—this policy was abandoned in later campaigns. Fat embolism and dehydration were not complications *per se* of abdominal injuries, and should be excluded.

To these should be added:

(ix) Intraperitoneal collections of pus, (*a*) subphrenic abscess, (*b*) pelvic abscess.

The table below gives the causes of death to show the relative frequency (Lt. Colonels G. M. Bastedo and D. W. B. Johnston, R.C.A.M.C.):

Causes and Time of Death

Cause	Time of death—in days post-operative									
	1	2	3	4	5	6	7–14	14–21	21–28	Totals
Non-recovery from shock	14	2		2						18
Anuria					1					1
Peritonitis		2								2
Hyperpyrexia			1							1
Gangrene of abdominal wall							1			1
Massive infection of pelvic wall								1		1
Plastic peritonitis									2	2
Cause unknown							2	1		3
Totals	14	4	1	2	1		3	2	2	29

Failure to recover after operation because of shock greatly predominates as a cause of death (62 per cent.), and the case labelled anuria probably also comes under this category, since anuria was merely the principal feature in a patient whose general condition was never good.

In Rob and Blackburn's series shock and haemorrhage were responsible for a fatal ending in a strikingly similar percentage of their deaths (61 per cent.). In this series of 210 abdominal cases, there were 78 deaths, i.e. a mortality of 37·1 per cent.

The causes of their 78 deaths were :—

Shock and haemorrhage	48
General peritonitis	9
Pulmonary oedema or broncho-pneumonia	8
Pulmonary embolus	3
Gas gangrene	2
Crush syndrome	1
Cholaemia	one each
Septicaemia	one each
Haemorrhage from the iliac vessels	one each
Cerebral abscess	one each
Acute pancreatitis	one each
Missed perforation	one each
Unknown (22 days after a liver wound)	one each

ABDOMINAL INJURIES UNDER SPECIAL CONDITIONS AND IN PARTICULAR AREAS

THE SURGERY OF THE ABDOMEN AND CHEST IN AIRBORNE SURGICAL UNITS

The genesis, circumstances and environment of an airborne surgical team or centre not unnaturally beget administrative problems, many of which were at any rate reasonably solved in the War of 1939–45, but in one respect all airborne surgical units are alike—the normal channels of casualty evacuation do not exist, so that the forward units may not make contact with the dressing station for some days. This is indeed the very *raison d'être* for the existence of a surgical team in an airborne formation.

Of the two abdominal cases which came under the care of Majors C. J. Longland and Lipman Kessel, neither could be rendered fit for laparotomy, although one open pneumothorax was successfully closed. Majors Cedric Goligher and G. C. Wells, by careful planning, had a more ambitious organisation and established an airborne surgical centre on four separate occasions; these observers operated on no fewer than 27 abdominal casualties and closed four sucking wounds of the chest; Major N. A. Miller in an airborne landing on D-day, saved several abdominal cases. One other surgeon of an airborne unit must be mentioned, Lieut. Colonel (now Professor) C. G. Rob, who distinguished himself in so many branches of military surgery. Rob dealt with 8 patients with abdominal wounds of whom 6 lived; one of the fatal cases had sustained a wound of the lung, liver and colon; the other death occurred in a man who had a gross wound of the small gut and mesentery. The successful cases included a suture and resection of intestine; and wounds of the colon in which a colostomy was performed either above or at the site of the injury. A liver and a kidney wound were packed, and bladder and urethral wounds were dealt with successfully by suprapubic drainage. Pentothal was the usual anaesthetic and, where necessary, chloroform and ether. The quantity of plasma for resuscitation was limited, so that the cases requiring transfusion were given whole blood obtained from men of the unit who had been previously grouped.

For further details regarding the surgical treatment of casualties in airborne units the reader is referred to articles written by those mentioned above who participated in airborne landings.

ABDOMINAL WOUNDS IN THE BURMA CAMPAIGNS

Fortunately abdominal casualties in the Burma campaigns were not frequent; thus, in the first three months of 1945 they comprised only 2–5 per cent. of the total casualties.

Certain circumstances might have been thought to militate against the recovery of chest and abdominal casualties in the Burma sphere of military operations:

1. *Climate.* Many parts of Burma and the Indo-Burman border are notable for the high humidity of the atmosphere, and the temperature is high in the pre-monsoon months. Adaptation to such a climate is not readily acquired by European troops, and dehydration and salt depletion are frequent. Inasmuch as belly wounds are denied fluid by the mouth pre-operatively, the abdominal casualty tends to start off with a considerable negative salt-water balance, and this may be forgotten in planning post-operative fluid needs. In many cases the wounded man benefits from the immediate institution of a saline drip rather than the blood and plasma which are usually immediately forthcoming. There was a tendency towards the adoption of this measure in the later phases of the campaign.

As the hot weather approached and conditions in the operating room became very trying, chloride and fluid replacement became of the greatest importance as a prophylactic against heat stroke.

2. *Racial Factor.* There is a fairly uniform impression that Indian patients do not recover so well or so frequently as British and Gurkha wounded. The reaction of the Indian to wounding is an apprehensive one; he is intolerant of tubes and needles, very restless and non-co-operative. Furthermore his state of nutrition is often a precariously adjusted one, especially as regards proteins, since religious prejudice and dietetic habit have accustomed him to a diet low in animal protein.

The language difficulty also acts inimically, and it is good policy to have Europeans in the same ward, so that the Indian sees his 'white brother' treated in the same way.

3. *The Supervention of Malaria.* At one period of the Burma campaign it was almost the invariable rule for the battle-casualty to develop frank

malaria on the second or third day after wounding and operation. The assumption naturally followed that the routine dosage of mepacrine was unable to suppress the disease in the presence of acute trauma; and this view gained considerable credence among surgeons. It was, however, difficult to be certain that the suppressive dose had been maintained at any rate on the day of wounding, and on the day of admission to hospital it must have been frequently omitted; the patient was usually a bad witness of the regularity of treatment. Even in 1945, when the mepacrine 'drill' had vastly improved, there were still considerable numbers of post-traumatic malarial cases, so that it did seem possible that injury to the bones, or severe shock with contraction of the spleen might have liberated the parasites from these depots.

The problem was sufficiently serious to warrant the institution of a full course of treatment in all save minor wounds, and in all cases undergoing treatment involving the administration of a general anaesthetic.

In particular, there was often difficulty in deciding at once whether post-operative temperature was due to malaria or to local wound complications, thereby leading to unnecessary inspection of dressings, removal of plaster, etc. Furthermore, the fever increased the difficulties, already great, of maintaining an adequate fluid balance; while the secondary anaemia following malaria undoubtedly predisposed to infection.

Where the oral route was not permissible, e.g. in belly cases, the drug was given by intramuscular injection.

4. The prevalence of skin diseases resulting from climatic conditions led to an increased risk of infection in wounds, and to delayed healing.

5. *Nature of Wounds*. The Japanese missiles had a habit of carrying not only clothing and equipment, but also jungle debris, leaves and dirt into deeper parts of the wounds.

6. *The Conditions and Hazards of Evacuation.*

7. *Diet*. A wounded man requires more protein than he does normally—a gramme of protein per pound of bodyweight is a rough, but fairly accurate assessment. To ensure that the wounded patient receives this amount, the following points need attention, particularly in the case of Indian patients:

(i) Meals should be properly prepared, made as attractive as possible, well served and spaced properly—smaller but frequent meals are best.

(ii) Milk, cheese, eggs and fish—all of which Indians can take—should be made use of when possible.

(iii) Curd made of tinned milk is regarded as a delicacy by Indian ordinary ranks; easily prepared, this is a first-class source of animal protein. It can be flavoured, if necessary, and the average Indian soldier will consume up to 5 pints of this a day.

(iv) In severe cases with complete loss of appetite, repeated plasma infusions should be given; the plasma may be made up to double or treble strength.

In view of the special conditions affecting surgery in the Burma campaign, the following rules were useful guides for the surgeon:—

1. Heat stroke or heat pyrexia was liable to occur if the patient was dehydrated; therefore operations, when possible, were restricted to the early morning.

2. Restoration of the salt fluid balance in dehydrated patients was of paramount importance.

3. The minimum of drapings, especially mackintosh sheets, was used.

4. Operations were performed as quickly as possible.

5. Especially in the hottest months, a continuous drip saline was kept running throughout the course of the operation.

6. It had to be remembered that exhaustion might also occur among surgical personnel.

AIR EVACUATION

Air was unquestionably the only possible method for evacuating casualties in the Burma campaign, with several hundred miles of road-lines and rail-less mountain and jungle between the forward units and the advanced base hospitals. Evacuation by transport planes—Dakotas—from C.C.S. level to the advanced base was for the most part regular and adequate, and not infrequently cases were back at Comilla within 36–48 hours of wounding, thereby making it possible to give practically every casualty the advantage of delayed suture.

Forward of the casualty clearing station the employment of light aircraft meant the rapid transfer of wounded virtually from the firing line to the C.C.S., *except at night and in high priority cases* which had *at all times* to be dealt with by the mobile surgical units at advanced surgical centres.

The *cases normally retained forward in the Army area* included (i) abdominal wounds, (ii) penetrating wounds of the chest, (iii) cases of specific wound infection (established or suspected), e.g. gas gangrene, tetanus, (iv) causes of damage to the main arterial supply to the limbs, in which there was doubt about the efficiency of the collateral circulation, (v) severe burns, (vi) injuries associated with severe shock (massive wounds of muscles), until the shock was completely controlled.

Light plane evacuation made possible the easy and rapid evacuation of casualties from the front to C.C.S. level during the day. However, flying stopped from 5 p.m. to 8 a.m. (i.e. 15 hours' cessation).

This night factor threatened to postpone the early operation treatment of a large number of casualties, and this danger had to be met by a modification in the use of the mobile surgical units (M.S.U.) which were most frequently deliberately attached to the main dressing station of a field ambulance close to the light 'air-head'.

Wherever possible, nursing sisters were sent forward to this centre, the military situation permitting.

(*a*) *Forward Evacuation*. The use of the light plane almost without exception superseded every other method of moving the wounded to the main forward operating centre; air-transport became a life-saving measure, for the trauma involved in ambulance journeys over the Burmese dirt-tracks was formidable.

The time in the air seldom exceeded forty-five minutes and the light aircraft flew low, so that practically all types of cases were safely carried.

The planes were quickly loaded with their single stretchers, and the close proximity of the air-strips to the medical units, and the allocation of planes solely to medical duties, avoided the unpleasant delays which occasionally occurred with large-scale evacuation by transport planes further back.

The principle clinical disadvantages were:

(i) The absence of night flying and therefore of night evacuation, necessitating the provision of advanced operating centres at the 'light air-head'.

(ii) It was impossible to continue resuscitation in the light plane during the journey, and it was therefore found expedient to deal with wounds causing a high degree of shock before evacuation.

No praise could be too high for the American squadrons of L5s. and the pilots who flew them; they were under the control of the D.D.M.S. Corps and the evacuation of casualties was a first priority task.

(*b*) *Transport Plane Evacuation*. It was this form of evacuation that caused most difficulty. The evacuation of casualties from C.C.S. to base hospital in time for modern methods of wound closure to be applied was achieved, and could only have been achieved, on this front by aircraft; their routine use was a tremendous advance on any previous method, but there were certain disadvantages, the most serious of which was due to the lack of co-ordination of their control with medical necessity.

Heavy aircraft carried casualties as their secondary duty only, their primary rôle being to carry forward reinforcements or supplies to the fighting divisions.

Theoretically, this duty fitted conveniently with loading casualties at the forward airfield and their delivery at the place where hospitals were grouped, but in fact there were numerous delays and annoyances; thus, it was often impossible to ascertain the expected time of arrival of aircraft, and patients were kept waiting for hours on the shadeless forward airfields, since the aircraft ran to a schedule and when they arrived could not wait for patients to be brought from the casualty clearing stations distant a mile or so away.

Tactical changes also compelled the use of forward airfields other than those at which air units were placed, and pilots were not always briefed to call at the appropriate airfield before their return.

Occasionally, especially when supply aircraft were used, they returned to what was for the medical department the wrong base.

Medical administration had only remote control through staff channels, and it was difficult to devise a system which could successfully meet an emergency. Consequently there were delays and irregularities in addition to those due to weather conditions, and they increased in the later stages of the campaign, with longer flights and fewer, hard-pressed aircraft. The 'time-lag' between the primary and secondary operations was thus often prolonged and always incalculable, and some of the surgical failures were undoubtedly due to this factor.

Moreover, the aircraft themselves were not especially fitted for ambulance work, apart from the usual racks and slings for stretchers: the heating system often failed; oxygen was seldom, if ever, available, and there were no attendant orderlies other than those temporarily supplied, with difficulty, by forward units.

Obviously an ideal air-evacuation service is not to be attained until specially equipped ambulance aircraft are earmarked for casualty evacuation of wounded as their primary task. When, as was the case in Burma, this was impracticable, an improvement in inter-service staff work was essential for surgical efficiency. (*See* R.A.F. Medical History, Vol. I, Chap. 10.)

WAR SURGERY IN MALAYA

The fighting in Malaya was of two main varieties; firstly, hand-to-hand fighting between small parties in the jungle where the unbelievably subdued light and the high, dense undergrowth reduced visibility to a few feet; secondly, ambushes on made roads or on mud tracks through rubber estates.

The weapons used by the bandits varied within rather wide limits; their best formations were well armed with modern automatic weapons and rifles in the use of which they were fairly well trained; in other formations only a few were so armed, the majority carrying shot-guns and a long weighted knife, the parang.

The number of shot-guns in Malaya must have been very large, since these weapons are used in country districts in peace-time to defend crops from herds of wild pig, for shooting game for food and destroying marauding wild animals. Each cartridge of these jungle shot-guns contains 15 solid steel balls or 'L.G.', each ball being about $\frac{3}{8}$ in. in diameter. The cartridges are easy to obtain and even when supplies are short can be made in the jungle, since the material for making the charge can be obtained from the tin mines. This weapon at short range will stop a charging wild pig in less than a yard, and as it discharges a cone of balls accurate sighting is unnecessary: it is therefore an ideal weapon for the

Chinese bandit, who is a notoriously poor marksman. He usually carries a weapon whose barrel and stock are shortened, thereby making it lighter, handy in the jungle and capable of being discharged from the hip. The Chinaman likes a short barrel, as his arms are shorter than the European.

Although the effective range of this weapon was less than two hundred yards, the wounds which it inflicted at close quarters in jungle fighting were characteristic and almost always fatal, except in the limbs. At any distance less than ten yards the victim was stopped 'in his tracks' and inasmuch as the close cluster of bullets was only just beginning to fan out, all the balls would probably penetrate. At this range the wound inflicted was a single, roughly circular one of 6 in. to a foot in diameter, and almost every vestige of skin and subcutaneous fat within the circle was destroyed; the edge of the wound was black, ragged and bleeding. The effect on the muscle below was characteristic: for a depth of 1 to 2 in. over the whole wound the muscle was uniformly pulped, semi-fluid, and completely destroyed. Abdominal wounds were almost always fatal within a few minutes, and post-mortem examination of such cases revealed on the average forty perforations of the bowel and abdominal viscera. Chest wounds at this range were characteristic in that the thoracic wall was 'stove in' from multiple fractures of each of a series of ribs, and the entire lung was transformed into a large haematoma-like mass.

In abdominal and chest wounds at ranges between 10 and 20 yards, the number of immediately fatal cases decreased, thus :

A Chinese policeman received a circular shot-gun wound measuring 3 × 2 in. in the right side of the abdomen, involving the middle third of the rectus abdominis. A field surgical team was despatched in an armoured ambulance train, and the patient was transfused within an hour and the abdomen opened within four hours of wounding. Six closely-set perforations could be made out in the posterior wall of the sheath of the pulped rectus muscle, and 14 separate wounds involving about 6½ ft. of the small intestine, and eight tears in the mesentery were found at operation. All the gut wounds were closed and the abdominal wall repaired. After a complicated and stormy post-operative course this man eventually recovered. (Captain John Hadfield's case.)

At ranges of 25 yards and over, the area of 'scatter' being greatly increased, each ball produced its own wound, and the depth of penetration diminished with the rapidly falling velocity.

A field surgical unit in Malaya operated under different conditions from units attached to large bodies of troops such as those who fought in the desert, where rapid motor transport was usually available, or in open country with many roads and railways. The area served in Malaya by each unit was much larger, the roads were few and all of them dangerous, and the facilities for setting up a mobile tented unit were extremely poor. After a short time it became obvious that the unit could only serve its purpose if it were made capable of moving surgeon, anaesthetist and two orderlies with adequate equipment to the headquarter company of the battalion in action. The move was effected by

Auster aeroplane to the nearest air-field and thence by convoy, by armoured train or by road by means of the unit's own transport. This practice partly solved the problem of the treatment of men who had been wounded deep in the jungle and had to be carried under tropical conditions to the jungle edge on bamboo stretchers, the journey taking one to two and a half days. By the time the road was reached, severely wounded cases urgently needed immediate transfusion and early operation. As in all tropical countries, long continued exertion, injury or blood loss was often followed by remarkably long periods of anuria associated with low plasma chloride and clearly due to excessive sweating. This possibility had to be continually borne in mind.

APPENDIX I

ABDOMINAL CASUALTIES IN NORWAY

In April 1940, 99 English wounded soldiers were treated in the local hospital at Lillehammer, Norway, by Dr. E. Murstad. There were 3 abdominal cases:

1. Gunshot wound in the left leg and in the left iliac fossa. Fifty-two hours. General condition very poor—laparotomy. Diffuse peritonitis with brownish fluid and fibrin on all intestines; no perforation of the small or large bowel was found. The man died the next day.
2. Gunshot wound in the left buttock. The exit in the right trochanteric region. On laparotomy was found a large retroperitoneal haematoma and haemorrhagic infiltration in the sigmoid rectum and bladder. There was pulsation in the intestinal arteries. He died the next day.
3. Anti-tank projectile in the left flank. Thirteen hours. X-ray showed a 9 × 2 cm. missile near the promontorium, the apex of the missile pointing to the left towards the wound of entrance. Laparotomy. Incision of the periosteum on the posterior wall of the peritoneal cavity and removal of the projectile. Recovery.

There were 3 chest injuries, all light cases, with no mortality.

APPENDIX II

NOTE ON THE TREATMENT OF ABDOMINAL WOUNDS IN THE RUSSIAN ARMY

All the Soviet writers proclaim the value of early operation, transfusion of blood in liberal quantities, and the retention of abdominal casualties after operation for as many days as the 'military situation' will permit. Most refer with enthusiasm to the use of local anaesthesia; Dridze employed it in 104 operations for gunshot wounds of the abdomen, and ether anaesthesia in only 32; but while he lauds regional anaesthesia as the best method for severely shocked people under ideal peace-time conditions, he admits its drawbacks and disadvantages in a field unit where there is perhaps only one operating table and possibly three or four abdominal cases are awaiting the surgeon's help.

Various figures relating to the mortality of abdominal injuries are to be found in these papers; some are derived from the author's own experience, others are gleaned from the literature. All seem agreed that penetrating wounds of the belly are associated with the highest mortality of any type of war injury.

Most surgeons will agree with their Soviet colleagues that multivisceral injuries are associated with a heavier mortality than injury limited to a single viscus.

Nikolaev sets out in tabulated form the mortality associated with injuries of the various organs from his experience in the various forward army hospitals where the abdominal surgery is performed. Where there is only a single wound of the small intestine the mortality ranges from 45 to 55 per cent.; multiple wounds of the small gut carry a very similar death rate of 50 to 54 per cent. Large intestine injuries are more fatal, since 57 to 74 per cent. die; although wounds of the colonic flexures appear more favourable—40 to 66 per cent. succumbing. Injuries of the stomach alone had a mortality of 33 to 48 per cent.; liver, 40 to 55 per cent.; the spleen, 45·4 per cent., although Petrov and Israel say 58 to 62 per cent.; the urinary bladder, 30 to 33 per cent. Where several organs are involved, mortality rises; small and large intestinal damage produces a mortality of 61 to 68 per cent.; stomach and small gut as much as 78 per cent.; stomach and colon no less than 77 to 94 per cent. Wounds of the liver and small gut are fraught with a fatality of 40 to 60 per cent.; not unexpectedly colon and liver have a higher risk, 66 to 82 per cent. In this series all the cases of spleen and small gut injury succumbed. Where bowel and urinary bladder were involved the mortality (70 per cent.) is about twice that of bladder injury alone. The author found that plurivisceral injury constituted 35 per cent. of his abdominal cases—rather a low percentage. (G. G.-T.)

Like British surgeons, the Soviet surgeons recommend suture rather than resection of bowel; resection is associated with a mortality of 57 to 60 per cent.; death is almost certain if more than 3 ft. of gut require ablation!

Aminiev's contribution is of interest not only because of the successful result in a severe left-sided thoraco-abdominal injury, but also because it contains some reference to other Russian surgical achievement. The author is justly proud of his own successful suture of 13 intestinal lacerations as well as a splenectomy, and he quoted the former Russian surgeon, Oppel, as having seen a man in the First World War recovering from 13 wounds of the gut that had been sutured, and the writer himself mentions a case from the Pavlov-Salvansko material who had survived 14 intestinal wounds. [However, cases operated on by several British surgeons recovered from an even larger number of wounds of the intestinal canal; A. L. Ledingham successfully sutured 16 rents in the small bowel, and one of the large, while Surgeon Rear-Admiral D'Arcy of the Royal Navy summarily dealt with 20 wounds in a scorched intestine by means of a 6-ft. resection, and in addition sutured a laceration in the sigmoid; 21 perforations must be almost a record]. The combination of abdominal and thoracic injury is admittedly severe; Aminiev quotes the mortality of the Pavlov-Selvansko material as 87 per cent., which is surely reminiscent of the earlier figures of the Battle of the Somme in 1916 for this type of injury.

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APPENDIX III

ABDOMINAL INJURY FROM V.1 AND V.2 INCIDENTS

The infrequency of intra-abdominal injury in the South-east of England from V.1 and V.2 incidents was noteworthy: G. H. McNab (1944) found only 3 cases of intraperitoneal lesion in 187 patients treated in one hospital for injuries sustained from V.1 explosions; R. C. Bell (1944) saw no case of penetrating abdominal wound in 259 patients injured under similar circumstances, while Miss M. M. C. Louden (1944) found less than 1 per cent. in over 800 injuries admitted to a hospital in South London.

Of 79 patients who had sustained abdominal visceral injury as disclosed on laparatomy, 14 showed no external wound and were suffering from injury inside the belly produced by blast or the collapse of buildings, etc. Glass proved a very potent cause of visceral injury and was responsible for wounds of the intestine, liver, spleen, the left gastric artery, the pregnant womb, etc.

SEX AND AGE

Of 95 cases of abdominal injury due to V.1 and V.2 explosions that were submitted to laparatomy, 50 were females. There were 16 casualties under 17 years of age, of whom 8 were under 10 years; in addition, there were in this particular series 2 foetuses injured *in utero* that subsequently succumbed.

At the other end of the age scale there were 8 over 65 years, of whom the eldest with numerous wounds of the intestine, who died on the operating table, was aged 86. A female casualty, aged 65, with a wound of the caecum was saved by Humphrey Nockolds, while W. H. L. Molesworth operated successfully on a man of 65, who had sustained a wound of the duodeno-jejunal flexure, several lacerations of the small gut and a tear of the meso-sigmoid.

Of 79 cases of intraperitoneal visceral injury produced by V.1 bombs (the 'flying bomb') and submitted to laparotomy 60 patients recovered (76 per cent. recovery-rate). Of 13 cases explored and disclosing only a haemoperitoneum, 1 succumbed.

During the V.2 ('rocket-bomb') period 16 cases of intraperitoneal visceral injury were submitted to operation, of whom only 9 recovered (56·2 per cent. recovery-rate).

Of the 6 intraperitoneal visceral injuries received during the shelling of Dover and submitted to laparotomy, only 1 perished.

The figures given represent intraperitoneal visceral injuries for which surgery was possible; cases of 'crush syndrome', retroperitoneal haematoma, and non-penetrating wounds of the abdominal wall are not included.

A dramatic case of abdominal injury due to rocket-bomb made a good recovery:

Case: A woman of 52 years had her abdomen transfixed by a rafter beam, when a large fragment of an exploding V.2 passed through the roof of her home. To release the patient from the wreckage under and by which she was pinned, the beam of wood had to be sawn through on each side of the woman's body. The piece of timber varied from 2 in. to 3 in. in diameter and measured 2 ft. in length and its jagged aperture of entry was below the 12th rib in the right lumbar region; its other extremity projected through another rent in the abdominal wall in the left iliac fossa. The beam had traversed the peritoneal cavity and passed through the great omentum, but the colon, though badly bruised, was not perforated, and the small gut showed no laceration.

More than one pound of assorted splinters and ceiling plaster was removed from the coelom; there was some bruising of the inferior pole of the right kidney, which was exposed in the depths of the lumbar wound. There were numerous other wounds, some of considerable severity. The patient made a good recovery. (Mr. John L. Stephen's case.)

Three other cases are worthy of note:

Case: A woman made a good recovery in St. Bartholomew's Hospital from multiple injuries due to a V.2 explosion on March 8, 1945. An enormous bomb-fragment measuring 4 in. × 6 in. was removed from the right hypochondrium; the 8th and 9th ribs were shattered, and liver, gall-bladder and colon were herniated through the large wound. Ultimately an excellent recovery resulted. (Mr. Harold Wilson's case.)

Case: A boy, 15 years of age, was admitted to hospital in a condition of severe shock one hour after a flying-bomb had exploded on his home. He had haematemesis and haematuria, and on laparotomy a considerable haemoperitoneum and some contusion of the small gut were revealed. The boy had also sustained a dislocation of the left hip joint which was reduced, and a fractured pelvis. Anuria was present forty-eight hours, but recovery ultimately took place. (T. Meyrick Thomas's case.)

Case: As a result of a V.2 incident a fragment of liver 3 in. × 2 in. × 1½ in. had been avulsed from the liver medial to the gall-bladder in a boy of 15 years. Recovery followed a successful operation in Whipps Cross Hospital. (Mr. W. E. Joseph's case.)

APPENDIX IV

Recovery-Rate of Abdominal Casualties in Various Theatres of War (1939–45)

Over-all recovery of 71 per cent. is reported in 5,105 cases of abdominal and thoraco-abdominal wounds in the B.L.A. (1945).

	Per cent.
Over-all recovery of abdominal wounds in the Middle East (Ogilvie)	43·4
Over-all recovery in the C.M.F. (1945)	45·4
2nd New Zealand Expeditionary Force (Italian Campaign) (Inclusive of every abdominal casualty reaching a medical unit alive, even an advance dressing station)	54
Recovery of abdominal casualties forming basis of Hunterian Lecture (1944) (Gordon-Taylor)	60
Recovery of abdominal casualties forming basis of Bradshaw Lecture (1942) (Gordon-Taylor)	51
A series of naval abdominal casualties (Immersion-blast, wounds in ships, etc., etc.)	50
Recovery of abdominal casualties from flying (V.1) bombs in Britain and submitted to operation	76
Recovery of abdominal casualties from rocket (V.2) bombs in Britain and submitted to operation	56·2
Recovery-rate from Cross-Channel shelling of S.E. England (abdominal)	84

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CHAPTER 5

ANAESTHESIA

(i)

Anaesthesia in the Royal Navy

By R. F. WOOLMER
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ANAESTHESIA in units of the Royal Navy during the war years presented certain special problems.

SEA-GOING SHIPS

Ships at sea are isolated units, and must be prepared to depend entirely on their own medical resources, which are necessarily limited. The problems involved are most clearly exemplified in the case of a ship carrying only one medical officer, who is solely responsible for the medical care of a body of men closely confined in a steel hull crammed with lethal machinery. If the ship is in action he may have to deal with large numbers of casualties, many of whom will require anaesthesia.

His choice of anaesthetic is limited by many factors. He cannot give more than a part of his attention to the anaesthesia, and must rely on unskilled assistance. For this reason the method adopted must be safe, simple and reliable. His equipment is of the simplest, and oxygen is the only compressed gas available. The hazard of fire and explosion is ever present, so that the use of inflammable vapours is inadvisable. The injuries to be treated may be very extensive, may produce much shock, and may involve the respiratory passages.

Such a combination of circumstances clearly points to regional analgesia or intravenous anaesthesia as the method of choice in most cases. Successful regional analgesia, however, demands more skill and experience than the average young medical officer has had the opportunity to acquire; and the calm, unhurried atmosphere which is needed for it cannot often be achieved.

Intravenous anaesthesia, too, is not without its hazards, especially in the presence of shock, as experience at Pearl Harbour (Halford, 1943) and in other incidents has demonstrated. In spite of this, the development of the intravenous route represents by far the greatest advance in war-time anaesthesia since 1918, and it has enabled medical officers to undertake tasks which would have been beyond their scope in the War of 1914–18. Even so, reports indicate that its use has not been so extensive as might have been expected, and this is probably due to lack of experience and want of confidence in the method.

In larger ships it is sometimes possible for a medical officer to give his whole attention to the anaesthetic, but the other difficulties attendant on anaesthesia in fighting ships remain, and the dispersal of medical parties and stores required on preparing for action, with the possibility of damage to communications, may nullify the advantage of greater numbers.

It is not possible to present any statistical information about anaesthetics given in fighting ships during the war. The range has been wide, including every type of traumatic surgery, as well as that occasioned by disease, and most types of anaesthesia not requiring compressed gases have been employed. Spinal analgesia, however, appears to have been used surprisingly seldom, though the relative indications for it at sea are far more numerous than they are on shore. It is true, of course, as Gordon-Taylor has pointed out, that spinal analgesia should not be considered in the presence of shock: but this prohibition excludes only a small proportion of the cases which would otherwise be suitable for it. The reason is probably to be found in lack of experience and training in the method. In the United States Navy, where it has been possible to give more attention to training, 'M.Os. in small ships have found spinal anaesthesia a godsend' (Gardner; McMullen and Thornton, 1942), and it has been much used in hospitals and hospital ships (Ferguson, 1944). The same is true of the Royal Canadian Navy (Stoddard, 1944).

SHORE ESTABLISHMENTS

The problems of anaesthesia in shore-based naval establishments are much simpler, and approximate closely to those in civilian practice. Short minor operations may be undertaken in the sick bay under general or local anaesthesia, but patients requiring more extensive surgery are transferred to naval hospitals. A sick bay on shore is not faced with the problems caused by isolation which occur in a ship, and it can always count on easy access to a fully equipped hospital (except in so far as communications may be disrupted by enemy action.).

HOSPITALS AND HOSPITAL SHIPS

Anaesthesia in naval hospitals and hospital ships is in the main similar to that in civilian hospitals. The most important difference—and this applies equally to all three Services—is that the patients consist almost exclusively of fit young men undergoing elective surgery of a type which carries a negligible mortality.

The incidence of post-operative chest complications appears to have been high, a tendency which has been noticed also in the other Services (Bird *et al.*, 1943; Lucas, 1944), and is probably attributable to over-smoking and to the increased incidence of upper respiratory infections due to crowding and bad weather.

EQUIPMENT AND SUPPLIES

The question of what equipment should be supplied for anaesthesia in the Royal Navy has been influenced by many factors. Equipment for use at sea must be simple, strong, compact and easily replaced. For inhalation anaesthesia, this limits the choice to mask and drop-bottle and the Oxford vaporiser. The Service Afloat Scale includes masks and drop-bottles (and chloroform and ether to put in them) for all ships, and many have also been supplied with the Oxford vaporiser, which first became available towards the end of 1940.

Pentothal and novutox are supplied to all ships, but the variety of syringes and needles is necessarily small. Lumbar puncture needles are carried, and drugs for spinal analgesia may be obtained by medical officers on demand.

The range of drugs and apparatus in naval hospitals and hospital ships is similar to that found in most civilian hospitals. Machines embodying the latest developments have been supplied to some of the larger hospitals, where all the recognised methods of anaesthesia are in use. Cyclopropane has been regularly employed in many hospitals and hospital ships, and curare was used in one hospital in 1945.

The question of resuscitation received a good deal of attention, and arrangements for transfusion and oxygen therapy were provided on a generous scale.

Supplies of anaesthetic equipment sometimes fell short, particularly on oversea establishments, but shortages were never serious or prolonged.

ANAESTHESIA IN THE TROPICS

A considerable proportion of the surgery undertaken in the Royal Navy during the war was carried out in tropical climates, and this had its effect on anaesthesia.

The idea—which had a wide currency early in the war—that open ether cannot be successfully used in the tropics is without foundation (*Proc. roy. Soc. Med.*, 1946), and the method has been successfully used in the hottest and moistest of atmospheres, but a great deal of wastage resulted from evaporation of ether, even from unopened bottles. This could be substantially reduced if ether for use in hot climates could be supplied in tins.

The possibility of heat stroke and ether convulsions had to be borne in mind; and it was often necessary to avoid the use of atropine before operation, and of mackintosh coverings on the patient during its course.

Pentothal came fully into its own in the tropics, but the prevalence of debility and impaired liver function due to malaria and other tropical diseases demanded that it be used with circumspection. When the Oxford vaporiser was used with high theatre temperature it was sometimes necessary to put cold rather than hot water into the water chamber, and failure to realise this sometimes led to difficulties

PERSONNEL AND TRAINING

The enormous wartime expansion of the Royal Navy, and the consequent multiplication of its scattered medical establishments, found it woefully short of trained anaesthetists. A large number of hospitals, hospital ships and sick quarters had to be provided with anaesthetists, and it was not always easy to find medical officers with sufficient experience to fill these positions. In addition, medical officers appointed to sea-going ships, particularly when they were single-handed, often felt the need of some instruction in the type of anaesthesia best suited to the conditions. So stringent were the demands on man-power, however, that though the need was recognised it was not found possible to give organised courses of instruction to more than ten medical officers during the war years, though a much larger number were able to receive extempore instruction as circumstances permitted, and a few were appointed as second anaesthetists at the larger hospitals for considerable periods. In the later years of the war the position became easier, as many medical officers who had little previous knowledge of anaesthesia were able to acquire proficiency.

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(ii)

Anaesthesia in the Army

BY ASHLEY S. DALY
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Little attention appears to have been paid to anaesthesia in the Army during the period between the two wars, and the outbreak of war in 1939 found the Service ill-equipped both as regards skilled personnel and modern apparatus. Anaesthesia was under the control of the Consulting Surgeon and only five regular officers had obtained the diploma in anaesthetics, two of whom were employed in their specialty at the outset of the war, and even these were transferred to administrative posts after a few months.

PERSONNEL, ORGANISATION, AND EQUIPMENT

The problem of personnel was to some extent solved by the absorption into the Service of civilian anaesthetists, but owing to the absence of a consultant or adviser in anaesthetics at the War Office a large number of officers with few or no credentials were created specialists, and this tended still further to discredit anaesthesia in the Army. Fortunately, at this time two senior civilian anaesthetists were successively posted to Millbank Hospital so that the authorities were able to make use, unofficially, of their knowledge and experience of personnel and equipment. This state of affairs continued until February 1941, when an adviser in anaesthetics was appointed to the War Office, the post being upgraded later to consultant status.

The appointment of an adviser brought about much-needed improvements, for by touring the various Commands, first in this country and later oversea, he was able to make personal contact with, and assess the capabilities of, the various anaesthetists, and to discover shortages and faults in apparatus and equipment. Training courses were also started to provide for the future supply of anaesthetists. Progress was hampered at first by difficulty in obtaining modern apparatus, and units, in the Middle East especially, were often short of essential equipment, the shortages being aggravated by shipping difficulties.

The next progressive step was the appointment of an adviser in anaesthetics in the Middle East, and later advisers were appointed to North Africa and Italy. India appointed a consultant in anaesthetics to G.H.Q. and an adviser to each of the four Commands. These Command advisers visited the various units and took a very active part in training and teaching, so that towards the end of the war training had developed to such a high state of efficiency as to enable each Command to have available a reserve supply of trained anaesthetists to make up for any wastage that might occur. Without this system of training there would have been a very considerable shortage of skilled anaesthetists.

Modern equipment was gradually substituted for that in use in 1939 with the result that towards the end of the war Army anaesthesia had reached a high standard. There were a number of first-rate anaesthetists using high-grade modern equipment, and these two factors were responsible for saving many lives and considerably shortening the convalescence of the wounded man.

ADVANCES IN TECHNIQUE

Turning from personnel, equipment and organisation to actual technique there is no doubt that war surgery gained immeasurably from the rapid and phenomenal advances in anaesthesia during the previous fifteen years. The great value of endotracheal administration during operations on the head, neck, thorax and abdomen; the inestimable boon of intravenous methods; the benefits of closed circuit in maintaining the patient's body heat and fluids and at the same time economising the consumption of anaesthetic gases; the excellent qualities of cyclopropane as an inhalation anaesthetic—all these were well appreciated before the war and their value was more than emphasised by the experience of war surgeons. In 1941 trilene made its appearance as a new anaesthetic agent and after due trial was distributed to the Forces. Non-inflammable, non-irritating and comparatively non-toxic, especially noted for its high analgesic properties, extremely economical in use, it promised to be a great help in the surgery of wounds. However, it soon became known that toxic compounds resulted from using it in closed circuit with soda-lime absorption. This largely ruled it out, for under Service conditions anaesthetic gases were almost always in short supply and the economy provided by absorption methods was essential. An interesting side-light on the change in anaesthetic methods from those of pre-war years was afforded by observing the large stocks of chloroform carried by military medical stores, and the comparatively negligible quantities used even when casualties were heaviest.

Local analgesia was used in a considerable number of cases towards the end of the war, especially in wounds of the abdomen where the local nerve block was combined with light general anaesthesia. One per cent. novocaine was the agent employed for the local infiltration, and light general anaesthesia was maintained, for choice with cyclopropane and oxygen; failing this the combination of nitrous oxide, oxygen and ether was employed. The slight amount of extra time consumed by this combined method was more than offset by the very marked improvement in the patient's condition compared with that where deep ether anaesthesia was the sole method employed.

Certain other factors are worthy of mention:

(*a*) It was officially recognised at long last that the administration of anaesthetics was a highly skilled occupation, that anaesthetists were indeed specialists, and that the skill and experience of the anaesthetists was in many cases far more important than the actual anaesthetic agent employed. Specialist anaesthetists or graded anaesthetists were appointed to all military medical units which carried a surgeon; that is to say, every field surgical unit and casualty clearing station had an anaesthetist and every general hospital at least one such officer. Those appointed were anaesthetists of some experience or officers who had successfully completed a course as trainees under a specialist in one of the larger hospitals. Whatever other duties they might undertake—resuscitation, medical, or regimental—their chief function was the giving of anaesthetics. Their quality and experience naturally varied but they were expected to provide, and did provide, adequate and safe anaesthesia for the varying conditions of military surgery. So far as possible it was the policy to give each anaesthetist experience both in forward units and in base hospitals, and to post the most experienced to maxillo-facial and thoracic units which demanded a very high degree of technical skill from their anaesthetists.

(*b*) The immeasurable value of intravenous anaesthesia—which in practice meant pentothal sodium—proved so useful and made the anaesthetist's work so much more expeditious that on all sides could be heard the question 'What should we do without pentothal?'. This was apart from the incalculable boon to the sick and wounded soldier, whose lot was already hard enough without submission to the stifling effects of old-fashioned induction. Methods of using pentothal varied. In 5 per cent. solution it was given in a single dose, either as the sole agent for short operations, or else to provide basal narcosis prior to inhalation. In the same strength it was used in repeated doses for longer operations. In ½ per cent. in saline it was run in as a continuous intravenous drip, or the stronger concentration was intermittently added to an already running saline or blood transfusion. Its great advantage lay in its provision in less than ten seconds of an unconscious patient from one who had been perhaps overstrained, apprehensive or even truculent. A survey of the anaesthetics used in North Africa and Italy during the winter of 1943–4 showed that in both rear and forward areas over 80 per cent. of the operations were performed with pentothal either as the sole or preliminary anaesthetic, and this increased to well over 90 per cent. towards the close of the war. A small number of untoward incidents confirmed what was already well known and what the Americans had bitterly learnt at Pearl Harbour: that a shocked wounded or sick man will not tolerate a full dose of pentothal any more than of any other depressant drug. Inexperienced administrators sometimes injected the whole contents of the ampoule regardless of the patient's condition. These incidents were few but they served to emphasise the need for experience even in such a simple matter as an intravenous administration.

(*c*) The introduction of the Oxford ether vaporiser which provided a calibrated strength of ether in air, as well as a safe endotracheal anaesthetic, without the employment of compressed anaesthetic gases. In addition it furnished an efficient means of inflating the patient's lungs in cases of emergency. The machine had its disadvantages chiefly in connexion with the induction of anaesthesia, but there is no doubt as to its great value in war surgery, because all that was required to use the machine was a supply of ether and hot water.

(iii)

Anaesthesia in the Royal Air Force

By R. R. MACINTOSH
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At the outbreak of war the R.A.F. medical organisation had to face the fact that the standard of anaesthetics in the Service compared unfavourably with that enjoyed by the civilian population in relation both to the number of specialists available, and the supply of up-to-date equipment, which was not influenced by the need for economy in public funds.

In the R.A.F. peace organisation, anaesthetics, and the delegation of anaesthetic duties to medical officers, were under the control of the Consultant in Surgery. An average of about 4,000 anaesthetics were given yearly in R.A.F. hospitals, but an increase was beginning to be apparent in 1938, and, in 1939, if the figures of the four months of the war are included, the total had risen to more than 9,000.

At that time medical officers with some experience of anaesthetics, and a few specialists, were available at R.A.F. hospitals. It was considered reasonable by those responsible for directing medical policy that in the wider interests of Service requirements, and of medical officers themselves, it was better to have several medical officers capable of giving an anaesthetic than to have a few who were specialists in anaesthesia. Cogent reasons for this policy were that the posting of experienced anaesthetists to every R.A.F. hospital would have been uneconomical, while the presence of a whole-time anaesthetist on establishment of a hospital might discourage the interest of others in the subject. It was also impossible to provide a career for those wholly employed in the speciality and circumstances did not allow them to attend civilian hospitals to further their experience. Opportunities were given, however, to a certain number of medical officers to obtain the diploma in anaesthetics, and, although the successful few were employed thereafter in this work, this was limited as a whole-time duty.

This system, while it might be regarded as satisfactory in peace-time, was readily appreciated to be inadequate as the war developed. Patients in peace-time were for the most part young and robust individuals subject to operations of a comparatively straightforward nature, and when necessary it was always possible to call on the services of an expert anaesthetist. It had always been fully realised that the ill, shocked and ex-sanguinated patient required careful anaesthesia; the differences between the experienced and the occasional anaesthetist were thrown more into relief when the seriously wounded had to be treated. Routine civilian operating lists had shown that lack of experience of the anaesthetist might well mean the difference between the life and death of the gravely ill patient.

PROBLEMS OF PERSONNEL

The problem was to equate supply with demand. It was apparent that there were insufficient experienced anaesthetists to meet even a fraction of the Service requirements, if experts were to be provided at all surgical units. The needs of the population were also very considerable. The aim, therefore, in the R.A.F. was to establish in the shortest possible time as complete an anaesthetic service as possible so that the skill of the surgeons might never be discounted by disproportionate lack of skill of the anaesthetists, and, *pari passu*, to accept specialists as they became available. It was clear that any intensive specialisation would deprive medical officers of the opportunity of gaining experience, and would curtail their employment, which might be of value in remote places where a knowledge of anaesthetics would continue to be required.

Some experienced officers were fortunately brought into the Service during the first year of the war and were placed at one or other of the larger R.A.F. hospitals; there they were able not only to use their ability directly but were in a position to impart it to others. This was the first step taken in training since 1938, when a permanent officer, who had himself obtained the D.A. in 1936, was instructed to train selected officers posted to R.A.F. Hospital, Halton, which was recognised in that year as a training hospital for the diploma. There were many difficulties in sparing medical officers to work away from their normal duties, partly owing to the expansion of the Air Force then occurring, but mainly to the dearth in recruitment. Actually, only one regular officer who had obtained his D.A. was available to be employed on anaesthetic work at Halton Hospital between January and September 1939, but from that date, owing to mobilisation requirements, no experienced serving officer could be made available to teach 'would-be' anaesthetists until some skilled anaesthetists began to be recruited into the R.A.F.V.R. from civilian practice.

In May 1941 the R.A.F. obtained the services of Professor R. R. Macintosh as Civilian Consultant in Anaesthetics to advise on the organisation necessary to meet anaesthetic requirements, the teaching of personnel, research, and also to take an active part in these duties. If a consultant had been available in peace-time the Service would have been better prepared for war. In October of the same year this consultant accepted a commission in the R.A.F.V.R. and thereafter served as a whole-time officer.

There were two important tasks at the outset: first, the obtaining and training of suitable medical officers as anaesthetists, and secondly, the determination of the most efficient equipment and its standardisation.

In 1941 it had been agreed that posts for anaesthetists should be created at all hospitals, and that specialist officers as they became available should be posted, in the rank of squadron leader, to the larger hospitals where they could be fully employed. Less qualified anaesthetists posted to the smaller hospitals would be required to do additional medical duties, as there was not enough anaesthetic work to keep them fully occupied; a consideration which applied to the aspirants in other specialties. This meant that the anaesthetist, while responsible for everything concerning anaesthetics in the hospital to which he was posted, would always be available for clinical duties. He was also available for the training of his medical and dental colleagues who would then be in a better position to give assistance in an emergency, as for example, if a station was severely attacked. In addition, the anaesthetist was responsible for resuscitation and oxygen therapy.

A further step in the development of the scheme was to gather information about young anaesthetists, or aspiring anaesthetists, who were already in the Air Force but who had been posted for general medical duties. The Army as the greatest user had, in the course of recruitment and allocation of medical man-power, taken in from civil life most of the specialist anaesthetists. For this reason, and because the R.A.F. had been asked to exercise economy so that the considerable demands of the Army throughout 1942 and 1943 could be met, only a few anaesthetists were available for entry into the R.A.F.

These circumstances made courses of training essential and these were arranged either at the Radcliffe Infirmary, Oxford, under the direct supervision of the consultant, or at R.A.F. hospitals where the future skilled anaesthetists would be placed. The courses were designed to ensure that medical officers posted as anaesthetists would be competent to undertake the work. Considerable success was achieved as is shown by the fact that 16 medical officers obtained their diploma of anaesthetics during the war. The training, however, was not without its problems. Every hospital anaesthetist attended a refresher course at the Radcliffe Infirmary, and eight of the busiest R.A.F. hospitals started elementary courses. Each Command was required to send a medical and a dental officer for the first fortnight of each month to one of these hospitals where elementary and fundamental principles were chiefly emphasised. Thus, in time, there was expected to be a supply of anaesthetists who had had some training in straightforward anaesthesia and in the particular care of the unconscious patient, and who could meet station demands in an emergency.

The difficulties experienced in running these courses arose mainly from having to take away officers from their routine duties for the period of the course, but there were several other intricacies which minimised the success which might have been achieved. Officers who appeared keen on first approach sometimes showed only a bare interest in real anaesthetic work, and it was sometimes found that harassed seniors, who could ill spare one of their staff, had sent the least useful officer. In these circumstances it was difficult for the training to achieve more than indifferent success. The fortnight which each course lasted was a very short period in which to learn anything of lasting value, and unfortunately many officers lost much of their dexterity and recently acquired knowledge on return to routine work where they did not have the opportunity to continue to practise. Again, courses sometimes coincided with periods of comparative inactivity on the surgical side of the hospital at which they were held. A hope that medical officers on these courses would be of help to their dental colleagues in explaining some of the more elementary points of general anaesthesia was not fulfilled in practice. In fact, it proved difficult to teach a medical and dental officer together because of the differences in their preliminary training. Accordingly, later in the running of the scheme, two medical officers were sent on a course together and then two dental officers on the next course.

In August 1941, the consultant in anaesthetics had recommended the feasibility of employing nursing sisters trained in anaesthetics. The Director-General of Medical Services and the Matron-in-Chief agreed in principle but thought it to some extent unsuitable, and any development of the scheme was found impracticable owing to the general shortage of nursing staff. However, individual anaesthetists were encouraged to train any available personnel who showed promise, for example members of the V.A.D., and Service nursing orderlies, so that they might be of real assistance in a subordinate rôle both during routine work and in emergencies. Indeed, some of those selected developed a degree of competence which well justified the project. This was not altogether surprising, as success in anaesthesia, as in many other spheres of medicine and surgery, depended to a large extent on skilled assistance resulting from training which could be given to, and readily absorbed by assistants such as experienced nursing orderlies. In the opinion of the consultant a single anaesthetist could be better served if assisted by well-trained orderlies than if assisted by an occasional medical officer, particularly when large numbers of casualties had to be treated. For instance, when the first batch of casualties from Normandy arrived at R.A.F. Hospital, Halton, one skilled anaesthetist was able to deal with 38 cases in ten hours using simple apparatus with the help of trained orderlies. Four operating tables were kept going continuously without mishap. The table on the following page shows the amount of work carried out on battle casualties at this hospital over a period of eleven months.

The problem as presented at Halton was mainly to provide a constant supply of lightly anaesthetised patients to enable four operating tables to be kept going without undue delay between cases. The anaesthetic rooms, divided from the pre-operative room by curtains only, received a constant flow of patients according to the needs of the surgeon. The patients had been given a pre-operative sedative approximately an hour before the estimated time of anaesthesia. The staff concerned with anaesthesia consisted of a medical officer, and one or two assistants trained in anaesthesia, further helped by nursing personnel otherwise engaged in the theatre. It was policy to interest everybody on the theatre staff in this work as far as possible.

The requirements at other R.A.F. hospitals were generally on a lesser scale, but the ease with which surgical lists could be worked through with the help of trained orderlies was equally appreciated by all anaesthetists.

Table showing the Numbers, Types and Percentages of Anaesthetics given in the Casualty Theatre, Royal Air Force Hospital, Halton, from June 16, 1944, *to April* 30, 1945, *inclusive.*

Anaesthetic	June	July	August	September	October	November	December	January	February	March	April	Totals	Percentage
Pentothal only . .	1	7	12	14	14	13	19	6	10	9	11	116	5·3
Gas, oxygen and ether	152	144	38	67	78	76	42	51	63	92	85	888	40
Oxford vaporiser .	67	286	386	208	36	36	33	38	12	11	44	1,157	52
Cyclopropane . .						1			6	16	17	40	2
Spinal . . .		1		1	1							3	
Local . . .		2	1		1	1						5	
Totals	220	440	437	290	130	127	94	95	91	128	157	2,209	

Such specially trained personnel were usually made responsible for the anaesthetic apparatus itself and the preparation of instruments for local anaesthesia. They could be quickly trained to look after patients as the operations ended, while the anaesthetist began on the next case. Patients could be given the benefits of local anaesthesia and kept under observation, allowing plenty of time to ensure that the injections were effective. They were also of great value in supervising the transport of the unconscious patient. The success of the scheme was such that it became routine for a corporal trained in anaesthetic duties to be attached to the specialist at each of the general hospitals.

PROBLEMS OF EQUIPMENT

These were considerable. Liaison between medical officers giving anaesthesia and those responsible for ordering the anaesthetic apparatus had not been very close before 1939 and during the early months of the war; anaesthetists perhaps lacked authority to demand important equipment and perhaps few of them were themselves aware of exactly what they wanted. One effect was, therefore, that the design and details of apparatus were left largely in the hands of the manufacturers, who delivered to the Services apparatus which was standard, but which few up-to-date practising anaesthetists would have chosen for their own use. The tendency for manufacturers to continue old methods of manufacture and production, and the difficulties attending a change in production, had to be overcome before the necessary improvement of equipment could be effected. Examples of the problems met were the fitting of Boyle's machines with inaccurate flow meters, and a carbon dioxide absorber of a design which was old-fashioned compared with those used in the United States and certain parts of this country; Clover's inhaler had been widely issued, but few who qualified after 1930 recognised or understood this apparatus, which, though good in the hands of those who knew how to compensate for its difficulties, was a difficult apparatus for those who were not experienced in its use. There were also delays in the repair and replacement of spare parts and even minor defects of apparatus were difficult to rectify.

Standardisation was considered essential, and one of the first steps was to bring the existing apparatus up to date and to convert all fittings and connexions to standardised patterns. Unserviceable apparatus or parts of it were replaced and the services of a civilian technician were obtained to undertake repairs on the spot. The position during 1941 showed rapid improvement, and the consultant in anaesthetics was able to say that the apparatus was good, was adaptable to all needs and was being well maintained. The equipment at hospitals often showed a tendency to become almost too lavish through certain young anaesthetists insisting on all the paraphernalia, gas, oxygen and cyclopropane. and other special apparatus which they hoped to use later in the field.

ORGANISATION OF PROCEDURE

In 1942 instructions were issued that all deaths within 48 hours of operation were to be notified at once to the consultant in anaesthetics in order that he could investigate the cause, and, if indicated, ensure that instructions were issued to avoid similar occurrences. The reporting of these cases also dissuaded inexperienced anaesthetists from accepting such happenings as entirely accidental, and not as the result of misjudgment or an error in technique which might have been avoided. All information which pointed to any misadventure was made available by the consultant and any information collected, or points observed by him on his visits to R.A.F. hospitals, which indicated faulty technique or wrong administration, were freely discussed on the spot and his constructive criticism made widely known. Similar liaison was maintained by correspondence with hospitals oversea.

The routine organisation and administration of anaesthetic procedure was also discussed under these arrangements. Attention was by no means focused on dramatic disasters, which fortunately were few; full attention was given to less serious and less obvious post-operative complications.

Problems arising from mistakes in giving or failing to give pre-medication were not unknown, and instances of failure to give pre-medication, and more important, the possible administration of a double dose by two different people, were brought to light. There were many opportunities for mistakes where a variety of individuals—for example, doctors, nursing orderlies and V.A.D. personnel—were concerned in the preparation of a case for operation. Accordingly the practice of pinning a label to the clothing of each patient for operation, giving details of the time and nature of pre-medication, was instituted in some hospitals.

Attention was also focused upon essentials during the recovery of the patient after operation, and more stress was laid in lectures given to sisters and orderlies on the care of the unconscious patient. The necessity of ensuring a good airway during the recovery period was emphasised, as well as the importance of posture in maintaining it. The instance of a patient—not in an R.A.F. hospital—who, recovering from an operation was found dead lying flat on his back was invariably used to stress the danger of leaving a patient while unconscious. In this instance the orderly some distance away maintained that respiratory obstruction could not have been the cause of death as a few minutes before the patient's breathing could be heard all over the ward. Under war conditions it was seldom possible to provide a nurse for each patient from the time of operation until full consciousness was recovered.

It was found necessary to issue warnings that electrical instruments might not be free from defects. Instruments were often damaged in transport. In one hospital an electrical bone-saw caused an electrical shock to both patient and anaesthetist, fortunately during an operation in which a non-inflammable anaesthetic was being used.

Many anaesthetists in the R.A.F. conducted experiments to try to discover how to minimise post-operative pulmonary complications, which were a serious problem throughout all Services. The anaesthetists concerned generally agreed with their civilian colleagues that the incidence of these complications was not governed so much by the particular anaesthetic used as by the site of the operation. Pulmonary complications usually occurred after an operation in which an incision was used which discouraged post-operative deep breathing and the clearing of the respiratory passages by coughing. They were also noted to occur particularly frequently after simple herniorrhaphy. An investigation of patients who had undergone this operation confirmed the fact, and showed that the more experienced anaesthetists, no matter which agent was used, had fewer complications than the occasional anaesthetist, and that no definite conclusions could be formulated about the dangers of particular anaesthetic agents. Regional anaesthesia did not appear to give more satisfactory results than any other method.

It was generally agreed that breathing exercises before and after operation were of definite value in the prevention of pulmonary complications. Chest exercises were therefore carried out in R.A.F. hospitals in conjunction with those prescribed by the surgeon and rehabilitation experts. The physiotherapists and rehabilitation orderlies were helpful in encouraging patients' enthusiasm for daily exercises. Where results were disappointing some unknown factor, such as infection in the wards, was sometimes responsible, but not infrequently the results could be related to the lack of enthusiasm shown by the patient who was uncooperative, over sensitive or nervous.

Research was carried out under the control of the consultant with two main objects—first, to discover how anaesthetic lore could be brought to bear on the problems of war, and second, to improve the methods, technique and apparatus of anaesthesia itself. In this a close liaison was maintained with the consultants in anaesthetics of the other Services and the civilian authorities.

In 1942 a Consultants Committee in Anaesthetics was formed, incorporating representatives from the Services, the Emergency Medical Service and from the various medical organisations of the United States of America and Canada. Standard fittings and apparatus were accepted as far as possible and some of the meetings were attended by the manufacturers for the discussion of mutual difficulties. Untoward incidents, such as use of doubtfully sterile spinal anaesthetic ampoules, or the occurrence of explosions, were reported and investigated, and resulted in steps being taken to prevent recurrences. Problems which arose as a result of specific military needs were also discussed at these meetings and investigation into them instigated.

Several such problems arose in the R.A.F., some of which were correlated to the work carried out by the R.A.F. Physiological Laboratory at Farnborough, such as those concerned with the effect of oxygen lack at high altitudes, or methods of breathing in reduced pressures, or under the pressure of several atmospheres. Many of the experiments necessitated the exposure of volunteers to considerable hazard.

THE OXFORD VAPORISER

The need for a compact and safe apparatus capable of delivering the vapour of a liquid anaesthetic in fixed proportions and quantities was regarded as an urgent problem. Work had begun at the Nuffield Department of Anaesthetics in Oxford after the Munich crisis to produce an anaesthetic apparatus particularly suited to war surgery. Ether was chosen as the agent because, among other things it was the safest and could be used without the provision of cumbersome gas cylinders. A simple and practical automatic machine was eventually evolved which was capable of producing anaesthesia for any operation. The apparatus made use of the property possessed by calcium chloride of maintaining a constant temperature of 30° C. while it remained as a mixture of its crystallised and liquid forms. Heat was supplied by hot water so contained that it lost its heat to the calcium chloride, which in turn maintained the temperature of the surrounding ether constantly at 30° C. The apparatus was easily portable and a single experienced anaesthetist could by its use supervise several anaesthetised patients at the same time. The value of the apparatus was proved by its use in busy civilian hospitals, where it was fully justified both by its efficiency in the operating theatre and by the satisfactory post-operative condition of patients. On all fronts it proved equally successful under Service conditions. In the R.A.F. it was made part of the equipment of all mobile field hospitals and was found to give good service under all conditions including those of the tropics. In the Far East campaign, where conditions were frequently far from ideal, the apparatus functioned efficiently and few anaesthetists preferred other types of apparatus after they had been convinced of the efficient functioning of the temperature-regulation mechanism in hot climates, even without the use of hot water. A prejudice, however, did exist against ether among some of the surgeons in the R.A.F., as indeed it existed elsewhere. This prejudice was ill-founded, and undoubtedly influenced anaesthetists in the R.A.F. general hospitals at home to use other inhalation anaesthetics rather more frequently than would have been the case had the choice been left entirely to the anaesthetist. This resulted in a loss of opportunity, among some anaesthetists, of becoming familiar with the vaporiser before being posted for duty in mobile field hospitals or advanced surgical teams.

CHOICE OF ANAESTHETIC

No restrictions were placed on anaesthetics in the R.A.F. concerning either the method of application or the type of anaesthetic agent. There were considerable variations in individual choice as statistics of operations at R.A.F. hospitals during the war clearly show. For instance, at one hospital one spinal was given to every two general anaesthetics, while at another similar hospital the proportion during the year was one spinal for every 100 general anaesthetics.

The choice of anaesthetics seemed to be influenced by the experience of the anaesthetist, and the stated preference of the surgeon. Teams which had worked together for some time were able by mutual experience to differentiate techniques appropriate to the occasion. For instance, some anaesthetists preferred cyclopropane for maxillo-facial injuries because it gave better relaxation of the masseter muscles than other anaesthetic agents. Pentothal was, however, universally popular in the field, particularly for wounds of the limbs and for minor surgical procedures. In war, its advantages certainly outweighed its main disadvantage, namely, the production of a dangerously deep level of anaesthesia before full muscular relaxation was obtained.

CHAPTER 6

ORTHOPAEDIC SURGERY

(i)

General Review of Orthopaedic Surgery

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INTRODUCTION

It was during the First World War that orthopaedic surgery, under the leadership and inspiration of Robert Jones, was first established on a sound basis as a well-defined branch of surgery, and its status as such was accorded proper recognition. Between the wars this position was consolidated and the field was widened to include almost every affection of the skeleto-motor system. At the same time there was a progressive increase in the number of surgeons specialising exclusively in orthopaedic work; in 1939 there were 98 members, and 191 associate members of the British Orthopaedic Association. The six years of the Second World War formed a further period of rapid growth both of our knowledge of orthopaedic surgery and of the number of surgeons acquiring this knowledge. The injuries of war afford unparalleled opportunities for study and advancement in many aspects of orthopaedic work and this is, of course, particularly true of fractures and other bone and joint injuries. Indeed, it may reasonably be claimed that in no other branch of medicine are these opportunities so great.

In general, the organisation of orthopaedic work during the war proved satisfactory. It was recognised by those responsible for administration that segregation of cases into special centres, provided the experts are good, gives the highest standard of treatment for those patients that can be segregated. The location of specialist centres in relation to the fighting zones naturally varied at the different fronts, being governed mainly by such factors as the nature of the terrain, state of the fighting, water supplies and transport. Complete segregation in an operational area was never practicable further forward than the base, for as Ogilvie said (1944), 'the farther forward a specialist unit is placed the poorer the equipment it can carry with it, the smaller the area it drains, the greater the number of cases in its own field that by-pass it, the larger the proportion of its time spent in idleness or work of the wrong sort'. On the other hand, when early evacuation is not required—as, for instance, in Malta, where casualties could be admitted to one of a group of first-class hospitals within a few hours and retained throughout the early weeks of their treatment—segregation under the care of specialists was practicable in every case. The same applied, of course, to air-raid casualties in England.

On the battle fronts orthopaedic cases, consisting mainly of open and closed fractures, joint injuries, nerve injuries and limb wounds, were handled along with other casualties at the field ambulance or field surgical unit. At these forward stations the best treatment was usually the simplest and safest. Early evacuation was essential, and there was neither the time nor the equipment for elaborate surgery. Resuscitation and simple wound excision, and adequate splinting without risk of constriction, were the main requirements. After minimal essential treatment, casualties were transported backwards to the casualty clearing stations, and major cases went direct to the orthopaedic wards in general hospitals, where the definitive treatment was carried out under the supervision of orthopaedic specialists. Long-term cases were usually transported to the United Kingdom as soon as medical and other considerations permitted. Soon after the landing in Normandy on June 6, 1944, most of the serious casualties from the West European fronts were evacuated by air to England, a suitable air base having been prepared and equipped for their reception at an airfield close to a large R.A.F. hospital, specially enlarged and manned to deal with casualties on a large scale. Cases were sorted here and distributed to appropriate hospitals, military and civilian, throughout the country. But as the fronts moved eastwards, Service hospitals with facilities for definitive treatment of orthopaedic patients were established in Western Europe.

Much thought was applied to the organisation of the orthopaedic work in the Fighting Services. Particularly was this so in the Royal Air Force, whose orthopaedic service will probably form a model for the future. Organised by Sir R. Watson-Jones, civilian consultant in orthopaedic surgery, it offered advantages of uniformity and team work which have not been surpassed either in civilian or military practice. It comprised seven main orthopaedic centres in Great Britain, and ultimately five oversea. Each was a unit of about 80–100 beds, contained within a general hospital, and staffed by one orthopaedic specialist with one or two assistant surgeons. Ancillary staff included two clinical secretaries, one radiographer, two rehabilitation orderlies, one plaster room orderly and one clinical photographer. In addition to the wards, three or four in number, accommodation included a consulting room, secretaries' room, out-patient waiting room, plaster room, photographic room and equipment store. The services of a trained orthopaedic sister were available in the operating theatre. Case records were kept on a uniform system common to all centres, out-patient and in-patient records being entered in the same case sheet to ensure continuity. Each surgeon was allowed full clinical freedom. There was no clinical 'direction' from above. But senior advice was readily available, for each centre was visited every two months or so by one of the consultants in orthopaedic surgery, Sir Reginald Watson-Jones and Air Commodore Osmond-Clarke, who exercised a general supervision, advised on the more difficult cases, and co-ordinated the work of all the centres. So effective was this liaison that each surgeon inevitably felt that he was a member of an active and enthusiastic team that was performing invaluable war service; and this inspiration must be attributed essentially to having the right men at the top. This point is worthy of emphasis, for had it been otherwise ill-feeling and jealousy might well have handicapped the efficiency of the service.

A further benefit has accrued from this carefully worked-out plan. Thanks to the uniform system of recording and the insistence upon the compilation of detailed case histories, a vast accumulation of valuable clinical material is available from which observations on many aspects of orthopaedic work have been and are being made.

Rehabilitation. The vitally important rôle of adequate rehabilitation in the restoration of full activity after injuries of the limbs and spine was already widely accepted by specialist orthopaedic surgeons before the war, though neglected by many who undertook the management of orthopaedic cases. Watson-Jones was in the forefront of those who enthusiastically advocated extension of the facilities that existed for rehabilitation; and it was largely through his influence that adequate facilities were developed for the rehabilitation of Service patients after injury. Rehabilitation should begin within a day or two of injury, and should be supervised while the patient remains in hospital by a fully trained staff. But the process should continue long after the gross features of the injury—be it a fracture, dislocation or soft tissue wound—have been overcome; and it is during this period that the facilities afforded by a well organised rehabilitation centre are so valuable. One of the most gratifying features of orthopaedic practice in the Services was that there were no difficulties in the way of transferring patients to a residential rehabilitation unit, where the greater part of the day was spent in restoring the full activities of the body, both physical and mental. This is in marked contrast to the situation which prevails in civilian practice, where patients are often reluctant to leave home to enter a rehabilitation centre; and there is little doubt that this difference was reflected in a more rapid and a more complete restoration of function in the Service patients, other factors being equal.

The organised rehabilitation centres of the Services were established as part of the general orthopaedic scheme. Thus, in the Royal Air Force, four main centres were in use during the greater part of the war. These were efficiently organised and well equipped. Like the orthopaedic units of the hospitals, they will probably serve as models for the future. To ensure that common interests were shared, and to promote a congenial atmosphere, patients were segregated into different centres according to their rank and trade. Thus the four different centres at

Loughborough, Hoylake, Cosford and Blackpool catered respectively for officers, non-commissioned aircrew, skilled tradesmen, and unskilled airmen. The importance of staffing these centres with the right type of personality—doctors, physiotherapists and instructors alike—was fully realised. Personnel were selected carefully for their capacity to inspire confidence and to foster a high morale among the patients; and in this they were successful to a superlative degree. Similar highly efficient units were organised by the Army both in Home and Overseas Commands, and in the Royal Navy.

ORTHOPAEDIC PROBLEMS IN BATTLE INJURIES

I. WOUNDS OF THE EXTREMITIES

In the Second World War, as in the First, open wounds of the extremities comprised about 70 per cent. of all injuries. In the second war there were many new factors that added to the complexity of battle injuries: the increased destructive power of modern bullets and shells; the high speeds of modern transport and combat vehicles on land and sea and in the air; the greatly increased casualty-causing effect of bomb blast, which, apart from injuries due to direct action, added burial of patients and crushing of limbs, followed sometimes by the crush syndrome; and the hazards associated with special tasks as, for example, parachuting. Thus injuries tended to be multiple and it was not uncommon to have to treat as many as a dozen or more separate problems in the same individual. On the other hand, these factors were very considerably offset by better medical organisation at all stages of prophylaxis and treatment, by segregation of special injuries, and by advances in chemotherapy—to mention but a few of the important improvements in the medical care of the wounded.

First-aid Treatment. There was a notable increase in the facilities for combating shock, haemorrhage and infection in the War of 1939–45 and improvements steadily occurred throughout its course. The field service dressing carried by everyone in uniform could be applied rapidly to a wound by the injured man himself or by a companion. Stretcher bearers, highly skilled in first-aid splinting, were quickly available. The fractured arm was bandaged to the trunk; the broken leg was immobilised on a Thomas's knee splint, in the application of which stretcher bearers and other medical personnel became very adept, though often working under most trying conditions. The importance of apparently small details was fully appreciated—blankets under as well as over the injured man, frequent hot sweet drinks (usually tea), no waste of time in getting the wounded evacuated, but nevertheless no jostling of the severely shocked patients. Morphine was readily available; for example, every bomber aircraft had a supply of half grain 'tubunic' ampoules for self-administration. Care was taken to record on the patient or his documents the amount given and when; until this precaution was introduced there had been a real danger of over-dosage by repeated injections. Haemorrhage was usually controlled adequately by the pressure of the field service dressing. Though tourniquets were discouraged in all Services, it was found that the knowledge that one was readily available helped to maintain morale. This was particularly true where men were working in small groups in circumstances of great hazard without easily obtained medical help—for example, a bomber crew. Instructions were given in the use of a tourniquet, emphasising that it was rarely necessary and that, if used, it should be released for a few minutes every fifteen or thirty minutes to test its efficacy and to allow oxygenation of the limb. When a tourniquet was applied and when morphine was given a conspicuous mark needed to be made in a prominent place either in the patient's documents or on his person—'T' (tourniquet) and 'M' (morphine) could be written on the forehead with an indelible pencil or with blood.

First-aid measures to combat infection were the early application of the field service dressing, the injection of anti-tetanic serum and gas-gangrene antitoxin, and the oral administration of 2½ gr. of sulphonamide, repeated as nearly as possible every three hours during evacuation to hospital; and eventually penicillin. But undoubtedly the greatest advance in first-aid treatment in the Second World War was the efficacy of resuscitation. Glucose-saline, plasma and blood were available on a large scale and at a very forward level—they could be administered in the aircraft before the injured man was removed, in the station sick quarters, at airfields, at the advanced dressing station and on board ship. Blood is the best replacement for blood. It must be used cautiously for shock, for excessive transfusion may be followed by renal failure.

EMERGENCY TREATMENT

Fresh Wounds. A great advance was the realisation of the importance of early wound treatment and the steps taken to make this treatment possible. As the result of well-planned evacuation—and particularly evacuation by air as in the Western Desert, Normandy and Western European campaigns—and the appropriate siting of hospitals, most casualties were operated upon within six to twelve hours. The use of a tourniquet was avoided so that viable tissues could be distinguished from those that were dead. The principles of treatment were:

(1) Thorough cleansing of the skin and the wound by washing with a detergent such as 2 per cent. 'C.T.A.B.' (cetyltrimethyl-ammonium-bromide).

(2) Excision of all damaged tissues, the removal of foreign bodies and debris (a preliminary radiograph was helpful), the slitting of deep fascia to obliterate pockets and to prevent ischaemia and necrosis of swollen muscles, and the control of haemorrhage with a minimum of catgut. The wound so treated has a free blood supply to all its walls and can

deal more effectively with any remaining bacteria. Tendons, muscles, deep fascia and nerves were not sutured. Bone fragments were preserved, if attached; when penicillin became freely available even completely detached fragments of bone could be preserved to act as 'chip grafts' and hasten union. Internal fixation of the bone was not employed on any scale by British surgeons.

(3) Drainage to prevent accumulation of exudate in which bacteria might thrive. During most of the war, wounds were left open, lightly packed (not plugged) with gauze. In certain regions, such as the thigh, in which gravity and an unobliterable dead space tended to produce accumulation of blood clot in the most dependent portion of the limb—'sump' formation—counter drainage was necessary.

(4) Immobilisation. Plaster-of-paris splinting was used almost without exception—the so-called 'closed plaster' method advocated first by Winnett Orr in the middle twenties for the treatment of osteomyelitis and compound fractures, and by Trueta in the late thirties for recent injuries. An important point in after-treatment was the elevation of the limb for 7 to 10 days after operation to minimise oedema.

Adequate supplies of penicillin led inevitably to experiments in the treatment of wounds. During a brief but regrettable phase some surgeons felt that chemotherapy would be a substitute for wound excision. This phase did not last long because the lesson of the rôle of antiseptics in wound treatment was re-learnt—no drug can remove clothing, metal or necrotic tissue from the wound. Attention was then directed to providing early skin cover for wounds. Eventually it was found possible to secure early healing in almost 90 per cent. of patients. When the skin loss was not severe, delayed primary suture (after 'undercutting' the skin edges), about five to ten days after excision of the wound, was often successful. When there had been extensive skin loss more complicated devices were often effective—pinch-grafts, split-skin grafts, rotation and advancement flaps, and pedicle grafts. None of these procedures were to be undertaken unless it was possible to keep the patient in the same hospital until the sutures were removed or until the fate of the graft was known. But they constituted a notable advance because reinfection from the exterior was minimised, healing was more rapid, the formation of scar tissue in muscle, fascia and skin was much less, a mobile and stable linear scar was often secured, and the definitive treatment of the fracture could be undertaken earlier, by whatever method appeared most desirable.

Wounds involving joints were treated on the same principles. It had already been shown by Spanish surgeons that joints were more resistant to infection than compound fractures; consequently successful excision of the wound was possible for longer periods after wounding than was the case in fractures. Furthermore, it was always permissible—though not always possible—to close the capsule. The capsule was opened sufficiently to allow adequate exploration of the joint, and foreign bodies, loose pieces of bone or articular cartilage and blood clot were removed. Foreign bodies embedded in bone were removed if easily accessible. A bullet which was relatively 'sterile' might be left, but irregular fragments of bomb or shell were removed if possible at the initial operation. The capsule was closed lightly with a minimum of fine plain catgut sutures, 100,000 units or so of penicillin were injected into the joint, a dry gauze or calico dressing was applied to the open skin wound, and the whole immobilised in a split plaster-of-paris splint with the joint in its position of 'physiological rest'. A window was cut in the splint away from the wound to allow repeated aspiration, which prevented stagnation and encouraged constant 'flushing' with fresh synovial fluid. Penicillin was injected into the joint at each aspiration in addition to its systemic administration. An important detail was the re-application of the lid to prevent 'window' oedema. Five days later, if all was favourable, the skin wound was closed by delayed primary suture or by skin grafting.

Wounds in which there was extensive and severe muscle damage, with or without fracture, were an anxious problem. There seems no doubt that some toxic substance capable of causing a profound fall in blood pressure is liberated from damaged muscle. (See Chap. 3.) Indeed, if several hours had passed before treatment was started, even large blood transfusions had little or no effect. If seen early, excision of the dead muscle was effective; but, in patients who failed to respond to resuscitation within half an hour, a rapid amputation offered the only hope of survival.

Infected Wounds. If more than twenty-four hours had elapsed from the time of wounding, excision could no longer prevent wound infection; organisms had by then passed deeply along fascial planes and lymphatics into cellular spaces. The correct procedure then was *incision.* The skin wound was enlarged, the fascia divided, and the bone or joint exposed to permit free drainage. The only tissues excised were necrotic pieces of tendon, fascia and particularly muscle. But the keynote of the operation was drainage—not excision. The wound was packed *very lightly* with gauze (with or without vaseline impregnation) and a complete plaster-of-paris splint applied.

Emergency Splinting. In home-based Services (the major effort of Bomber Command was from this island throughout the European War) it happened that the wounded man received his emergency and definitive treatment in the same hospital. This was not always so, especially in the Navy and Army. After the soft-part wound had been dealt with and the wound had healed or was healing uneventfully, the patient had to be transferred to a base hospital. Splintage sufficient to immobilise the fracture, but not aiming at maintaining reduction even if this had been achieved, was required. Many problems arose before the most satisfactory splintage was perfected. The journey was sometimes long and nearly always arduous, unless air ambulance facilities were available. On the whole, plaster-of-paris proved the most satisfactory splint if applied over padding, and if split throughout its whole length. For the upper extremity the shoulder spica had to be discarded because of the space the projecting arm occupied in a crowded ambulance, ship, train, or plane. Instead, the thoraco-brachial splint was devised for shoulder and upper arm injuries. A long plaster-of-paris strip passed from the root of the neck over the outer aspect of the shoulder and arm to the elbow, crossed the olecranon and returned almost to the axilla on the inner aspect of the arm; the elbow was supported at the right angle by a cuff and collar sling. Wool was applied liberally in the axilla and around the chest wall and the whole extremity then secured to the trunk by plaster-of-paris bandages. Forearm wounds were immobilised in a well-padded split plaster splint extending from the axilla to the metacarpal heads and secured to the trunk in the same way as the thoraco-brachial splint (Plate I).

In the lower extremity the most difficult problems were buttock wounds and fractures of the femur. The application of a plaster-of-paris hip spica requires skill, help, a suitable table and water. In the Western Desert water was often scarce, help was limited, and there was no suitable table. In the course of travelling down a long line of evacuation, especially when a battle was in progress, severely injured patients became dehydrated and emaciated to a degree where pressures on the bony points of the pelvis were inevitable in a spica. Furthermore, it was bulky. Because of these difficulties the 'Tobruk' splint was devised by the Australians. It is a Thomas's splint with fixed skin traction. The limb is well padded and the whole encased in plaster-of-paris, which is well moulded along the bars of the splint. Important points of detail are that one-third of the limb should be in front of the bars and two-thirds behind; the knee should be flexed through ten degrees over a pad or by bending the splint; the plaster should stop about three inches above the malleoli which, with the tendo Achillis, should be well padded; the ring must be kept away from the perineum by inserting two or three field dressings between the great trochanter and the ring of the splint and holding them in place with the encircling plaster-of-paris bandages; the skin extension straps must be tightened by an occasional turn of the Spanish windlass, otherwise pain develops. This remained the standard method of splintage for the remainder of the war in injuries of the thigh and knee. For buttock wounds the posterior half of the ring of the Thomas's splint was removed and the 'Tobruk' incorporated in a plaster-of-paris spica (Plate II).

DEFINITIVE TREATMENT

Uncomplicated Wounds. When penicillin and segregation until the stitches were removed made it possible to treat these injuries by primary or delayed primary suture, no special treatment was required. Indeed, it was possible to return some 90 per cent. to duty without evacuation to the base.

Open Joint Injuries. Joint injuries rarely required any surgical procedure more definitive than the emergency treatment (see page 239). There is no doubt that penicillin altered the prognosis most favourably. With early healing of the wound and no joint infection, rehabilitation could be started within a few weeks, and very often a full or useful range of painless movement was regained. Where joint surfaces had been extensively damaged, arthrodesis or arthroplasty was necessary at a later date.

Open Fractures. If the fracture became infected, the treatment used in all Services was that advocated by Winnett Orr and Trueta. The wound was encouraged to heal from the depths, and sequestra were removed as and if they occurred. They were allowed to separate but were then removed gently with the least possible delay because of their adverse effect on union. Review of a large series of cases treated in the Royal Air Force showed that the most frequent cause of delayed union and non-union in fractures of the femur and of the tibia was infection. Nevertheless there was one important exception to early removal of sequestra. A sequestrum comprising the whole thickness of the shaft of a long bone, and especially the femur or the tibia, should not be removed until an involucrum has formed and there is no fear of collapse of the periosteal tube. In such cases the plaster splint should be changed as infrequently as possible and with the greatest care to avoid damage to the newly formed callus.

Occasionally skeletal traction on a transfixion pin was necessary to secure full length when the definitive reduction was being carried out at the base. The pin was incorporated in the plaster, the very greatest care being taken to avoid distraction—next to infection the commonest cause of delayed union. To hasten healing, skin grafting was performed as soon as sequestration ceased and when the bone was covered with healthy granulation tissue.

Closed Fractures. Almost every method of treatment was tried in closed fractures, whether they had been open initially or not. Emphasis was always laid on the dangers of operating upon a fracture unless perfect aseptic facilities could be commanded. If these were not available fractures were much better treated by simple manipulation, thereafter maintaining length and particularly normal antero-posterior, lateral and rotational alignment in plaster-of-paris or on a Thomas's splint. Transverse fractures were usually reduced by manipulation or traction and maintained in plaster-of-paris, immobilising the joints immediately above and below. Occasionally open reduction and plating was performed, mostly in humeral, femoral and tibial fractures. Early in the war, oblique fractures were treated by continuous traction for several weeks, with subsequent immobilisation in plaster-of-paris, but delayed union due to distraction was a too frequent complication. Consequently, most oblique fractures were explored, reduced under vision and fixed by one or two oblique screws, the wound closed, and a complete plaster splint applied including the joint above and the joint below the fracture. A few surgeons were using internal fixation as the only splint—avoiding plaster—especially in tibial and forearm fractures, but the method did not become general.

Towards the end of the war Burns had begun to revive an old method of operative treatment—intra-medullary fixation—using a large tri-flanged nail driven upwards from the fracture site and then down into the distal fragment after reduction. About the same time a similar method of internal fixation began to be seen in returning prisoners-of-war. The method had been described by Kuntscher of Kiel in 1940 and was extensively used by the Germans. Experience has shown that it possesses a very real place in fracture treatment, especially in transverse fractures of the mid-shaft of the femur and occasionally also in the humerus and tibia. The great advantage in femoral fractures was the restoration of early and complete mobility of the knee joint, without the 'grating' so commonly found after prolonged immobilisation in plaster-of-paris.

COMPLICATIONS

Infection. It was inevitable under war conditions that some wounds became infected. When they did they were treated by incision, drainage, immobilisation, and chemotherapy as already described. Established infection of a joint, particularly the deep-seated joints like the hip and shoulder, caused much anxiety. To establish adequate drainage by wide incisions and at the same time to splint the joint demanded great ingenuity, and it was not possible to postulate any standard method. Most superficial joints responded to aspiration or open drainage and immobilisation. In the deeper joints it was sometimes necessary to excise one component of the joint—for example, the head of the femur or humerus—to ensure free drainage. British surgeons did not find that wide excision of joints, as practised by Continental and Russian surgeons, was helpful as an early procedure. If infection were overcome, the reconstructive problem posed by a flail joint and a very short limb was a formidable one. Amputation was occasionally—very occasionally—necessary in infected fractures and joint injuries. By and large there were only three indications for amputation: complete loss of the blood supply to the distal portion of the limb resulting in gangrene; severe uncontrollable toxaemia from extensive muscle damage; and gas gangrene.

Gas gangrene remained one of the bogeys of the surgeon dealing with battle casualties. Nevertheless, its incidence and mortality, which had been reduced by competent surgery in the War of 1914–18 to 1 per cent. and 22 per cent. respectively, was further reduced in the War of 1939–45 until the mortality was in the neighbourhood of 10 per cent. The factors responsible for improvement were not so much antitoxin—important though its administration was—as early recognition, early excision of dead and damaged muscle which is the tissue above all others where clostridia flourish; avoidance of constriction of the blood vessels of the injured extremity whether by tourniquet, bandage or splint; and chemotherapy, to which penicillin made a great contribution. In established infection by gas-forming organisms the most vigorous immediate treatment was essential—blood transfusion, chemotherapy, and radical excision of all tissues which did not bleed. This ranged from removal of part or whole of a muscle or muscle groups to amputation. It proved important not to rely for diagnosis on the appearance of air in the radiograph or on palpation of air beneath a wound, for air will usually enter the tissues after any wound; nor could reliance be placed on malodour, or even on the presence of gas, because certain streptococci produced a 'gas' myositis severe enough to resemble locally a clostridial infection. Unfortunately, a number of limbs were amputated because these criteria were accepted as evidence of gas gangrene. Clostridial infection is indicated by an insignificant pyrexia, a very rapid feeble pulse, a low blood-pressure and severe mental changes varying from anxiety to marked euphoria; in other words, a severe toxaemia with peripheral vascular collapse occurring within forty-eight hours of wounding. It is a condition easily recognised by the surgeon with war experience.

Tetanus was an uncommon complication, no doubt because of the protection afforded by the routine administration of tetanus toxoid to all personnel, because of the early use of anti-tetanic serum after wounding, and particularly because of early and adequate wound excision.

Secondary haemorrhage became increasingly rare as infection became well controlled by efficient surgery and penicillin. When it did occur it could be controlled completely only by proximal ligation of the main vessel. Ligation of the common femoral artery was usually followed by gangrene, even when an attempt to 'open up' collateral vessels had been made by lumbar sympathetic block.

Burns. Severe burns were a frequent complication of fractures in the crews of aircraft, tanks and ships. First or second degree burns usually healed readily under the plaster-of-paris splint immobilising the fracture. Burns of third degree presented a formidable problem for which no hard-and-fast rules could be formulated, except that the injury which caused the greater immediate risk to life had first priority in treatment—and this was usually the burn. Otherwise the limb was maintained in the best possible clinical alignment by whatever splint provided both immobilisation and access to the burns for dressing and early skin grafting. Plaster-of-paris splints with windows cut over the burned areas were the best compromise. A 'burns' centre and an orthopaedic unit in the same hospital, as in the Royal Air Force organisation, allowed a combined effort by the plastic and orthopaedic surgeons, which was of enormous value.

Fat Embolism. This complication was commoner than had been thought; it probably accounted for 5 per cent. of deaths in all fractures in civilian and Service personnel. Its aetiology is unknown. The fat may arise by embolism from a fractured bone or it may be precipitated in the blood stream as the result of a general metabolic disturbance. There is evidence that it acts not only by mechanical obstruction of vessels but by liberating fatty acids which erode and rupture the vessel wall. The clinical picture is typical. Within twenty-four to thirty-six hours after injury the patient, heretofore normal, develops pyrexia, is alternatively comatose and fully conscious and is cyanosed, develops petechial haemorrhages around the base of the neck and in the conjunctival sacs, and has characteristic retinal changes consisting of perivascular oedema and haemorrhage along the course of the retinal vessels. The clinical signs are often attributed to delirium, concussion, delayed shock, blast and pneumonia. There are two main clinical types; the *pulmonary* type, which develops gradually, resembles acute oedema of the lungs and has a fair prognosis; and the *cerebral* type which comes on much more rapidly and from which recovery is exceptional. Ligation of the main vein draining the injured area has been tried—for example, the profunda femoris vein in leg injuries—with indecisive results. Otherwise there is no treatment apart from the prophylactic measures of disturbing the fracture and the patient as little as possible.

2. PERIPHERAL NERVE INJURIES

Early in the war it was realised that peripheral nerve injuries would be as formidable a problem as in the First World War. Thanks largely to George Riddoch it was decided to set up an organisation to provide the best facilities for treatment and research (see Chapter 11). Before the War of 1914–18 very little was known about this subject. No really authoritative works were available, and the only noteworthy contributions had been those of Weir Mitchell (1872) and Sherren (1908). The problem was therefore one that had to be tackled from the beginning when enormous numbers of patients with nerve injuries began to fill the hospitals in 1914–15. It was at this time that nerve injuries came to be included within the definition of orthopaedic surgery. The cases were handled at the special orthopaedic centres set up at the instigation of Sir Robert Jones, notably at Alder Hey in Liverpool and at Shepherds Bush in London. Although the organisation and the treatment afforded (which included a comprehensive service of physiotherapy) were excellent, the documentation and follow-up system were unfortunately inadequate; and in consequence the results of much valuable experience were never available. Platt and Bristow, in presenting a report on peripheral nerve injuries to the International Society of Surgery in 1923, were forced to rely largely on impressions in reaching their conclusions. In brief, they found that end-to-end suture was the only operation likely to yield favourable results after division of a nerve, and that even the best results fell far short of perfection. Methods of bridging a gap, whether by neuroplasty, tubulisation, or nerve grafts, were condemned except when no means of getting the stumps into end-to-end contact was practicable; but under these circumstances they advised that a graft should be employed. In the main these conclusions were borne out during the war though the indications for autogenous nerve grafting were extended slightly.

Organisation, 1939–45. Cases of peripheral nerve injury were handled during the war at three main centres in England and two in Scotland. Note-taking and recording were systematised on a uniform plan by the Peripheral Nerve Injuries Committee of the Medical Research Council, under the chairmanship of George Riddoch; and in co-operation with the Ministry of Pensions an efficient follow-up scheme was established and continued in operation until 1949. Thus the basis exists for the formulation of final conclusions of the greatest value.

Clinical Review, 1939–45. In his Robert Jones lecture in 1945 Bristow said: 'Looking back and comparing the surgery of the War of 1914–18 and of the years which immediately followed, with the surgery of the present war, it is doubtful whether there has been any great advance in technique or in operative skill which would lead us to expect an improvement in results'. Nevertheless certain advances were made in methods of diagnosis and in technique. These include improvements in electrical testing; electromyography; the sweat test—very useful in clinical examination; and the use of fibrinogen plasma as a cement for joining nerve ends.

Some of the more important conclusions reached after careful analysis of many hundreds of cases were as follows. Though primary suture was seldom practicable in the active phases of war—and in any case its merits are debatable—it was generally agreed that secondary suture should be carried out as early as possible, subject to satisfactory healing of the wound, because of the development of irreversible tissue changes that follow division of a nerve. These include a progressively harmful shrinkage of the Schwann tubes in the peripheral stump of the nerve (Holmes and Young, 1942; Sanders and Young, 1944); progressive atrophy of denervated muscle, with interstitial fibrosis and disappearance of motor end-plate (Gutmann and Young, 1944; Bowden and Gutmann, 1944); and similar though less well understood changes in sensory end-organs and other tissues. 'Although there is a good prospect of repairing a nerve successfully at any time up to one year after injury, there is little doubt that the sooner repair is carried out the better, and with this in view all possible steps should be taken to obtain early healing of wounds or union of a fracture' (Seddon, 1947).

After complete division of a nerve the best results undoubtedly followed end-to-end suture, where practicable. But this statement requires qualification, for it has been shown that if the gap closed is large, for example, 11 cm. in the case of the lateral popliteal nerve or 9 cm. in the case of the median, the post-operative stretching of joints immobilised in extremes of movement necessary to secure end-to-end apposition of the divided nerve, however carefully carried out, damages the nerve by traction to such an extent as to preclude useful recovery (Highet and Holmes, 1943; Highet and Sanders, 1943). In suitable cases devices to enable end-to-end suture to be performed without placing joints in grotesque positions were employed. These included wide exposure and mobilisation of the nerve, transposition, and bone shortening. As in the War of 1914–18, even the best results usually fell far short of perfection; in particular, functional recovery of the intrinsic muscles of the hand and foot, and return of accurate and localised appreciation of light touch and compass-point discrimination were very unusual. Prognosis was better after suture of distal divisions than of proximal, and in nerves that were mainly sensory or mainly motor than in mixed nerves. A sensory or motor fibre will grow down any empty Schwann sheath, whether originally motor or sensory; but a sensory fibre will make no connexion with a motor end-plate, and a motor fibre will make no connexion with a sensory end-organ. In the upper limb the prognosis for recovery of nerve function after division of a major nerve was better for the radial nerve than for the median or ulnar. On the other hand, if adequate recovery did not occur, the residual disability was greatest after median division and least after radial division, for radial paralysis could be largely compensated by appropriate tendon transplantation. In the lower limb, experience confirmed the impressions left from the War of 1914–18 that recovery was disappointingly infrequent after sciatic nerve suture. Nevertheless, the prognosis was better after division of the medial popliteal component than after division of the lateral popliteal component; and approximately half the patients regained some sensation in the sole of the foot. Investigations have now shown beyond doubt the importance of galvanic stimulation in preventing atrophy and fibrosis of muscles cut off for long periods from their motor nerve supply.

The results of nerve-grafting were investigated particularly by Seddon (1947). His conclusion was that heterogeneous and homogeneous grafts were useless; and that autogenous nerve-grafting alone offered any prospect of success. He considered autogenous grafting well worth while in cases in which end-to-end suture was impracticable or would entail excessive shortening (and therefore excessive subsequent stretching) of the nerve. The length of the gap that can be bridged by grafts is limited by the difficulty of obtaining sufficient peripheral nervous tissue to build up a graft of adequate diameter, which should be at least as great as that of the divided nerve; frequently this must be achieved by cable grafts. Seddon found indications for autogenous grafting in 59 (8·6 per cent.) of 699 cases of nerve division requiring operative repair. In no less than 20 (38·5 per cent.) of 52 cases adequately followed up recovery was as good as that seen after the most satisfactory end-to-end suture of the same nerve injured at the same level; and useful recovery was secured in a further 15 cases, so that the operation was felt to have been of definite value in 67 per cent. of his cases.

To summarise the lessons of both wars: (1) There is no indication for immediate suture. This must never be attempted in a wound grossly contaminated (and is probably always best delayed). (2) The optimum time for suture is about three or four weeks after division. By then the extent of interstitial fibrosis is recognisable and the correct length of stump to be resected can be assessed. Delay beyond this period lessens the prospects of recovery. (3) The more distally placed the division of the nerve is in the limb the better the prognosis after suture. (4) The technique of suture is most important. The assumption of the extremes of joint movement to maintain end-to-end contact of divided nerve ends is inadvisable, because the conductivity of the nerve may be seriously impaired by the subsequent stretching that is necessary to restore the posture of the limb to normal. (5) Autogenous nerve grafting has a definite place in treatment. (6) Post-operative treatment, including galvanic muscle stimulation, is of great importance. (7) The whole problem of investigation and treatment of peripheral nerve injuries is so highly specialised that segregation of these injuries in special centres is strongly indicated, especially in war when these injuries are so frequent.

3. MAJOR AMPUTATIONS

> 'Amputation or Dismembring is the most lamentable part of chirurgery, it were therefore the honour of a surgeon never to use dismembring at all if it were possible for him to heale all he undertaketh.' (Woodall.)

This was as true in 1939 as it was 300 years before, when John Woodall published his surgical treatise entitled 'The Surgeon's Mate' (1639). It is therefore satisfactory to record that, from the orthopaedic point of view, one of the most notable features of the Second World War as compared with the First was the great reduction in the number of amputations that were necessary.

A further cause for satisfaction—though not for complacency—is the great improvement that has been made in the design, construction and fitting of prosthetic appliances, an achievement for which the close co-operation between the limb-fitting surgeons of the Ministry of Pensions and the leading appliance makers has been mainly responsible. It is thus true to say that in the War of 1939–45 the risk of losing a limb, even after severe wounds, was relatively remote; and, when amputation proved inevitable, the prospect of regaining satisfactory function—at any rate in the lower limb— was excellent.

It is necessary now to examine the causes for the reduced incidence of amputation. They can be divided for discussion into two groups, though the factors are to a certain extent inter-related. In the first place, the indications for amputation have been considerably narrowed since the War of 1914–18; and secondly, improvements in surgical technique, in chemotherapy, and in the general management of wounds and injuries of all kinds, have so altered the prognosis that circumstances necessitating amputation seldom arise.

In his lecture-courses on fractures during the war years, Watson-Jones taught that almost the only indication for immediate amputation after injury to the limbs was irreparable interruption of the main blood-vessels of the limb. Loss of soft tissue or bone, however extensive, was not to be regarded in itself as sufficient indication for immediate amputation. This conservative attitude in the early post-injury stage was a notable advance over the practice in the War of 1914–18, when a severe compound fracture with extensive bone or soft tissue loss was often felt to demand immediate amputation. That is not to say that amputation was never performed for infection or for extensive tissue loss. Not uncommonly it was thought advisable, in the interests of the patient's general condition, or for other reasons, to remove a grossly infected and severely damaged limb—but not before a reasonable trial of conservative methods had been made. Similarly a more conservative attitude was adopted with regard to the treatment of gross pyogenic infections of bone after compound fractures, and to anaerobic infections of muscle. It had been shown between the wars (Winnett Orr, Trueta) that infection of bone after compound fractures could be overcome, with minimal discomfort to the patient, by the 'closed plaster' technique. Anaerobic infection by gas-forming organisms was not accepted inevitably as an indication for amputation; a proportion at least of these cases could be spared from amputation by a combination of adequate surgical excision of diseased tissue and chemotherapy.

Improvements in the early treatment of wounds had an important influence upon the reduced frequency of amputation. Briefly, advances were due to: (1) prevention of gross infection by better immediate treatment—that is, by careful excision of all devitalised tissue, by chemotherapy, by blood transfusion where necessary, and by delayed primary suture or secondary suture when appropriate; and (2) the combating of established infection by providing adequate surgical drainage, sequestrectomy, and immobilisation. Mention must also be made of the fact that the high state of physical fitness of the men, and the better conditions under which they fought as compared with previous wars, must have been a significant factor in the success of the conservative policy that generally prevailed in the management of limb injuries. Men were not only trained to a high pitch of physical fitness—much more so than the average civilian—but were able to maintain it because of relatively good living conditions that were possible in most theatres of war, except during the active phases of battle. A further point worthy of note is that there was relatively little contamination of wounds with spore-bearing soil, such as led to a high incidence of tetanus and gas gangrene during the First World War.

The Planning of Amputations. Surgical policy towards amputation has undergone important modifications, apart from the narrowing of its indications. Revised recommendations as to the site of amputation and the technique of its performance are based upon observations made on the results of large numbers of amputations performed in the First World War. Opinion among surgeons who saw and handled these cases was crystallising before the beginning of the war; and subsequent experience has shown that the conclusions they reached were essentially sound. It is largely because of the exemplary work of the Ministry of Pensions in maintaining properly documented records, and in co-operating whole-heartedly with the limb-makers, that this fruitful observation has been possible. Perkins writes, 'Gone are the days when the surgeon's word was law, at least in regard to amputations. . . Nowadays surgeons have to submit to advice; for amputation is a means to an end—the end being to restore to the patient his former capacity for earning a livelihood. . . This is done by supplying him with a suitable prosthesis; and the best-looking and most efficient prosthesis can only be fitted to amputation stumps of particular length and shape . . . The advice of the limb-fitting surgeons should be accepted without reserve'. Co-operation between the operating surgeon and the limb-maker is essential to a successful functional result; and the limb-fitting surgeon served as a useful intermediary between the two. From his wide experience of the management of amputation stumps, both good and bad, combined with his mechanical knowledge of the human frame and of prosthetic appliances, he was able to give advice which was readily accepted by the operating surgeon.

Site of Amputation. At one time it was thought that the ideal position to take weight was on the end of the stump, and the stump was accordingly left long. The Syme, the Stokes-Gritti and the supra-condylar amputations were designed for end-bearing; but a study of the records of patients who had had amputations of this type showed that end-bearing stumps did not last. Limb-fitting surgeons formed the opinion that the end-bearing principle should be discarded in favour of side-bearing or preferably ischial-bearing stumps, and this was the policy that prevailed in Great Britain throughout the war. This being the case, long stumps were no longer desirable. Experience had shown that long stumps were liable to circulatory impairment in the course of years, and many patients have had to submit to re-amputation. In the case of the lower limb (particularly below the knee) it was found that the shorter the stump the better was its nutrition. On the other hand sufficient length must be retained to give adequate control of the prosthesis, and to allow a margin for trimming of the stump if ulceration or other complications should occur. Consideration of these various factors led to the recommendation of four standard amputation stumps, two in the lower limb and two in the upper limb. These were as follows: below the knee, 5½ in. of tibia; above the knee, 11 in. measured from the great trochanter; below the elbow, 7 in. measured from the olecranon process; above the elbow, 8 in. measured from the tip of the acromion process. These were the only major amputations advised.

The Syme amputation, often performed during the First World War, was seldom employed in the War of 1939–45 on the advice of the limb-fitting surgeons. It was disliked mainly because of the difficulty in fitting a natural looking prosthesis, there being insufficient room for the mechanical ankle; and also because of the liability of the stump to ulceration or circulatory changes. Nevertheless the Syme operation, and the Stokes-Gritti are still advocated in Canada and other countries, where it is claimed that trouble with these end-bearing stumps is uncommon. At the end of the war the subject was still a matter for discussion, the general opinion being that the Syme amputation should not be advised for a woman, and that in a man it should only be performed when there was a good chance of securing primary healing. As Perkins states, 'the occasions must be few when it is possible to do a clean Syme amputation and yet not have sufficient skin to retain the os calcis. It is likely that many amputees with successful Syme amputations could have been left with part of a foot'.

In cases of hand injury there was no change in the long established policy of preserving every millimetre of thumb or fingers that could be saved. One or more digital remnants with sensation and movement were still found to be more useful to the patient than the best artificial hand. Similarly in the foot there was a tendency—though not universally applied—to advise 'conservative' amputation. Partial amputation of the foot gives excellent results, for, even in those where equino-varus deformity has developed, the foot can be made plantigrade and stabilised by tendon transplants and arthrodeses.

Provisional and Final Amputation. In spite of the advantages offered by early surgery and chemotherapy, surgical policy was still to exercise caution and to do a two-stage operation when amputation was performed in the presence of established or potential infection. Unless the surgeon could guarantee a stump that would satisfy the requirements of the limb-fitting surgeon, he was urged to plan two operations: a preliminary or provisional amputation, followed at a later date, when conditions were suitable, by the definitive or final amputation. Provisional amputation was usually carried out as low as was permitted by the lesion, in order to leave an ample margin for the later definitive amputation. The so-called guillotine amputation, common in the First World War, was very seldom performed. Though it provides good drainage, it leaves an excessively large area to heal by granulation. Instead, provisional amputation was performed by the flap technique on similar lines to the final amputation; the only difference being that the fascia and skin were not sutured immediately—nevertheless, if infection did not occur, delayed primary suture or secondary suture was often possible.

'Ideally, final amputation should not be performed unless primary healing can be guaranteed, and this cannot be guaranteed while the stump remains unhealed' (Perkins). This was the general policy; but exception was often made when a small terminal ulcer was slow in healing, provided it had a healthy appearance and was not surrounded by an area of oedema or tenderness.

Trends in Operative Technique. To a large extent the technique of amputation became standardised, mainly as a result of the teaching of Ministry of Pensions' surgeons experienced in amputation and limb-fitting. Flaps were designed to give a transverse rather than an antero-posterior scar, placed terminally in the upper limb but often posteriorly in the lower limb. Flaps usually included skin, subcutaneous tissue and deep fascia, but no muscle. The importance of preserving the deep fascia, to ensure free mobility of the skin over the deeper tissues, was frequently stressed. The necessity for very careful and painstaking ligation of all bleeding vessels, if haematoma formation were to be avoided, was recognised by most surgeons. Coagulation by diathermy was not widely used because it was felt that the resulting dead tissue stimulated an inflammatory reaction. Attempts to avoid neuroma formation by such methods as crushing the divided nerve-ends or injecting them with alcohol were abandoned. Most surgeons did nothing at all to the nerves beyond dividing them cleanly with a sharp knife and applying a ligature if bleeding occurred. On the question of drainage there was some divergence of opinion. Undoubtedly the commonest practice was to employ a drain for twenty-four or forty-eight hours but in the later years of the war there was a tendency among some surgeons to rely on scrupulous haemostasis and external pressure to prevent the formation of a haematoma. In the experience of many, however, these measures were not sufficient, and a troublesome haematoma was liable to form in spite of the greatest care. The case for omitting drainage was certainly never firmly established.

Special Types of Amputation. In Great Britain the influence of the limb-fitting surgeons, who worked in close co-operation with the limb makers, led to a conservative attitude and opposed experimentation with the more unorthodox types of amputation stump. In the opinion of some this outlook may be open to criticism; but on the other hand it will be claimed that by adhering to a policy which was believed to be right and by progressive development of prosthetic appliances to a very high level of efficiency, results have been achieved that are inferior to none. In other countries, and in particular in Germany, Italy and the United States, much work was done in an attempt to secure an upper limb stump that would permit improved function and better control. Two special amputations that were evolved were the cineplastic amputation and the Krukenberg amputation. Neither has been employed to any extent in Great Britain. The *cineplastic amputation* was first tried, and quickly abandoned, after the First World War; its possibilities were felt worthy of reconsideration in the light of improvements in surgical technique and in the design and manufacture of prosthetic appliances during the last twenty years. It aims at isolating opposing muscles in the stump and harnessing them to an artificial hand. Although some good results have been claimed, it has not been shown conclusively that they are superior to those achieved with the later types of artificial hand activated from the shoulder.

The *Krukenberg* amputation aims at the formation of a space between the stumps of the radius and ulna, and the development of the power of opposition between them. This type of stump was developed mainly in Germany. A large series of cases was studied at the end of the war by Eyre-Brook: there is no doubt that many excellent functional results have been obtained. The greatest advantage perhaps lies in the fact that sensitivity is retained in the new 'digits', a feature of particular significance in patients who have also been blinded, but of tremendous value also in others. The disadvantages are that the stump is unsightly and short, though an artificial hand of the orthodox type may be worn for dress occasions.

On the whole it is fair to say that the final place that these special amputations will occupy in the field of amputation surgery has not yet been determined.

SPECIAL WAR HAZARDS OF ORTHOPAEDIC INTEREST

Apart from gun-shot wounds and explosive injuries of all kinds, there were special hazards of the war that were found to be specially liable to produce certain types of injury or disease of interest to the orthopaedic surgeon. The most important were aircraft crashes, parachute injuries, and shipwreck.

AIRCRAFT CRASHES

Aircraft accidents accounted for very large numbers of casualties, usually affecting trained and valuable men. Orthopaedic problems of great complexity were often presented. The problem of the severely shocked patient with multiple fractures—up to a dozen or more major fractures in the same individual—and often severe burns as well, was one of the most difficult in orthopaedic surgery. Other injuries that have come to be regarded as almost peculiar to flying accidents are fractures of the astragalus, and burns of characteristic distribution over the face and hands. These injuries are described more fully elsewhere in this work.

PARACHUTE INJURIES (see also R.A.F. Medical History, Vol. II, Chap. 6)

Injuries resulting from parachute descents were less frequent and less serious than might have been expected, a fact that can be attributed to a very careful and thorough training programme. Moreover, many of the injuries that did occur were considered by medical officers and trainers to be due to avoidable faults in the technique of jumping and landing. Injury may occur at three separate stages of a parachute descent: (i) during the exit from the aircraft; (ii) during the development of the parachute; and (iii) on landing. *Exit from the aircraft* may be either through a door in the side of the fuselage or through a hole in the floor. In the door exit the static line (a webbing belt attaching the parachute bag to the aircraft) must be held correctly in the left hand, otherwise it may become hooked under the left arm and force it up into hyper-abduction, straining or dislocating the shoulder. In the floor exit there is risk of the face or forehead striking the opposite side of the aperture if the precaution of hyper-extending the neck during the exit is neglected. *During development* (filling) of the parachute the main risk is of a foot or limb becoming caught in the rigging lines, causing a strain or bruise, or sometimes a friction burn. These injuries result from faulty exit from the aircraft, causing the man to somersault or twist. Injury is usually not severe and extraction of a tangled limb is almost always possible before landing. It is *on landing* that most injuries occur, and the commonest injuries are strain or fracture of the ankle, and concussion. Strain or rupture of the ligaments of the knee, dislocation of the shoulder or acromio-clavicular joint, and strain of the superior tibio-fibular joint are not uncommon. Fractures, apart from those of the ankle and occasionally the tibia and fibula, are infrequent. Most of these injuries are avoidable if the correct technique of landing is adhered to; an important point is that the feet and knees should be held together, the toes pointing across the line of drift. It is interesting to note that before 1943 American Army parachutists were trained to land with the feet apart; 19 per cent. of the injuries were fractures, almost all affecting the lower limb (Tobin *et al.*, 1941). In a large British series the percentage of fractures was only 8·5 (Essex-Lopresti, 1946). In June 1943 the Americans adopted the British technique of landing with the feet and knees together, and this was followed by a large decrease in the casualty rate (Lord and Coutts, 1944).

Shipwreck and Exposure. Exposure and other hazards after shipwreck presented a wide variety of problems, many of them nutritional and medical, but some of orthopaedic interest (see special chapters). From the orthopaedic point of view the main risks were those of immersion foot and frostbite.

OTHER DISEASES AND INJURIES

FRACTURES OF THE SPINE

Important advances in the management of fractures of the spine had been made in the years before the war, and orthopaedic surgeons were confident in their ability to achieve results vastly superior to those of the First World War. Two factors of major importance were: first, the technique of reduction by hyperextension, followed by immobilisation in a plaster jacket, which permitted the patient to be ambulant; and second, the insistence upon adequate and well-supervised rehabilitation, started in hospital within a few days of the injury, and continued at the rehabilitation centre throughout the period of immobilisation and for some weeks afterwards. Adequately treated on these lines, most patients with uncomplicated compression fractures of the lumbar and lumbo-dorsal region could return to full duty within eighteen to twenty weeks of the injury; and many of them were capable of doing useful work even while still in plaster. Indeed, in the critical phases of the air war in 1940 a number of pilots were known to have undertaken operational flights while still encased in a plaster jacket.

Another important aspect of the problems associated with fractures of the spine, from a historical point of view, is the study of the mechanism of the injury and the development of measures designed to prevent it, or at least minimise its occurrence during the activities and hazards of war. It had long been established, of course, that most compression fractures of the spine resulted from violent flexion; and the high incidence of severe spinal fractures resulting from aircraft crashes and crash landings was traced to lack of precautionary measures in the matter of seating and design of restraining harness. When a person is seated facing forwards, strapped round the waist, a sudden arrest of the forward movement of the aircraft must inevitably cause the upper part of the trunk to be jerked violently forward while the pelvis and lower trunk are restrained by the strap. This is precisely the type of violence that is liable to cause compression fractures of the spine. The remedy lay in the redesign of restraining harness and the allocation of definite 'crash positions' to members of the crew, to be adopted during take-off, landing, and in emergencies. Harness was designed to restrain the shoulders and upper spine as well as the waist: the safest seating position in time of emergency was found to be that in which the passenger faces the tail of the aircraft, the spine and occiput being supported against a rigid vertical member, preferably forming part of the structure of the fuselage. In the event of a sudden arrest of forward movement such a seating position minimised the risks of injury to the head, neck and spine, and helped to prevent the occupants from being flung across the aircraft in crashes and heavy landings. There is no doubt that these precautionary measures, evolved during the war years, were responsible for the avoidance of countless major injuries in flying accidents.

Fractures complicated by spinal cord lesions. Though the treatment of uncomplicated compression fractures of the spine gave results that were generally satisfactory, the management of cases complicated by paraplegia presented difficulties that were often insuperable. The death rate was high, both from shock in the early stages, and from secondary infective lesions of the kidneys, lungs or skin. Furthermore, owing to the extreme violence of many war injuries, particularly those resulting from air crashes, collapse of buildings and the like, the incidence of cord damage associated with fracture of the spine was relatively high, when compared with civilian injuries in peace-time, and many cases were complicated by permanent paraplegia.

In the treatment of these paraplegic patients, apart from the prevention of pressure sores and urinary infection, the most important necessity was to preserve the patient's morale. In this connexion the value of special centres, staffed by the right type of surgeon, nurse and physiotherapist, must be stressed. A notable example of such a centre during the war was that at Stoke Mandeville, administered by the Ministry of Pensions. Hundreds of patients with severe spinal cord lesions were cared for at this hospital, and many have gained a remarkable degree of recuperation, some to the extent of going out to remunerative work. Nevertheless this injury remains one of the most piteous tragedies that can befall mankind (see Chapter 10 ii).

PROLAPSED INTERVERTEBRAL DISC

It was only after the publication of the admirable work of Mixter and Barr in 1934 that prolapsed intervertebral disc began to arouse general interest. By the time the war started the frequency and importance of disc lesions as a cause of sciatica and low back pain had already achieved wide, if not general, acceptance. Nevertheless there was still much to be learnt about their pathology, clinical features, and treatment, and there were few surgeons who had a large experience of the operation for removal of a protruded disc. Thus the war years coincided with a period of clinical investigation and research into the various problems presented by this relatively 'new' disease. Much of the clinical material consisted of patients from the Services, for disc prolapse occurs frequently in early adult life and is often initiated by injury.

Although patients with sciatica were admitted to every general hospital for investigation and conservative treatment, the usual practice, in patients who were considered to require operation, was to transfer them to a neurosurgical centre or to an orthopaedic centre where the necessary facilities and skill were at hand. A number of military hospitals were suitably equipped—the neurosurgical centres at Oxford and the Canadian Centre at Basingstoke were notable examples—but many Service patients were admitted under the care of civilian surgeons of the Emergency Medical Service.

In the early years of the war the significance of injury in the causation of disc prolapse was not generally appreciated. As experience accumulated the relation between injury to the spine and subsequent signs of disc prolapse was established beyond reasonable doubt. This aspect of the problem is likely to be of importance when the question of attributability to injury in the Services arises. A typical history of prolapsed intervertebral disc is as follows. A few days, weeks, or months after a fall on the buttocks or other injury that jarred the spine the patient is suddenly seized, while stooping or twisting, with agonising pain in the lumbar region of the spine. At first the pain is so intense that he is unable to move; he rests in bed and after a few days the severity of the pain lessens. After a variable period of days or weeks the pain is felt to radiate to one or other buttock and down the back or outer side of the thigh and calf as far as the ankle. At the same time a sensation of 'pins and needles' or a feeling of numbness may develop. A story such as this is almost invariably indicative of a prolapsed disc; and when the onset is preceded by a jarring injury to the spine it must usually be presumed that the injury caused partial rupture of the annulus fibrosus of one of the lowermost lumbar discs, which was completed often by a trivial strain.

Injuries of this type are common enough in civilian life; but they are even more liable to occur during the varied activities demanded by war service. Common examples were crash landings in aircraft; buffeting of a ship after underwater explosion; violence due to blast; or simply a fall into a slit trench during the 'blackout'.

Treatment. As might be expected with such a new field of surgery there was no general agreement as to how these cases of prolapsed intervertebral disc should be treated. Many surgeons held the view that most patients could be cured or satisfactorily relieved by conservative measures alone. By resting the spine, either by recumbency or immobilisation in plaster, they sought to secure recession or shrinkage of the disc material, with consequent relief of nerve-root pressure. Their case was supported by the observation, in the years before the pathology of prolapsed disc was known, that patients suffering from sciatica usually recovered after a time, whatever the treatment adopted. On the other hand the advocates of early operation claimed that operative removal of the offending disc was the most rapid and efficient method of relieving the symptoms and of ensuring freedom from recurrence. As a matter of fact, whether the treatment adopted was conservative or operative, the results in Service patients were often disappointing. Although it was usually possible to secure a large measure of relief by conservative treatment in most cases, and by operative treatment in the rest, many patients were unable to continue to perform their duties satisfactorily and were eventually invalided from the Service or placed in a low medical category, because of residual aching pain in the back or recurrent attacks of sciatic pain. There are no reliable statistics from British sources to show what proportion of Service patients operated on for prolapsed disc were returned to full duty. A general opinion among surgeons who handled numbers of these cases is that the figure was in the region of 50 per cent. or slightly less.

Localisation of the lesion. In the early years of the war the opinion was widely held that an attempt should be made to confirm the diagnosis and to determine the level of the protrusion by myelography. A heavy iodised oil ('lipiodol') was usually employed as the contrast medium. But as more experience was gained, the radiological method of localisation did not prove entirely satisfactory. In the first place it was often unreliable; for it was found that negative myelograms did not necessarily exclude a disc protrusion. And secondly, the iodised oil that remained within the spinal theca was suspected of being the cause of nerve-root irritation. Moreover the technique was somewhat difficult and laborious, as well as being uncomfortable for the patient. For these reasons diagnostic myelography was largely abandoned during the later years of the war, or was reserved for cases in which the diagnosis was uncertain or the possibility of spinal neoplasm was suspected. And in spite of the introduction of more suitable contrast media, which can be largely removed by aspiration after myelography has been carried out, the method did not return to general favour among British surgeons. They preferred to rely, in the straightforward case, upon the history and clinical features, and upon a routine exploration of both the L.4–5 disc and L.5–S.1 disc.

Operative technique. Variations of technique from surgeon to surgeon were mainly matters of detail, such as the extent of the exposure and the amount of disc tissue removed. Many orthopaedic surgeons preferred a rather wide exposure, with removal of a large part of the appropriate laminae as well as the ligamentum flavum, in order to obtain a direct view of the suspected disc. At the other extreme were the surgeons who worked entirely in the interlaminar space, removing the ligamentum flavum but no bone, and depending largely on the sense of palpation for the detection of abnormalities of the disc.

The question whether the affected segments of the spine should be fused at the same time that the disc was removed was a further matter of individual opinion. As pointed out by Barr (1947), there are theoretical reasons for advising fusion in every case, and his series of cases from the Massachusetts General Hospital in Boston, U.S.A., showed slightly better late results than a comparable series treated without fusion. But whether the difference is sufficient to justify the additional risks of mortality or morbidity is doubtful. Certainly the general policy during the war, among both neurosurgeons and orthopaedic surgeons, was opposed to the combined operation of disc exploration and spinal fusion. It was nevertheless appreciated and accepted that the occasional late effects of disc prolapse—gross narrowing of the disc space with osteo-arthritic lipping of the joint margins, consequent upon shrinkage of the disc—may render localised spinal fusion advisable after a period of years.

ANKYLOSING SPONDYLITIS

A remarkably high incidence of ankylosing spondylitis among Service patients was noted by orthopaedic surgeons during the war. It is possible that it was due to the fact that the disease begins most commonly in males of 20 to 30 years of age—precisely that group which forms a large proportion of serving men. Nevertheless it is difficult to exclude the possibility that some other factor, as yet unknown, was partly responible for the rather surprisingly large numbers of cases, many of which seemed to have their origin during service oversea. As the cause of ankylosing spondylitis remains unknown, it has been impossible to assess the factors that might lead to an increase in its incidence. The disability associated with ankylosing spondylitis usually led to the patient's discharge as unfit for further service. Nevertheless it is of interest to note that the war years coincided with a period during which the treatment of ankylosing spondylitis by irradiation with X-rays was under trial. The reported results were encouraging, and it appears that in most cases temporary arrest of the disease can be expected; the symptoms are ameliorated and the blood-sedimentation rate tends to fall eventually after treatment. Deep X-ray therapy was in fact the only treatment which gave sufficient relief of symptoms to allow Service personnel, particularly aircrews, to return to full duty. In the later years of the war it was the usual practice to refer the patients to a suitably equipped civilian hospital for observation, so that X-ray treatment after their discharge from the Service would be available if required.

RECURRENT DISLOCATION OF THE SHOULDER

This injury, rather uncommon in peace-time surgical practice, was seen relatively more often among Service patients because it is a disability that chiefly affects young male adults. In the orthopaedic service of the Royal Air Force about 200 patients were treated for recurrent dislocation of the shoulder between 1940 and 1945 inclusive. Since many of these patients would probably have been invalided from the

Service if the disability had persisted the possibility of successful operative repair was important.

Cause. The initial dislocation was always due to injury. The usual mechanism was a fall on the outstretched hand, often occurring during a game of football or from a 'spill' from a bicycle. But there are records of at least two cases of abduction-extension violence that are of interest. In each case the patient was the pilot of a light aircraft. While manoeuvring the aircraft on the ground he put the arm out sideways from the cockpit (90 degrees abduction with the arm in the coronal plane). The force of the slipstream hyperextended the arm and caused anterior dislocation of the shoulder. At operation, typical findings were present.

Pathology. It has now been reasonably well established—partly as a result of observations made from clinical material collected during the war (Adams, 1948)—that the pathology of recurrent dislocation of the shoulder consists in two important elements, which may be described as the soft tissue lesion and the bone lesion. The soft tissue lesion is the stripping of the anterior part of the capsule from the front of the neck of the scapula, so that a pocket is formed into which the head of the humerus slips after riding over the anterior glenoid margin. Associated with this capsular stripping—but probably a less important factor mechanically—is a partial detachment of the glenoid labrum from the bony rim of the glenoid fossa (Bankart, 1938). The bone lesion consists of a defect of the postero-lateral aspect of the articular surface of the head of the humerus, almost certainly initiated by a compression fracture occurring at the time of the first or a subsequent dislocation, and becoming progressively larger (Hill and Sachs, 1942). The mechanical effect of the defect is to permit the head of the humerus to slip easily over the anterior glenoid margin into the capsular pocket described above.

Treatment. The most striking fact that was brought to light by observation of patients operated upon during the war was that out of fifty-nine cases treated by the Nicola operation there was subsequent recurrence of the dislocation in no fewer than twenty-one, a failure rate of 36 per cent. It is therefore clear that this operation, formerly much used, should be abandoned—at any rate in the Fighting Services. Operations designed to correct the fundamental pathological lesions, particularly the stripping of the capsule from the front of the neck of the scapula, were far more successful. In the Royal Air Force there were only two recurrences in thirty-seven cases treated by the Putti–Platt operation, and one recurrence in eighteen cases treated by the Bankart operation (Adams, 1948). When operation was successful in restoring stability the function of the shoulder was usually satisfactory; patients were able to resume their former duties, in many cases including operational flying.

SUPRASPINATUS SYNDROME

The problem of the painful shoulder, with or without a history of previous injury, was met with rather frequently at orthopaedic centres, and clinical research was undertaken by a number of surgeons in an attempt to correlate the various pathological features that may be present. The 'supraspinatus syndrome', characterised by a typical painful arc in the mid-range of abduction, aroused particular interest because of the possibility of gaining satisfactory relief in obstinate cases by the operation of excision of the acromion, a procedure first advocated in this country by Watson-Jones. The operation was not employed to any considerable extent until 1942–3, but the encouraging results that were reported led to its wider adoption during the following years. It was clearly indicated only after an adequate trial of conservative treatment had failed to relieve the symptoms, and even then only if the disability was severe enough to justify operation. But in these resistant cases—which previously would have necessitated down-grading or invaliding—it has been shown that excision of the acromion is often successful in restoring full function to the limb, and the operation is now established as a useful contribution to the surgery of the shoulder.

FRACTURES OF THE CARPAL SCAPHOID (NAVICULAR)

Fracture of the carpal scaphoid is predominantly a fracture of young male adults, in whom fracture of the lower end of the radius is relatively uncommon. Thus it was not surprising to find that in Service patients fractures of the scaphoid were among the commonest injuries of the upper limb; and their economic significance was correspondingly great.

Nature of causative injury. There was no specific injury peculiar to the war which could be made accountable for the high incidence of scaphoid fractures. The usual cause was an injury of rather trivial nature, such as would be met with in peace-time. Nevertheless, the conditions of life during the war years undoubtedly led to an increased incidence of rather simple accidents. Thus the prevalent use of bicycles, resulting from the petrol restrictions, led to an increased number of spills; the blackout was responsible for innumerable falls; and the vast number of heavy Service vehicles was indirectly responsible for many back-fire accidents. These were the types of injury that caused fractures of the scaphoid.

Special problems of scaphoid fractures. It is widely agreed that fully 90 per cent. of all fractures of the scaphoid unite satisfactorily provided adequate treatment is begun soon after the injury. Nevertheless there is a small percentage of these fractures—probably between 5 and 10 per cent.—that do not progress satisfactorily and may lead to prolonged or permanent disability. The usual causes of poor results are two: first, impairment of the blood supply of the proximal fragment, leading to avascular necrosis; and second, delay in diagnosis and consequently in instituting effective treatment. The first of these factors is entirely fortuitous and depends on individual circumstances such as the site of fracture and the arrangement of the blood vessels. It is the second factor which is of importance in that it should be largely preventable. A story often heard during the war—as it is in civilian practice—was that the patient fell onto the outstretched hand, injuring the wrist, some weeks or months previously; he saw the medical officer, who regarded the injury as a strain and advised treatment by strapping; but the pain persisted, he had difficulty in carrying on with his work, and was therefore sent to the hospital for X-ray. In these patients the fracture had often been present for so long that the chances of securing bony union were seriously impaired. The obvious moral is that doctors should be educated to regard injuries of the wrist, particularly when due to falls or back-fires, with suspicion, and to insist on early radiographic examination in at least three planes; and this should be repeated three weeks later if symptoms persist. In doubtful cases it is safer to assume that a fracture is present until subsequent radiographs prove otherwise.

Treatment was mainly along established lines. Immobilisation in plaster was continued for as long as six months if necessary. It was in the occasional case of non-union that some differences of opinion arose. Some surgeons made an attempt to solve the problem by bone-grafting operations, and an ingenious technique for inserting a graft under radiographic control, with minimal disturbance of the soft tissue attachments of the scaphoid, was devised by Armstrong. But the advocates of bone-grafting overlooked the fact that the symptoms in cases of ununited fracture of the scaphoid of long standing are due to secondary osteo-arthritic changes rather than to the fracture itself, and these are unlikely to be benefited by an operation designed to secure union of the fracture. Because of the indifferent results in many cases after grafting, the general tendency, in the later years of the war, was to avoid operation for un-united scaphoid fractures unless the disability was sufficient to justify arthrodesis of the wrist. An exception was often made when there was avascular necrosis of the proximal fragment. Because of the danger that degeneration of the articular cartilage which covers the avascular fragment might lead to early osteo-arthritis in the wrist joint, many surgeons preferred to excise this fragment as soon as the significant density changes became apparent in the radiographs.

INJURIES OF THE HAND TENDONS

Tendon injuries of the hand have an economic importance far greater than their frequency would suggest. Even in war, tendon injuries are uncommon in comparison with other injuries of the body; but the problems to be faced in attempting to restore the delicate mechanism of the hand have so often defeated the most expert surgeon that permanent disability has come to be expected, particularly in flexor tendon injuries. In time of war by no means every injury to the tendons of the hand lends itself to reconstructive surgery. After gun-shot wounds and gross crushing injuries, particularly when complicated by infection, the problem is rather one of preserving and making the best use of what is left than of attempting reconstructive measures. The remarks that follow are accordingly concerned mainly with simple tendon division, either as an isolated lesion or associated with injury to other structures of the hand, rather than with the grosser and more mutilating hand injuries.

Comment on the subject of tendon injuries is called for, mainly because advances and improvements in the technique of tendon reconstruction, stimulated before the war by Bunnell, of San Francisco, were developed with considerable success at a number of British centres during the war. Advances have been based upon a more rational conception of the detailed anatomy and pathology of the hand tendons and their reaction to injury, as well as upon improvements in surgical technique and materials. It has also become increasingly clear that special qualities—qualities of endless patience, perseverance, persuasion, and great manual dexterity—must be possessed or acquired by all who seek success in this difficult field. Reconstructive surgery of tendons is in no sense an urgent matter. Even after long delay the chances of successful repair are not significantly lessened, provided mobility of all the joints has been preserved. This type of surgery should therefore be undertaken only where adequate facilities and the necessary technical skill are available; indeed there are powerful arguments in favour of concentrating this work in special centres.

Nature of causative injury. Apart from injuries due to gun-shot wounds, tendon divisions in the hand were not associated particularly with any special activity of war. As in peace-time, injury was due usually to accidental laceration by knives, broken glass, or other sharp edges. Nevertheless in a few cases injury was directly due to encounters with the enemy. An example is that of a nursing sister who, stabbed in the abdomen by a bandit armed with a dagger, grasped the blade of the knife with both her hands as it was being withdrawn. Escaping death by a narrow margin, she was left with gross disability of the hands because of severance of almost every flexor tendon of the fingers. Ten years earlier such a catastrophic tendon injury would undoubtedly have led to almost complete crippling of the hands. But thanks to the skilful use of modern methods and technique a remarkable restoration of function was achieved in this patient (Pulvertaft, 1948) Plate III.

Clinical review. Experience during the war has shown that the prognosis after tendon division depends largely upon three major factors; (1) the tendon affected and the site of the injury; (2) the presence or absence of associated injury to the other structures of the hand—

particularly the nerves, bones and joints—and of infection; and (3) the planning of the reconstructive operation and the surgical technique.

The site of injury. It has long been known that the outlook is far more favourable in divisions of the extensor tendons than in those of the flexor tendons. This fact was amply confirmed by experience during the war. Nevertheless there are special types of extensor tendon division, particularly those near the insertion of the finger extensors to the middle or distal phalanges, in which the prognosis is relatively poor. In divisions of the flexor tendons the prognosis is always very uncertain; and the most unfavourable single injury is division of both flexor tendons within the digital sheath at the level of the proximal phalanx.

Associated injuries. Surgeons skilled in this field recognised that the tendon problem must be assessed in relation to concomitant injuries of other structures of the hand, particularly the bones, joints and nerves. It was found that as a general rule these associated injuries should take precedence over the tendon injury; for it is useless to attempt tendon reconstruction in the presence of recent fractures, joint stiffness, or insensitivity due to nerve lesions. In cases of complex injury to the hand, tendon-reconstruction should be considered only after the structure of the hand has been restored sufficiently to make the chances of success reasonably promising.

Surgical technique. Improvements developed during the war include better planning of reconstructive operations and a better choice of suture materials. Furthermore, the importance of a carefully supervised programme of post-operative physiotherapy and rehabilitation has been recognised. Without this the most carefully planned and scrupulously executed operation will often fail.

A few examples of the manner in which tendon problems have been tackled on rational lines will serve to illustrate the more important developments in reconstructive tendon surgery.

1. *Extensor tendons. Mallet finger* is one type of extensor tendon injury that has given very indifferent results in the past. The reason for this was that the pathological anatomy was not fully appreciated. In any long-standing case of mallet finger it will be observed that power of extension movement of the distal interphalangeal joint is present; from the fully flexed position the phalanx can be straightened to within 20 or 30 degrees of full extension. In other words, continuity of the tendon is restored by the natural process of healing. The defect lies in the fact that union occurs with lengthening. Because the extensor tendon is anchored also to the middle phalanx, the slack cannot be taken up as it would be after a more proximal severance. The aim of any reconstructive operation should be, not to attempt to reattach the end of the tendon to its bony insertion (it has already regained its attachment), but to shorten the tendon by an amount equal to its lengthening (usually about 2 mm.). The appropriate technique has been described by

A. Front view B. Side view C. Back view

PLATE I. Thoraco-brachial 'box' plaster used for transport of compound injuries of shoulder and arm. The arm and chest are *liberally padded* and enclosed in plaster-of-Paris extending over both shoulders and gripping the iliac crests below.

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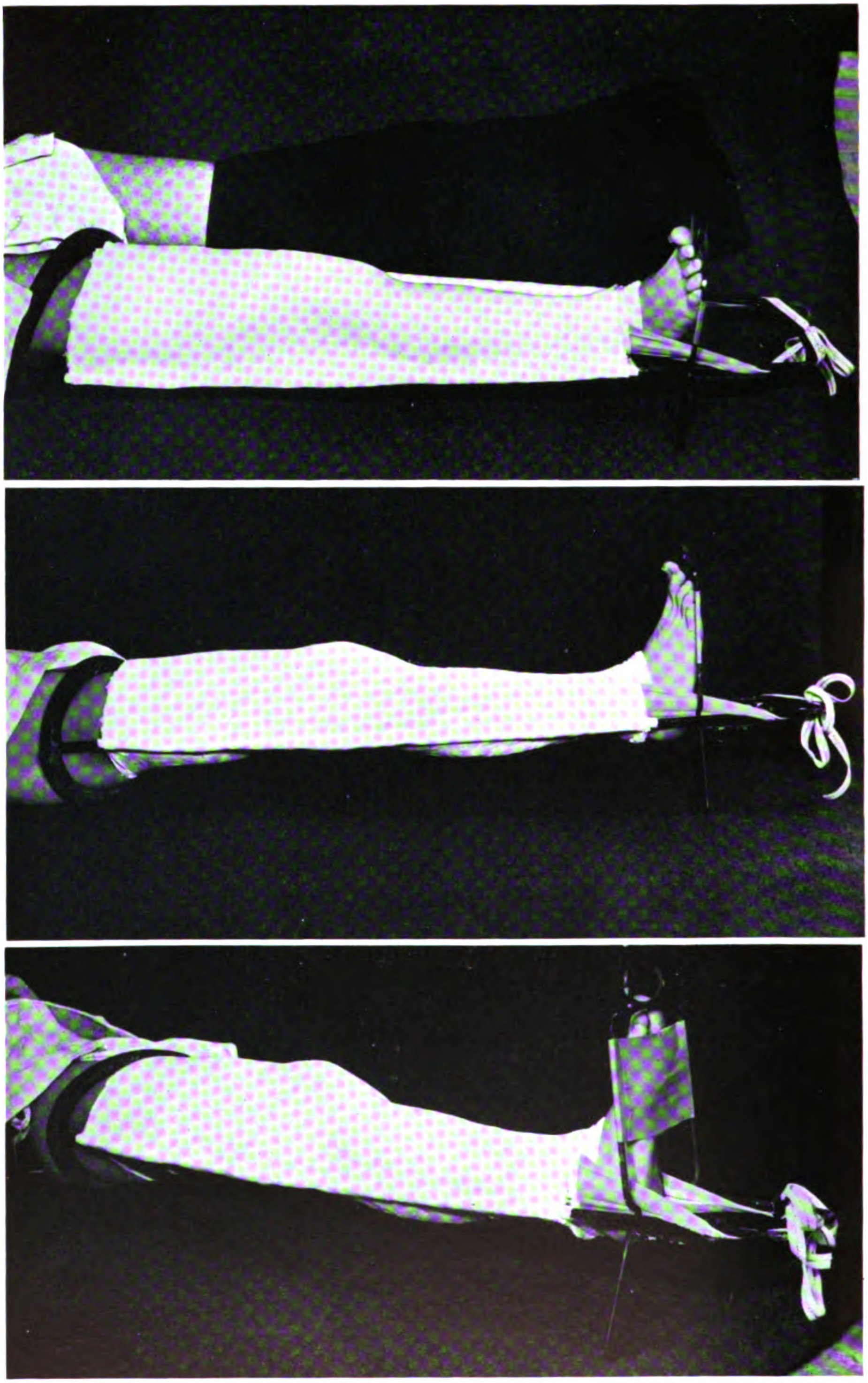

PLATE II. Tobruk splint. Thomas splint with fixed skin extension. Overall plaster-of-Paris applied well moulded to the limb. Ankle and foot not included but supported by a foot-rest. If the ring is not a comfortable fit around the groin, a pad of wool or felt should be inserted between the greater trochanter and the splint.

(*a*) Multiple healed scars.

(*b*) Showing inability to flex inter-phalangeal joints. (The sublimis to the little finger is intact.)

(*c*) and (*d*) Showing range of movement after tendon grafts to index, middle and ring fingers.

PLATE III. Division of both flexor tendons of index, middle, and ring fingers and the profundus tendon to the little finger.

Photographs from Orthopaedic Dept. *Derby Royal Infirmary*
By courtesy of Mr. R. Guy Pulvertaft, F.R.C.S.

Pulvertaft. He advocates excision of a short length of the tendon over the middle of the middle phalanx rather than near its insertion, where the operative approach necessarily traverses scar tissue and may interfere with the function of the joint.

2. *Flexor tendons.* In the management of these notoriously difficult injuries the new principles of tendon surgery, developed and expanded during the war, find their particular application. Flexor-tendon divisions in the palm may be repaired by direct suture with a reasonable expectation of success. But experience has shown that when the tendons are divided within the digital sheaths the principle of direct suture is unsound. The suture line invariably becomes anchored to the surrounding tissues, and a stiff and useless finger is the result. The new principle that has emerged is that no suture line should be placed within the digital sheath, except at its distal extremity. To fulfil this ideal, a tendon divided within the sheath must be removed from the mid-palmar level to its insertion into the distal phalanx. The excised length of tendon must be replaced by a free tendon graft, preferably from a tendon that has an investment of paratenon, such as the palmaris longus. In making the tendon junctions it is very important that an inert material such as stainless steel wire be used (Plate III).

The perfection of a technique along these lines has enabled a number of surgeons to show results that would have seemed incredible twenty years ago. Even now, success is not to be expected in more than a moderate proportion of cases. The prospect however is entirely different from the situation that formerly obtained, in which these injuries were considered to be so completely irreparable that primary amputation was often advocated.

DISLOCATION AND FRACTURE-DISLOCATION OF THE HIP

These were not uncommon injuries. Most cases resulted from road or aircraft accidents rather than from the more direct effects of war. It is of interest to note that even in the activities of peace-time the incidence of dislocation of the hip has increased with the progressive mechanisation of transport in all its forms. Armstrong reviewed 100 cases collected from all the orthopaedic centres of the Royal Air Force; 53 were due to aircraft accidents and 36 to road accidents. With few exceptions dislocation was caused by violence acting in the line of the shaft of the femur and was of the posterior type. In the exceptional cases the cause was excessive abduction, and the displacement either anterior or posterior. Armstrong showed that the nature and severity of the injury had an important bearing on the prognosis. He classified his cases into four groups: (1) simple dislocation; (2) dislocation with fracture of the acetabular rim; (3) dislocation with fracture of the acetabular floor; and (4) dislocation with fracture of the femoral head. The results were best after simple dislocation: 35 out of 46 patients regained normal function of the hip, and only one was complicated by sciatic nerve injury. After dislocation with fracture of the acetabular rim 27 out of 43 patients regained a normal hip, and there were three cases of sciatic nerve injury. After dislocation with fracture of the acetabular floor the results were poor: in all the seven cases in this group there was some degree of distortion of the joint surface and clinical evidence of degenerative arthritis. When dislocation was associated with fracture of the femoral head the result depended largely on the extent of the fracture; normal function of the hip was restored in two out of five cases.

INTERNAL DERANGEMENT OF THE KNEE-JOINT

In any community of young men, one of whose main recreations is football, the incidence of internal derangements of the knee-joint is so great, and the period of disability is often so prolonged, that these injuries must be regarded as of considerable economic significance. Moreover, the greater the degree of physical fitness that is required, the more important does the problem become. This general experience was amply confirmed during the war, when closed knee injuries accounted for large numbers of admissions to the orthopaedic wards and hundreds of semilunar cartilages were excised annually from Service patients. The main problem that had to be faced was how to restore full function to the knee and get the patient back to full duty in the shortest possible time.

With regard to diagnosis, most surgeons continued to rely upon the evidence afforded by accurate and very detailed history, together with a careful physical examination. In the absence of clinical signs it was necessary to consider the history with the greatest care and in so doing to assess the reliability of the patient's statements—though in the experience of most orthopaedic surgeons malingering was uncommon. In certain occupations of war where many lives were often dependent upon the physical fitness of a single man, such as the pilot of an aircraft, it was important that the possibility of accidents due to sudden locking of a knee should be reduced to a minimum. For this reason excision of a semilunar cartilage for suspected tear was sometimes advised simply on the evidence afforded by an accurate history; and it is of much interest to note that in the great majority of such cases the diagnosis was confirmed at operation. Nevertheless, it is the experience of every surgeon that from time to time a knee joint is opened only to reveal that the suspected cartilage shows no tear. In an attempt to avoid such errors a number of surgeons developed the technique of air arthrography. The technique was described by Somerville in 1946; and he was able to claim correct predictions in 95 per cent. of 324 knees examined. But unfortunately air arthrography has certain limitations which render it less useful than might be expected. One important difficulty is that the technique of radiography and the interpretation of the radiographs demand a specialised knowledge and skill that is not readily acquired by the surgeon who uses air arthrography only for cases presenting difficulty in diagnosis. On the other hand, it is hardly justifiable to subject every patient with symptoms of internal derangement of the knee to air arthrography in order to gain the necessary experience, both because of the additional time required in hospital and because of the occasional joint reactions that follow the injection of air.

With regard to treatment, it was generally agreed among the more experienced surgeons that the possibility of getting a patient with an uncomplicated tear of the semilunar cartilage back to full physical activity with the minimum of delay depended upon two important factors: first, clean removal of the entire cartilage with the least possible trauma to the tissues of the joint; and secondly, adequate physiotherapy and rehabilitation. When these factors were favourable it was usually possible to return a patient of good physique to full activity within eight to twelve weeks from the time of operation—three weeks in hospital and between five and nine weeks at a suitable rehabilitation centre. Failure to achieve this result was due usually to poor operative technique, to inadequate physiotherapy, or to some complicating lesion such as osteo-arthritis or gross ligamentous damage.

FRACTURES OF THE PATELLA

Throughout the war there was much discussion as to the relative value of internal fixation and of excision in the treatment of transverse fractures of the patella. The contention of Brooke (1937) that the function of the knee after excision of the patella is as good as or better than that of a normal knee had been received with scepticism by many surgeons, who felt that the patella, by holding the quadriceps tendon away from the joint, gave to the knee extensors a mechanical advantage the loss of which would be expected to impair the function of the knee if the patella were removed. There was some clinical support for this argument, in the observation that after excision of the patella there was a tendency for a 'lag' in extension—that is, inability to hold full active extension against gravity—to persist; and often there was difficulty in climbing, and particularly descending, ladders and stairs with a normal agility. On the other hand it was claimed by members of the opposing school that these deficiencies after excision of the patella were due to poor technique in repairing the quadriceps tendon and to inadequate physiotherapy in the post-operative period. There is no doubt that this is partly true.

After the war the problem was reviewed by Scott (1949) who investigated a series of 196 cases of fracture of the patella treated at the orthopaedic centres of the Royal Air Force during the war. The treatment adopted was; excision of the whole bone, 101; excision of part of the bone, 33; open reduction and internal fixation, 18; internal fixation with later excision, 14; no operation, 30. The late results of excision of the patella, assessed two to five years after treatment, showed that in most cases there was considerable residual disability. Only 5 per cent. of the patients considered that their knees were as good as normal; 90 per cent. complained of aching, and 60 per cent. complained of 'giving way'. The series of cases treated by internal fixation was too small to permit reliable comparisons to be made. Scott's analysis established that some residual disability was usual after excision of the patella; it did not determine whether the residual disability would have been likely to be less if treatment had been by reduction and internal fixation rather than by excision.

There seems little doubt that comminuted fractures are best treated by excision and adequate repair of the extensor apparatus. The treatment of non-comminuted transverse fractures is still debatable, whether the fragments are equal or not. Compound fractures are usually comminuted, and excision (early or delayed until the skin wound is healed) probably ensures the maximum function.

FRACTURE OF THE ASTRAGALUS (TALUS)

Fracture of the astragalus was an injury confined mainly to the victims of aircraft crashes, and particularly to pilots. It was caused by the mid-tarsal region of the foot being driven forcibly downwards on to the rudder bar. Typically the fracture line extended vertically across the neck of the astragalus. In about half the cases the fracture was associated with posterior dislocation of the body of the astragalus, which was often rotated through as much as 180 degrees and torn from its soft tissue attachments. The fracture was often compound. It was even known for the whole of the body of the astragalus to be extruded and lost through the wound.

Because it is an uncommon injury in peace-time, many surgeons were unfamiliar with the many problems that its treatment presents. When the fracture was uncomplicated and perfect reduction was secured, a satisfactory result could be expected after simple immobilisation in plaster until union occurred; but often the fracture was complicated by gross infection, by comminution of the joint surfaces, or by avascular necrosis of the body of the astragalus. Infection sometimes led to sequestration of the body of the astragalus, which had to be removed before healing was secured. Comminution and avascular necrosis led sooner or later to degenerative arthritis of severe degree, which often necessitated arthrodesis of the ankle joint, subastragaloid joint, or both. When the body of the astragalus was lost, whether at the time of injury or from subsequent infection, the best results followed tibio-calcaneal fusion.

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(ii)

Rehabilitation of Orthopaedic Cases in the Emergency Medical Services

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The general plan for rehabilitation of orthopaedic cases in the Emergency Medical Services was founded on the experience gained in the Special Military Hospitals set up by Sir Robert Jones during the War of 1914–18. In this war, however, a real effort was made to provide at least some facilities for rehabilitation in all E.M.S. hospitals treating the injured, these facilities being available for every type of case in the hospital, whether medical or surgical, Service or civilian, male or female. The careful and thorough mechanical cleansing of wounds, with excision of all dead and damaged tissue, universally insisted upon, and the immediate application, in all suitable cases, of plaster as the best means of ensuring complete immobilisation of injured soft parts as well as of broken bones, resulted in a great reduction in the proportion of cases with severe and prolonged suppuration, as compared with those wounded in the earlier years of the previous war. This improvement in the results was aided by chemotherapy.

The closed plaster method with infrequent dressings (Winnett-Orr and Trueta) proved its value in the early months of the war and contributed to the earlier healing of wounds and the union of fractures, making it possible to commence ancillary methods of treatment relatively early. Infection in contaminated compound fractures was more limited and spreading osteomyelitis much less common; the result was a reduction both in frequency and degree of the permanent disability. As the war went on and penicillin became available in increasing quantities, it was gradually realised that early successful closure of wounds, in spite of infection, and in spite of the presence of a fracture, was possible in a very large proportion of cases. When suture was impossible skin grafts were utilised. Delayed primary suture, successfully practised at the latter part of the War of 1914–18 by a limited number of surgeons, in this war became the routine to be followed on arrival at a base hospital whenever closure was anatomically possible and infection, if present, was not severe. The widespread success of early closure of wounds was of immense value to the patients both physically and psychologically. Movement of adjacent joints was commenced early, even before the removal of stitches; and there was a great improvement in the time spent in bed and in hospital, and in the degree of permanent disability. As an example of the value of plaster used 'at the front', may be mentioned the so-called Tobruk plaster for compound fractures of the femur. These cases, with few exceptions, travelled in comfort, and arrived in good condition at the base hospital, some after crossing the Channel in a landing craft, so that at the first dressing it was found possible to suture the wound, and this with an excellent chance of complete success. The advantage from every point of view to a patient with a comminuted femur was obvious. They could be, and were, treated as closed fractures. The period of invalidism was greatly reduced and the sufferers were enabled to return much earlier to an active and useful life.

ADVANCES IN ANCILLARY TREATMENT

The general plan and the various departments for medical rehabilitation were the same as those made use of in the War of 1914–18. Improvements of undoubted value were made but these were concerned with detail rather than with the general plan. Far more attention was paid to preserving and restoring the patient's general physical condition than formerly.

Facilities and equipment for rehabilitation were provided by the Ministry of Health at every orthopaedic centre and fracture A hospital not already in possession of these, a total of over 80 hospitals. Some of the orthopaedic centres used an auxiliary hospital as an annexe to the main hospital for the later stages of rehabilitation, and thus increased their bed accommodation. An instructor in physical training was included in the staff of each hospital.

In the E.M.S., continuity of control by the team responsible for a soldier's surgical treatment until he was fit for transfer to a convalescent depot, was considered of the utmost importance. For this reason the carrying out of rehabilitation in a limited number of special centres—such as were formed in the R.A.F.—was regarded as inadvisable.

As advocated for some years by H. E. Griffiths and a few others, treatment from an early stage was directed to the patient generally and not only to the injured limb, and thus general physical deterioration was prevented as far as possible. Comparing the methods adopted for the ancillary treatment of orthopaedic cases with those employed in the War of 1914–18, the following innovations may be noted:

For bed patients

(1) Active exercises for the trunk and limbs generally and, as far as possible, for the injured limb or spine in particular, were commenced at the earliest possible moment. Quadriceps drill for knee cases before walking was permitted became a routine. At Hexham Emergency Hospital, C. G. Irwin installed the apparatus necessary to enable an instructor to broadcast to all wards the orders for bed exercises, and in this way overcame the shortage of masseuses, who were unable to supervise the exercises in each individual ward.

(2) Movement of the fingers and toes received particular attention, but it was not always remembered that this must be commenced early and supplemented by passive movements of the digits if stiffness was to be prevented, particularly in paralysed limbs.

(3) Occupational therapy of the handicraft type, was encouraged for all bed-patients for its diversional and psychological value; in suitable cases with injuries of the upper limb the work was selected for its physical value.

For ambulatory cases

(1) *Active exercises.* Four types of exercises were made use of (i) holding or stabilising exercises, a group of muscles being contracted with or without the resistance of gravity, but without movement of the adjacent joint. (ii) Contraction of a muscle or muscles induced by voluntary contraction of synergics. (iii) Rhythmic exercises involving movement, with or without resistance by means of weights and pulleys, and (iv) free movements in classes and games. Active exercises were used to a much greater extent and much earlier as a form of general as well as local treatment. Patients with a leg in plaster frequently joined in the exercises and games as far as possible. Combined and competitive games played a larger part than they used to, the classes being held as far as possible in the open air. One advantage these possessed was that they favoured increased mobility of stiff joints without directing attention to the damaged limb (Griffiths, 1943). E. A. Nicoll (1941) laid stress on the importance of increase in muscular power as the range of movement improved, so that the muscles could act as 'shock absorbers' and protect the joints from strain. He rightly referred to the risk of joint strains if games were indulged in too early. Since games rarely induced full movement of any particular joint, individual exercises under the eye of a masseuse were essential to restore a full range of movement in all directions.

(2) *Class exercises*, in the earlier stages under a masseuse and later under a P.T. instructor, were found useful for cases of a special type, e.g. knees, feet, etc. In the early stages the exercises were performed while sitting; in the more advanced classes the patients were on their feet.

(3) '*Auto-assisted movements*'. Cords and pulleys were widely used to enable the healthy limb to assist the injured one, the movements being entirely under the control of the patient.

(4) *Resisted exercises* by means of pulleys and weights were used to an increasing extent in many centres but not in all. The load needed to conform to the degree of return of power in the muscles

(Nicoll, 1943). Similar apparatus was also used to eliminate gravity and friction by suspending the limb during the performance of active exercises (Porritt and Guthrie-Smith, 1931).

(5) *Games.* The playing of indoor and outdoor games during leisure hours was encouraged.

(6) *Passive treatment* except for the fingers and toes, was used much less. Massage in the average case was used only to a small extent, no more than it is used after exercise for an athlete in training. Greater use was, of course, made of it for persistent oedema of an extremity and for a paralysed limb. Faradism was used much less than formerly for the quadriceps in knee cases since earlier active exercises rendered it unnecessary in many cases. It became more generally realised that active exercises were superior to passive treatment for restoring movement, and for improving the circulation, as well as for increasing power.

(7) *Occupational therapy* by means of the lighter forms of handicraft was much more generally used, while the heavier types of work, except carpentering and gardening, were less often provided. Heavy work in a shop was largely replaced by vigorous P.T. and games, as often as possible in the open air. In all suitable cases an occupation was selected as being the most likely to assist in return of function in the injured part. Trained occupational therapists were available and these, with the help of partially trained or untrained assistants, directed the patient's work. Expert carpenters were in common use as workshop instructors; when other types of work were available suitable instructors were employed. Wood-cutting, log-heaving, and special strenuous work for miners were made use of in some centres. Physical training instructors, for the most part from the Army, with a limited amount of additional training in remedial work, were used extensively, in fact in all E.M.S. and many auxiliary hospitals with a sufficient number of Service patients. When an instructor was not available the classes were supervised by a masseuse.

TREATMENT OF FRACTURE CASES

As regards fracture cases, new methods, and the more general use of old methods not used previously as much as they might have been, undoubtedly hastened recovery, and reduced the number of intractably stiff joints, even though some of these methods could not be entirely freed from the suspicion of having led sometimes to delay in the union of a fracture. To quote instances, the insertion of a pin as a method of immobilisation of a fractured neck of the femur enabled movement of the hip and other joints to be commenced at once. On the other hand, skeletal traction while facilitating correction of shortening in a fractured femur, and allowing early movements of the knee joint, undoubtedly led to distraction of fragments in many cases, with the inevitable result of delay in union or even the development of definite non-union.

Among these methods the following were noteworthy:

(1) *Early use of the damaged limb*, all joints not necessarily immobilised by splints being systematically moved from the first. In addition, muscles enclosed within the plaster casts or other splintage were, in the absence of a wound, exercised from the first, in spite of the fact that the joint on which these muscles acted was immobilised. Synergic muscles were induced to contract by movements of the muscles with which they were associated. For instance in the case of a leg enclosed in plaster the calf muscles were made to contract by vigorous dorsiflexion of the toes (Perkins, 1938; Griffiths, 1943).

(2) *Earlier movement of the knee joint* was encouraged by several surgeons in cases of fracture of the femur. This was facilitated by the introduction of skeletal traction and early suture of wounds. (Young, 1942; Burns and Young, 1944, 1945; Charnley, 1944; Fisk, 1944.)

(3) *Early weight-bearing* in fractures of the leg. This was made possible by the greatly extended use of plaster as a method of splintage, the amount of padding being reduced considerably and by some surgeons entirely eliminated. The patients were taught to walk with the leg in plaster as naturally as possible; by this means unnecessary wasting of the muscles was prevented and the circulation was maintained. Cases with uncomplicated Pott's fracture were bearing weight on the damaged ankle within a day or two of the accident. B. H. Burns and R. H. Young (1942) treated an increasing number of simple tibial fractures by internal fixation, and often without any form of external splintage, long screws piercing both cortices being used, and movements of the adjacent joints being encouraged from the start. Weight-bearing at a relatively early date was allowed. Though the results were good in the hands of these surgeons, this line of treatment called for very special judgment, skill and care.

(4) *Uncomplicated spinal fractures* were splinted in hyperextension in plaster jackets, the displacement and deformity being corrected as far as possible (Watson-Jones, 1931). Exercises for the spinal muscles were started within a few days and performed with increasing vigour throughout the whole period during which the jacket was worn, usually about four months; on the removal of the jacket they were continued with variations and ever-increasing vigour in the gymnasium till mobility and power were fully restored. Patients treated in this way were out of bed and walking within

ten days of the accident. In no type of fracture have improved methods of treatment brought about such dramatic improvements in end results as in spinal fractures.

In injuries of the back with the fractures confined to the lumbar tranverse processes the fractures were disregarded. As soon as the pain allowed—and the pain is usually severe for a few days—activity was encouraged. The patients were often out of bed in less than a fortnight, and gradually progressed till the most vigorous exercises were indulged in. There is evidence that in some other types of severe injury, e.g., fractures and fracture-dislocations of the pelvis, rehabilitation may be surprisingly successful and complete, in spite of the gross unreduced deformity and displacement revealed in X-ray films. In spinal injuries complicated by paraplegia the importance of early passive movements of the hips and knees became increasingly realised. By this means obstinate stiffness of the joints was prevented, and sitting in a wheel chair became possible at a relatively early date, with obvious advantage to the irreparable paraplegic from every point of view; occupational therapy could be prescribed with a view to the work becoming of wage-earning value. The work done for paraplegics at Stoke Mandeville was outstanding. (See page 422.)

Fractures of the os calcis, both simple and compound, occurred in considerable numbers. A cause of this injury peculiar to war was the sudden uplift of the deck of a ship that was mined or torpedoed. As many as seven fractures of the os calcis occurred from this cause in a single ship. The explosion of a landmine was another frequent cause; in some of these cases the injury was very much more extensive. No matter how great the care taken over the setting of the simple fracture and with the after-treatment, the results were extraordinarily bad, so bad indeed that extreme views have been taken by some surgeons as to how these should be dealt with; these vary between simple rest in bed for two or three months, no attempt being made to correct deformity, but movements of the toes, tarsal joints and ankle being insisted upon from the first, and drastic operative measures (Bankart, 1942). Rehabilitation of these cases has always proved one of the most difficult problems: there has been an increasing tendency however, towards conservative treatment, operation being reserved for those in which this treatment failed. Correction of deformity, as far as possible, and fixation in plaster for no longer than two or three weeks, followed by active mobilisation but without weight-bearing, became a popular routine and provided better results.

An important group much increased in this war consisted of severe fractures among despatch riders. These fractures resulted from direct violence, were comminuted, not infrequently compound and often multiple. The lower limbs, quite often both, suffered more often than the upper, and fractures of the femur, tibia and fibula all in the same leg were frequently seen. Union of these fractures was often delayed, owing—in part at least it is believed—to the excessive violence causing the fractures; rehabilitation was only too commonly prolonged, while many were left with a permanent disability.

Fracture of the femur only too often entailed discharge from the Service, when soldiers were the sufferers. The nine months allowed by the War Office was not quite enough to complete the rehabilitation of many of these cases, even of those without complications.

With regard to *fractures of the patella*, there was a tendency—an unfortunate tendency many believed—to excise the bone in cases that could be adequately treated by suture without undue difficulty. It was found that in spite of every effort to restore function in these knees after excision of the patella, in a large proportion voluntary extension remained incomplete, at least for several months, while in addition fixation of the joint was sometimes limited seriously. A sense of insecurity was complained of in many. It is true, however, that a few soldiers have been returned to duty in Category A1 in spite of the imperfection of the extensor apparatus of the knee. Much more investigation of the late results will be required before final judgment is passed on this operation, but our present knowledge strongly indicates (i) the wisdom of confining this operation, in the young and middle-aged at any rate, to cases in which the patella is grossly comminuted, with or without a wound, (ii) that the way in which the operation is completed may be the most important factor in determining whether or not complete rehabilitation proves possible. The report by Scott (1949) on the late results of cases of fracture of the patella treated by excision, though it provoked some criticism, certainly supports the cautious views expressed above.

With regard to *gun-shot wounds of the knee*, Burns and Young (1945) reported 101 cases, in which they had obtained or anticipated a normal knee in 74 per cent. Only 11 cases were stiff. Whenever possible the wound was sutured (delayed primary suture), quadriceps exercises were started at once, and flexion of the joint after about ten days. These results are considerably better than those achieved in the War of 1914–18. A. E. Porritt, R. K. Debenham and C. C. Ross (1945) reported that of 75 cases of wounds of the knee joint, 33 had over 90 degrees flexion eight months later, while another 15 had over 45.

Wounds of the *elbow joint* provide another instance of the final result depending far more on the severity of the initial injury and the degree of infection than on ancillary treatment. In a flail elbow suitable exercises against increasing resistance may do much to stabilise the joint. In 48 cases of wound of the elbow the late results were ankylosis in 17, flail joint in 4, over 30 degrees movement in 22, and less than 30 in 5. (Buxton, 1943.)

The great frequency of *fractures of the carpal scaphoid* among soldiers and airmen was not noted in the War of 1914–18. No doubt many cases were missed. Here again early diagnosis and early efficient treatment by reduction, if necessary, and plaster, did more than anything towards obtaining bony union and a painless wrist. Ancillary treatment could do little towards rehabilitating these cases. (Annotation in *Lancet*, April 3, 1943.) S. A. S. Malkin at Harlow Wood Orthopaedic Hospital found the average stay in hospital was about six months. Fortunately non-union of this bone is not necessarily associated with disability, especially in non-manual workers. The functional results after removal of the scaphoid alone have not been good, and surgeons became more in favour of removal of all the carpal bones of the first row, as an alternative procedure to arthrodesis. T. P. McMurray (1942) found that even in the good results following removal of the scaphoid alone the grip was materially weakened.

In the view of the majority of surgeons *manipulation*, as a means of restoring movement to joints following fractures of one or more bones of a limb, particularly after wounds, was only occasionally indicated. The error of manipulating a stiff knee after a severe compound fracture of the femur due to binding of the quadriceps to the femur at the site of fracture was widely appreciated. If manipulation were resorted to it was felt that little should be done at a sitting.

FOOT AND KNEE TROUBLES DURING TRAINING

Among peace-time troubles occurring among the troops in training and calling for treatment in E.M.S. hospitals, the following types of case demanded special notice.

Feet constituted a real problem, particularly among recruits. It was estimated that from a third to a half or even more of the cases referred to an Orthopaedic Centre for an opinion were 'feet'. The education of the regimental medical officer and early recognition of the cases in need of advice from a specialist resulted in a larger proportion of these men being returned to duty. The usual cause of trouble was fatigue, sometimes the result of too hasty training, in men whose feet were either normal or showed only a minor degree of congenital variation, such as hallux valgus, pes planus and cavus, metatarsus elevatus or supinated fore-foot. Experience showed the uselessness of trying to hurry these cases of foot-strain back to duty. A few weeks spent in a judicious mixture of rest, complete to begin with, and remedial exercises, proved well worth while, and frequently resulted in permanent return to full duty (Lambrinudi, 1942). Operative treatment for foot troubles in serving soldiers was discouraged: rarely can a soldier return to duty after operation, no matter how judicious the ancillary treatment. March fracture of a metatarsal was not uncommon in recruits, the first symptoms usually occurring towards the end of a long march. The cause was gross fatigue of the muscles controlling and supporting the foot occurring in a young man with little reserve of strength in his bones. In many cases union of the fracture occurred without resort to immobilisation of the foot in plaster.

'*Knees*' were admitted in large numbers, and sometimes segregated in special wards, the injury in many, possibly in most, cases being sustained during a game of football. Large numbers of cartilage operations were performed on soldiers and for various reasons the results were not always as good as one could desire. Quadriceps drill, commenced before operation and continued with increasing vigour afterwards was regarded as of paramount importance, whatever the lesion. Faradism to the muscles was applied much less than it used to be. Massage was employed only to the extent an athlete enjoys it after exercise. Simple contraction of the quadriceps to begin with was followed by a straight-leg-raising while the patient was still in bed. Exercises against increasing resistance, using pulleys and weights, were used extensively in the later stages, but care was found to be necessary. Nicoll (1943) called attention to the fact that the vastus internus, an important muscle to the knee joint, only comes into action in the last 15 degrees of extension unless a special effort is made. Cases should be fit for a convalescent depot in five to seven weeks after meniscectomy. The hamstrings sometimes required a special attention before running was possible.

At Harlow Wood Orthopaedic Hospital 77 per cent. of patients operated upon were returned to duty in Category A1. It is now known, however, that some of these had to be degraded later. In another centre (Horton) 71 per cent. of a group of knees were returned to duty after operation without lowering their respective categories. These satisfactory figures are attributed by S. A. S. Malkin (1943) largely to the efficiency of the after-treatment, but accuracy of diagnosis and judicious selection of cases for operation must be regarded as of equal importance. T. P. McMurray, in a convalescent depot receiving cases from a number of hospitals, found only 56 per cent. of 206 cases with a good or fairly good result after operation, while in 21 per cent. the results were definitely bad. In those with a good result the average total stay in hospital and convalescent depot was twelve and a half weeks. This agrees fairly closely with the findings of J. J. R. Duthie and J. G. Macleod (1943) who reported the average time off duty after operation in 186 cases was eighty-two days. The longer the total history the longer the time before return to duty. Malkin (1943) found mild arthritis as a complication of a cartilage lesion had little effect on the time off duty.

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(iii)

Closed Plaster Treatment of Wounds

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Little had been written on the treatment of wounds in the fifteen years before 1939 until Trueta published his monograph on the results obtained by his methods of treatment of battle and air-raid casualties (1938–9). The method which he described became known as the closed plaster technique.

It was unfortunate that the 'immobilisation in plaster' aspect of the method should have been the one chosen for naming it. If it had been called 'cleansing of wounds and the excision of dead tissue', much controversy might have been avoided and a better understanding of the salient points achieved. It will therefore be useful to give a brief historical review of the development of the technique and to define it more accurately.

Trueta, in his first lecture in this country (1939) and in his monograph, included ten points of importance in the treatment of the fresh wound:

In the General Plan:	Sorting Resuscitation Early operation Immobilisation Posturisation
In the Operation:	Washing Incision and excision of devitalised tissue No suture Drainage Plaster

In the early years of the war the misunderstandings in relation to this subject were many, and misquotations have often been very revealing. The discussion of such words as excision, débridement, trimming, toilet, and their relation to closed, windowed, padded, skin-tight and other types of plasters revealed the uncertainty and the lack of agreement and understanding of the principles involved.

It is interesting to recall that each one of the points mentioned here has been previously stated to be important.

Larrey, in his *Mémoires de Chirurgie Militaire*, gave his opinion concerning the importance of 'débridement' and excision of dead tissue, and also the importance of early operation. Pirogoff continued the practice of excision of wounds and used plaster-of-paris to cover wounds soon after Mathysen first described the technique.

Ollier in 1872 described the 'occlusive' technique—complete immobilisation of a wound in plaster—and gave as the two reasons for its virtue that '(1) it protected the wound by an isolating substance excluding infective germs, and (2) provided absolute and persistent immobilisation of the wounded region in a rigid structure which enclosed all those parts of which movement could in any way affect the divided tissues'. An interesting point about Ollier's method is that he stressed the importance of immobilisation to the exclusion of excision of the wound. The importance of wound excision was not appreciated in the early stages of the War of 1914–18 and in reading the medical history of that conflict one is impressed by certain general trends. The very bad results of the first year improved greatly as a result of renewed emphasis on the value of excision. This was followed by brief set-backs, due to the enthusiasm at the improvement in results following wound excision causing some to advocate primary suture, and later to the over-emphasis of the value of antiseptics. Then, towards the end of the war, early operation, excision, early secondary suture, and immobilisation were all described and their importance stressed, though this conception was not general and still suffered from some over-confidence in the value of antiseptics. Also excision of a wound was then considered inadvisable after the first twenty-four hours, or as soon as there was evidence of infection.

Winnett Orr's contribution to war surgery was to modify the emphasis placed on antiseptics by the Carrel-Dakin method and to revert to Ollier's 'occlusive technique', but also to do what Ollier failed to do—that is, to give equal importance to the value of drainage—by laying the wound open and leaving it so. The treatment was described for infected compound fractures and osteomyelitis (Winnett Orr, 1941).

The 'closed plaster' technique may well be looked upon therefore as a re-arrangement and re-orientation and revision of the methods used at the end of the War of 1914–18. This re-orientation was of great importance as it emphasised principles and indicated methods by which these principles could best be applied. When war started in Spain in 1936 and Trueta expounded the principles and technique of his method of treatment, the same arguments were heard there that became so familiar in England three years later; but by the end of that war a technique had been evolved which yielded results superior to anything previously reported in war surgery. This method had been tried on various fronts and by many people and there was general agreement on all essential points (d'Harcourt *et al.*, 1940).

When the Second World War was imminent, and after it started, this technique under various names became the centre of an important and sometimes bitter controversy. The two main reasons were failure to agree as to definition and method in relation to certain points like excision and drainage, and attempts to pick out single steps in the technique, to emphasise their importance to the exclusion of others. This, along with the much disputed paternity of the method, made any name for it difficult and the one which became generally used, unsuitable. The general trend of feeling among the critics of the technique was at first that it was new and not good, and later that it was good but not new.

The mistake most frequently made in the early stages was due to over-emphasis on the procedures of leaving the wounds open, using plaster to protect them and to immobilising the soft tissue and bones, concluding from this that the procedure was the same as that described by Winnett Orr. An essential element that was overlooked was that this technique was intended to be applied to fresh wounds and was designed to prevent infection and not to treat established bone sepsis. Another point of great importance (and one which still is not sufficiently appreciated) was the change in the purpose and type of wound excision. Even at the end of the War of 1914–18, when the importance of this step was given due emphasis, wound excision was considered by most surgeons, primarily as a means of getting rid of infection. All accounts refer to the removal of 'contaminated' tissues. The conception of removal of 'bacteria' was the one generally accepted in 1918, although Forbes Fraser *et al.* (1918) gave a clear and accurate description of the procedure: 'to excise a very narrow margin of skin round the wound in the form of an ellipse—to prolong the incisions sufficiently to obtain a full exposure of the track, and then, with the help of good retraction to remove its walls with scissors or knife. As little healthy tissue as possible is removed but soiled, dead, or severely bruised muscles are snipped away till healthy, contracting bleeding tissue is exposed' . . . 'differs entirely from ideally aseptic excision *en bloc* which aims at removing the whole track from outside without cutting into it.' Despite the correct description of excision found here we still find the words 'track', 'wall' (of the wound) and 'soiled' (contaminated) used. These words have almost completely disappeared from the modern surgical vocabulary.

The unnecessary method of excision *en bloc* was again repeatedly described during the period 1939–43. Excision of living tissue caused needless mutilation and was a factor in encouraging the use of local sulphonamides and later penicillin as a method of replacing, instead of complementing, wound excision. It also led to much discussion of words previously mentioned and the practice of such procedures as 'trimming'. This phase was comparable to that already mentioned in the War of 1914–18 in which there was great enthusiasm for antiseptics as substitutes for excision.

Another point frequently raised in criticism of the plaster technique was the difficulty of early recognition of gas gangrene in wounds completely enclosed in plaster. There was indeed some danger from the application of plaster to patients in whom no efficient wound excision had previously been carried out. Fulminating gas gangrene can and should be diagnosed more readily by attention to the general than to the local condition. To wait for diagnostic local signs may lead to much loss of valuable time. It was not sufficiently understood that with the proper use of this technique in all its details gas gangrene became a very rare condition and anaerobic cellulitis only slightly more frequent—as was pointed out by Trueta in his review of wounds treated in Catalonia during the Spanish War.

The technique of plaster immobilisation was the subject of much discussion in the early stages of the war. Immobilisation was generally accepted as desirable for major soft-tissue injuries and for fractures. The three controversial points were: the value of plaster, the method of its use, and its dangers and complications. Plaster minimised secondary trauma to soft tissues and thereby decreased pain and shock, and allowed the transportation of the wounded with relative comfort, and by its protection of the wound prevented secondary infection ; it also reduced to a minimum the lymph flow in the limb, and consequently the absorption of toxic products from the wound area. This point was of particular importance in burns and infected wounds. In relation to the application of plaster two requirements developed which governed this, and provided these were appreciated certain variations in technique could be accepted. The essentials were that the plaster should exert a gentle and uniform pressure on the wound and immobilise the affected area and the joints above and below it. It should encourage active drainage of the fresh wound and therefore no non-absorbent material such as 'cotton-wool' made from wood, or petroleum-jelly gauze, should be used for drainage. This procedure never really achieved its correct place as a method of keeping a fresh uninfected wound dry and in its best state for early suture or grafting. Petroleum-jelly gauze—the method of passive drainage of pus—continued to be the most general method of drainage of both fresh and infected wounds.

The greatest source of complications was the practice of using a closed plaster without preliminary wound excision, and the failure to split it from end to end to allow for swelling. Other complications arose from immobilisation of joints in the wrong position, from pressure over bony points, from continued immobilisation when it was no longer required, and from other purely technical faults. Yet another cause of complication was the lack of appreciation of the need to elevate the limb after re-application of plaster.

There was a tendency in the early days of the war to believe that the local and general use of the sulphonamides would make the requirements of wound excision less exacting. This was found to be wrong, as it was demonstrated that the bacterial flora in wounds treated under similar conditions with and without the use of local sulphonamide was practically the same. Penicillin was introduced experimentally and in small quantities in 1943 at about the same time when this faith in the sulphonamides was on the wane, and led to a resurgence of hope that it would succeed where the other had failed.

One development which, though not strictly part of the closed plaster technique, requires mention at this stage, is that of wound closure. In Trueta's original monograph the only emphasis in this direction was that there should be no immediate suture of war wounds. This was considered to be a necessary emphasis at this stage, because careful analysis in 1919 had shown that secondary suture gave better results than primary, even in cases operated on within twelve hours, and his own results strongly supported these findings, but the method came in for much criticism on this account. The importance of early skin cover was the argument used to support both primary suture and immediate skin grafting. No one seriously disputed the importance of early skin cover, but certain other things had to be learned first. To advocate primary suture when few of the surgeons doing the work had any appreciable first-hand experience of the treatment, even of open civilian injuries, was dangerous to say the least, and experience in battle and air-raid casualties showed that immediate skin grafting, however attractive an idea, was seldom possible.

As the general standard of wound treatment improved, the question of early closure arose again in many theatres. Nowhere was primary suture of wounds advised, except in relation to penicillin treatment of wounds, and this procedure was given up after only brief trial. The tendency was for earlier and earlier secondary suture to be done until the delayed primary method of 48 hours was recommended. An important factor accepted in relation to the secondary suture of wounds is that the surgeon suturing the wound should be responsible for the patient during the days that follow the suture. If the patient must be evacuated, the suture should be delayed until he is admitted to a centre where suture and post-operative course may be in the charge of the same surgeon.

Various steps in the treatment were 'discovered' during the war; for example, the importance of washing was 'popularised' by the fact that wounded who spent long hours in the sea were relatively free from infection. Also, in 1944, the method was unjustifiably condemned because it failed to give a good result in a patient left untouched in a complete plaster for twenty-seven days, in spite of the fact that no wound excision had been carried out before the plaster was applied and that there were continuous general signs of severe infection.

It is difficult to assess the progress of a technique each step of which was capable of such varied interpretation, in which there was a tendency by many to agree with certain points and practise these and to ignore or even actively oppose others. Every method is subjected to this, and if its principles are sound they remain and the method is improved by progressive modification.

Perhaps the best way of judging the forms of treatment described in the early stages of the war is to review the methods described in the later stages. From *The Trend of Forward Surgery in Italy* (July 1944) circulated by the consulting surgeon to the Allied Armies in Italy, the headings under which the 'Principles of Forward Surgery' were described were: (i) the time factor, (ii) the principles of excision of wounds, (iii) essential points in plaster work, and (iv) special regions. Further on he states: 'the full treatment of wounds therefore is thorough washing of a wide surround of skin with soap and water, application of some antiseptic, excision of the wound, a 'frosting' of sulphanilamide, adequate splinting, and, where thought appropriate, a note on the Field Medical card, "probably suitable for secondary suture" '.

In his review of compound fractures MacFarlane (1945) picks out one particular development as being of great importance and that is the early closure of wounds—'We have witnessed in these five years a change from the closed plaster open wound technique, by which most of the early wounds were treated, to an era of delayed closure in 90 per cent. of all compound fractures'. For the possibility and relative speed of this development he gives credit to the 'lesson learned from Trueta's experience in the Spanish Civil War', and to penicillin which 'undoubtedly has played its part. It is impossible to say yet how great is that part in relation to careful surgery'. 'Penicillin has been the instrument through which the attention of surgeons has been called to the possibilities of delayed suture. There may be a tendency to ascribe increased success and the limitation of sepsis to chemotherapy. There is as yet little evidence that such is a correct assumption'. Evidence is then produced to show that it is, in fact, an incorrect assumption.

As has already been mentioned, certain trends in wound treatment were obvious during the War of 1914–18. The progress of the closed plaster technique can best be summarised by taking note of similar tendencies in the War of 1939–45. At the beginning of the war, the method offered the alternative to the antiseptic treatment of wounds. It was accepted by the majority, at first cautiously and with some misgiving, as a method of treatment of infected wounds. As opportunities for trial increased more surgeons came to understand the various steps involved and to appreciate the importance of each, in particular the excision of devitalised tissue, and also to see the potentialities of the method as applied to the fresh wound. This came about to a considerable extent as a result of the treatment of air-raid casualties. Another important factor at this stage was the appreciation that sulphonamides had their greatest value as a prophylactic and as a complement to the technique rather than as a substitute for any part of it. As the experience of the surgeons increased and the re-organisation for transport and resuscitation improved, the next logical development was the emphasis on wound closure. The dictum that primary suture of war wounds was wrong had been so widely accepted that there was little tendency to attempt that procedure. This was a point of great importance and a tribute to those who had consistently fought primary suture of war wounds, and the emphasis then turned to early secondary suture. This came about the same time as penicillin became available in sufficient quantity to be used in the same way that the sulphonamides had been used earlier. As the drug was in every way a more suitable one than the sulphonamides, being less toxic and more powerful against all the common organisms, there was once again a brief tendency in certain quarters to advise its use after little or no wound excision, and in association with primary suture.

In the case of the invasion of Normandy, as soon as our hold on the Continent was sufficiently secure to allow of organised surgical units and base hospitals, the majority of wounds of the extremities came back in plaster. For the first two weeks many of the patients had arrived with only field dressings.

The plaster technique was more general in the British Service than in the American Army. The directive that fractures of long bones should be treated by skeletal traction meant that many wounds associated with fractures were not treated in plaster, and perhaps also because of this the practice of treating soft-tissue wounds in plaster was less general.

By the end of the war it was the general practice in the British Army to immobilise in plaster any major soft-tissue wound of an extremity whether or not there was a fracture.

It seems fair to say that no broad principle in the technique described by Trueta in relation to the treatment of the wound and the patient has been found to be unsound or superfluous. The most important addition, apart from chemotherapy, was the early wound closure by suturing. It was not until the final campaign on the Continent that it was generally agreed that the main points described in the wrongly named 'closed plaster' technique—along with the prophylactic and therapeutic use of the antibiotic drugs—produced the best results.

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CHAPTER 7

BURNS

(i)

General Treatment of Burns

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THE problem of the treatment of burns was of much greater importance in the War of 1939–45 than in that of 1914–18. The great extension of air-warfare, the increased use of tanks and other armoured vehicles, and the many other purposes to which petrol was put, furnished constant opportunities for burns. In the Army, particularly in the Mediterranean area, many extensive burns with large areas of skin-destruction occurred. In a certain period in 1942 in North Africa, burns comprised 1·5 per cent. of the total casualties, and as many as 27 per cent. of the casualties admitted to hospital of the personnel from the armoured fighting vehicles. It was noteworthy that in the Army the careless domestic use of petrol accounted for a greater number of burn casualties than the actual fighting. The common cause for this type of accident was the careless use of the 'desert stove', in which petrol was soaked in sand contained in a tin, or the wasteful and risky custom of utilising petrol for cleaning clothes and destroying vermin. Even in periods of sustained fighting (in North Africa) the ratio of accidental to battle-casualty burns was 2·3 to 1 (Porritt.) The Navy frequently had to face the problem of a large number of burns inflicted at the same time. Hot blasts of air from shell explosions or the back-flash from guns led to many burns of a superficial type and numbers of serious cases resulted from explosions in ships.* A particularly serious kind of burn resulted from men being plunged into a sea which was covered by a layer of hot oil which had been liberated from a ship sinking after an explosion; the bodies of those who had to keep afloat in such a sea were severely burnt at the level of the water-oil mixture. At the Pearl Harbour attack 50 per cent. of the casualties from the ships were due to burns, of which many were of this type.

Burns in the Royal Air Force† (A. M. Pamphlet 168, 1944) were more or less of standard type, and, as the circumstances in which they occurred were usually peculiar to flying they differed somewhat from those in other services. The aviator's burn had a characteristic distribution involving chiefly the face and hands, with or without other significant areas, such as the legs and thighs; it might affect the whole

* Plate V.

† See R.A.F. Medical History, Vol. I, Chap. 6.

of the hands, and even when the pilot wore gloves often caused an encircling burn of the wrist. Many burns occurred on crash-landings and were often associated with other injuries. Considerable protection against these burns was afforded by the wearing of helmets, goggles and gloves, and the occasional neglect to wear these led sometimes to disaster (Plates VI–IX).

The indiscriminate bombing of cities caused many burns among the civilian population. These were treated in the various hospitals administered by the Emergency Medical Services.

During the War of 1914–18 the only notable developments in the treatment of burns had been the adoption of the local application of a solution of picric acid (which acted as an antiseptic coagulant), and the attempt to form a protective covering for the burnt area by spraying it with a paraffin preparation called 'ambrine'. It was found that toxic symptoms sometimes resulted from the use of picric acid, and owing to the adherent coagulum formed by the drug the wound sometimes tended to become deeper. For the latter reason the Naval authorities abandoned the use of picric acid for burns in 1916.

Between the wars Davidson of Detroit (in 1925) introduced the tannic acid treatment of burns, whereby an aqueous solution of the acid (2½ per cent. strength) was applied to the burnt area by means of gauze pads soaked in the solution; when the part was tanned brown the gauze was removed and the part left exposed. This application caused minimal trauma, gave greater comfort, required less frequent dressings and (it was claimed) limited the loss of body-fluid and diminished secondary infection, and in fact more than halved the mortality from burns. Other surgeons who adopted this method used much stronger solutions—up to 20 per cent.

In 1933 Aldrich recommended the application of a 1 per cent. solution of gentian violet to burns on account of its better germicidal action than tannic acid. To this he sometimes added acriviolet and brilliant green (triple dye) which were more inimical to the gram-negative bacteria. Bettmann in 1935 suggested the application of 5 per cent. tannic acid followed by a sponging over with a 10 per cent. solution of silver nitrate.

At the beginning of the war in 1939 the above were the chief local applications in use, with tannic acid as the popular favourite. If sepsis developed it was treated by fomentations or antiseptic dressings. The general treatment consisted in giving morphine for pain, keeping the patient warm, allowing him drinks by mouth, and administering intravenous saline solution, gum acacia solution or blood to combat shock. It was very soon found that these measures were inadequate and during the course of the war important advances were made in treatment.

There were several reasons why improvements followed. In the first place probably for the first time in the history of surgery it was realised that burns presented special problems of their own which needed expert investigation—a fact which became more obvious and insistent as the number of burn casualties continued to increase. In Britain a special co-ordinating sub-committee was formed by the Medical Research Council in 1940 to consider the treatment of burns, and in 1942 a Burns Sub-Committee of the Council's War Wounds Committee was formed to supervise research work on the subject. At the same time special Burns Centres were being set up by the Service and civil authorities in different parts of the country; in these centres burns were segregated and attended by officers specially skilled in the techniques required. In the United States also in 1942 there was formed a special Committee of the National Research Council for the purpose of research work on burns. By these means very careful and valuable work was done, and the results from all quarters collated and compared by the supervising committees. Moreover constant contact was maintained between the research centres and the clinical field at home and abroad, so that there was no serious delay between the scientific advance and its clinical application.

The importance of trained staff and team-work in the treatment of burns became obvious in the course of the war, and as a result of these experiences it is likely that in the future, if the best results are to be obtained, severe burns may need to be treated in special centres.

The advances in the treatment of burns during the war may be grouped under the following five headings, each of which will be considered separately, though there is necessarily a considerable amount of overlapping between them:

1. Methods of relieving pain.
2. Local treatment of the burnt area.
3. Prevention and treatment of shock by replacement of body-fluid.
4. Prevention of sepsis.
5. Early skin grafting.

1. METHODS OF RELIEVING PAIN

Despite the warning of some observers (e.g. Weidenfeld, 1902) that the administration of morphine to a burnt patient might be dangerous, the general consensus of opinion during the war was that it was a necessary drug for the relief of pain and for quieting mental distress. Few however went so far as to say that it was without danger and most preferred to give repeated smaller doses rather than an initial heroic dose. So far as experimental work was concerned, Elman's results with dogs showed that the administration of morphine and barbiturates was harmful (1944).

The question whether pain could be relieved by any local application was investigated by Colebrook, Gibson and Todd, who published their conclusions in 1944. Their experiments were made on human volunteers and their conclusions were that cold water or a watery cream afforded temporary relief to the pain of a burn; and that inclusion of an analgesic in a locally applied cream gave relief which was not very constant. On the whole they advised against the inclusion of an analgesic in a local application, for the relief of pain was not certain nor complete, and there was some danger of a toxic effect when the burn was extensive. Moreover, amateurs who might have to apply the cream as first-aid would hardly be competent to discriminate in this matter. However, the R.A.F. provided a mildly anaesthetic anti-burn cream in the first-aid outfit for aircrews which could easily be removed and which contained a substance for protection against sunburn. It had a melting point of 115° F., and its formula was:

	Percentage
Titanium dioxide 90 per cent.	10·0
Wool fat	15·0
Vaseline	5·0
Lanette wax . .	10·0
Glycerine	25·0
Manucol 4 per cent. . .	35·0
Drop of 0·1 per cent. chlorocresol as preservative	

(Air Ministry Pamphlet 168, 1944, p. 13.)

2. LOCAL TREATMENT OF THE BURNT AREA

During the evacuation from Dunkirk, many members of the Expeditionary Force were severely burnt both on retreat and on the beaches while awaiting rescue, and many burns also occurred among the ship's companies of the rescuing destroyers and small craft; these were nearly all treated as a first-aid measure by a tannic acid jelly. It was found that the results left much to be desired. Sepsis was not prevented, profound and even fatal toxaemia sometimes followed, and the constricting effect of the coagulum in many cases caused serious necrosis of the fingers and toes. Necrosis was likely to occur with a circumferential burn of a finger; inflammation was set up, the finger swelled greatly and caused severe pain which needed to be controlled by morphine and only ceased when the finger necrosed (Plate III).

In the Navy, where sometimes hundreds of burns had to be treated at a moment's notice and there might be considerable delay before reaching a base hospital, simplicity of treatment was demanded and this was provided by the use of a triple dye jelly (brilliant green 0·1 per cent., gentian violet 1 per cent., euflavine 0·1 per cent. in a water-soluble base) supplied in tubes; this was found very useful and formed a less rigid coagulum than that caused by tannic acid. The ship's first-aid outfit also carried small tannic acid pellets from which a 2 per cent. tannic acid solution could readily be made.

The experience of the Dunkirk casualties and of the Royal Air Force in the Battle of Britain, led to the disuse of tannic acid for burns of the face, hands or toes in all the Services, but for a time this did not apply to its use for other parts of the body, for in June 1941 the instructions issued by the E.M.S. still recommended either immediate coagulation followed by exposure of the burn till the coagulum was removed, or alternatively coagulation by a jelly or applied dressings containing the drug which were to be retained until the coagulum separated. (The solutions recommended were either silver nitrate 10 per cent., or tannic acid 10 per cent., or silver nitrate 10 per cent. followed by tannic acid 5 per cent., or gentian violet jelly or triple dye.) (Plate I.)

It was about this time that the local application of sulphanilamide began to come into use. In March 1941 Colebrook published his experiences of that drug applied locally to burns, with the significant comment that local chemotherapy with this drug might often get rid of streptococcal infection in a few days. In April of the same year Hooker and Lam published their account of three cases in which they had tanned most of the burnt surface but applied sulphanilamide to the rest of the area; they found that the sulphanilamide was rapidly absorbed into the general circulation and (apparently not knowing of Colebrook's work) stated that 'it is possible that further experience will produce a technique whereby the drug can be used as a routine in a prophylactic manner to prevent streptococcal infection'. It is significant that in the E.M.S. memorandum issued in June 1941 it was already recommended that for the face and fingers the part should be dusted with sulphanilamide powder and over that *tulle gras* should be applied.

Experiences from the clinical field in North Africa reinforced the opinions formed at home. Porritt, writing of the treatment of burns in that field of war remarked 'During the Wavell period practically all burns were tanned in forward areas. The results were depressing in the extreme. Nine out of ten arrived at the base septic and in poor general condition'. To the raw areas left after removal of the tan it was found that the best application was a suspension of sulphanilamide in oil or petroleum jelly. Later many burns were treated by this preparation of sulphanilamide in oil applied on lint and left on for ten to fifteen days, after which skin-grafting was done. Sulphanilamide was found to allow quicker healing than silver-nitrate tan. The possibility of serious symptoms resulting from absorption of toxic doses of sulphanilamide from extensive burnt areas had to be remembered.

At the Pearl Harbour disaster in December 1941, the chief local remedy was one or other of the sulphonamides, though gentian violet, tannic acid and boric acid wet dressings were also used.

In 1942 the scales were more heavily weighted against tannic acid by the proof furnished by Wells, Humphrey and Coll that, when applied to large burnt surfaces that drug was sometimes responsible for a fatal toxaemia consequent on a hepatic necrosis, a fact which Wells had suspected after some experimental work in 1940. To this type of necrosis attention had been called in 1938 by W. C. Wilson, but at that time its connexion with tannic acid was not suspected. It was about the middle of 1942 that Wilson, after his visit to North Africa, came independently to the same conclusion as to the toxicity of tannic acid, and the connexion of that drug with necrosis of the liver was confirmed by Barnes, Rossiter, E. J. Clark, G. R. Cameron and others (1943). This put a stop to the use of tannic acid except for small burns from which little absorption was possible.

With the virtual abandonment of tannic acid and the tendency to abandon all coagulant treatment the field was left open for the trial and adoption of any method which promised to give good clinical results. The trend was towards simple antiseptic dressings. In November 1942 occurred the dreadful civilian disaster at Cocoanut Grove, Boston, in which several hundreds were burnt to death. Oliver Cope (1943) and his colleagues treated more than 100 burnt patients from this holocaust and their experiences led them to conclude that there was no need for a preliminary cleansing of the burn, and that simple boric acid ointment applied to the uncleansed burn gave good results so long as a sulphonamide was administered along with the intravenous plasma. These clinical experiences were supported by the experimental work of Dingwall and Andrus (1944).

At the Glasgow Burns Unit extensive researches were carried out. Here the conclusion was reached that for severe burns the best first-aid treatment was merely to apply a sterile cloth, and to bring the patient to hospital immediately. Cleansing was done without an anaesthetic by gently swabbing with a 1 per cent. solution of 'cetavlon' (Cetyl trimethyl ammonium bromide) which had been recommended by Barnes (1942) as a useful detergent antiseptic. After cleansing the burnt area it was recommended to apply a 3 per cent. sulphonamide cream for extensive burns and a 10 per cent. similar cream for smaller burns (where the risk of absorption was less). Both Colebrook and Oliver Cope stressed the importance of aseptic technique in dressing burns.

Though there was considerable difference of technique in the various hospitals and clinics the general tendency from 1942 to 1944 was to make use of a sulphonamide either locally or generally. In the later North African campaigns, where over 6,000 burns occurred within one year, a sulphonamide was applied either by insufflation or suspended in petroleum jelly.

For armoured fighting vehicles a tin was supplied containing three large squares of gauze impregnated with a 14 per cent. mixture of sulphanilamide in petroleum jelly, sufficient to cover face and both hands; in the forward areas the Stannard glove (made of impervious material) containing 10 g. of sulphanilamide in powder, was applied straight to the burnt hand without any preliminary cleansing, and the men were able to move their fingers painlessly in the mixture of serum and sulphanilamide with which the glove soon became filled. Neville Robinson (Ogilvie, 1943–4) obtained good results by treating burnt hands by the application of triple dye mixed with a 1 in 4 solution of *sapo mollis*. One part of sapo mollis (B.P.) was mixed with 3 parts of water and sterilised by boiling; equal parts of the soap solution and triple dye were then mixed together to form the application which was sprayed on to the affected part by means of a de Vilbis or similar spray in the operating theatre with all due aseptic precautions. Only if the burn were already septic was preliminary irrigation with normal saline carried out before the application of the mixture. To prevent sepsis entering under the edge of the coagulum it was found advisable to cover an area extending at least one inch beyond the obvious periphery of the burn. The triple-dye soft-soap mixture produced a fine soft and supple coagulum, which permitted movement of the fingers and affected joints, and was thus free from the major disadvantage of other coagulants. Robinson's results were impressive and this method of treatment should be remembered. By 1944 the Royal Air Force were recommending the use of the sulphanilamide containing (No. 9) cream of the Glasgow Unit. The formula for this was:

	Percentage
Sulphanilamide	3·0
Cetyl-trimethyl ammon. bromide	1·0
Castor oil	25·0
Beeswax	1·8
Wool fat	1·8
Cetyl alcohol	5·0
Glycerin	10·0
Water	52·4

The last period of the war coincided with the advent of penicillin, and in view of the common streptococcal infection of burns it was inevitable that this drug should be tried as a local application. Florey and Cairns in 1943 reported that a 1 per cent. penicillin in sulphonamide powder had eliminated streptococci from the surfaces of burns, and at the Birmingham Burns Unit Colebrook experimented with various strengths of penicillin either combined with sulphonamide or by itself.

In 1944 the Medical Research Council War Memorandum 12 gave three methods of using penicillin on burns:

(1) Solutions of 100–1,000 units of penicillin per cubic centimetre applied by compress.

(2) A cream with 100–400 units per gramme.

(3) A powder in which the penicillin was diluted to 500–5,000 units per gramme for insufflation.

Penicillin soon proved itself to be an efficient means of getting rid of the streptococci and at the end of the war, either by itself or combined with sulphonamide, was the method of choice for the local treatment of burns.

Though we have related the commonly used methods, necessarily in a succinct manner, there were at the same time other methods used in the various clinics, though none of them ever gained the same vogue as those described above. We shall enumerate them briefly.

The Saline Bath. Continuous or intermittent water or saline baths had been recommended by various authorities at different times during the past fifty years; the method was revived by Blair and Brown in the fourth decade of this century, and in England was developed during the war in a special manner by McIndoe to deal with severe limb burns (1940a and b, 1944). For full details the chapter on the Saline Bath

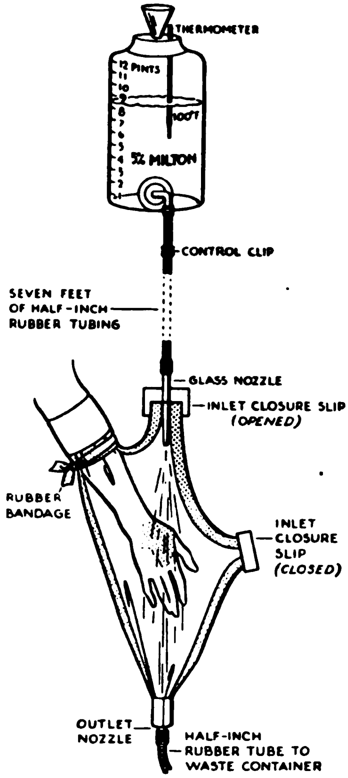

FIG. 1.—Showing method of use of Irrigation Envelope for burn of hand.

Treatment of Burns and the published articles must be consulted but the main points are as follows:

The patient was placed daily in a bath of continuous flowing physiological saline solution at a constant temperature for a period of one hour. The burns were then dusted with sulphanilamide powder and covered with *tulle gras*; in a subsequent bath the *tulle gras* was floated off. It was claimed that the method encouraged movement and the early removal of sloughs. It was used with great success at several centres but was not suitable unless special facilities were provided. At the Glasgow

Royal Infirmary the method was reserved for burns involving the perineum.

The Bunyan-Stannard Irrigation Envelope. The impervious envelope devised by Stannard and Bunyan (1941) permitted the burnt surface to be irrigated by a solution of electrolytic hypochlorite. A similar device was recommended by Douglas in the United States in 1944. The envelopes were water-tight covers of coated silk which enclosed the affected limb. They were sealed proximally but inlet and outlet openings were arranged to permit of the irrigation. It was claimed that this method relieved pain, controlled infection, dissolved necrotic tissue, stimulated repair and led to early restoration of function. The fact that it required special apparatus prevented its being adopted when simpler and equally efficient methods were available. (See Fig 1 and Plate II.)

Pressure Dressings were used extensively particularly by the American surgeons (Siler, Allen, Mason, 1941). Siler (1941) covered the wound with vaseline gauze strips on top of which were placed flat gauze dressings covered by fluffed sponges, and pressure was exerted over this by a folded gauze roll. Koch (1944) showed that the compress prevented loss of fluid, but pointed out that the pressure must not interfere with the circulation, and that increased comfort resulted if the affected limb were elevated. The pressure method was simply a modification which could be applied as an addition to other forms of treatment.

Closed Plaster Method. This method was used to a limited extent. Roulston (1941) treated a series of cases by covering them with gauze impregnated with petroleum jelly, covered by plaster which was changed every ten to fourteen days. At each dressing the joint-positions were changed to prevent contractures. Glen, Gilbert and Drinker (1943) demonstrated that in experimental animals the application of plaster reduced the lymph-flow from the injured area and prevented local oedema. This method was developed by J. M. Barnes for the treatment of burns of the hands in 1942. The hand was cleaned and covered with a layer of fine-mesh bandage and immobilised by the direct application of plaster-of-paris. The hand was fixed in the position of function, i.e. slight dorsiflexion of the wrist, 60 degrees flexion at the metacarpo-phalangeal joints and 45 degrees flexion at the interphalangeal joints with the thumb opposed to the index finger. The limb was elevated to prevent pain and oedema. The initial dressing was left on for ten to twenty-one days and it allowed comfortable transport of the patient.

Mention should be made of Cooper Pendelton's (1943) paraffin wax method of treatment which had been in use for years in some parts of the United States and was brought into use for some of the naval burns at Pearl Harbour. Without any preliminary débridement a melted paraffin-wax mixture was sprayed on to the burn by means of a large ordinary household 'Flit' gun. The reservoir of the gun was placed in a water bath until the contents were liquid and the heat tested against the operator's own hand, and then against an unburnt part of the patient to give him confidence that it was not too hot. It was then sprayed lightly and evenly over the whole burnt area. When the coating wore off it was re-applied. Excessive secretion or debris could be got rid of by washing off the wax with warm sterile water, showers or small hand spray. Free serum drainage was allowed from the edges of the lesion. This method greatly reduced the average daily dressing time in the wards. A slight disadvantage of the method was that it required hot water to be available. The composition of the wax was as follows: Paraffin wax 670, petrolatum 250, liq. petrolati 150, cod liver oil 50, sulphanilamide powder 50, menthol 1, camphor 1, oil of eucalyptus 1.

Other forms of occlusive dressing were tried. Pickrell (1942) used a spray of sulphadiazine with triethanolamine, methyl cellulose and other substances, while Farr (1944) tried a medicated cellophane in order to obtain a transparent yet protective covering film. Coagulated and medicated plasma was experimented with by several observers (Pollock, Macfarlane and others) while Curtis and Brewer (1944) tried films containing casein. None of these dressings came into general use (Plate IV).

An antiseptic application which was for a time used in 1943 was propamidine. Morley and Bentley (1943) stated that the preparation, used in a 0·1 per cent. lanette wax or water-soluble jelly base, formed an ideal first-aid preparation for burns. Dressings needed to be changed at forty-eight hour intervals, but it was unwise to continue its application for more than ten days at a time. Streptococci were eliminated from the wound by this means. With the introduction of penicillin propamidine fell into disuse.

Excision of the Burnt Area. For certain cases in which it was obvious that the whole thickness of the skin was destroyed, Wilms (1901) and Wells (1929) recommended immediate excision of the affected area of skin and prompt grafting—a method which provided an ideal means of treatment. Early in this war Oliver Cope in the U.S.A. and Gillies in the United Kingdom advocated this treatment for certain selected cases. Colebrook also stated that many deep burns of circumscribed and limited extent could be excised and grafted on the day of the accident with great advantage to the patient; but he also added that it needed great experience to judge which particular burn was suitable for this form of treatment. The method could only be considered suitable for use at a centre where there was a staff with special experience of burns.

During the five years of the war, by a process of trial and error, the general conclusion was reached that simplicity of both first-aid and definitive treatment gave best results. For first aid the application of vaseline gauze, sulphanilamide-vaseline gauze or merely a sterile or cleanly laundered cloth proved sufficient. For plenary or definitive treatment, after gentle cleansing under an anaesthetic (sometimes merely under the influence of morphine), or in some clinics without any preliminary cleansing, the careful application of one of the same dressings, or better still a penicillin ointment, or sulphanilamide-penicillin ointment gave best results. The coagulants were abandoned except for certain cases in the Navy where the triple dye contained in tubes proved very convenient.

Burns of the Air-passages

Burns of the air-passages gave rise to special problems. Hot gases, steam, or even flame might be inhaled or be forced into the air-passages. The patient did not always realise that a burn was responsible for the ensuing pain in the mouth and throat, difficulty in swallowing and (if the larynx and bronchi were involved) hoarseness and difficulty in breathing. In severe cases the air passages became filled with frothy fluid and mucus, and asphyxia gradually developed with anxiety lapsing into apathy and coma. Oedema of the glottis with stridor sometimes developed. If the patient survived, sepsis of the affected areas soon supervened.

Burns of the mouth, fauces and pharynx soon became covered with tenacious mucus which covered a red, raw, and swollen surface. The course of the case revealed whether the lower air passages had been affected by the burn.

Treatment of these cases was particularly difficult. Usually there were burns of the skin also and the giving of plasma, so essential for skin-burns, was likely to cause increased exudation into the air passages and increase the danger of asphyxia. Transfusion had sometimes to be somewhat delayed, and given very slowly, as long as three-quarters of an hour being taken over the administration of the first pint, and subsequently slower rates used. Tracheotomy was performed promptly if laryngeal obstruction developed. In every case the anoxia needed to be treated by the prompt and continued administration of oxygen. When the nasal passages were burned, the nasal BLB mask could not be used.

Whenever possible, accompanying skin burns were treated without the use of general anaesthesia. Even intravenous anaesthesia was not without danger. If general anaesthesia had to be used, endo-tracheal nitrous-oxide–oxygen given by a skilled anaesthetist offered the best chance for the patient.

3. PREVENTION AND TREATMENT OF SHOCK BY REPLACEMENT OF FLUID

The diminution of the volume of circulating blood has long been known to be an accompaniment of shock. One of the most important advances in the treatment of burns was due to the fact that it was recognised that the shock of burns was accompanied by, and perhaps largely due to, the withdrawal of fluid from the circulation, either by external loss, or by a process of oedema into the parts affected. This led to the natural corollary that one should replace the lost fluid. It had indeed been known for many years that burns were accompanied by a great loss of albuminous fluid which led to a concentration of the blood, but no therapeutic action had followed this knowledge. So long ago as 1881 Tappeiner (quoted by Harkins) had written:

> 'I believe therefore that the cause of death of every case of burns involving an extensive amount of skin, which do not immediately destroy life, is characterised by a blood-concentration due to the transudation of albuminous fluid in the burnt skin areas, and this demands the therapeutic measure of transfusion, particularly of a serous fluid'.

It is a remarkable fact that many later observers confirmed this finding without carrying out the final recommendation, and it was left to the necessities of the war to put this measure to an adequate clinical test. It must, however, be remembered that before this war there was no Blood Transfusion Service available to supply large quantities of plasma.

Cuthbertson (1945) and others showed that an excess of protein was lost from the body of a burnt patient not only by reason of the destroyed skin and other tissues, and the exudate collected in the blebs and oedematous tissues, but also on account of the increase in nitrogenous metabolism which causes an excessive breakdown of protein after any form of injury. This increase in metabolism was greater from the fourth to the eighth day after the occurrence of the burn or other injury. He calculated that in the case of a burn involving the whole thickness of the skin over 60 per cent. of the body, there would be a loss of 2·0 kg. of body protein during the first ten days following injury. The negative nitrogen balance could often be made good by a sufficient increase in the intake of protein and carbohydrate in the diet, but when the patient's appetite failed there was the greater need for the replacement of protein by the intravenous injection of serum, plasma or blood.

A few years before the war Weiner, Rowlette and Elman (1936) found that within an hour or two of infliction of a burn a blood-count showed that the red cells increased to values of six million or more per c.mm.; they concluded that in severe burns large amounts of protein were needed, that water, electrolytes and glucose alone were not only ineffective but might lead to deleterious results, and that the injection of blood-plasma was more efficacious than whole blood. In 1939 Russell Elkinton tried both blood and plasma to combat the loss of fluid in some cases of burns, and came to the conclusion that 'plasma transfusion to replace the loss of plasma and its protein would seem to be the most rational therapy'.

The subject was investigated by Black, at Oxford in 1940, who not only confirmed the value of plasma, but worked out a formula whereby the amount of plasma needed could be computed. As a rough estimate Black stated that in severe burns about one litre of plasma should be given before operation, and about two litres after operation, given at the rate of about 100 drops a minute. It should be remembered that whole blood might be needed in patients showing a notable anaemia. Many if not most burnt patients developed some anaemia; a reduction in the red-cell count was the rule following the initial period of haemo-concentration, and was attributed to haemolysis due to the actual burn. Later anaemia might be due to sepsis, to depletion of body-protein, or even, as Cuthbertson suggested, to defective function of the bone-marrow.

It was noted by several observers that the loss of fluid began very soon after the infliction of the burn. Penberthy (1936) demonstrated that blood-concentration and loss of fluid began within an hour of the burn and continued for twenty-four or forty-eight hours. The amount lost might be many litres. The clinical value of plasma transfusion in burns was very soon clearly demonstrated; Wilson, Harkins, Romence and Lam, Gibson and Brown all showed how this fluid replacement would either entirely prevent, or at least mitigate burn-shock. As Gibson and Brown (1944) wrote, 'the almost complete absence of shock manifestations in patients with burns of 40–50 per cent. of the body surface, in whom replacement was adequate, is an eloquent tribute to the therapeutic usefulness of this treatment of burns'.

It was found that prevention of shock by prophylactic administration of plasma was more efficacious than curing shock when once it had developed. Efforts were made to estimate the amount of plasma necessary for any particular case. Elkington, Wolff and Lee (1940) evolved one formula and Black (1940) another, but both these were rather too involved. Harkins (1942) recommended the repeated observation of the blood-concentration and said the simplest technique was to give 100 c.cm. of plasma for every point the haematocrit reading was above 45 (for adults). If the plasma-protein level were below normal, then an additional 25 per cent. should be added for every gramme the protein level was below 6 g. per 100 c.cm. An alternative way was to give 50 c.cm. of plasma for every point the haemoglobin was above the normal 100. When red cell counts were the basis for calculation Harkins advised 50 c.cm. plasma should be given for every 100,000 the red cells exceed 5 million. For first-aid treatment when laboratory assistance was not handy, 50 c.cm. plasma for every 1 per cent. of the body surface affected by a blistering burn was advised. The method of estimating the extent of skin-surface devised by Berkow (1931) was recommended (Fig. 2). Low blood-pressure as an indication for fluid replacement was misleading, for severely shocked patients occasionally showed a normal or high blood-pressure and by the time the blood-presssure fell it might be too late to reverse the process.

At the Burns Unit at Glasgow it was found necessary to give much larger doses of plasma than would have been given by the adoption of haematocrit readings as a guide; by the Harkins formula the amounts were much too small to treat shock effectively. Amounts of plasma varying from 2 even up to 7 litres were found necessary according to the extent and severity of the burns. The plasma was given intravenously through a cannula by the drip method, and it was found necessary to give the first few pints at a quicker rate than the later amounts. This

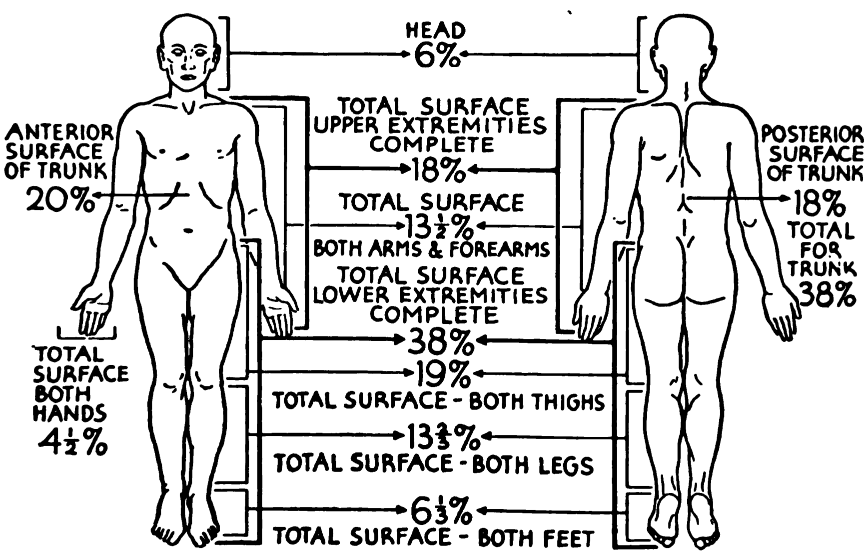

FIG. 2.—Diagram showing how to calculate the percentage of body surface involved in any burnt area. (After Berkow.)

necessity of giving the first instalment of plasma at a fairly quick rate was a general clinical finding everywhere and was specially commented on by Ogilvie (1943–4) in North Africa. Ogilvie found that the plasma transfusion usually successfully combated burn-shock. It was found that 8 to 12 pints might be required within the first forty-eight hours. Wilson pointed out that it was safer to give plasma than to withhold it on theoretical considerations; he also stressed the point that, if plasma were not immediately available, blood was always preferable to saline or glucose saline, for haemoconcentration in itself was not of great importance.

At the Glasgow Burns Unit attempts were made to ascertain clinically which burn cases required replacement therapy and which would get well without it. It was found that transfusion was necessary for adults in whom 15 per cent. and for children in whom 5–10 per cent. of the body surface was affected. The following practical points were stressed. Transfusion should be begun as early as possible and given sufficiently rapidly to restore the blood-volume to its presumed original level. The rate should be controlled, when possible, by repeated blood-estimations. In the absence of blood-readings the blood-pressure and pulse-rate might be used as criteria, but they were less reliable. Care needed to be taken, particularly in children, not to give the transfusion too quickly. The replacement of fluid should be continued for at least 24 hours after the occurrence of the burn, even though the blood-readings were normal. Sometimes it was wise to continue the injection of glucose after the plasma had been discontinued. In North Africa and other fields of active service the combating of burn-shock by the administration of plasma was carried out in advanced units, as well as in base hospitals, both efficiently and successfully and undoubtedly resulted in the saving of many lives.

We may here usefully quote some advice from the Memorandum No. 6 on the treatment of burns, compiled by the Consulting Surgeon in North Africa in 1943:

'If plasma or serum is not available whole blood should be used during the first 48 hours in preference to saline or glucose-saline infusions. After 48 hours when the dangerous shock has passed and the injured capillaries are no longer abnormally permeable, intravenous infusions of saline or glucose-saline can be used to augment fluid administration.

'Extensively burned men require large amounts of fluid by mouth. The urinary output should be measured and charted; an output of 1,500 c.cm. in 24 hours should be aimed at, and it should not be allowed to fall below 700 c.cm. When extra fluid is given intravenously for more than two days, attention must be paid to the salt balance. In hot climates there is often a chloride deficiency and normal saline (0·8 per cent. NaCl) or normal saline with 5 per cent. glucose in distilled water should be given till chlorides appear in the urine. Thereafter three pints of glucose in distilled water should be given to every one of saline or saline-glucose.'

4. PREVENTION OF SEPSIS

In former days one of the common causes of death from burns was from septic infection of the affected area and the consequent complications. During the war many efforts were made to minimise or prevent such sepsis and one of the major advances was a near approach to this achievement. If sepsis were to be avoided the pathogenic organisms already on the skin must be destroyed, and precautions taken to prevent any further pathogens from reaching the burnt area. The surface of a burnt area is likely to be sterilised by the same heat which causes the burn, and this consideration led some surgeons to maintain that there was no need to subject the patient to the ordeal of an anaesthetic in order to cleanse the surface of the burn, or even of a cleansing without an anaesthetic. Oliver Cope and his colleagues entirely omitted the preliminary cleansing and applied boric acid dressings immediately and obtained good results. The burns at Pearl Harbour were given no preliminary débridement nor cleansing and the simple first-aid dressing served as plenary treatment; sepsis was combated (as at the Cocoanut Grove disaster) by giving sulphonamides internally (intravenously). Yet throughout the war most surgeons continued to perform a preliminary cleansing of the surface before applying the definitive dressing. Of course the barbarous and shock-producing method whereby the surface was scrubbed with a nail-brush was abandoned, and in its place a gentle swabbing with lint soaked in a detergent or antiseptic solution, or merely in saline solution, was instituted; as a rule an anaesthetic was given, though in the Royal Air Force sometimes morphine was found sufficient. The dead tissue was removed and in some cases the loose epithelium over blisters cut away. After Barnes (1942) had pointed out the special merits of cetavlon as an antiseptic and detergent Colebrook (1944) proved that these claims were borne out by the clinical trials, in which a 1 per cent. solution was most useful for the preliminary cleansing of burns. Cetavlon was thereafter largely used in the Services for this purpose.

It was at one time thought that the coagulant method of treating burns prevented sepsis, but this was soon found not to be true, for sepsis sometimes occurred under the coagulum. When the surface of a burn was already septic many were the ways adopted in order to get rid of the pathogenic organisms. Various antiseptic applications were tried. Acriflavine, boric acid, hypochlorite solution, cod liver oil, propamidine and the sulphonamide preparations each had their advocates. Following on the work of Colebrook, however, clinical opinion gradually decided in favour of some form of sulphonamide application for the main dressing, as has already been related in the previous section. After the advent of penicillin that drug was at first added to a sulphonamide ointment for application to burns, but later it was found that a penicillin cream could by itself rid the burnt and septic area of pathogenic streptococci within a few days. Colebrook found that an adequate local application of either sulphonamides or penicillin obviated the need for systemic administration of either of these drugs.

Oliver Cope and Colebrook, and in fact all careful observers, stressed the importance of adopting every possible aseptic precaution in dressing burns, so as to avoid the contamination of the area by pathogens derived from the person of the dresser, from neighbouring septic wounds or from blankets or clothing. The wearing of sterile gowns, masks and gloves by the dresser, the adoption of the no-touch technique, the (so far as possible) separation of burn cases from the neighbourhood of septic cases, were insisted upon.

The fitting culmination of the war efforts in the treatment of burns was achieved at the Birmingham Accident Hospital where, in the last two years of the war, it was proved by Colebrook and his colleagues that the surface of a burn could be rendered approximately aseptic within a few days, and kept aseptic until healing was sufficient to justify grafting. After cleansing of the burn and adequate replacement of fluid by plasma the burnt surface was treated, later in the war, by local application of penicillin-sulphonamide cream, and later by penicillin cream alone. Thereafter dressings were infrequent and were always carried out in a special aseptic chamber devised by Bourdillon and put into practice by Colebrook. This chamber was continuously supplied with an abundant stream of twice-filtered and warmed air (1,000 cubic feet per minute) which escaped by a single exit and carried with it any particles and bacteria which might have been liberated from the patient's bandages and dressings. An interval of five minutes was allowed between one patient's dressing and the next, so that the air might be re-cleansed. Care was taken that the whole affected area was well covered by the dressing, and soaked dressings were never allowed to remain uncovered. This was a necessary precaution, for it was proved that when a dressing is soaked through by serum it is virtually transformed into a semi-solid mass of culture medium, and pathogens conveyed to the outer bandages, either from contact or from bedding or from the air, will readily grow through to the underlying wound. This can happen within a few hours. The interposition of a sheet of cellophane prevented such an accident.

By the above means at the Birmingham Accident Clinic the treatment of burns was revolutionised. Within a few days clinical manifestation of any streptococcal infection was abolished and silent infections were reduced to a negligible minimum. Healing was rapid and painless, grafting could be undertaken much earlier, and the time of stay in hospital was considerably shortened.

This remarkable achievement points the way to methods whereby burns may rapidly be converted into clean granulating wounds. Though the aseptic chamber may not be practicable in any but special centres the lesson is clear that aseptic methods in dressing burns are a necessity. The lesson of the war may, it is to be hoped, lead to the formation of special burn-units in every large centre of population, so that these serious injuries may be treated with expert skill by a team of doctors who can put into practice the important lessons taught by the War of 1939–45.

5. SKIN GRAFTING FOR BURNS

During the course of the war it was increasingly realised that the final result was much better in proportion to the rate at which the raw surface was covered by new epithelium. Large exposed raw surfaces led to diminution of general strength by the continued loss of fluid from the surface, and delay in healing caused increased formation of fibrous tissue and great contracture, deformity and limitation of movement. Clarkson (1946) pointed out that almost every patient with 1,000 sq. cm. or more of raw granulating surface remained constitutionally ill until the raw area was reduced substantially below that figure; he noted also that the anaemia which, in cases of extensive skin-loss, commenced within a week of its occurrence, could not be fully remedied by blood transfusion until a considerable part of the raw surface was covered by grafting.

The problem of replacing burnt skin or covering raw surfaces with new skin was at first complicated by the almost constant presence of septic organisms, particularly the streptococcus, on the exposed surfaces. There were, of course, occasions on which it was possible to carry out primary excision of a burnt area of skin with immediate grafting of the underlying raw area, but these opportunities were not common. Early in the war two observations permitted earlier skin grafting to be performed with success. In March 1941, Colebrook announced that the local application of a sulphonamide to a septic surface would render it almost free from infecting streptococci within two or three days. In the same year Mowlem, a strong advocate of early skin grafting, discovered that a large proportion of successful skin-grafts could be obtained even on a septic burn-surface if a layer of sulphanilamide were placed between the graft and the septic granulations. The advent of penicillin made the problem of getting rid of the streptococcus relatively simple, and thereafter surfaces could be prepared so that a graft would be successful in almost every case. The continued use of penicillin or sulphonamides created conditions very favourable to the growth of *B. pyocyaneus* and *B. proteus*, and the presence of these organisms often necessitated the use of 'postage-grafts' instead of sheet grafts. Even when penicillin was used locally it was considered a wise or even necessary procedure to make sure, by culture made a day or two before grafting, that the surface was free from infection with the haemolytic streptococcus.

During the course of the war the old classification of burns devised by Dupuytren was criticised and simpler distinctions were put forward. The Germans and Americans described three degrees, of which the first was a simple erythema, the second vesication with or without involvement of the corium, and the third going down to and destroying part of the subcutaneous tissues. Most extensive burns vary in depth in different parts and in any case it was frequently difficult to determine clinically between the second and third degree as described above. There were several attempts made to distinguish the depth of a burn by staining the surface with dyes. J. A. Dingwall (1943) injected 10 c.cm. of 20 per cent. sodium fluorescein intravenously and found that the deeply burnt patches showed up blue-black, while the areas still covered with any live epithelium were revealed as yellow-green patches. A simpler method was that of Patey and Scarff (1944) who found that areas of complete dermal destruction could be demonstrated by applying a modified Van Gieson's stain. The stain was a 0·2 per cent. solution of acid fuchsin in a half-saturated solution of picric acid in water (about 1 per cent.). If there was still a layer of intact epithelium, the area stained red; with other degrees of dermal necrosis a yellowish tinge appeared, while with marked necrosis the area showed bright yellow without any red. In practice the classification of burns into three degrees was little used, for the important clinical distinction lay between superficial burns in which there was destruction of epidermis with or without part of the dermis, and deep burns in which the whole thickness of the skin had been destroyed. Staining methods of determining the depth of a burn were in fact little used, for in any case after about a fortnight the areas of full-skin destruction could be accurately assessed by clinical examination. Where the condition of the patient permitted, it was then a wise procedure to excise the sloughs under anaesthesia and to graft the raw surface in one or more stages, so that the whole area was in suitable circumstances covered within about a month after the injury. When the condition of the patient did not warrant operative removal of sloughing skin, every encouragement was given for the natural separation of the sloughs. Saline baths, careful dressing and removal of marginal crusts and dead matter and sometimes the use of hypochlorite solutions and local application of a 5 per cent. solution of trypsin were of value.

With regard to the technique of skin-grafting there were several advances. Though, as Mowlem (1944) pointed out, whole thickness grafts were needed where colour and texture of the skin and freedom of contracture were important, as for example on the face or hands, yet the common type of graft used was that of split skin. The cutting of the graft was made more easy by the use of the dermatome which was described by Padgett (1939) in the very year that war broke out. This ingenious instrument allowed the use of donor areas which would not otherwise have been available, e.g. the skin of the abdomen and the back of the chest.

It was found that autogenous grafts were generally necessary. Grafts taken even from homologous donors were of very limited value (Medawar, 1943). A method was devised whereby a raw surface could be more rapidly healed; this consisted in cutting the split-skin graft into numerous equal-sized rectangular pieces about the size of small postage stamps and placing them symmetrically over the raw surface. By this means the growing edges of the grafts were greatly extended and drainage of any exuding fluid assisted.

Sano (1943) suggested a method of fixation of skin grafts by means of plasma and white-cell extract. According to Clarkson the same effect could be obtained by applying to the deep surface of the graft a 50 per cent. solution of gum acacia. The former method had the disadvantage that it necessitated the withdrawal of blood from the patient to provide the plasma and cell extract. The method was later modified by Clark *et al.* (1945), to use human plasma and thrombin obtained from the Blood Transfusion Service.

During the course of the war it was sometimes found useful to take advantage of the fact that skin-grafts which had been cut could be kept in cold storage for two or three weeks without losing their vitality and ability to grow when transplanted. This facility often prevented the waste of skin-grafts, which, after being cut, could not be immediately utilised (Webster, 1944 a and b).

There is no doubt that the healing of raw granulating surfaces left by burns was very greatly facilitated and the time of healing considerably shortened by early skin-grafting and improvement in technique.

At the same time that healing was expedited by grafting, the function of the affected part was restored by early activity, particularly in the case of the hands. Oedema which tended to hamper movement was diminished by elevation, movement of the part was encouraged and the patient was allowed out of bed as soon as possible, often long before skin-grafting was feasible. By these means a much greater and more rapid restoration of function was effected.

CHEMICAL BURNS

Acids and Alkalis. Chemical burns were more common than in any previous war, for many chemical works and buildings containing strong acids and alkalis were bombed and the caustic fluid scattered on to persons nearby. As Wakeley pointed out, both acids and alkalis were often stored in the same building and in the confusion of an air raid it was frequently impossible to differentiate between them to enable the natural antidote to be applied. The essential treatment was to wash the burnt area in running water. So that this might be done promptly, some establishments kept handy a large deep porcelain trough through which water was constantly running, and in which the affected person might plunge his burnt hand, arm, face, or even the whole body in order to dilute the caustic fluid quickly and freely. Otherwise a running tap would serve the same purpose. If the exact nature of the caustic fluid were known the chemical antidote could be applied. The local treatment of the burn then followed the usual lines for thermal burns.

Phosphorus Burns. Phosphorus was used as a constituent part of incendiary bombs and tracer bullets and as a consequence there were occasional cases of phosphorus burns. The phosphorus was sometimes used as a mixture of the red and yellow solid varieties, but in other instances (as in some incendiary bombs) it was (together with rubber) dissolved in carbon-bisulphide solution. Phosphorus smoke screens, even though they sometimes contained small particles of unaltered phosphorus, were usually not capable of causing burns, but the bursting of a smoke bomb was known occasionally to cause phosphorus burns among those in the vicinity. Injuries caused by tracer bullets led to a deposit of phosphorus in the deeper tissues and, according to Flury (1944), cases of generalised poisoning sometimes occurred in the Luftwaffe from this cause. Very dramatic was the incident recounted by Squadron Leader Meekison (Livingston, 1948) who extracted a bullet from a wound in an airman's thigh, whereupon the bullet, on exposure to air, smoked and burst into flame which required immersion in the hand-lotion bowl for its extinction; this surprising occurrence caused greater precautions to be taken in regard to anaesthetics. At the R.A.F. Hospital at Ely about two dozen cases of wounds burnt by the phosphorus in the bullets occurred in the course of a few months in 1942. In 1942 Blaxland published an account of a case of fatal phosphorus poisoning resulting from a wound caused by an explosive bullet containing phosphorus. Identical bullets were found to contain a charge of high explosive and 3½ gr. of phosphorus, i.e. double the minimum fatal dose. At the necropsy the cut surface of the liver was of a dull yellow colour and microscopical section showed extensive necrosis with fatty degeneration.

The presence of phosphorus in a wound could usually be detected by the characteristic acrid pungent smell, sometimes by the emission of fumes and, in the dark, by the presence of luminosity. At the wound of entry of a tracer bullet there was usually a dark grey, brown or black scab. Affected muscle was stained grey and smoked on exposure. Healing was slower than normal.

The treatment of phosphorus burns had for its objects:

(1) the prevention of further burning by keeping the part moist;
(2) the removal as soon as possible of any particles of phosphorus on the skin or in the wound;
(3) the removal or chemical change of any remaining element by suitable applications; and
(4) the application of a dressing for the burn which always resulted. In all cases it was wise to take repeated blood counts and to give blood transfusions when needed.

(1) The first essential was to keep the part moist so that the phosphorus could not oxidise and burn. The affected part was, when possible, immersed in water or alternatively moist cloths were applied. No fibrous or dry material was allowed to touch the wound. The importance of this precaution was emphasised by the fact mentioned above that on one occasion, after it had been extracted from a patient's thigh, a bullet smoked, burst into flame and had to be immersed in lotion. This incident pointed also to the need for special precaution in the

matter of choice of anaesthetic when dealing with a wound contaminated with phosphorus.

(2) While the part was immersed, any particles of phosphorus remaining in the wound were removed with the aid of gauze held in forceps. The method of Obermer (1943), who advised that the skin should be anaesthetised by local infiltration and then scraped with a scalpel, did not find general acceptance.

(3) There was fairly general agreement that the best initial treatment of the part was with a solution of sodium bicarbonate—2 teaspoonfuls to the pint of water. Instead of a solution, Godding and Notton (1942) recommended the application of an alkaline powder which was applied from a dredger and moistened. The powder was applied till effervescence ceased. (The constitution of the powder was MgO 10, borax 5, sodii bicarb 85.) After treatment by the alkaline solution or paste most observers recommended the use of a solution of copper sulphate (1 or 2 per cent.) with which the affected part was thoroughly washed or rubbed; this destroyed minute particles of phosphorus and rendered larger particles obvious by blackening them so that they could be more easily removed mechanically. Jones (1942) recommended the further soaking of the part in a solution of bicarbonate of soda for half an hour.

(4) The part was then dressed as for a thermal burn. When the phosphorus was in solution with carbon-bisulphide and rubber, Goldblatt and Oakeshott (1943) recommended a special formula containing copper in an oil-soluble form. The constitution was:

Copper oleate . .	25 g.
dissolved in trichlorethylene	35 g.
Turkey red oil . .	25 g.
Surgical spirit . .	15 g. (when rubber present)

One of the most serious incidents involving phosphorus burns occurred in the Mediterranean Area. On August 4, 1943, a fire broke out among some phosphorus smoke floats in the forward cargo hold of a merchant ship in harbour at Algiers. For safety the ship was towed outside the harbour, and the destroyer *Arrow* went alongside her to assist. An explosion then took place which disintegrated the merchant ship and caused a fire in H.M.S. *Arrow*; 33 of the ship's company of the *Arrow* were killed outright and 58 survivors were taken at once to the hospital ship a short distance away, of whom 38 were suffering with extensive first, second and third degree phosphorus burns. While these were on board the hospital ship it was noted that the hair, skin and clothes were actually smoking. Treatment was carried out by wet saline dressings varied by copper sulphate compresses, after which triple dye and sulphonamide powder were applied in that order. The majority were comfortable within twenty-four hours, and were then evacuated so that the later results were not known. The surgeon who dealt with them recorded the urgent need for removing the clothing and hair of such cases at once, and for applying wet dressings liberally before undertaking more extensive examination. He also commented on the absence of that psychological disturbance which was frequently associated with burns received in action.

In 1943 two cases of phosphorus burn were treated at Rooksdown House Centre. The account of the incident is appended:

> Two children, aged 7 and 8, were accidentally burnt while playing with a phosphorus bomb on July 27, 1943. They were both admitted to Winchester Hospital and the burns were washed with sodium-bicarbonate and dressed with wet sodium-bicarbonate dressings. They were transferred immediately to Rooksdown House. Child A had extensive second degree burns on the backs of the legs and thighs and a patch of full thickness destruction on the back of the left thigh about 4 in. square. Child B was more severely burned and had lost the skin from the greater part of the back of the right leg from the gluteal region to the ankle and on the left side from the gluteal region to the knee. She also had splash burns on the face and right hand and arm. On admission to Rooksdown House the burns were cleaned with 1 per cent. copper sulphate and in the case of the more seriously burned child active phosphorus was still found in many areas. This was neutralised satisfactorily with the copper sulphate. The rate of healing was slow in both cases and multiple grafting operations were done but it was not until December of the same year that epithelialisation was complete. The scars which arose from these burns were in both cases keloidal and unstable. Active contraction took place necessitating re-excision and Thiersch grafting in one case and X-ray therapy in the other.

ELECTRIC BURNS

The increased use of electricity in the working of the various mechanical devices necessary for the efficient functioning of a modern warship was responsible for an increased number of electrical burns, particularly in the Navy. The damage done by the electric current followed the course which it took through the body from its entry to its exit. A good description of these burns was given by Wakeley (1941). The severity of the lesion depended upon the amount of electric energy, the area of contact and the duration of current. At the point of entry of the current it left its mark as a small superficial greyish-white area or a deeper sharply defined area of necrosis. In severer cases a larger area of gangrene occurred. It was noted that the lesions tended to enlarge for the first two or three weeks. Wakeley described a lesion which he called *electrical metallisation* due to impregnation of the epidermis by volatilised metal. This occurred when the burn was due to an electric light arc where the metal was molten and was carried into the tissues with the current. The affected skin was discoloured by the fine metallic particles which, being in the tissues, could not be washed away. The slighter degrees were treated by the application of gentian violet jelly. In more severe cases shock was a feature which demanded immediate treatment. Where necrosis of a finger occurred amputation was necessary. Apart from this the local lesions were treated as for thermal burns.

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(ii)

The Saline Bath Treatment of Burns

BY G. H. MORLEY
O.B.E., F.R.C.S.

Early in the war doubt was cast upon the wisdom of treating certain burns by coagulation with tannic acid. Several bad results were noticed at the evacuation from Dunkirk, but the interesting observation was made that many burnt patients who had been immersed in sea-water suffered less from the effects of infection than was expected. This was one of the factors which led to the extensive trial, especially in the Air Force, of the saline method of treatment of burns. An experimental saline bath had already been installed at the Queen Victoria Hospital, East Grinstead, and, as a result of the work carried on there under E.M.S. auspices, a more rational method of treatment was evolved. In April 1940, the Consultant in Plastic Surgery to the R.A.F., on the basis of this experience, obtained through the Director-General of Medical Services an order prohibiting the use of coagulants on the face and hands of R.A.F. flying personnel. This prohibition was later extended to other Services, not without considerable opposition.

The summer of 1940 brought the air Battle of Britain and the exposure of valuable aircrews to the effects of fire in the air. High-speed aircraft on fire can be compared with a gigantic petrol blow-lamp—reservoirs of high-octane petrol and glycol being ignited and, in the enclosed fuselage of the aircraft, blown into intense heat by the blast of air from the airspeed of the machine. The face and hands of the pilot were often unprotected, the backs of the hands being most exposed during manipulation of the cover of the enclosed cockpit in the process of escape by parachute. A type of burn resulted which had not been previously experienced, the airman's burn.

THE AIRMAN'S BURN

This is a burn of almost unvarying characteristics due to the sudden exposure of unprotected parts of the body to intense, dry heat or to flame, as though the entire patient was thrust into a furnace for a few seconds and withdrawn. The distribution is characteristic:

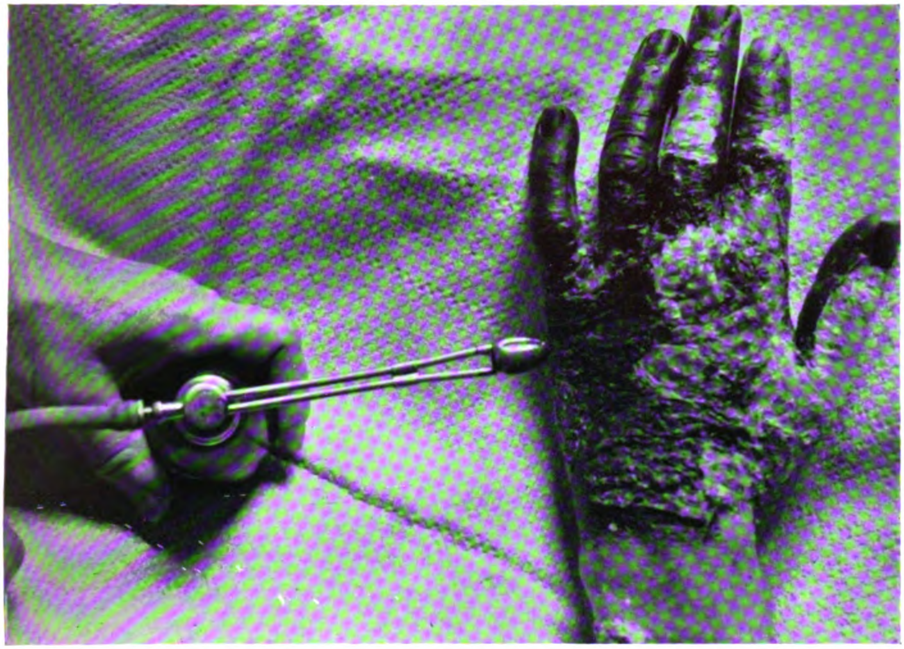

PLATE I. Application of triple dye to burnt hand of Airman.

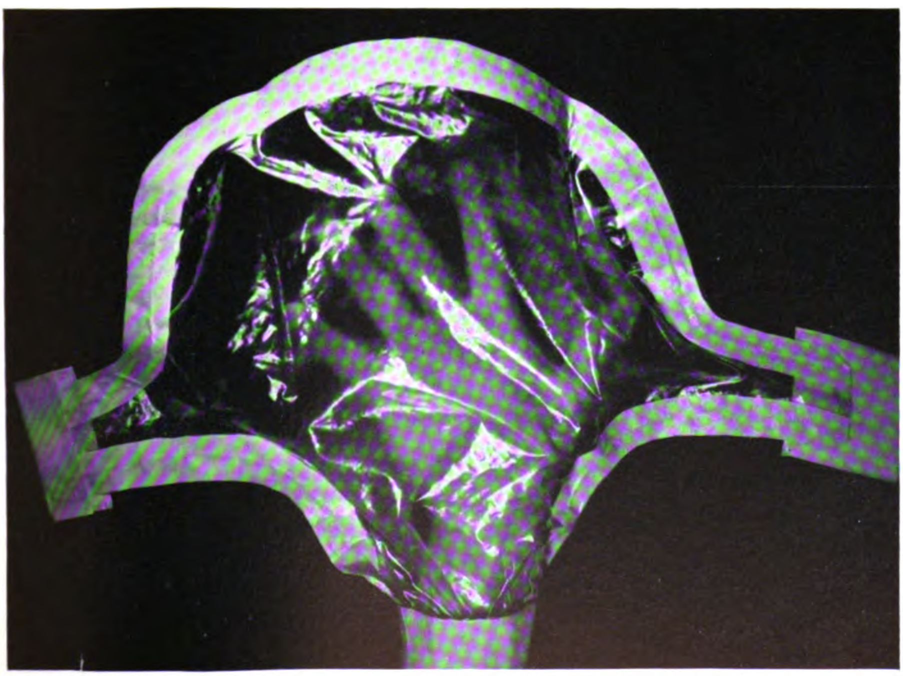

PLATE II. Irrigation Envelope applied to the hand.

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(*a*)

Burn of hand treated with tannic acid showing terminal necrosis.

(*b*)

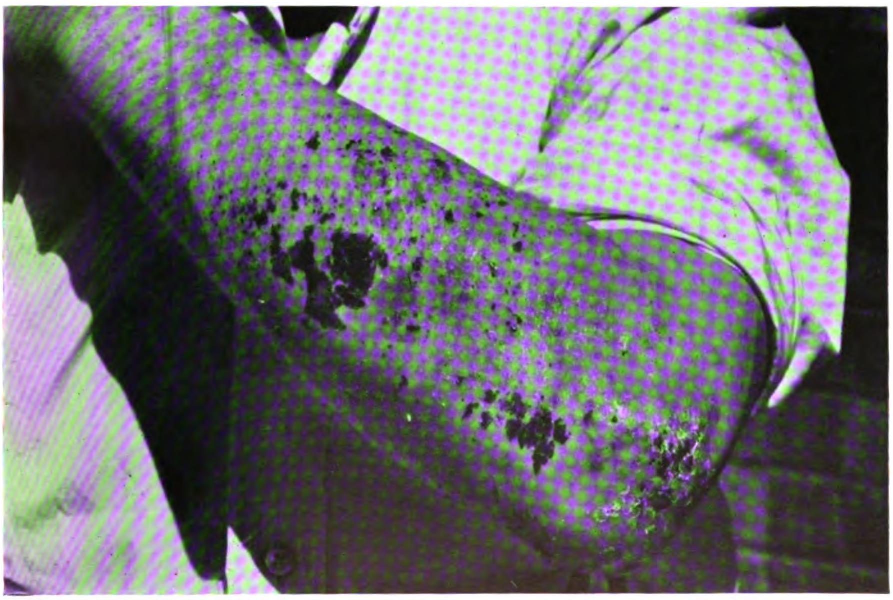
Skiagram of hand shown in preceding picture.

(*c*)

Keloid scarring of hands due to second- and third-degree burns. This could have been prevented by early skin grafting.

PLATE III.

This patient received the above condition of the entire forearm from what is known as a splash burn. A portion of the burnt area was denuded of its blister covering. The same coated with shop dirt can be seen curled up as dark streaks. All the blisters had collapsed and the serum contents spread over the burn area. The shiny appearance is due to the cellophane. No cleansing of any kind was carried out—merely the free application of albumin.



The same case twelve days later. Most of the cellophane removed for photographic purposes. Some remains as small dark patches. This man returned to hard work on the fifteenth day. Such cases treated by the methods at that time in current use, tannic acid compress etc., usually took as many weeks to heal.

PLATE IV.

R.N. School of Photography, Portsmouth

PLATE V. Protective Mask used in the Navy to protect from the back-flash of guns.

PLATE VI. (1) Burns of Airman's hands.

PLATE VII. (2) Burns of Airman's hands.

Colour Photographs by Hennell
of the Metal Box Company, Ltd.

PLATE VIII. (3). Burns of Airman's hands (but different man from (1) and (2)).

PLATE IX. (4) Burns of Airman's hands.

Colour photographs by Hennell
of the Metal Box Company, Ltd.

Removing tulle gras dressings ; saline solution keeps uncovered areas moist.

PLATE X.

Nursing Mirror

Attending to burnt areas while other areas are kept moist.

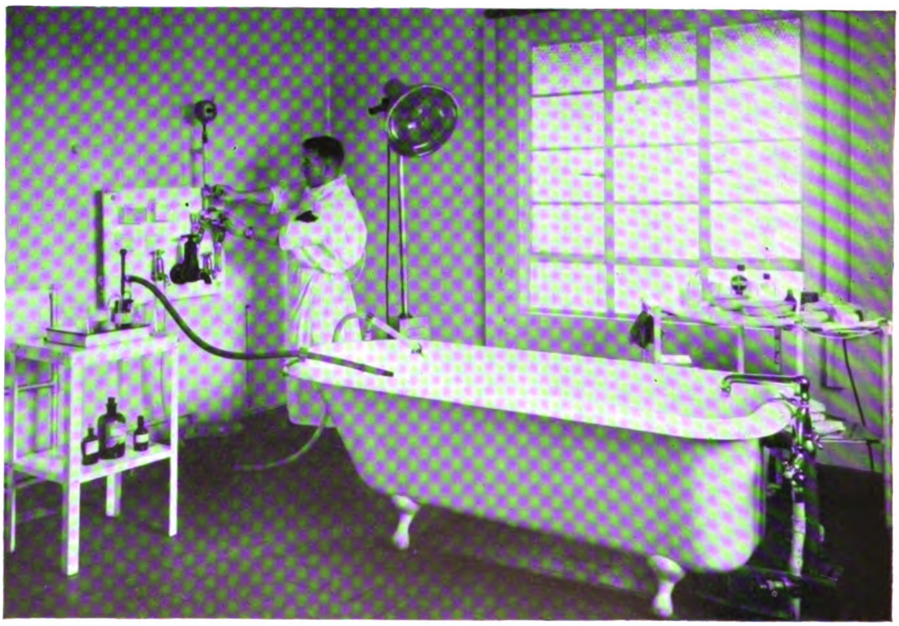
PLATE XI.

Nursing Mirror

Nursing Mirror

Out of the bath and on to a bed covered with a rubber sheet.

PLATE XII.



Nursing Mirror

PLATE XIII. Pix Bath used showing thermostatic control on the wall.

(i) Both wrists and hands, particularly the backs, and the fingers, but often the entire surface of the hands. If gloves have been worn, only the wrists are involved. Holes in glove fingers have been responsible for severe localised burns, the protected areas escaping. The importance of wearing intact gloves is therefore obvious.

(ii) The face in the 'Helmet area'. When goggles are pushed back, the forehead, eyebrows and eyelids may be severely burned. Usually, the eyelids near the lash edges escape. The eyes themselves are not often burned. The oxygen mask may protect the mouth but the cheeks, nose and ears are often involved.

(iii) The neck between the chin and collar, extending on both sides to the mastoid area.

(iv) The anterior and inner surfaces of the thighs if the trousers are thin. The lower legs between the trousers and boot-tops if flying boots are not properly adjusted. These areas are less often involved than the hands, face and neck.

Deep, searing burns, usually of third degree, involved areas of tremendous functional importance—the hands and the eyelids in particular. The possibility of great functional disability in these areas was so strong that special treatment had to be instituted for them, and this consideration formed the basis of the conception and formation of the Burn and Plastic Surgery Centres of the Royal Air Force.

The effect of coagulating the burned surface of eyelids was to render them rigid and immobile; this caused great difficulty in cases where the eyes required treatment. If the burn was of third degree sepsis was usual, and a rapidly developing ectropion exposed the globe, or corneal ulceration and perforation occurred beneath the coagulum. In the case of encircling burns of the fingers and hands, the unyielding coagulum restricted the post-traumatic oedematous swelling, causing intense pain and occluding the digital vessels between the coagulum and the phalanges. Necrosis of the fingers occurred, particularly at the tips, and a resistant immobility of the healed fingers was later observed which was described as 'frozen fingers': this was assumed to be due to the organisation of exudate around the delicate tendons and their sheaths which compose the intricate intrinsic mechanism of the hands and fingers.

R.A.F. COMMITTEE ON TREATMENT OF BURNS

In September 1940, the Director-General of Medical Services of the Royal Air Force formed a committee composed of the Consultants in Surgery and in Plastic Surgery to consider the problem of these burns and to formulate a policy of treatment. The fundamentals of their recommendations were:

(i) *Condemnation of coagulant treatment* for encircling burns of limbs and fingers, of the face, flexures, perineum and genitalia, whatever the depth of the burn. Contra-indication of this treatment in cases of extensive third degree burns.

(ii) *Institution of an open technique* in the treatment of such burns by immersion in physiologically normal saline, and the dressing of such areas with an atraumatic dressing of *tulle gras* and wet normal saline packs. This was particularly enjoined for:—

(*a*) *Ab initio* treatment of all types of burns involving the face, hands and feet, flexures and perineum.

(*b*) *Ab initio* treatment of third degree burns in any area.

(*c*) The removal of tannic acid or other coagula with underlying sepsis.

(*d*) The preparation of all raw areas which required to be grafted with skin.

(iii) *The formation of Burn Centres* at the larger Royal Air Force Hospitals which had been geographically disposed to conform with the operational requirements of the Service.

(iv) *The establishment and training of teams* of surgeons, nursing sisters and burn treatment orderlies in the rudiments of plastic surgery in its particular application to the treatment of the specialised 'Airman's Burn', and its immediate complications.

FOUNDATION AND EVOLUTION OF THE BURN TREATMENT CENTRES

The first burns centres with facilities for carrying out treatment under the new open technique were established at Halton in July 1941, and at Ely, Cambridgeshire, in August 1941. It was considered advisable that burns' centres should be constructed as annexes to general hospitals, for by this method excellent laboratory facilities were provided, skilled nurses were more readily obtained and consultation with colleagues in other special departments easily arranged; moreover transport of casualties was more convenient.

The maternity blocks of these selected general hospitals were found to be the most suitable in design for adaptation to burns' centres because of a problem common to burn infections and to puerperal sepsis, namely, the control and elimination of infections, particularly of cross-infections, arising from the haemolytic streptococcus.

THE SALINE BATH

A bath was required in which very ill patients could be immersed in a copious, physiologically normal solution of saline, maintained at a constant temperature and at a constant salinity.

Such a bath was developed and perfected by Sir Archibald McIndoe with the engineering collaboration of Air Ministry Directorate-General of Works. The conception is believed to have originated with Dr. Barret Brown of St. Louis.

To maintain the temperature, the bath has steadily to be replenished with warm saline. This demands an efficient and accurate dosing apparatus to supply the correct amount of salt to the inflow in order to maintain the correct concentration of the saline at 0·9 per cent. NaCl.

The inflowing warm water passes through a half-gallon siphon cistern from which, when full, it siphons in a gush past an ejector valve which sucks in a dose of concentrated (20 per cent.) brine solution from an adjacent container. The volume of water passing in each gush is constant at half a gallon, constant also is the strength of the brine solution. A delicate adjustment was designed to regulate the volume of the brine which can be sucked into each half gallon of water as it siphons past the ejector valve. By this arrangement the correct amount of salt is added to each half gallon of warm water as it flows towards the bath.

Because of the salt content of the bath water, those fittings which are constantly immersed have to be made of a material which will resist the corrosive action of the salt. The drain pipes and plugs and the brine-tanks dosing apparatus are made of ebonite. The electrically-operated pump, required to pump brine into a 'header tank' for the dosing apparatus, has also to be made of ebonite and its driving shaft requires a protective cover of stone; this delicate piece of mechanism requires careful and intelligent handling. Owing to the electrical conductivity of the saline solution, which is a good electrolyte, it is imperative to ensure that each and every portion of the equipment is methodically 'earthed'.

The baths were fitted into the burns centre so that patients in their beds could readily be wheeled to the side of the bath. The beds themselves had therefore to be easy to handle and easily movable. Floors had to be smooth; doorways and corridors wide. The bath room or compartment had to have sufficient space for the patient to be dressed on his bed, after his bath. It was necessary to have easy access all around the bed and to allow for dressing-trolleys, a radiant heat lamp, and for more than one attendant when extensive areas had to be dressed. The radiant heat lamp was used to prevent the patient becoming chilled during the process of drying and dressing his burns. One 'Solux' radiant lamp of 1,000 wattage was required for each bath (Plate XIII).

FUNDAMENTALS OF BURN THERAPY AS APPLIED IN THE R.A.F.

It is not the purpose here to give a full description of the technical aspect of the treatment of burns. To achieve a better understanding of the organisation and administration, however, it is necessary at this stage to provide a descriptive outline of the work undertaken in a burns' centre, and the opportunity is taken to indicate the equipment and routine of the centre at the varying stages of treatment.

PROTECTION

Since it was necessary to abandon hope of reducing the mortality of prolonged exposure to fire, emphasis was laid on reducing morbidity in the burns of those who survived. It was therefore stressed that aircrew should wear gloves with complete cuffs to protect the hands and wrists, particularly during the more anxious moments of the take-off and landing. It was also stressed that at these times the flying helmet and goggles should be correctly adjusted. Comparison of the burns with and without protection of the hands provide convincing evidence of the protection afforded by quite light gloves.

FIRST-AID TREATMENT OF BURNS IN THE R.A.F. (*main features*):

(*a*) *Diminution of immediate shock* by the application of warmth and the administration of morphine in full dosage.

(*b*) *Protective covering of the burn* with aseptic or clean linen, or an oiled silk envelope, if available and convenient, in order to prevent further contamination of the area.

(*c*) *Early transfer direct to a burns' centre* before the onset of real, or secondary shock—i.e. within 7 hours.

(*d*) *In all ordinary circumstances the cleansing of a burn should not be undertaken as a first-aid measure.* Interference with the burned area under difficult conditions increases the chances of secondary infection and takes up much of the short and precious time available for the safe transfer of the patient before the onset of shock. For this same reason, the administration of a general anaesthetic is contra-indicated.

DEFINITIVE TREATMENT IN THE BURNS' CENTRE

The *principle of treatment* is the painless, atraumatic and open method of dressing combined with chemotherapy. The initial stage of treatment is essentially devoted to the saving of life.

(*a*) *Shock.* True or secondary shock in burns begins to become apparent five to seven hours after the injury. Exposure and cold precipitate the onset of shock. In the early hours, shock is frequently concealed but, after five to seven hours, the clinical picture rapidly deteriorates. A fall in blood-pressure and an increase in the concentration of haemoglobin in the blood-stream are noted. If possible, an hourly check is kept on these two clinical features; in practice it may be difficult to find an uninjured area in which to take blood-pressure readings, but it is always possible to obtain blood for checking the haemoconcentration. Shock is controlled by the intravenous administration of plasma; the amount administered has to be judged in each case by observations of the haemoconcentration. Blood transfusions are usually contra-indicated at this stage, unless there has been loss of blood through associated injury; later in the course of treatment, blood transfusions are valuable to combat the progressive anaemia which is commonly seen. Warmth in bed is best achieved by the use of either the electric blanket, if the patient will tolerate it, or 'Restor' sectional radiant heat cradle. Care must be taken not to over-heat the surface of the patient. The object is to restore a normal surface temperature not exceeding 99° F., otherwise dilatation of the surface blood vessels may further reduce the volume of the circulating blood and thereby increase the symptoms of shock.

(*b*) *Cleansing.* No hard-and-fast rule can be laid down, as treatment has to be adjusted to individual requirements. In general, however, the cleansing of the burn is undertaken an hour or two after admission to the burns' centre, the purpose being to interpose this treatment after the relief of primary shock and before the onset of secondary shock. Should an anaesthetic be necessary, undoubtedly the administration of intravenous morphine is to be preferred to that of a general anaesthetic; the latter is not to be recommended in view of the predisposition of burn-patients to chest complications.

(*c*) *The initial bath* is kept to the shortest possible duration because of the anticipation of the onset of true shock. If extensive areas are involved it is advisable to have several assistants working at the same time to expedite what would otherwise be a laborious task. It is worth while explaining to the patient that the bath is painless; otherwise before he is immersed, he may have heard that he is to be placed in a bath of salt water and will be apprehensive lest it should be painful. If the bath water is maintained strictly at 0·9 per cent. NaCL, it is painless and soothing, but 0·15 per cent. hyper- or hypo-tonic saline will cause pain. It is easy to keep within the prescribed limit by regularly testing the saline. It is sometimes advisable to commence the administration of intravenous plasma before the patient is placed in this bath and to continue it during the cleansing process.

(*d*) The *initial dressing* may be of a semi-occlusal type if it seems likely that life is going to be in serious danger from the severity of shock during the next few days. In such cases, the application of a cream spread on sheets of sterile gauze is recommended. Glasgow No. 9 cream may be used or a cream of sulphanilamide 3 per cent. with penicillin may be preferred. The Glasgow cream has proved very satisfactory for use during the first few days.

Glasgow No. 9 Cream

	Per cent.
Sulphanilamide	3
Cetyl trimethyl ammonium bromide (CTAB)	1
Castor oil	25
Beeswax	1·8
Woolfat	1·8
Cetyl alcohol	5
Glycerine	10
Water	52·4

It should be noted that this cream, advised by Dr. Leonard Colebrook, cannot be heated for sterilisation but is self-sterilising as far as the ordinary non-sporing organisms are concerned. It may be left *in situ* for two or three days, but should thereafter be removed lest a dermatitis should result.

(*e*) On return to bed, *treatment for shock* is commenced, if it has not already been necessary to institute it; and it is advisable to administer a prophylactic dose of 3,000 units of anti-tetanic serum.

(*f*) Subsequent treatment consists, after the control of shock, of *daily saline baths*, the duration of which must vary with the individual, judging by the extent of the areas involved and the reaction of the patient to the slightly exhausting process of movement and dressing. Usually a patient with a severe burn will be quite comfortable for one hour, and this period may be taken as a rough average of the length of stay in the bath. In cases which are heavily infected it may be necessary either to prolong the duration or institute two shorter baths each day until the infection is under control. It must be emphasised that no golden rule can be laid down as to the frequency or the duration of these baths; they are determined by so many factors, chief among which are the experience of the surgeon and the skill of his assistants.

(*g*) *The painless removal of dressings* is an outstanding feature of the saline bath. The outer dressings are removed before the patient is immersed, but all adherent dressings are allowed to become thoroughly soaked in the bath and the patient is always encouraged to move himself and his limbs as freely as he likes in order that these adherent dressings may be wafted from the surface of his burns by the action of the saline. Sloughs are removed by the attendants as they become detached, using McIndoe's fine dissecting forceps and scissors for this purpose. Pain should never be caused by this process. Full aseptic care is taken during the bath and it is absolutely imperative that attendants wear cellophane-lined face masks and are properly clad in sterile gowns and gloves as though they were in an operating theatre. Unless quite impracticable, the patient must also wear a face mask, otherwise he may infect his own burns (Plates X and XI).

(*h*) As the bath provides excellent opportunity for painless movement, tissues being relaxed in the warmth, and weight supported in the saline, rehabilitation may be said to commence at this stage of treatment. Patients are encouraged to perform deliberate controlled exercises especially of the fingers. Purposeless flapping of the hand is useless. Each set of joints must be put through a full range of movement or a steady attempt must be made to achieve the maximum possible.

(*i*) *After the bath* the patient is placed upon his bed which is covered by a waterproof over which is spread a sterile sheet, and kept warm by a radiant-heat lamp; he is dried and his burns are then dressed (Plate XII).

(*j*) *Dressing*. The dressings are designed to permit free exchange of exudate and saline, and to be non-adherent; this prevents, as far as possible, the tearing away of delicate films of surviving or growing epithelium and, at the same time, facilitates removal, helping to make each treatment painless and to remove the awful apprehension of each dressing which used, not uncommonly, to be seen in burned patients.

Burned surfaces are sprayed with sulphanilamide powder, with or without an admixture of penicillin. They are then covered with one layer of *tulle gras* and then with sterile gauze wet with saline. In the case of the fingers, each finger is individually dressed in order to prevent interdigital adhesion and webbing. Similar dressings are placed upon the face, holes being arranged over the eyes, nostrils and mouth. Between baths these dressings are not permitted to become dry but are moistened hourly with saline, which is poured over the dressing from a small sterile glass flask (undine). This can be performed during the rest or sleep of the patient without disturbing him.

In bed the burned parts, whenever practicable and always in the case of hands, are elevated to encourage the drainage of tissue exudate and the diminution of oedema. Hands are not permitted to be laid upon a flat surface, when the fingers will be straightened, but are supported on plaster slabs or light plastic or aluminium splints in the position of function—fingers slightly flexed and the thumb opposed to the palm. Similarly, care is taken to prevent avoidable deformities in all burned areas.

As soon as oedema subsides, patients with burned hands are encouraged to do as much with them to help themselves as possible. Every attention must be paid throughout to the morale of the patient and the sooner he ceases to be helpless the more he will be encouraged to greater effort towards complete recovery. Use and exercise are beneficial to the injured part and stimulating to the patient himself. It is not enough to dress and skin-graft his injuries; it is necessary at the same time to raise his morale from the depths of despair, to let him see patients who have been similarly injured and who have prevailed against their disabilities. There is a place for sympathy, but in misplaced pity the greatest disservice can be done to these patients. They are particularly sensitive to any prospect of disfigurement or helplessness. Visitors should be warned not to display shock or dismay, but to encourage an atmosphere of hopeful confidence. This aspect of treatment is much neglected in discourses upon technique, but it militates, equally with the more material problems of healing, towards the complete restoration of the patient to normality.

(*k*) *Preparation of burned surfaces for skin-grafting* is expedited by this technique of the saline bath and dressings. The object is to prepare a surface of granulation tissue which is flat and smooth, almost painless, and which does not bleed freely unless grossly traumatised. Such a surface, accompanied by a film of freshly growing epithelium at its margins, is characteristic of clean, uninfected granulations. The contrary is true of infected granulations; they are hypertrophic, œdematous, painful and bleed readily at the slightest touch. The treatment of such granulations is to rid the surface of infection and to apply the dressings with moderate elastic pressure; most particularly to be condemned is the practice of cauterising the surface by the application of the silver-nitrate stick, which only adds further sloughs to the injured surface. The only proper use for silver nitrate in a burns centre is in the solution used for testing the strength of the bath saline.

(*l*) *Skin-grafting*. The surgeon must be trained in the requirements of plastic surgery, must be able to look ahead and foresee any reconstructive surgery which may be necessary in the long-term plan of recovery. Sites are selected and kept untouched which would be essentially valuable in future repair work.

The underlying policy is to obtain the quickest healing which can be achieved, whether by natural growth or by skin-grafting. By these means, and by no other, can avoidable deformities be in fact prevented. The longer a granulating surface is left uncovered by epithelium, the greater will be the depth and density of the fibrous tissue which results from the organisation of granulation tissue. As fibrous tissue contracts, so it constricts the fine blood vessels and renders the surface more and more anaemic, until it is so deficient of blood supply that epithelium cannot be nourished over the area; callous indolent ulceration results, or troublesome breakdown of healed scars occurs. Further granulation tissue results from such breakdown and the vicious circle is complete.

With eyelids which are burned and develop cicatricial ectropion, the need to graft with skin is urgent. The surgeon must release the lid and secure the natural cover for the cornea without any delay. Fortunately, skin-grafts take excellently on the eyelids provided that the two greatest causes of failure are eliminated—haematoma and haemolytic streptococcal infections. Failure to release the eyelids and to cover the part by Esser's epithelial outlay operation will be to ensure corneal ulceration and perforation and blindness.

The technique here described has borne the test of time and the trial of very many cases. It has been largely dictated by the characteristics peculiar to the burns and other injuries met with among aviators. Before the War of 1939–45, open cockpit aircraft were the rule and the airman's burn had not been experienced in sufficient numbers to deserve notice. It is, therefore, reasonable to surmise that, with the adoption of enclosed cockpits and higher-speed aircraft, this type of burn is likely to occur more frequently in the future, although at the same time, more effective fire-preventing mechanisms are being perfected. That modifications and improvements in technique will eventually attend increasing experience and knowledge, no one will doubt.

CHAPTER 8

PLASTIC SURGERY

Introductory

By Sir HAROLD GILLIES
C.B.E., F.R.C.S.

THE history of the plastic surgery of this war cannot adequately be appreciated without a brief outline of its previous course.

The powerful urge to repair people after the ravages of trauma or disease has enlisted the sympathies of surgeons from the very earliest recorded days—in Vedic India the operation for remaking the nose was a comparatively common practice. Throughout the ages sporadic plastic surgical operations of all kinds were performed. Some great advances were made in the Italian school by Tagliacozzi and others; later, in Europe and the U.S.A., much advance had been made in corrective operations for deformities in addition to restorative operations for defects. These were carried out mainly by the specialists in their own sphere of work; thus the ophthalmic surgeon was apt to do eye-plastics, the nose surgeon rhinoplastics and the general surgeon the treatment of cancer and congenital defects. Serious and comprehensive books on plastic surgery with many plans and designs for operations were available before the War of 1914–18, but it was the great number of destructive lesions in trench warfare that stimulated all the European and American surgeons to concentrate their energies on the subject. Vast numbers of wounded patients were available in special units in all the countries engaged in the war, and out of this rose the need for and acknowledgment of plastic work as a definite special department of surgery.

In the inter-war period consolidation of the advances made was achieved by the work of a small group of surgeons in Great Britain and a much larger group in the United States. In other parts of Europe the progress was not quite so evident, except perhaps in the treatment of congenital defects and of those defects of contour that may be regarded as reduction operations. The work of Veau and Axhausen in the repair of cleft palates and the British attack on this subject all marked a very great advance on previous results. In the U.S.A., many units were developed which were devoted solely to reconstructive and plastic surgery, and a vast amount of the reduction type of surgery was also done. In this country few general hospitals had recognised the value of the attachment of a surgeon specially devoted to plastic work, and at the beginning of the War of 1939–45 there were very few trained plastic surgeons. By a scheme of intensive training at four main centres, however, it was soon possible to staff a number of well-equipped units in England

and Scotland. The Services meanwhile, particularly the Army and the R.A.F., needed their own plastic units, and in the Army six maxillo-facial teams were trained in this country and served with the armies in India, Africa, Italy and France. The R.A.F. established a number of plastic units concentrating on the treatment of severe burns. At the beginning of the war it was considered likely that there would be a large number of burns, which indeed proved to be the fact. Not only was there a large number of burns in the Air Force, but the Navy and Army had an immense casualty list of burns of various degrees. Probably the biggest advance in the treatment of the injured was that of the burnt individual, and this treatment was the outcome of research by the bacteriologist, biochemist, the general physician and the plastic surgeon, who kept on reiterating to those who were treating burns that covering the wound with skin was the essential factor. All deep localised burns could be excised and grafted immediately after injury. The victim of extensive mixed burns was kept alive by a proper use of blood and plasma transfusions, by control of the haemoglobin and fluid loss, by prevention of infection, and by the early skin-grafting of all denuded areas.

TECHNICAL ADVANCES

The most striking of these was the sureness of the taking and application of skin-grafts for all purposes, and the covering at the earliest possible moment of all raw surfaces, whether from burns, gunshot or other trauma. The maxillo-facial fracture work was consolidated and improved and emphasis was laid on the value of the early reposition and the retention of fragments in their normal position. The saving in hospital hours and man-power by the primary treatment of wounds was very considerable, as illustrated by the remarkable acceleration in the return-to-duty rate. This was especially evidenced in the work of the forward section of the maxillo-facial teams in Italy and elsewhere, where the co-operative association with the ophthalmic surgeons and neuro-surgeons formed a happy trio.

Hand Surgery. The first great advance here was made in the burnt hand, particularly the one that had healed up under treatment by tannic acid. This kind of hand was usually well healed but was encased in a firm bag of scar tissue which very seriously limited movement. In the simpler defects, where the lesion was a small loss of skin, the plastic department very rapidly demonstrated to the Services the value of a relieving skin-graft, usually a dermatome graft at the healed stage. But later in the war such grafts were not found to be so necessary because the skin was often replaced earlier. In the severer cases the attack was continued by freeing the joints and adherent tendons and by section of the transverse metacarpal ligament. Where extensor tendons were involved and destroyed, as often happens in a burnt hand, free grafts of palmaris longus or plantaris were used to join up tendons and these were prevented from adhering by running them through the fat tissue of a flap of skin brought there for the purpose. Various other manœuvres for the burnt hand were adopted and much of the work was done in conjunction with the orthopaedic surgeon or the orthopaedically trained plastic surgeon. One cannot help noting the great influence of Sterling Bunnell (1928, 1941, 1944) in this class of surgery, and his personal encouragement and advice was of great value. In industrial accidents cut flexor tendons also were often very successfully dealt with. The burnt hand usually exhibited constriction of the interdigital webs. When a local flap was available, that was generally used to form the base of the web, so as to prevent the contraction that a free graft sometimes undergoes in this area. A flap was only used for the base of the web; the sides of the web were free grafted. Pollicisation of the index finger in a hand in which the thumb had been destroyed proved very successful. In some of the worst hands the cleavage operation had its place, and the grafting of toes for fingers was successfully accomplished on several occasions.

CO-OPERATION

Team work with the general surgeon was a very satisfactory feature of this war; and its application to the civilian, as in large cancer-destruction of the face, marked a step forward in surgical organisation. The plastic team, fully prepared, waits at the back of the theatre while the surgical team removes the cancer. When the general surgeon has finished, the plastic team steps in and does the repair. Here we see a true guiding line for the team work of the future, and no little credit should be given to the plastic surgeon in this respect.

Co-operation was the rule between the plastic surgeon and the general or orthopaedic surgeon in regard to the large limb injuries with loss of skin and bone. Often it was considered correct procedure to use the cross-leg flap and medullary chip bone-grafts in the restoration of the shaft of the tibia, an operation which was usually carried out by orthopaedic and plastic teams. The value of the cross-leg flap has been amply demonstrated as a sound procedure. The bone-graft in general has undergone many phases but there is nothing very particular about this except the work of Mowlem (1944a) on cancellous chips. These medullary grafts have stood the test and can be employed at a much earlier date than would be safe when using a block mixed graft. At the same time the old methods still have their place. It is still notoriously difficult to employ a bone-graft inside a tube pedicle flap, as the blood supply is often not adequate to preserve the graft.

The treatment of fractures of the superior maxilla underwent a slight change. Before the experience of this war it was considered inadvisable to restore the maxilla with anything but a dental appliance, but these appliances are very cumbersome and difficult for the patient throughout his life, and it is now thought that the surgeon should more often aim at a bony restoration of the arch of the maxilla. Bone-graft struts in the maxilla have given good results. In some cases the maxilla after osteotomy has been mobilised and forcibly replaced into its correct position, thus restoring the normal contour.

Eyebrows were commonly made by a free graft of scalp-skin in a single strip of suitable width, or by a series of very narrow strips; more rarely an artery pedicle flap based on the superficial temporal artery was employed for this purpose.

One further device which has come to stay is that of tattooing in order to colour skin-grafts. We have yet to learn all about the colour of skin transplants but there is some evidence to show that the whole-thickness skin from behind the ear makes a perfectly coloured lower eyelid and often a good patch on the nose, but it may be too red in other situations, and skin from the inner side of the arm may be too white. Wolfe grafts are inclined to show pigmented patches and therefore the aid of tattooing is a practical pursuit. The hairless flap in the middle of the beard can be tattooed as well as the red margin of the lip or a white coloured graft.

Treatment of loss of the penis from gunshot injuries owes much to the work of Frumkin (1944), whose procedure has been enormously improved by the addition of an efficient urethra. Two means of making this urethra are used: (1) where the urethra is lined with Thiersch graft carried on a rubber tube and (2) where the urethra is made by a skin flap tunnel. The latter appears to be quite effective and the former is satisfactory except that it requires much after care to avoid contraction.

Anaesthesia. Plastic surgery requires a high standard of anaesthesia and there is no doubt that this need was one reason for the development of greatly improved anaesthetic technique in the War of 1914–18 in which the work of Magill was outstanding.

During the War of 1939–45 plastic surgeons were excellently served by their anaesthetists who, by their careful observation of the patient both before and after operation, greatly helped to avoid the chest complications, which are so liable to follow this type of serious injury.

From this short story of the development of plastic surgery it must be abundantly evident that there is an immense field of research available to the surgeon of the future and this research should be combined with all other branches of science. To increase the blood supply to the flaps, to provide a good trophic nerve-supply and to improve the colour of grafts are only a few of the outstanding problems. The plastic surgeon is anxious to see improvements in his methods so that ideal restorations can be regularly achieved. He has to take a three-dimensional view in order to get contour effects, and his planning of shapes demands the facility of a sculptor and a painter.

(i)

Organisation and Work of Plastic Units

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The great importance of plastic surgery in dealing with the terrible wounds inflicted by modern missiles was realised in the War of 1914–18, and before war broke out in 1939 preparations had been outlined to provide suitable and special teams to deal with plastic work. The centres established in connexion with the Emergency Medical Services formed the foundation and training ground for the extensions of the plastic surgical service into the Army, Navy and Air Force. It was fortunate that Sir Harold Gillies was available to guide, advise and supervise the various arrangements made both at home and abroad.

As early as March 1939 in connexion with the Emergency Medical Services (E.M.S.) a conference was held at the Ministry of Health to consider the provision of maxillo-facial centres, with dental officers attached.

At the outset of the war the central E.M.S. plastic and maxillo-facial unit was at Rooksdown House, Park Prewett Hospital, Basingstoke, under the control of Sir Harold Gillies; there was a centre at Hill End Mental Hospital, St. Albans, and another at Queen Victoria Hospital, East Grinstead. The Ministry of Pensions, which had taken over the responsibility for the large Sidcup centre at the Queen's Hospital in 1920, continued to treat cases there till 1925, when the 70 remaining cases of facial injury were transferred to Queen Mary's Hospital, Roehampton. With them were also transferred the plastic and dental surgeons and nursing staff. The work on Service injuries continued up to 1939 although the numbers treated steadily diminished. In 1939 the plastic-surgery service at Queen Mary's Hospital, Roehampton, under the direction of Mr. Pomfret Kilner, was enlarged, but the additional accommodation for maxillo-facial injuries was never used to capacity, since most of the air-raid and Service casualties in the early days of the war were admitted to E.M.S. hospitals.

From time to time as the need arose further centres were formed in various parts of the country. The main centres were at Shotley Bridge in Durham (1939), at St. James's Hospital, Leeds (1939), at Baguley, Manchester (1940), at Liverpool, Broad Green (1940) and at Gloucester City (1943), though an earlier unit had been in existence at Cheltenham.

In Scotland the war led to the birth and development of plastic surgery. There were centres at Bangour, West Lothian (1940) and at Ballochmyle (Ayrshire); in addition there was an auxiliary unit at Stracathro (Brechin, 1940) and a jaw unit at Raigmore, Inverness (1941). At Bangour, 15 miles from Edinburgh, there was the closest co-operation between the plastic unit and other special departments—neurosurgery, otolaryngology, the peripheral nerve and vascular unit and the orthopaedic unit—and students were taught the treatment of war wounds in the hospital. From 1941 to 1946 a total of 2,166 patients were treated there. The hospital at Ballochmyle was 33 miles south of Glasgow. The unit could, in an emergency, have accommodated 300 patients, and was well equipped in every way. From 1941 to 1947 a total of 2,384 patients passed through the hospital. At the request of the Scottish Command, courses in maxillo-facial surgery were run for officers of the Army Dental Corps. The units at Raigmore and Stracathro Hospitals dealt with cases from North and North-East Scotland and were staffed from Inverness and Aberdeen.

In 1941 it became evident that Roehampton was very vulnerable and a fully equipped and well staffed plastic unit was established by the Ministry of Pensions under the charge of Mr. Kilner, at the large E.M.S. hospital at Stoke Mandeville. At first there were 80 beds in the unit, but later it expanded to 185 beds. The cases admitted to Stoke Mandeville were not limited to pensioners but were accepted on a broad basis from the male and female personnel of all the Services; in addition air-raid casualties and patients from the waiting lists of civilian hospitals found admission there. At times the accommodation was exceeded, e.g. after the attacks on Dieppe and St. Nazaire, the London air raids, the Campaigns in Africa and Italy, and the invasion of Normandy.

There was no fixed plastic centre in the Army or Navy, but several special plastic surgical teams were trained for service in the R.A.M.C. abroad. In the Navy in 1940 a medical officer was selected and trained in plastic surgery at East Grinstead; thereafter he carried out duties which were mainly of an advisory nature with a view to transferring to E.M.S. centres such naval cases as needed plastic treatment.

Though it was agreed that there should be a unified Service in maxillo-facial surgery and that most of the plastic work should be centred round the E.M.S. units, yet the Royal Air Force had several important centres of its own, both for maxillo-facial injuries and for burns. The R.A.F.

maxillo-facial centres were situated at Ely, Cosford, East Grinstead, Halton and Wroughton; there were also burn centres at Halton, Cosford, Rauceby, Ely, East Grinstead and St. Athan.

Generally speaking, the major part of the plastic work was done in the various E.M.S. centres and some account of their work will be given first. The preliminary arrangements worked out well in practice. Many months before the outbreak of war the sites for the establishment of plastic units to serve London had been selected. Orders for the essential equipment were in the hands of manufacturers, and the various surgeons, dental surgeons and anaesthetists had been chosen and advised as to their commitments. Thus the senior members of the staff were at their appointed posts by the early afternoon of September 3, 1939. The next few weeks were occupied in rendering the buildings more suitable for their new purpose, and in this work unstinted help was given by the permanent staff of the hospitals. At Hill End, for example, within less than a month operating rooms had been improvised and operative work begun. The initial lack of casualties made it possible to begin work on the numerous patients on the waiting lists of the London hospitals. The work done in the last three months of the year laid the foundations of experience which were to stand in good stead in the times of greater strain which followed.

In 1940, the early months, still free from war casualties, were spent in consolidation of the new teams and in the commencement of work on the control of surface infection by the sulphonamides. It was found possible to eliminate streptococci and staphylococci from extensive raw areas, but much work had to be done before the possible untoward effects of absorption of the drug were proved to be rare occurrences. A new and important experimental advance was made at Hill End by Mowlem (1941a; 1944b) who showed that the application of sulphonamide (or a mixture of various members of that group of drugs) to a wound before the application of a skin-graft minimised or prevented infection and led to spectacularly successful results. This technique soon came into general use.

In 1940 the outbreak of actual fighting oversea, culminating in the retreat to and evacuation from Dunkirk, provided the first battle casualties. With these cases there was inevitable delay in the provision of first-aid treatment, and the power of controlling surface infections provided by the sulphonamides was not only instrumental in saving lives, but also in the elimination of the long period of wound preparation which had hitherto preceded and delayed reparative surgery. Such a saving in time resulted in a much earlier restoration to normality with less opportunity for that loss of function so often consequent upon infection and disuse. Apart from this there was also the fact that each patient was retained in hospital for less time than had been anticipated and there was therefore an increased turnover of patients.

Following this period there came the Battle of Britain, and with it the serious problem of the extensively burned airman. The special distribution and crippling effects of these burns called for every effort to repair the damage and preserve as much function as possible. It was soon realised that the extent and degree of the burns commonly encountered in Service personnel bore little relationship to the, as a rule, less serious lesions met with in peace-time. Many cases of extensive burns, which in pre-war days would almost certainly have succumbed, were saved by the timely intravenous administration of large quantities of plasma or serum or of whole blood. This was indeed one of the most valuable technical advances achieved during the war. In the treatment of the shock accompanying acute burns, a type of case frequently dealt with in plastic units, plasma and serum proved of very great importance during the stage of haemal concentration. (See also article on Burns.)

At Rooksdown House (Park Prewett) some experimental work was done on the use of concentrated serum, which appeared to have certain advantages over normal strength or diluted serum. In burns of the face with gross swelling the oedema could be markedly reduced within an hour or so and the patient's comfort much increased by the use of four times concentrated serum. The method was later discussed with the colonel in charge of the Canadian Hospital No. 1 Neurosurgical Unit and was found to have a useful application in reducing cerebral oedema during operations on the brain. At Park Prewett also washed red corpuscles were found to be of great assistance in the treatment of burns during the phase of acute infection with anaemia, and particularly in patients who had received an overdose of plasma. Packed red cells also provided a simple method of increasing oxygen-carrying capacity without increasing the burden on the cardio-vascular system. Bottled whole blood was freely given, more particularly in the early years of the war. Many air-raid casualties who had received previous treatment elsewhere were thus rapidly rendered fit for operation at a plastic unit or judged fit for discharge as convalescent after a whole blood transfusion. Severe reactions from blood transfusion were rare. The life-saving measure of transfusion of plasma was not without its dangers; the occasional occurrence of jaundice, which appeared to be related to the administration of serum or plasma, led to greater caution in its administration.

The limitations and dangers of the use of tannic acid and the other coagulants in the treatment of burns soon became evident and other methods of treatment were developed. The main problems were how soonest to get rid of the dead or dying skin and to cover the resulting raw surface with a new epithelial coat. If there were delay in procuring the new epithelial covering there was the additional problem of maintaining function until the wound had healed up.

The ideal treatment by immediate excision of the damaged skin and grafting of the raw surface could not be applied to extensive areas, and its application to burns of more limited extent was often unattainable, either by reason of uncertainty as to the survival of the patient, or by the technical impracticability. The alternative plan therefore was to eliminate the burned skin at the earliest possible moment by saline baths, by local application of trypsin or hypochlorites, or merely by simple dressings. Sloughs were removed as they loosened. In the units run by the Ministry of Pensions burns were frequently treated by means of the Bunyan-Stannard (1941) envelope and hypochlorite solution; this method proved very satisfactory.

Special mention must be made of the treatment by saline baths—a method particularly developed and practised by McIndoe at East Grinstead (see Chapter 7)—and used extensively in the Royal Air Force hospitals. The sulphonamides given parenterally or applied locally could be expected to control the worst contaminations of the wound, and within two or three weeks of the injury grafts of skin could be applied either as a temporary dressing to conserve function, or as a permanent covering.

The treatment of so many cases of burns in the same ward or building was complicated by the serious problem of cross-infection. Extensive loss of skin and large granulating surfaces provided a ready culture ground for organisms which could easily be transmitted from one case to another in dust, by the fingers of those who dressed the wounds, or even by the expired breath of those who attended to the patient. Infection might even occur from another part of the patient himself. Work on this problem was done in many centres. Particular mention should be made of the work of A. A. Miles and of Leonard Colebrook and their colleagues who threw much light on the subject. (See Volume on Medicine and Pathology, Chapter 23.) The methods devised by these and other workers were tried out in the plastic units; for instance, under the auspices of the Medical Research Council, Dr. Spooner was lent to the Hill End Unit for six months, and by alterations in the general handling of the patients was able to reduce the problem to workable proportions. Suction methods of cleaning wards replaced the old dust-pan and brush; floors and bed-linen were treated with spindle oil and the 'no touch' technique was introduced as a routine in all dressings. Surgical masks were regularly used by all nursing personnel. In general the technique of the operating room was applied as far as was practicable to the wards. In the testing of these methods it was necessary to have a close co-operation between the surgeon and the bacteriologist. Fortunately this was available in most if not in all the units. The excellent arrangements made by the consultant pathologist to the E.M.S. provided bacteriological help to all the plastic units, and in some instances the unit was served by a special laboratory of its own. At Hill End, through the generosity of the 'Bundles for Britain' organisation, money was provided for the erection and maintenance of a special laboratory which at first dealt solely with the problems of the plastic unit; later this laboratory, which was under the general supervision of Professor Garrod, served other departments of the hospital.

Problems somewhat similar to those furnished by severe burns resulted from lesions due to frostbite. Frostbite as the result of exposure to cold is a well recognised condition common in those parts of the world where there are severe winters. Similar conditions may occur at any time of the year at high altitudes, e.g. above the snow line on the Alps or the Himalayas. Similarly an unprotected person in an aeroplane may suffer severe frostbite. During the war it sometimes happened at a high altitude that an enemy bullet shattered the front of the pilot's cabin and exposed the face and hands of the pilot to a current of extremely cold air which caused serious lesions. Extensive gangrene of the skin of the face and adjacent parts sometimes resulted, and this deplorable condition required a series of complex plastic operations in order to make good the loss of tissue (Plates III–VII).

The later months of 1940 and the early part of 1941 brought night bombing and its particular problems. Flying glass became the greatest cause of facial injuries and presented great difficulties, not because of any new technical problems but because the complete removal of all fragments might occupy many hours. This was often impracticable on account of the patient's poor condition, but with adequate chemotherapy residual fragments were seldom a cause of troublesome infection. Many cases were referred to plastic units some weeks after healing had occurred on account of marked disfigurement due to bluish-black scars scattered all over the face.* There was usually little or no loss of tissue and good results were obtained by multiple scar excisions and removal of the fragments of glass. A tragic complication of some of the cases was the loss of one or both eyes due to perforating wounds caused by glass fragments. Such cases frequently needed a reconstruction of the eyelids and socket before prostheses could be fitted. Many of these cases were treated in a special unit stationed first at St. Dunstan's, Church Stretton, and later at Stoke Mandeville. At both these places the patients had the great advantage of combined plastic and ophthalmic care (Professor Kilner and Dr. Davenport), and in addition were provided with the specially skilled nursing and general attention so necessary to those who were being initiated into a life of blindness, and furnishing that 'blind surround' which was of the utmost value.

The haphazard nature of night bombing made great demands on the mobile teams attached to the units, and it is satisfactory to record that seldom or never was there delay in answering the request for help.

* Plate I (*a*) and (*b*).

SOME NEW TECHNIQUES

Replacement of skin loss over an open fracture was not a new idea but the technique was advanced early in the war. There were many methods of attempting to convert an open into a closed fracture, either by relief incisions, advancement, or rotation flaps; but the idea of making good the skin loss by means of a free split-skin graft was not used, so far as can be ascertained, before 1940. At that time the vogue of treating recent compound fractures in plaster-of-paris was being generally adopted, and in many patients, who had been wounded in the evacuation from Dunkirk and passed through the hospital at Deal, this method of split-skin graft was first practised in the Royal Navy. The best results were obtained in recent wounds in connexion with open fractures which were seen early enough to be excised. After excision haemostasis was secured, the wound insufflated with sulphonamide powder, a split-skin graft cut and applied to the wound, which was sutured at the margins and covered with *tulle gras*. Pressure was maintained with cotton-wool pledgets which had been soaked in 1/8,000 solution of acriflavine in liquid paraffin, and the whole limb enclosed in plaster-of-paris. This method gave the best results in dealing with the more deeply placed bones when the compound fracture was recent, but in the older fractures, even of the more superficial bones such as the tibia and ulna, the method was very successfully practised at the time when the first change of plaster dressing was performed. This was generally towards the end of the second week of treatment. In both types of case, sepsis was controlled by means of the sulphonamides. The advent of penicillin greatly changed the local treatment of open fractures, but it is well to place on record methods which were successfully practised before penicillin was available.

It was in 1941 that several other new techniques were devised or developed. Two of these call for special mention.

The first was the use of *metal pins to control the mobile fragments of a fractured mandible* (Mowlem *et al.*, 1941). The pins were driven into the fragments and the protruding portions were rigidly fixed by external nuts and cross-pieces and thereby excellent control of the bony fragments was attained. It was in reality the application to the lower jaw of the same principle as that applied to the long bones by Roger Anderson. (See Chapter 9: Maxillo-Facial injuries.) This method led to the abandoning of some of the older methods for fixation of the edentulous mandible or for fractures behind the tooth-bearing area, but it did not in any way supersede the accepted methods which were still applicable when teeth were present. It did in fact enable the surgeon to obtain control of those fractures which had hitherto been uncontrollable.

A point of some importance in the use of the earlier appliances was the occurrence of electrolysis owing to the use of dissimilar metals in the apparatus. It was not always possible completely to avoid the use of different metals, since it was essential to use silver on the teeth and some other form of metal inserted as a pin in the posterior fragment. The coupling between the two was often made with a third type of metal bringing with it the risk of electrolytic current. No harm was done provided that the actual pins were of vitallium or some other metal which was not ionisable. Stainless steel could not be relied upon for this purpose. It was therefore still worth while in some cases to use an insulator somewhere in the chain so as to break any electrolytic circuit.

Work on a second new technique was begun early in 1941 by Rainsford Mowlem (1944a) at Hill End Hospital—the use of a *cancellous chip bone-graft*. This technique was based upon observations made during the seven years preceding its introduction that the successful transplantation of bone depended more upon the survival of the bone cells contained within it than upon the persistence of the bony mass itself. It was an original and fruitful idea which opened up a very profitable line of development.

The first case of the kind was done early in 1941. In making good the loss of part of the frontal bone a section of cancellous tissue from the ilium was cut into fragments and through a small incision the chips were inserted in two layers so that they overlapped the exposed bony margins of the defect and each other. Spaces of some millimetres were left between adjoining fragments to permit the permeation of blood. In ten days the whole mass was clinically sound and firmly united with the cranium. This experience somewhat altered the outlook on the technique of bone grafting for the method was shown to be of general application. In all cases the graft was derived from the crest and outer plate of the ilium. The excised block of bone was divided into chips of various sizes usually about $1 \times 0{\cdot}5 \times 0{\cdot}2$ cm. For filling gaps in the face and skull the basic technique was always much the same. A small skin incision was deepened to the appropriate level, and undermining carried out to expose the area to be grafted. The correct contour was obtained by building up chips to the requisite level. Fixation by pressure bandage for four to six days was then carried out.

Mandibular defects were also successfully treated by this method. Gaps of anything from $\frac{1}{4}$ in. to half the jaw were successfully made good. The technique for jaw-grafting was as follows. The ends of the bone were immobilised by dental cap splints or external bone pins, or both. Dense eburnated bone, which often forms at the free ends was removed and scarred soft tissue was excised. The bony ends were bevelled to provide the maximum bleeding surface. Then a longish graft $\frac{1}{16}$ in. thick and $\frac{1}{2}$ in. wide was put into position on the deep aspect of the bone ends; by spanning the gap this prevented the soft tissue from bulging into the defect and protected the chips from movement transmitted from the floor of the mouth. Then the smaller chips were laid over this so as to overlap the mandibular ends and restore the contour. No special method of fixation was adopted, but the subcutaneous tissues were sewn together over the parts and the skin sutured with a small gap left for a drainage tube. The average time between the operation and the removal of all splintage was about twenty-seven days. X-rays showed that fusion began in about a fortnight but clinical rigidity preceded radiographic fusion. This type of operation succeeded even when septic discharge had only recently ceased. Power-driven saws or burrs were not used in this operation, since it was thought they might engender sufficient heat to damage the vessels and the bone cells, on whose immediate response the whole process of healing depended. The same type of graft was successfully applied to cases of non-union of the tibia, radius or ulna; rigidity of the bone usually occurred in from seven to twelve weeks after operation. It was claimed that this method showed increased operative simplicity, decreased post-operative recovery time and added certainty of results.

The chip bone-graft gained general acceptance and was made use of in other plastic units. By the additional provision of external skeletal fixation to control the position of the bone-ends these grafts were shown to possess strong osteogenic and infection-resisting capacity, and, as a result, many cases of bone loss in the mandible were successfully bone-grafted at a very early stage—some within as short a time as four weeks from the time of wounding. J. B. Cuthbert (1944) proved the worth of the chip bone-graft in comminuted fractures of the mandible which, under conservative methods of treatment took an average time of twenty-eight weeks to unite. In a consecutive series of 25 cases of this type, often grossly contaminated, he was thereby enabled to obtain bony union in every case within an average time of ten weeks. The method was also applied to some cases of wounds of the leg with loss of skin and a varying amount of tibia. The source from which the chips were taken was usually the crest of the ilium.

Chip grafts were in some cases used by units on active service near the front line. In the Army they came into general use in 1944 and were quite frequently performed by No. 1 Unit, and by the special unit which worked in close conjunction with No. 1, on those cases evacuated from the Balkans. In view of the poor and dirty local conditions in South-east Italy the results they obtained were noteworthy and testified to the value of this technique for obtaining union with bone loss in the mandible.

Chip Grafts	*Failed*	*Successful*	*Total*
1. Teeth on both fragments .	2	13	15
2. Edentulous posterior fragment	1	29	30

The average time to produce union was 36–42 days. There was delayed union in 3 cases—the times being 49, 60 and 78 days.

Some experimental work was done in 1941 with a view to producing a flexible elastic coating which would carry a bacteriostatic concentration of sulphonamides and which could be applied to wounds. Nothing very definite had emerged before the need for it disappeared with the introduction of penicillin.

The early years of the war witnessed considerable increase in our knowledge of the various types of crush fractures of the facial bones with a corresponding improvement in the methods of treatment. (See article on maxillo-facial injuries). The work of James and Fickling (1941) on fractures of the facial bones was extended by the careful clinical researches of McIndoe (1941) who described the usual types of fractures associated with injuries of the middle third of the face. He pointed out how often the bony nasal arch or a wider circle of bone is pushed back and impacted into the ethmoid cells and urged the necessity of correcting any resulting deformity at the earliest possible moment. When possible he recommended immediate replacement with fixation but when for any reason delay was necessary he advised replacement by slow traction. By these means deformity was corrected and (in cases where there was nasal obstruction) the nasal passages re-opened.

It was in this year that the British plastic units first received visits from the U.S. surgeons, who were the advance guards of the units which in the ensuing years were to be a constant source of stimulation and enthusiasm.

REHABILITATION

The year 1942 was not remarkable for any particular technical development but the number of cases treated at the plastic units increased steadily and the work went on smoothly. About this time it became obvious that there was a need for some useful job for patients to do between the various stages of the reparative operations, or after the operations had been completed but before full use of the affected part had been restored. Contacts with industrial firms took place and after consultation with various manufacturers it was arranged that certain patients should be allowed to work in the factories at jobs which were considered to be within their power. In this way were employed men who were disabled either from accidents which had occurred in the factory itself or in other civilian and Service occupations. The surgeon saw to it that the type of work would be of benefit in the re-education and restoration of the affected part. This development was clearly related to the later institution in the hospitals themselves of a rehabilitation and re-settlement department. The officer in charge of this made contact with the war factories from which many of the civilian casualties had come. Rehabilitation workshops were set up in these factories with which the surgeon kept closely in touch. Injured workmen and others were enabled to work on machines producing war materials, and modifications were made to assist in the re-education of damaged hands and legs, and the value of such an adjuvant to the usual post-operative procedures was immediately apparent. The scheme was enlarged to bring real work to those men in the wards who could not immediately go to the factory. The result was that the patient was able to do remunerative and useful work from a day or two after his injury; production was increased; and, best of all, the duration of disability was materially shortened. This scheme offered a pattern which it was hoped would be adaptable to the conditions which would ensue after the close of the war.

PENICILLIN IN SURGICAL USE

The year 1943 was notable for the introduction of the antibiotic penicillin into surgical use, and for the successful trial of tissue-glues and thrombin for the fixation of skin-grafts.

The Penicillin Trials Committee of the Medical Research Council provided supplies of the new drug which were used in the work of the plastic units. Troubles arising from impurities in the drug were responsible for many early difficulties in application, but the extraordinary and unparalleled antibiotic properties of the drug were soon proved beyond doubt. Its availability made it possible to follow the practice of immediate closure of the wound after performing operations in certain types of osteomyelitis. Infections of the jaw, often caused by mouth-organisms which were almost invariably sensitive to penicillin, were the particular interest of the plastic surgeon, and it was found possible to obtain primary healing within one week of operation.

Such results were so encouraging that the whole question of surgical intervention in the presence of bone infection was reviewed and improvements in the character and speed of repair obtained. For example, in acute osteomyelitis of the lower jaw it became possible to remove all the diseased tissue, which usually consisted of the lower border, outer table and medullary portion, and leave the very thin lingual plate of the bone *in situ;* the wound was sewn up but two small-bore rubber tubes were inserted through separate stab wounds—one to run along the upper border of the residual bone and the other along the lower edge. If the organism were penicillin-sensitive (and it usually was) penicillin was introduced through the tubes each day (Mowlem). It was found that if there were an opening into the mouth it was unwise to continue the introduction of penicillin for more than about five days for otherwise there was trouble with secondary infection with resistant organisms, often of a coliform type. Penicillin medication within the mouth, or in an area likely to be contaminated from the mouth, was therefore usually confined to a period of four days at a time.

The continued use of penicillin and the sulphonamide group solved many problems but produced others. The insensitive organisms of the coliform group and *Pseudomonas pyocyanea* and *B. proteus* began to create difficulties which hitherto had not been encountered. None of the suggested remedies was found efficient and surgical technique had accordingly to be modified when they were present. Chronic infection of bone was found difficult to eradicate. The actinomyces proved to be sensitive to penicillin and infection by that fungus could usually be controlled by prolonged treatment with fairly large doses of the drug. Local application had little effect on the fungoid infection.

Excellent results were obtained by the use of penicillin mouth pastilles. Apart from the control of infections caused by Vincent's organisms, it was found that intra-oral surgery was rendered more certain and less liable to secondary disturbance if the pastilles were employed.

At Park Prewett several cases of loss of both lower lip and mandible were treated in stages. The method proved fairly satisfactory and was as follows:

(*a*) Completion of the lips, i.e. the 'mouth ring', by the use of fan flaps from the cheeks.

(*b*) Closure of the fistula below the new lower lip by mucosal flaps on the inner side and a large rotation flap of the whole neck on the outer side.

(*c*) Restoration of the mandible by bone-grafting, followed by further bone-grafting with onlay cancellous bone-grafts or, in some cases with fragmented cartilage grafts, to produce a normal chin prominence.

(*d*) The final stage was the fitting of a lower denture after the provision of a buccal inlay.

By this method of approach a series of new lower lips and chins was made, utilising local material, with resultant harmony in skin colour and texture.

SKIN GRAFTING

One of the chief difficulties in skin-grafting was that of cutting suitable skin-grafts, for it required considerable experience in that art to acquire the requisite dexterity. Just before the war Padgett (1939) described his dermatome, which simplified the cutting of grafts. On receiving a report about this device the Ministry of Health agreed to import it, and it soon became an invaluable aid to the plastic and general surgeon.

The epithelium of a skin-graft grows from the whole of the free edge of the graft and when dealing with a large raw surface more speedy healing can be obtained by the application of many small grafts in place of one large graft. This principle was recognised as long ago as 1870 when Nelson Dobson described excellent results from splitting up fine shavings of skin into small pieces before grafting them on to a raw surface. Charles Steele (1870) also wrote that 'the portion removed is easily cut up, if desired, on the thumb nail, and each portion can be well applied with the point of the scalpel'. The method of applying multiple

(1) (2) (3)

FIG. 1 illustrates the condition in which the patient was received at Hill End, who had been working in a dispensary which was hit by a high explosive. The major pieces of glass have already been removed, but the whole face was a mass of minute fragments (almost dust) which were responsible for so much infection and breakdown that she passed through stages (2) and (3) to end up as stage (4).

PLATE I (*a*).

[*Facing page* 336

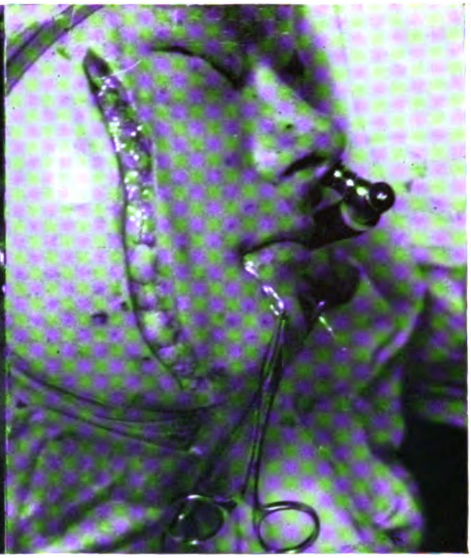
(4)

(5)

(6)

Stage (5) shows the early phases of secondary repair and it is of interest that eleven surgical knives were used in carrying out this because of minute fragments of glass and though stage (6) is not the completed stage, it is getting very close thereto.

PLATE I (*b*)



1. Mine wound of face. Compound fracture of mandible involving 543| of the mouth. Compound fracture of maxilla and antrum.

2. After thorough toilet, edge excision (1 mm.), closure of mouth by mucosal flaps, dental fixation and extractions.

3. Skin closed.

4. Result in two weeks. Union of mandibular fracture took three weeks.

Plate II. Primary Closure of Major Facial Wounds.

1, 2, 3, 4. Example of mine wound causing combined fracture of both upper and lower jaws involving teeth and antra. Treated by excisions, primary closure, fixation, and healed with stitches out and free from dressings in three to five days.

PLATE III. High Altitude Exposure (Stage 1).

PLATE IV. High Altitude Exposure (Stage 2).

Colour photographs by Hennell of the Metal Box Company, Ltd.

PLATE V. High Altitude Exposure (Stage 3).

PLATE VI. High Altitude Exposure (Stage 4).

Colour photographs by Hennell of the Metal Box Company, Ltd.

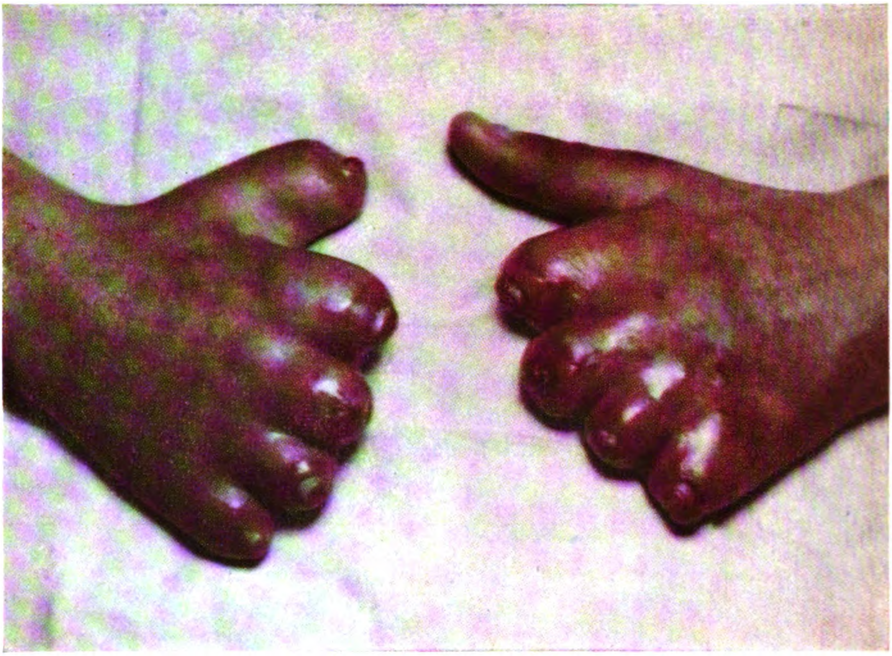


PLATE VII. High Altitude Exposure (final stage).

Colour photograph by Hennell of the Metal Box Company, Ltd.

small grafts was however only occasionally used until the technique was developed by Gabarro and by Bodenham, who both independently published papers on the subject in 1943.

A graft of the desired thickness, but considerably less in extent than the surface to be grafted—one sixth to one ninth according to Gabarro—was cut from a suitable donor-area. The graft, with raw surface uppermost was then applied flat either on a piece of *tulle gras* (Bodenham) or on a piece of the greasy and sterile paper supplied with the boxes of *tulle gras* (Gabarro). Gabarro then cut paper and graft into strips, applied the strips to another piece of similar paper and divided the new arrangement into strips, cutting this time at right angles to the previous cut; by this means strips of spaced small square grafts were formed ready to be applied to the granulating surface. Bodenham, after applying the large graft to *tulle gras*, cut it into small squares which were applied (raw surface up) at suitable intervals to another piece of *tulle gras* cut to the size of the area to be grafted, and this was carefully laid on the raw surface. The size of the separate squares was stated by Gabarro to be $\frac{1}{4}$ to $\frac{1}{10}$ inch, but McIndoe (1943) used squares $\frac{1}{2}$ to 1 inch, which he termed 'postage stamp' grafts. The distance between the separate small grafts was about one-fifth inch and allowed for the escape of discharge from the raw surface. The squares were usually fixed in position by strips of *tulle gras*, criss-crossing the grafted area, but sometimes plaster-of-paris was used for immobilisation. The first dressing was not done for about a week after grafting. Healing was usually rapid and owing to the many growing edges the epithelium sometimes grew at the astonishingly daily average of 100 per cent. of the original graft.

The plastic surgeon in past times had occasional difficulty in ensuring that the skin grafts remained attached to the site of grafting until healing was complete. Moderate but firm pressure was the main method adopted to procure union but this was difficult to apply to such parts as the tip of the nose and the angle of the jaw. It was in 1943 that Sano first published his method of using fibrin glues to attach grafts to the underlying bed until healing had occurred. Sano (1943a, b; 1944) recommended the use of the patient's plasma, and by mixing it with Tyrode's solution to which heparin had been added he kept it fluid, until it was required. The glue was applied to the underside of the graft immediately before it was laid upon the raw tissue to be grafted, and clotting was induced by a previous application to the graft-bed of a macerated preparation of the patient's own red cells and leucocytes. According to Medawar (1945), who closely investigated the process, the solution percolated into the apposed surfaces and clotted to form a moderately tenacious fibrin jelly. The clotting process could be hastened and made more uniform by mixing the fluid plasma, immediately before use, with a solution of calcium chloride or with viper venom, or tissue extract, or thrombin; the choice of coagulant depended upon the treatment which the plasma received on withdrawal in order to keep it fluid.

The technique was widely used and increased the success of free-grafting operations. Haemostasis was much more complete, firm adhesion of the graft to the bed was usually secured and post-operative haematoma formation was reduced in incidence; moreover, less elaborate methods of suturing and fixation were found to be adequate when this technique was used. The early experiments with the method produced a rather disappointingly small number of cases in which really firm adhesion of the graft was achieved within a few minutes, but later it was found that almost uniformly firm adhesion was obtained by the simple expedient of pressing a large warm swab on to the grafts and maintaining the pressure for about a minute. Apparently the application of heat ensured the rapid formation of a first clot.

The Sano technique was modified in certain directions. The clotting agent was replaced by more concentrated tissue extracts, or preferably by a solution of thrombin. The rapid clotting so achieved was an improvement but did not overcome the most serious defect of Sano's original method, i.e. that an unfortified plasma clot was too flabby to make a really safe glue. Medawar fortified the plasma by increasing its fibrinogen content and better results were then obtained. The impression was gained that with the thrombin-fibrinogen technique there was less pigmentation of the graft than in cases where the technique was not used, but no explanation was forthcoming to account for this observation.

The value of the fibrin-glue method of fixation of grafts was undoubted, though as is often the case with new techniques its importance was at first overstressed. But it took its place, particularly in the application of complicated grafts to irregular recipient areas. In this connexion the work of Medawar on the fate of homografts should be mentioned. It had long been noticed that skin grafts cut from any donor would initially take almost as well as autografts, and remained intact for a period varying from three to ten weeks. Then suddenly the graft would disintegrate and fade away. The reason for this failure to take permanently was not known. Medawar (1943) carefully considered the possible causes for such failures, and felt compelled to reject both the natural immunity (blood group) theory and the cellular-reaction theory of Loeb. He came to the conclusion that the grafted tissues were genetically different from those of the host and acted as iso-antigens which called forth, after the usual latent period, iso-antibodies, which destroyed the graft. This view was supported by the time-relation of the process and by the fact that, if a second set of homografts be applied when the reaction against a first set from the same donor is at its height, degenerative changes begin in the second set at once without any latent period. Several methods for mitigating the homograft reaction have been suggested but none have succeeded, so that it still remains necessary for the patient to supply his own graft.

It is convenient to recount here the advances made in the late treatment of cases in which the skin and sometimes the tendons of the back of the hand were destroyed (Cuthbert, 1945).

The deformities produced by loss of skin alone were most commonly the result of burns, but occasionally followed an avulsion injury. The natural scarring which followed produced a narrowing of the transverse arch of the hand, adduction of the metacarpals and limitation of movement of the metacarpo-phalangeal joints, which remained in extension or hyper-extension. Such a crippled hand could be restored to approximately normal function by excision of the scar, division of the capsule of each contracted joint and the application of suitable grafts to the raw area. When in addition the extensor tendons were destroyed or adherent, further measures were necessary. This injury might render both flexion and extension of the metacarpo-phalangeal joint impossible. In such cases in addition to scar excision and capsulotomy, the distal and proximal ends of the destroyed tendons were isolated, a tendon graft (from the plantaris tendon) sewn to the distal end and passed through the fatty layer of an abdominal skin flap which was brought in apposition with the raw surface. The proximal end of the tendon graft was sewn to the appropriate extensor tendon at the level of the wrist. The base of the abdominal flap was divided in three weeks' time. When there was destruction of the extensor expansion dorsal to the proximal interphalangeal joint, the finger was usually flexed and sometimes fixed. In the less severe cases this could be dealt with by excision of scar, capsulotomy, tendon and skin grafting, but in the cases where the proximal interphalangeal joint was involved there was need either for arthroplasty or arthrodesis (in mid-flexion) of that joint. In some hand-injuries there was loss of skin, tendon and bone, and in these cases there were varying degrees of deformity and limitation of movement. The treatment varied according to whether or not there was joint damage. When the joints were not involved the methods described above with the additional insertion of a bone-graft, usually sufficed. It was found advisable to perform the bone-graft some time before the tendon grafting. When the joint had been rendered immobile it was sometimes possible to perform arthroplasty. Cuthbert in one case successfully transplanted an entire 4th metatarso-phalangeal joint to make good the destruction of the interphalangeal joint of the thumb; the joint was fixed in position by stainless steel wire and the extensor-tendon-grafting was done later. In suturing tendons Cuthbert used a continuous stitch of fine stainless steel carried on an eyeless needle. This work on injuries of the hand constituted a great and valuable advance.

The year 1944 saw the culmination of the work of the plastic units. The tempo accelerated until D-day and the invasion of Normandy.

Experienced surgeons, dental surgeons and anaesthetists were at that time sent down to the South Coast in preparation for the reception of casualties direct from the beaches of Normandy. This arrangement continued for about two months after which most of the casualties came rapidly through from the Continent to the base hospitals and the various special units dealing with particular types of injury. Special and serious cases were often flown direct to the plastic units which were kept busy with a continuous stream of cases for many months. The work went on smoothly and uninterruptedly until the war was brought to a victorious conclusion.

Some idea of the amount of work done in the plastic centres may be obtained by considering the numbers of patients admitted to and the operations performed at representative units. At Rooksdown House during 1939–46, 4,665 patients were admitted and 10,128 operations performed. During the same period at East Grinstead there were 10,683 admissions and for these patients 9,181 operations were required. At the Ministry of Pensions Unit working at Roehampton and Stoke Mandeville during the period September 1939 to August 1948 there were performed 8,577 operations upon 5,300 patients. These figures speak for themselves.

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(ii)

War History of Plastic Surgery in the Army

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While the plastic units in the United Kingdom were working as has been related above, the provision of similar units for the Army in the field gradually took shape. For the most part the members of such units were trained at one of the Home Centres.

At the beginning of hostilities in 1939, specialisation in the Army Medical Services was still in its earliest stage. There was no establishment for maxillo-facial experts either as surgeons in the R.A.M.C. or as dental specialists in the Army Dental Corps. The first move towards the establishment of specialist centres came with the posting to France in December 1939 and March 1940, of two plastic surgeons—the first to the Dieppe sub-area and the second to the Boulogne sub-area—those centres on the lines of evacuation most suitable for the siting of specialist units. These officers were employed as general surgeons on the strength of 1,000-bedded hospitals.

A maxillo-facial committee of the B.E.F. was formed and met twice at Dieppe to advise on the development of specialist treatment in the Army. The chief initiative was taken by the D.D.D.S. and it would be difficult to speak too highly of his enthusiasm and interest. The point here is, however, that the surgical aspect of maxillo-facial treatment was subordinated to the dental treatment of these cases, and one felt that the chief function of the R.A.M.C. officer was to administer the medical side of the unit, because the dental officer, by reason of his single qualification, could not have complete command of patients in hospital beds. Otherwise the surgeon would merely be called in to do a preliminary wound toilet, control haemorrhage and, should the holding policy justify it, remove sequestra where necessary. We did not anticipate that the early surgical treatment of these cases would increase in importance as described below, nor that with the title 'maxillo-facial' the units would be called upon to treat such a variety of conditions that had previously been left to the general surgeon.

When the blow fell in the spring of 1940, there were two specialist units ready to treat men wounded in the face and jaws, one at Dieppe and one at Boulogne; labels for the direction of patients to these centres were available and for a short time patients came back according to plan. However, by the time the 51st Division made its counter-attack on the Somme, Boulogne had fallen, Dieppe had been evacuated, and any wounded had to travel to La Baule in Brittany and be embarked at St. Nazaire. The first phase was over, but plans had been laid for future developments; the professional experience gained was nil, the administrative experience just a small beginning.

In 1940, Sir Harold Gillies received the appointment of Honorary Consulting Surgeon (Plastic) to the Army at Home. He had the responsibility of advising the War Office on specialist personnel for the maxillo-facial units, on equipment, and on the professional aspects pertaining to the work of the new unit. It was not until late in the war that he was able to visit the units abroad, and then only the No. 5 and No. 6 with which he had already a strong liaison. By attending meetings with other consultants in the War Office, he was able to exert some influence towards the wider employment of specialists in his own field, and played a not inconsiderable part in furthering the ideal of early wound closure and the resurfacing of the area denuded of skin by shell wounds and by burning.

FORMATION AND LOCATION OF THE UNITS

No. 1 Maxillo-facial Unit. This unit was formed in Alexandria in the Spring of 1941 and disbanded four and a half years later. Together with No. 2 Unit, it treated cases from the desert, also casualties from the Sudan, Eritrea, Greece and Crete, and from the Battle of Alamein. In February 1943, it was split into two sections. The advanced section moved to Tripoli and then to Syracuse in Sicily in August. The two sections joined up at Catania in September and then moved to the Italian mainland, the advanced section being administered by the Eighth Army, the rear section being at the base. (The moves of this and other units are shown in an Appendix.) During the period in Italy, the unit took all the maxillo-facial casualties on the East side. The complex nature of the Eighth Army meant that it received Dominion troops, (Canadians, New Zealanders, South Africans, and Indian Army) and Allied troops (Polish Corps, Greek Brigade, and Palestine Brigade). In addition, the rear section treated and held many of Tito's Partisans from the National Liberation Army of Jugoslavia. While in the Middle East, the unit was undertaking reconstructive work on long-term cases from British units. While in Italy these cases were evacuated to No. 4 Unit at Algiers and at Naples on the shorter line back to England; similar cases from the Dominions and Allied Forces were evacuated to the No. 2 Unit in the Middle East. The only reconstructive work possible at that time was on long-term casualties from the Balkans and on German prisoners-of-war for whom there was no evacuation. On May 12, 1945, when No. 4 Unit left Italy for B.L.A., No. 1 Unit took over, being given a second forward section at Florence. The Unit was disbanded on October 31, 1945.

No. 2 Maxillo-facial Unit. This unit mobilised at Basingstoke (Rooksdown House) late in 1940 and went oversea to reach Jerusalem in August 1941. Here it treated battle casualties from the Syrian campaign.

In November of that year it moved to Heliopolis, where it was attached to No. 9 General Hospital close to the airport. Together with No. 1 Unit it treated cases from the Libyan campaign and shared the extra flow of cases from the battlefield of Alamein. It changed location again but once—moving to 15th (Scot.) General Hospital a few miles away in October 1943. Here it received a number of long-term cases of all nationalities and, after the move of No. 1 Unit to the Central Mediterranean Force, it was the only unit in the Middle East. Patients evacuated to New Zealand, South Africa and the Far East passed through Cairo on their way home, and many of these required attention en route.

No. 3 Maxillo-facial Unit. This unit mobilised at Aldershot in March 1942 and was posted to Ranikhet, United Provinces, India. This is a Himalayan Hill Station situated at an altitude of 6,000 feet, which provided an ideal climate for all types of plastic surgery. Here the unit treated injured personnel from the whole of India, cases from the Burma evacuation and from the Middle East. In the summer of 1943, casualties came back from the Arakhan campaign and in 1944 (March) a large number of seriously wounded patients were received when the Japanese attacked Imphal and Kohima. The Fourteenth Army campaign started later in 1944 and the disposition of the maxillo-facial units left much to be desired and proved a bitter disappointment to the teams. No. 1 Indian Unit was moved backwards some 1,100 miles from Calcutta and ordered to take Indian casualties only. No. 3 Unit was ordered to open up at Ranchi and posted to a parent unit that did not expect to open for three months. Eventually, the unit was split into two halves—a rear section which moved to Comilla, where there was the most forward airstrip to which casualties were flown from C.C.Ss.; and an advanced light section which moved to Akyab in preparation for the landing at Rangoon. This light section was landed here on 'D-day plus 4', but, owing to the absence of enemy action, little war surgery was encountered. The travails of this unit were not yet over, for the light section was transported from Rangoon to Bombay via Calcutta and then back to the main section, a distance of 5,000 miles, without ever treating a patient. The importance of the early treatment of maxillo-facial patients had been proved to the hilt in all other campaigns, and it is rather sad to read in the O.C.'s unit report—written late in the campaign after the unit moved to Comilla—'. . . we saw fewer of the toxic and under-nourished cases than we had seen at Ranchi. Frequently the cases there were fourteen days old and had had no, or little, early treatment, and were often starving, and their wounds full of maggots'.

No. 4 Maxillo-facial Unit. This unit was formed at Basingstoke (Rooksdown House) in August 1942 and landed at Algiers in November, where it became the specialist unit for the First Army in North Africa. Throughout the campaign up to the fall of Tunis it was attached to a general hospital at the base just inland from Algiers, overlooking Sidi

Feruch Bay. An attempt was made to send forward a section as had been done with the Eighth Army, who were advancing in the opposite direction, and finally during the last month of the campaign a lightly equipped section opened at C.C.S. level. Unfortunately, there was no surgeon with this section and the scope of its activities was correspondingly limited. From May 1943 until April 1944, the unit received long-term cases from the No. 1 Unit in Italy and ran a very large burns' centre of its own. However, in January 1944, an advanced section was despatched to Naples and was joined in April by the main body of the unit in preparation for the Battle of Cassino. This battle taxed the strength of the unit to the utmost, for, working with two surgeons, two general duty officers, and two dental surgeons, it received 221 maxillo-facial cases in twelve days and did 200 operations in that time. The unit once again split into two sections and in June 1944 a forward section was flown to Frosinore and then reached Rome by road. It then came under the control of the Eighth Army as did the similar section of No. 1 M.F.U. on the other side of the mountains. The rear section, remaining at Naples, received casualties from its forward section and long-term cases from the No. 1 Unit on the east coast. In its turn it evacuated by ship to England and by hospital train to the east coast, where the No. 1 unit received cases routed for the Middle East. This unit made outstanding contributions to the surgery of the C.M.F. and gave a spectacular photographic display of the scope of maxillo-facial surgery at the Rome Conference in February 1945. After the close of hostilities in Italy the unit moved to B.L.A., reaching its new destination on June 1, 1945. It was disbanded in September 1945.

No. 5 Maxillo-facial Unit. This unit, and the No. 6 Unit, were formed early in 1944 in preparation for the campaign in Normandy. It was appropriate, therefore, that from April to June the No. 5 Unit should have been working as a team in the E.M.S. Unit at Basingstoke—the centre to which they were destined to send the greatest number of those cases requiring evacuation to the United Kingdom. This preliminary period was most valuable, and by the time the unit landed in France each member had had practical experience of the work required of him and the efficiency of the unit was thus increased. The early patients in the Normandy Campaign were flown directly over to the civilian unit at Park Prewett. So efficient was the evacuation that several men arrived within twelve hours of wounding. As soon as it reached Normandy on June 28, the unit was split into two sections, but worked for the greater part of the time as a single whole. This unit made a long journey across Northern Europe, crossing the Rhine in March 1945. It did rather different work from the units preceding it in that it was functioning as an advanced unit for the English-based E.M.S. centres. Its holding policy was, therefore, quite different, patients being evacuated by air with no delay. In contrast with the Middle East and Central

Mediterranean Force Units, it had little opportunity to treat burns or to perform plastic reconstructions. Instead it concentrated on the primary treatment of face and jaw wounds, performing some 1854 operations in 11 months and passing through its hands over 900 jaw cases in that short period. The threat to move the unit to the Far East in the autumn of 1945 was averted by the cessation of hostilities there, and the unit disbanded with effect from October 21, 1945.

No. 6 *Maxillo-facial Unit.* This unit, formed at the same time as No. 5 Unit, had a preliminary three months' work in an E.M.S. centre, being attached to Hill End Hospital, St. Albans, from February 28 to June 2, 1944. This period sufficed to get the unit working well as a team and it embarked for France on June 26. From Bayeux it moved parallel with the No. 5 Unit, but was further north and was closely associated with the Canadian Army. The neurosurgical unit with which it co-operated was a Canadian one and it was attached to Canadian General Hospitals from September 1944 to April 1945. Although divided into two sections, these worked together as one team most of the time and were not employed in the same manner as were the sections in the Italian campaign. As with the No. 5 Unit, the policy was to evacuate patients to E.M.S. units in the United Kingdom and not to hold cases in the unit's wards that were unlikely to be fit for duty in more than a month from the time of first admission. The unit returned to the United Kingdom and was disbanded in the autumn of 1945.

THE INDIAN UNITS

In addition to these six British units, two Indian units were formed in India and officered by British officers. In Italy a unit known as the 'ad hoc' Unit was organised to deal with maxillo-facial patients from the Balkans.

The two Indian maxillo-facial units were organised in 1943. Their establishment was modelled on that of the British units and the specialist personnel were the same and all European. The Indian other ranks in the establishment were nine in number and consisted of the following: one havildar clerk, five ambulance sepoys (batmen), one sweeper, one water-carrier and one nursing sepoy. Neither of these units was split for any length of time, and they were both employed essentially as base units.

No. 1 *Indian.* This unit was formed in Calcutta in June 1943, and attached to No. 47 British General Hospital where few beds were available. In consequence, patients had to be passed on and the holding policy was a short one. Better facilities were found on the move to Barrackpore (Bengal) in April 1944 and the unit then had at its disposal enough beds for 60 British O.Rs., 120 Indian O.Rs. and officer accommodation. However, the high temperatures and extreme humidity necessitated the transfer of many plastic cases to No. 3 British M.F.U.

at Ranikhet. There were no E.N.T. or eye specialists nearer than Calcutta, some 22 miles away, the Head Injuries Centre was some 800 miles away, and the Peripheral Nerve Unit was at Poona at least 2,000 miles away. However, the unit was kept busy with the admission of British, Indian and negro battle casualties from S.E.A.C. and accident cases from Eastern Command; 50 per cent. of these cases were jaw injuries, mostly eight or ten days old. In December 1944, the unit transferred all its patients and moved to Lucknow, United Provinces, being very busy right up to August 1945. The climatic conditions were poor with temperatures up to 117° F., and dust storms that rendered conditions of asepsis almost unattainable. The more difficult cases for repair had to be sent up to the hills where a section of the unit opened up at Ranikhet. Since the casualties were mostly received about three weeks after injury with little preliminary treatment, the problem of irrigations and dressings was a big one, and sisters and orderlies (British and Indian) had to be borrowed in appreciable numbers. After V.J. day, the unit continued to work on long-term patients and did not disband until 1946.

No. 2 Indian. This unit was raised at Poona in the Spring of 1943, and remained attached to No. 3 Indian Base General Hospital in the same location during 1943 and 1944. The team worked also (by invitation) in neighbouring hospitals both in Poona and in Kirkee nearby. For its patients, the unit drew from a wide field. Casualties from the Indian Army in Italy, from P.A.I. Force, from the No. 3 (Brit.) Unit further east, from the whole of Southern Command and from Ceylon, were sent to this unit. In addition there were naval cases from Bombay and R.A.F. cases that required interim treatment before being flown home. In December 1944, the unit moved to Secunderabad but still received patients from the same sources. In addition now, more casualties were received from S.E.A.C. Many of these travelled by sea to Madras or Vizagapatam and thence by rail to No. 128 British General Hospital which was now the parent unit. At the end of the war, this team had some 150 patients under treatment, getting steadily more busy right up to V.J. day.

There is no doubt that the conditions under which the Indian Units were working left much to be desired, and in all it was not possible to reach a higher standard of treatment than that seen in the War of 1914–18. The management of the cases in transit was poor, and frequently no dressings were done on the trains during journeys lasting several days. The feeding of facial casualties with a rubber tube on a feeding cup seemed to be unknown. The treatment of burns was a difficult problem and saline baths or irrigation treatment of any kind almost impracticable. The No. 1 Indian Unit, by starting fires in the open before 6 a.m., was able to provide enough hot water for about two hot baths a day which had to be wheeled into the ward. Burn dressings had to be done on ward beds in a dust-laden atmosphere with the punkahs going. The units felt that better provision of forward maxillo-facial services, and the establishment of the base units up in the hills instead of in the plains, would have made a big difference to the results obtained in India.

The 'Ad Hoc' Unit, Italy. This small unit was specially formed on the advice of the Consulting Surgeon (base areas) C.M.F. within the war establishment of a British General Hospital. It was located at Andria near Bari, and was busy from October 1944, to April 1945, with Jugoslav and Albanian casualties. It worked in close relationship to No. 1 Maxillo-Facial Unit which was also treating casualties from the Balkans.

EMPLOYMENT OF MAXILLO-FACIAL UNITS IN THE FIELD

The important lesson in the employment of maxillo-facial units learnt in the war was the concept of early treatment and the evolution of the forward unit. The first conception of having such a unit only at the base was abandoned in 1943. The results of the surgical treatment of the soft-tissue injuries showed that a forward unit was essential: not only could patients be returned to duty without having to be evacuated, but many long-term cases were saved many months of stay in hospital.

The base unit still proved essential and so it came about that the small establishment of the unit was called upon to split into two halves. (See later under War Establishment). Each half was completely self-contained. There were advantages here, in that, with a complete understanding between the two sections and a unit commander familiar with the problems of both, there was ensured a continuity of treatment that proved of great advantage to patient and surgeon alike. The disadvantage of splitting the unit was never fully realised even in 1944, and this is that it places too much strain on each section. The maxillo-facial unit at Cassino (No. 4) was held intact, and for the greater part of the campaign in Northern Europe the Nos. 5 and 6 units worked as a whole and not in sections—being employed as forward units for United Kingdom base units.

The second lesson was the importance of the association of maxillo-facial units with other specialist units, notably neurosurgical and ophthalmic. The value of the association was first tested by No. 1 Unit in Italy in 1943 and was proved up to the hilt before March 1944. This association came to be known as the 'Trinity' and proved itself to be a pattern for other units later. It was, of course, essential to maintain a close link with a general surgical team as well. The importance of this liaison of teams is stressed in the following points:

(1) Before the institution of the 'Trinity' the correct disposal of a 'head' casualty (using the term in the fullest sense) was a difficult problem of sorting. The location of the three specialist teams concerned in a C.C.S. on the focal point of evacuation greatly simplified the disposal of these cases. For instance, a patient initially regarded as a 'face' might subsequently prove to be largely a neurosurgical problem. In many cases a dual or even a triple specialist responsibility was involved and the 'Trinity' provided this.

(2) Combined operations were often necessary for the casualty to obtain the best treatment at one session and at the earliest possible moment. No. 1 Maxillo-Facial Unit reported that one in six patients admitted had eye injuries, while more than one in twenty had associated severe cranial wounds. No. 4 Maxillo-Facial Unit, reporting the treatment of casualties after the Cassino Battle (May 12–26, 1944) gave even higher figures. They stated that in 25 per cent. of cases an ophthalmic opinion was required and in 14 per cent. of cases ophthalmic treatment had to be instituted. There were associated head wounds in 8 per cent. of cases and limb and trunk wounds in 15–20 per cent.

(3) Three specialist teams working in this way fused into a larger team. They understood each other's methods, and the combined problems of certain cases could be studied in their true perspective.

(4) Each individual unit could handle a greater volume of casualties when working in association with the other units and many patients were spared the separate operative visitations of two surgeons on two separate occasions.

The placing of the maxillo-facial units was governed by the number of units available, by the expected number of casualties and by the methods of evacuation employed. Normally, with forward areas, there was a C.C.S. dealing with evacuation by air, sited close to the airport. This might be regarded as the focal point of evacuation, and, with the specialist units close to this point, patients were not by-passed as they would have been had the units been too far forward. All evacuation to the rear in Europe was by air and in consequence the rear sections and base units were close to the airport receiving casualties. As the medical bases were also often on the sea coast at important harbours, sea evacuation was employed a great deal in the Middle East and Central Mediterranean Force.

When air evacuation was first instituted, there was some reluctance to send patients with intermaxillary fixation by means of travel that might embarrass respiration and possibly lead to the aspiration of vomit. There is no reference to any fatalities in the reports of the units. One unit attempted to send wire-cutters with the patients but these were never returned and the plan was abandoned. It can be said that maxillo-facial casualties travelled well by air, and the method was ideal for any patients who might suffer if kept travelling for long periods without specialised care and attention.

There were several instances of wastage or misuse of maxillo-facial units during the war, but generally speaking, they were remarkably few. The placing of the units in India was somewhat inexplicable but perhaps governed by difficulties of evacuation and the need to treat coloured troops and white troops in separate units. In Italy the retention of half a maxillo-facial unit to treat a resting corps was embarrassing to the half of the unit that was overworked. In Northern Europe, the only criticism might be that some of the unit moves were unnecessary, and that longer 'hops' would have been in the interests both of the patients and of the unit treating them.

THE WAR ESTABLISHMENT

The following points have been discussed with all unit commanders, who are in complete agreement:

(1) A consultant in plastic surgery should be available to visit units in the field as well as home units.

(2) Units should be larger. Instead of being divisible into two sections they should be increased to the equivalent of three sections. With a divided unit, the forward section was over-burdened during a battle and the rear section between battles. The addition of extra personnel would allow a freer exchange between forward areas and the base and would relieve pressure of work.

(3) Additional personnel were required for the operating theatres. When the units were divided, the only personnel available were one Sister Q.A.I.M.N.S. and two assistants to run two theatres some hundreds of miles apart. The borrowing of staff proved to be unsatisfactory.

(4) Nursing sisters for ward work were shown to be urgently required within the establishment. The nursing of maxillo-facial and plastic surgery patients and patients with burns, requires a degree of skill and experience that was often lacking in those sisters lent by the parent units. One unit commander (No. 5) ascribed fatal results to lack of experience in the nursing staff provided, 'It was also found that the ward staff were hopelessly inadequate for this type of work, and within a short space of time one or two post-operative deaths occurred, due to lack of observation in the wards'.

(5) Additional personnel were required but not obtained in order to deal with the records. Full typewritten notes could not be kept without employing a dental clerk orderly for the purpose and this was clearly a misuse of specialist personnel. From the end of 1944, photographic equipment was provided but with no technician to take or develop the photographic records.

Other points are more controversial and not all unit commanders are in agreement on them:

(1) The designation 'maxillo-facial' was not sufficiently all-embracing. The value of plastic surgery in the repair of injuries to the limbs was often missed. One A.D.M.S. inspecting a unit noticed an amputation stump being treated by a tubed pedicle flap and remarked with impish humour, 'Ah, poaching I see'! 'Plastic surgery and jaw injury units' would have been preferred as a title.

(2) The rank of major was considered by some unit commanders to be a handicap in the negotiations for accommodation in parent units. They felt that they were at a disadvantage vis-à-vis the officer commanding a C.C.S. or the Lieut. Colonel i/c of the surgical division of a general hospital.

(3) It was at one time debated whether the 'Trinity' with one surgical team should be given a separate war establishment of its own and be completely independent of parent units. This would appear a

logical solution of some of the difficulties mentioned both in personnel and equipment, but a discussion on this point is out of place where history alone is in question.

EQUIPMENT OF UNITS

The maxillo-facial units had no transport since, unlike their neuro-surgical colleagues, they were not regarded as mobile units. This meant that the unit commander was expected to borrow transport on every conceivable occasion, whether he wanted to visit his other section, his superior officer, the medical stores or even plan a unit move.

The maxillo-facial units had no generators and depended again on their colleagues or on the parent units to provide power. Even at the base, complete power-failures were not uncommon, with failure of lighting and suction. Other deficiencies were particularly noticed in theatre equipment, notably operating tables, spot lights, and anaesthetic apparatus. However, all unit commanders expressed appreciation of the special instruments provided for their units, grafting razors, needle holders, forceps, etc. being admirably selected and of a high quality.

Those units that were fortunate enough to obtain photographic equipment—Nos. 1 (incomplete set), 4, 5, 6—all found the 'Kodak' clinical camera heavy and bulky under field conditions.

Supplies were often difficult to obtain. Casting silver was replaced on occasion by coins or by silverware purchased from the local bazaar and melted down. Embedding material was made from sand and plaster, the sand being fetched from the seashore and then washed and dried. Roger Anderson pins were unobtainable for long periods and Kirschner wires were cut down for use instead. All units owe a debt of gratitude to R.E.M.E. who always co-operated with great skill to replace deficiencies. The Middle East units depended entirely on this branch of the Service for their extra-oral pin-fixation apparatus.

Lastly, to the vast number of foreign hospitals, both enemy and friendly, who unwittingly supplied the maxillo-facial units with instruments, cabinets, theatre trollies, operating tables and lights, a word of thanks is not amiss; these were quite invaluable.

Suggestions for modification in war establishment and in equipment were made but never implemented before the end of hostilities.

PROFESSIONAL RECORDS AND EXPERIENCE

A full statistical survey of the work performed by the British Army maxillo-facial units has proved to be impossible. It is only possible to give figures from consolidated reports prepared voluntarily by certain unit commanders, and even then strictly comparable figures cannot be given.

Cases and Mortality

Total number of cases treated by:—		
No. 1 M.F.U. (September 1943–May 1945)		11,123 cases
No. 4 M.F.U. (October 1942–May 1945)		
No. 5 M.F.U. (June 1944–May 1945)		
No. 2 M.F.U. (1941–1943)		
Total number of deaths	134	
Mortality	1·1 per cent.	

In all, the six units treated some 15,000 patients.

The mortality in terms of the facial injury was only worked out by two units:—

	No. 1 1943–5	*No.* 4 1942–5
Total number of new maxillo-facial cases	3,229	3,400
Total number of deaths attributable to maxillo-facial injury	24	15
Mortality	per cent. 0·74	per cent. 0·44

As mentioned earlier in this report, the primary task allotted to the maxillo-facial units was the treatment of fractures of the facial bones. That this was eventually much influenced by the early treatment of the facial injury is indisputable. A statistical survey of the work of three of the units gives some idea of the volume of work performed by the teams.

Number of jaw cases treated by:—	
No. 1 (September 1943–5)	4,812
No. 4 (October 1942–5)	
No. 5 (June 1944–5)	

In all units the treatment of the accident fractures was very similar to that in the civilian units at home.

TREATMENT OF BATTLE CASUALTIES

Several points in the treatment of battle casualties may be mentioned here.

(*a*) *Surgical Treatment of the Bone Fragments with Comminution.* The policy for the comminuted bone fragments varied from that adopted by the large civilian centres in the United Kingdom by being rather more conservative. All agreed that dirty bone fragments, separated from all blood supply, should be removed; but all were not in agreement on a really radical policy of a bold clean-out with a view to grafting. After a month, if there was failure to heal, then a sequestrectomy was undertaken, followed if necessary by further intervention of the same kind. However, once the decision was made that bone-grafting would be necessary, then the policy of a radical clean-out of bone fragments was accepted.

(*b*) *Primary Bone-Grafts.* Primary bone-grafting was tried by No. 5 Unit on 12 cases. This experiment was unique and noteworthy. 'Five of the twelve cases obtained satisfactory bone union after a long time. Five obtained consolidation of part of the gap, and two failed completely three or four months afterwards, owing to a flare-up of infection.' No other unit was bold enough to attempt this treatment under the conditions pertaining to forward surgery.

(*c*) *Method of Fixation of Bone Fragments.* The technique employed by the dental officers is reflected in this summary of treatments:

	No. 1 September 1943–5	No. 4 October 1942–5	No. 5 June 1944–5
Intermaxillary fixation by wire alone .	215	534	514
Intermaxillary fixation by the application of cast-metal cap splints . .	544	448	269
Intermaxillary fixation by the use of peralveolar and circumferential wires	18	45	82
Intermaxillary fixation by interosseous wires	?	17	20
Fixation by extra-oral pinning . .	34	22	94
Fixation to plaster caps . . .	101	?	103
Gunning splints	17	?	56

There was much controversy in the Central Mediterranean Force as to whether early cap splinting was a good thing; the No. 1 Unit were firm believers in it and applied many splints within twenty-four to forty-eight hours of wounding, and the No. 4 Unit delayed such splinting and relied on wire intermaxillary fixation in a larger proportion of their cases. In certain instances—for example in fractures of the middle third of the face, fractures of the mandible where the upper jaw was edentulous, and in many simple uncomplicated fractures—fixation by cast-metal cap splints was accomplished to everybody's satisfaction. Occasionally, of course, teeth involved were included in the splint at first application and had to be removed out of the splint later in treatment. The application of splints did not lead to any delay in evacuation. Over all the cases treated by No. 1 Unit in the forward area, there was hardly twenty-four hours of difference in the length of stay of the splinted patient as compared with the patient treated by other methods of fixation. In order to overcome X-ray difficulties at C.C.S. level, the unit supplied intra-oral and occlusal films that proved valuable. The real difficulty was that the very type of case that most required early splinting was the comminuted type with many teeth involved and few available for capping, and that this was so often the case and required the most nursing attention, the best radiological assistance, and the most considered opinion. The choice of method depended on the judgment of the dental officer and on the skill in casting of the dental mechanics. In order to facilitate quick opening up of the dental laboratory on a unit move a trailer was designed and put into operation by the No. 1 unit. But the unit soon afterwards ceased to move very often and the mobile laboratory became more useful as a store room. In the future something of this nature, but equipped carefully and scientifically, would be very welcome in any unit doing forward maxillo-facial surgery.

Primary Repair of Facial Wounds. The evolution of the principle of wound closure in facial injuries is interestingly shown in the reports of the units. No. 2 Maxillo-facial Unit in the Middle East had to contend with the rough general surgery of the desert. 'It is our impression that the gunshot wounds of the face that heal the quickest are those that have had the least operative treatment in the forward area'. When the first forward section of a maxillo-facial unit was placed in a position to treat the facial injuries early, a new note crept into the reports. No. 1 Unit, in the first quarterly report of 1944, wrote: 'Complete closure of battle wounds by suture has been accomplished at the primary operation in 28 cases. In every case first intention healing has been obtained during the period of observation in the advanced section.' These results were very encouraging and represent what can be done with careful selection of cases. It is true that many of them were not large wounds, but in four of these patients there was either comminution with involvement of the antrum, the frontal sinus, or the mastoid air cells. 'A properly executed primary suture should effect considerable time-saving in healing. In large wounds communicating with the mouth it has not been found practicable to close the wound in layers, even when little tissue loss is apparent'. The next step was in April and May of 1944. The whole of No. 4 Unit was engaged in Naples in what was then a 'mass clinical experiment of doing a primary closure with particular reference to excluding the buccal cavity from continuity with the fracture site for all facial wounds'. This was the first time in which the policy of closure was extended to cover the full range of injuries without selection of cases (excluding mine wounds). With the opening of the campaign in Northern Europe, the policy of producing water-tight closures in wounds involving the mouth was continued by the No. 5 unit. 'If the wound is simply débrided and left open, the constant salivary dribble rapidly covers the wound with dirty greenish sloughs, leads to chronic sepsis and the formation of considerable scar tissue and contractions. Simple suture of the mucous membrane alone is seldom successful in sealing off the mouth cavity unless backed by closure of skin and subcutaneous tissues. . . . Recently several such cases have been closed completely at the initial operation by using a large rotation flap from the adjacent cheek and neck'. The experience of the O.C. No. 6 Unit is recounted as being along the same lines, with perhaps just that note of caution to temper enthusiasm. He started off by being extremely radical with regard to bone removal, and at the end of the operation he made a desperate effort to obtain primary skin cover by means of local flaps and skin-grafts. As time went on he became less radical and he also became very dubious as to the wisdom of attempting local flaps when the skin was bruised or otherwise damaged. Towards the end of the campaign he was doing a complete débridement of dead and dying tissue and regarded this as the most important thing. Local flaps were only attempted if there was little bruising and damage to the surrounding skin. He felt that it was better under these circumstances to leave the wound open.

In all, the greater number of battle wounds of the face lent themselves well to primary closure. The advantages were:

(1) Rapid return to normal of the individual with early return to duty.

(2) Diminution in the incidence of infective sequelae, and effect on the rates of union of underlying fractures.

(3) Undoubted diminution in the number of operations, both intermediary and definitive, to which the man wounded about the face and jaws had to be subjected.

None of the reports mentioned the ultimate character of the scar lines resulting from these primary sutures.

Primary Thiersch Grafts. All units found that free skin-grafts took well and were of great value in the initial treatment of cases with skin loss. The cosmetic results of these grafts were often disappointing and later in treatment the grafts often had to be removed or replaced. Often the initial skin loss was more apparent than real and the grafted area could be excised without difficulty.

Delayed Primary Suture. Delayed primary suture in face wounds did not carry any real advantage and often led to disappointing cosmetic results. No. 2 Unit stated 'Secondary suture of an unhealed facial wound is, in our opinion, a major surgical blunder'. There were cases, however, in which the time of stay in hospital could be shortened by such treatment, but the surgeons came to realise that scar correction would almost certainly be necessary at a later date.

Burns. All the maxillo-facial units were asked to treat the severe burns with skin loss. The gruelling work involved, with its drudgery of patch-grafts and dressings, taxed the resources of these small units to the limit. It would appear that No. 4 Maxillo-Facial Unit treated more burnt patients than all the other units together and its achievement merits more than the brief discussion possible. Its figures were as follows:

Total number (October 1942–April 1945)	910	
Accidents	607	
Battle Casualties	303	
Deaths—Early	7	16
Late	9	

The use of petrol for cooking and 'brewing-up' was responsible for a very high number of severe accidents. No. 5 Unit was the only one in which battle-casualty burns formed the majority of cases treated.

The policy of No. 4 Maxillo-Facial Unit can be summarised as follows:

(*a*) First dressings and assessment of the patient was always performed in the operating theatre.

(*b*) Ward dressings were done in a dressing room with no-touch technique.

(*c*) A saline bath was improvised and housed in a fly-proof room adjoining the burns ward. This proved a great asset in the treatment of serious burns, particularly those with extensive sloughs, and those with atrophy of muscles and stiffness of joints.

(*d*) A high protein diet, of high Vitamin C content with some 3,000 calories, was arranged with the hospital kitchen.

(*e*) It was a routine to remove sloughs directly the destroyed area was demarcated, early in the third week, except for the most extensive cases in which the sloughs were removed at two to three sittings over the third and fourth weeks.

Patch-grafts were applied two to four days after the slough had separated. If at the first dressing it was probable that more than a fortnight would elapse before healing could take place, further grafts were applied. Over 200 of the patients treated by this unit required grafting. In the other units, the treatment was taken at a rather slower rate. In the Middle East, before the introduction of penicillin, sulphonamide powder with vaseline gauze and saline dressings or baths were employed as a routine. No. 1 Maxillo-Facial Unit on the east side of Italy found the Bunyan-Stannard envelopes of great value and employed Dakin's solution as irrigating fluid. The units in Northern Europe treated a very high proportion of battle-casualty burns but were not in a position to hold patients long enough to publish any figures of value. The compression dressings seen in the American centres were tried by No. 4 Unit but the correct type of cotton waste was not available.

Treatment of Respiratory Obstruction. One of the more striking things about the campaign from the standpoint of facial injuries was the relatively low number of tracheotomies that were needed during the treatment of severe jaw injuries. The transportation of the wounded in the prone position with the head downwards, the employment of external fixation to control the middle fragment and particularly the introduction of the wide-bore nasopharyngeal tube, all helped to keep the airway clear. At the commencement of hostilities it was thought that a tracheotomy set should be in the kit of every R.M.O. and yet in 901 jaw cases (total cases 1839) the No. 5 Unit only made mention of 31 tracheotomies and 7 laryngotomies. Even this is the highest incidence of these operations in any unit records.

Treatment of Haemorrhage. Secondary haemorrhage, that much-dreaded complication of facial injuries, is mentioned very little in the unit records. As the campaign progressed, the institution of routine primary wound closures and the perfection of chemotherapy placed this complication very low in the list of possible hazards, and it was seen only in cases that had received inadequate early treatment (such as prisoners-of-war, patients from the Balkans and patients in the Far East). A number of carotid ligations were performed for primary haemorrhage by all units, and, ahead of them, by some field surgical units. The advanced section of No. 1 Unit in Tripoli reported two cases of common carotid ligation followed by complete recovery (1943).

Reconstructive Surgery. The only units that were able to perform reconstructive surgery were Nos. 1, 2, 3 and 4 Units, the Indian Units and the 'ad hoc' team in Italy. The teams in Northern Europe were not holding cases long enough for them to embark on any complicated procedures. All units employed the technique current in the larger centres in the United Kingdom.

Late Wound Closures. No. 4 Unit produced notable results in the treatment of long-standing open wounds by late closure. The greater number of these cases were in their wards in North Africa before the institution of delayed primary suture by the British Medical Services as a routine. The technique they employed was as follows:

		Cases
Approximation and secondary suture		52
Local flaps (transposed and rotated)		32
Free grafts		81
Patch-grafts	62 cases	
Sheet-grafts	19 cases	
Combined operations (local flaps combined with sheet-grafts)		21
Cross-leg and belly-to-arm flaps		8

Their results were:—	
Died	2
1 traumatic hip amputation with faecal fistula and septicaemia; died eightieth day	
1 massive wound of hip; died with jaundice and coma on seventy-second day	
Soundly healed in 4 weeks	170
Soundly healed in 8 weeks	6
Evacuated untreated	3

THE JUGOSLAV EVACUATION

On December 23, 1943, a member of the rear section of the No. 1 Unit visited the first hospital to be established for Jugoslav Partisans evacuated to Italy. Up to June 1945, the unit treated some 255 patients from this volunteer army, and from the similar partisan forces of Albania. This work was taken over by the 'ad hoc' team from October 1944 to April 1945, and later both teams worked together.

These Partisans gave fantastic stories. Many had been shot in the face at close quarters, and then left to die on the field. Many had evacuated themselves by any transport they could find, by bullock cart, bicycle, or on their own feet. Their ages varied from 6 years to 84, but they were mostly between 18 and 28 years old. The majority of the patients were facial casualties, the jaws being fractured in 164 cases:

Fractures of the mandible	117
Fractures of the maxilla	27
Fractures of the maxilla and mandible	20

The interest in these cases was manifold. First, it was amazing to see what nature alone could do towards obtaining healing and union in cases that were for the most part missile injuries. There was no medical service or specialist treatment available to the greater number of these wounded men, and yet they survived, and returned to duty to get on with their job till their wounds healed up and their fractures united after sequestrum formation. Then, secondly, there were many patients with gross tissue loss on whom an initial repair operation had been attempted, resulting in considerable distortion of the normal relationships. In these cases it proved necessary to start all over again, establish the initial defect and then plan the reconstruction. Of all the cases treated at least 46 were quite serious reconstructive problems demanding multiple operations. Thirdly, in the first six months of 1944, when food supplies in Jugoslavia were dreadfully curtailed, the casualties were arriving in a condition of debility and dehydration. Many of the patients who, apart from being on short rations, had feeding difficulty by virtue of their injury, would readily absorb 2–3 pints of saline from a rectal drip. One of the thrills in the work was to watch the improvement of a jaw-casualty with properly organised feeding and with immobilisation of the fracture. A high protein diet transformed many of these emaciated men, apparently of about 50 years of age, into round-faced healthy young Slavs.

In planning a reconstruction, the most essential steps—e.g. the closure of a defect or the bone-graft to a mandible—had to be taken first, because the patients might have to be evacuated beyond specialist help, or else the British personnel might have been required forward. Tubed pedicle flaps were out of the question if local tissue was available to provide anything like the necessary material for repair. Purely cosmetic operations such as unimportant scar excisions, the restoration of eye sockets, etc. had to be deferred on account of the pressure of more urgent work. There was no chance of sending a patient out of hospital for three months between stages of operations. The result was that while concentrating on function, the finer cosmetic points had to be left on one side.

ANAESTHESIA

No history of the maxillo-facial units in the Army would be complete without a mention of the part played by the anaesthetists in the teams. The surgeon did not have to be present at every operation performed by his colleagues, and yet the specialist anaesthetist was always there. When the teams split up, one or other of the sections would rely on the anaesthetist of the neurosurgical team, who was also expected to anaesthetise any ophthalmic cases in the care of the 'Trinity'. It was not until 1945, before the final push, that each team was allowed two anaesthetists on establishment.

The apparatus supplied to the Middle East, and at first employed also in the Central Mediterranean Force, was the Oxford vaporiser. In the early days, no N_2O was available. Later every unit received a Heidbrink apparatus. Practically every case was induced with pentothal and then intubated, and it was interesting to see the almost perfect technique displayed by the anaesthetist. With the tube down, he would then have to get on with other cases and watch several patients being operated upon at the same time. In one instance it is recorded that the anaesthetist found it possible to run three operations concurrently and at the same time to repair a scalp wound under local anaesthesia in another corner of the operating theatre.

After experiences in the Middle East, pentothal was avoided in cases of burns, but one patient is reported to have died in the Central Mediterranean Force after being given 2·5 g. of this drug. Another death occurred in the B.L.A. after the use of a 1 per cent. solution of avertin given intravenously, but it was by no means proved that the death was due to the anaesthetic. Altogether there is no evidence that inhalation anaesthesia in the maxillo-facial units carried any mortality at all—quite a remarkable record and probably unmatched by any army in the world.

APPENDIX

C.M.F. Locations of No. 1 and No. 4 Maxillo-Facial Units

No. 1 M.F.U.:		
Rear Section	Alexandria	March 1941
	Catania	September 6, 1943
	Bari	October 26, 1943
	Barletta	March 13, 1944
	Bari	June 1945
Advanced Section	Tripoli	February 1943
	Catania	September 6, 1943
	Taranto	September 22, 1943
	Barletta	September 30, 1943
	Foggia	October 13, 1943
	San Servero	October 28, 1943
	Vasto	December 17, 1943
	Ancona	July 5, 1944
	Noretto	August 1944
	Rimini	September 1944–June 1945
	Bari	June 1945
No. 4 M.F.U.:		
Rear Section	Algiers	November 1942
	Naples	April 1944
	B.L.A.	May 1945
Advanced Section	Rome	June 1944
	Orvieto	
	Castiglione (Lake Trasimeno)	July 1944
	Arezzo	September 1944
	Florence	December 29, 1944
	Naples, B.L.A.	May 1945

Locations of No. 5 and No. 6 Maxillo-Facial Units

No. 5 M.F.U.:		
Rear Section	Bayeux	June 20, 1944
	Brussels	September 19, 1944
	Eindhoven	February 21, 1945
	Schloss Wissen	March 31, 1945
	Cette	May 3, 1945
	Brunswick	June 27, 1945
Advanced Section	Ryes	July 1, 1944
	Evreux	August 31, 1944
	Brussels	September 8, 1944
	Hesse (Germany)	March 28, 1945
	Sulingen	May 1, 1945
	Cette	May 3, 1945

No. 6 *M.F.U.:*		
Rear Section	Bayeux . . .	June 30, 1944
	Reviers	July 1, 1944
	Cailly-en-Rouen . .	September 11, 1944
	Antwerp . . .	October 6, 1944
	Turnhoud . . .	December 7, 1944
	Nijmegen . . .	April 2, 1945
	Cloppenburg . .	April 30, 1945
	Nijmegen . . .	May 24, 1945
	Antwerp . . .	June 4, 1945

CHAPTER 9

MAXILLO-FACIAL INJURIES

By Sir W. KELSEY FRY
K.B.E., M.C., M.R.C.S., M.D.S., F.D.S.

In 1939 the status of the treatment of maxillo-facial injuries was substantially the same as described in 'The Report to the Army Council on Maxillo-Facial Injuries' (1935). This report was based to a very large extent on the experience of gunshot wounds in the War of 1914–18, but contained as well the accumulated peace-time knowledge.

In the period 1939–41 it became clear that two new types of injury were occurring, namely 'crush injuries' (Fry, *et al.*, 1942) from aeroplane and car accidents, often associated with brain injuries (some experience of these had been gained in America owing to the prevalence of automobile accidents); and 'crush injuries' from air raids associated with a high degree of shock. Both these types demanded rather different treatment from the gunshot injury where the patient's general condition was usually good.

The main characteristics of crush injuries of the face are the multiplicity of linear fractures of either the upper or lower jaws or both, and of the facial bones; the amount of traumatic displacement; the absence (as a rule) of comminution or loss of bone; the absence (as a rule) of severe soft tissue laceration; and the presence of associated injury such as brain damage and shock.

In 1944 another type of injury occurred as a result of the flying bombs; namely glass injuries, characterised by the clean incised wounds both of hard and soft tissue. The fractures of the bones did not occur at the points of structural weakness, but at the point of impact of the sharp edge of the glass, and atypical fractures resulted.

ADVANCES IN TREATMENT

Advances in the treatment of fractures of the jaws may conveniently be described under two main heads:

A. Advances in the Technique of Immobilisation, which include the fixation of the fragments by mechanical means and their reduction whether by mechanical or surgical means.

B. Advances in Surgery, which include the control of infection, immediate treatment of the soft tissues, and bone-grafting. It is not within the scope of this section to deal with soft tissue surgery or bone-grafting, except in so far as it affects the treatment of the fractures.

At the outset it should be remarked that little advance was made upon the fundamental principles of treatment laid down in 1914–18. Most improvements were improvements of technique.

A. TECHNIQUE OF IMMOBILISATION

Cap Splints versus Wiring Methods. In the Report to the Army Council on 'Maxillo-Facial Injuries' (1935) some difference of opinion was evident as to the relative merits of the cast metal cap splint and fixation by intermaxillary wiring as a means of immobilisation of the fragments. This difference of opinion was over their relative merits in the treatment of gunshot injuries of the jaws (not civilian or crush types). There is but little doubt that, in the severe gunshot type of injury of the jaws, cap splints are much to be preferred for definitive treatment. But it may be well at this point to summarise the indications for each method. The fewer the natural teeth remaining and the longer the patient is going to be under treatment, the greater is the need for the cast metal cap splint. For example it would be courting disaster to undertake the definitive treatment of a gunshot wound of the mandible involving loss of bone without using metal cap splints (assuming the patient to have sufficient natural teeth). On the other hand, wiring methods are indicated where the treatment is going to be of short duration and there are plenty of teeth available. It has, of necessity, to be used for the first-aid treatment of all cases where neither time nor facilities permit the construction of cap splints.

Acrylic Splints. Cast tin and vulcanite splints, made in such a way that they could be opened to be placed on the teeth, then closed and locked into position again, were used in the War of 1914–18 (Bruhn, 1915). With the advent of acrylic resins this type of splint has been revived (Waldron, *et al.*, 1944; Mackta, 1944). While some operators favour it, most are of the opinion that it is but a poor substitute for the metal cap splint. In those circumstances where cap splints are indicated, but not available, they may give better service than wiring methods. Acrylic splints also have a use in the completion of some of the simpler cases which have been treated initially by intermaxillary wiring. There comes a time in these cases when the fracture is partially united and the patient really quite fit to return to light duties, but for the fact that his teeth are fixed together, necessitating a special diet. If at this stage the wires are removed and a split acrylic splint made for the affected jaw it is often possible to discharge the patient from hospital to a convalescent home or light duties.

Cap Splints. In the War of 1914–18 metal cap splints were either swaged or cast. Swaging is now obsolete for this purpose, casting being much quicker and more adaptable. Since that time many advances have been made in casting technique generally, and the application of these improvements, e.g. wax expansion, to the construction of cap splints has resulted in better fitting splints (Fry, *et al.*, 1942).

'Separate' Cap Splint Method. The use of this method dates back to 1914–18 so that it cannot be considered a recent advance. But the value and simplicity of the method was not widely appreciated or practised.

To-day its use has become quite general and the appreciation of its merits widespread; such a change in itself appears to be a distinct advance. As used in 1914–18 separate cap splints were made for the groups of teeth on each fragment, and one for the opposing sound jaw. The splints were cemented to the teeth *before* reduction was attempted (as opposed to the 'pre-arranged' cap splint where reduction is attempted at the time of cementation). After the cement was set, reduction was effected by pulling the fragments up into occlusion against the opposing splint by intermaxillary wires, thus using the opposing sound jaw as a splint for the fractured one. At a later date, when the fracture had healed sufficiently to prevent displacement from recurring, the separate splints were removed, joined together in correct relationship by a bar soldered between them, and then recemented for the remainder of the treatment, thus dispensing with the intermaxillary fixation and permitting movement to the mandible. The disadvantages of the method as described are two: first, removing and replacing the splints is laborious; sometimes they may be damaged during removal, when new ones have to be made; and secondly, it is no longer possible, once the splints have been soldered together, to test the fracture for consolidation by clinical examination. This latter point is important, for it is not possible to test it radiographically either; so that it sometimes occurs that the 'joined up' splint is removed before the fracture is quite united and it, or another, has to be put back for a third time.

Screw Connecting Bar. The answers to both these disadvantages were found in the use of the screw connecting bar (Fry, *et al.*, 1942). Small brass 'localising plates' are soldered to each separate splint before cementation on to the groups of teeth. After reduction and fixation to the opposing cap splint by intermaxillary wires, another set of brass plates is screwed to the first, and their relationship determined by plaster-of-paris. When the plaster has set the screws are removed and the second set of brass plates joined up by a bar soldered between them outside the mouth. Finally, the appliance is fitted back into the mouth and screwed firmly into position, thus fixing the two fragments together when, in suitable cases and at a suitable time, the intermaxillary fixation can be dispensed with. The advantages of this modification, which has been widely used with satisfaction, are: first, the screw connecting bar provides better immobilisation than intermaxillary wiring (although intermaxillary wiring is satisfactory); secondly, some cases can be permitted the use of the mandible at a very early stage in their treatment; and thirdly, the progress of healing can be tested easily at any time by removing the screw connecting bar.

Precision Locks, Flanges, Extra-oral Extensions. It was not a very great step from the screw connecting bar to the use of such an appliance to fix the upper and lower jaws together (Plate I). Many appliances had been used for this purpose, in particular the split tube and pin. But none of these had proved entirely satisfactory; they all suffered from the defect that they had to be made and finished before the splints were cemented, with the inevitable result that they seldom fitted accurately. Screws were then used with equal success for the fixing of such things as horizontal and vertical flanges, and later for extra-oral extensions. (Plate II).

Rapidly made Screw Connecting Bars. In the ordinary way there is never any need for haste in the construction of the screw connecting bar, for the fragments are quite adequately immobilised by the intermaxillary wires. But there are a few cases where both jaws are fractured and the one cannot readily be used as a splint for the other. In these cases a recent modification of the screw connecting bar may prove useful (Toomey, 1944). It depends in principle upon the consolidation of a flexible stranded bar of wires by soft soldering in the mouth.

FRACTURES OF THE UPPER JAW

Owing to their comparative rarity, the treatment of fractures of the upper jaw was in a very backward state in 1939. At this time the standard textbook treatment was the application of a Kingsley splint. Only the first gropings towards a more effective technique had begun, and nothing very much had been published. All the appliances devised up to this time had as their basic idea immobilisation of the upper jaw *only* to the skull by some form of extra-oral extension. Such a treatment has not been found effective and it was only when a new principle (Fry, *et al.*, 1942) was employed, namely the immobilisation of the uninjured mandible and its use as a splint for the upper jaw, that real progress was made. Attempts to immobilise the upper jaw without first fixing it to the lower jaw failed because (*a*) with the Kingsley splint the occlusal surfaces of the teeth are covered by the appliance, so that it was impossible to test the occlusion of the teeth to find the correct position for the upper jaw; hence malunion was not uncommon; (*b*) it has not so far proved possible to immobilise the upper jaw effectively enough to permit eating upon it. If, however, the upper and lower teeth are fixed together in normal occlusion, and the lower fixed to a plaster headcap by means of rods and universal joints, a very satisfactory degree of immobilisation of the upper in correct position can be achieved (Plate III).

The method of choice is to fit upper and lower cap splints; the lower (or upper if more convenient) cap splint is provided with a forward extension from the mouth. Reduction is effected, the teeth fixed together in normal occlusion and the assemblage finally prevented from being moved up and down by rods and universal joints and a plaster headcap. This gave good results, and with further experience certain modifications and limitations became obvious.

(1) It was found that the plaster headcap, while effective enough as an immobilisation appliance, was almost useless for reduction, i.e. it did not prove effective as a base for spring traction in a forward direction.

(2) The plaster headcap is not completely stable; according to the shape of the patient's head and the amount of subcutaneous fat, movement of the order of $\frac{1}{8}$ in. to $\frac{1}{4}$ in. is possible. Theoretically, such a degree of movement should be disastrous and prevent healing of the fracture, but in practice this was not found to be so. Having fixed the upper and lower teeth together, the amount of vertical movement of the chin is estimated; if it is less than $\frac{1}{4}$ in. a plaster headcap and extension are contra-indicated. If the movement is more than $\frac{1}{4}$ in. they will limit it to this amount, thus serving a useful purpose. As the fracture consolidates so will the vertical movement lessen until the time comes when it is $\frac{1}{4}$ in. or less. At this time the headcap, etc. should be removed, for its further use tends to retard healing.

(3) Initially very solid rods and universal joints were used; this has not been found essential and a comparatively light extension has been found equally effective.

Some difference of opinion exists as to whether a single rod in the midline, or a pair external to the eyes, give the best result. This does not seem a matter of importance, good results being seen from both methods.

First-Aid Measures. While the Kingsley splint is now obsolete for the definitive treatment of upper jaw fractures, it remains an excellent first-aid expedient for the support of a mobile 'floater' fracture when it has been displaced downwards so far as to embarrass the breathing. But it should not be used for more than a short time owing to the rapidity with which consolidation occurs. The Kingsley splint has been found to be very much more stable if a third support from the incisor region to a head harness is used. In the absence of facilities for the construction of cap splints, very effective treatment can still be provided by means of wire only. The upper and lower teeth are fixed in normal occlusion and if the vertical movement exceeds $\frac{1}{4}$ in. wires are fastened to the lower teeth in the premolar regions, passed through the cheeks and fastened to suitable extensions on a plaster headcap, thus preventing the mandible from being moved downwards. Despite the fact that it can be moved upwards, the degree of immobilisation attained is very effective and the results from this simple treatment have been very gratifying. Its disadvantage as compared with cap splints is that it is not quite so comfortable or hygienic. Another means of immobilising the mandible when wiring methods only are available is by means of a Roger Anderson pin driven into the lower border of the mandible in the symphysis region, and fixed to the headcap in the usual manner by universal joints and rods (Buxton, *et al.*, 1941). A further and simpler first-aid measure for immobilising the mandible, which holds much promise, is to fix the extension to the upper and lower arch wire by ligating it to them with wire, followed by the usual rods and universal joints.

Plaster Headcaps. The plaster headcaps described in the pre-1939 textbooks have been improved considerably (Fry, *et al.*, 1942). Generally speaking it has been found that the simpler the better, and at the present time three 2-in. plaster bandages based on one layer of stockinette and one layer of crêpe bandage have been found adequate. There are various modifications of this technique which give substantially similar results.

Reduction of Upper Jaw Fractures. Reduction of fractures of the upper jaw has been much improved; briefly there are three methods now in general use:

(*a*) Where the upper jaw is freely movable, tightening of the intermaxillary wires (without anaesthesia) is adequate.

(*b*) Where it is driven up and impacted into the superstructure of facial bones, a considerable degree of force may be necessary to effect reduction. Under general anaesthesia this is applied by means of lion forceps, one beak in the palate and the other high in the labial buccal sulcus. By rotatory motions combined with strong forward traction the upper jaw is reduced.

(*c*) Where the patient is too ill for operation, reduction may often be effected by means of weight traction applied to the upper jaw by suitable means (Plate IV).

In those patients whose treatment for one reason or another has been delayed and consolidation in bad position has occurred, method (*b*) is used, followed immediately by (*c*) if (*b*) has not been completely effective. Upper jaw fractures unite very rapidly (it is thought mostly by fibrous tissue) and the lesson which has been emphasised by the war is that reduction should be effected at the earliest possible moment. Delay, especially in the impacted type, makes the reduction more difficult or even impossible.

OTHER BONES OF THE FACE

The other bones of the face do not fall within the dental field, but their fixation sometimes depends upon the jaws or the plaster headcap. For example, when there is a depressed malar bone in conjunction with a fractured upper jaw, the packing up of the malar by means of gauze and Whitehead's Varnish is dependent on the fixation of the upper jaw and floor of the antrum by the dental surgeon. Sometimes use is made of a wire passed through the body of the malar and fastened to an extension upon a plaster headcap. Combined fracture of the nasal bones and jaws presents some anaesthetic difficulties, for the manipulation of the nasal bones precludes the use of a nasal Magill catheter, and the manipulation of the jaws often precludes the use of a catheter by the mouth. No really satisfactory solution of this difficulty has yet been found, though in some cases the nasal bones are done with the use of an oral catheter, then a nasal catheter is used while the jaws are being manipulated. The disadvantage of this procedure is that the passage of the nasal catheter may disturb the nasal bones.

COMBINED UPPER AND LOWER JAW FRACTURES

At one time these combined injuries were a nightmare to those who had to treat them, for with the use of the Kingsley splint to immobilise the upper jaw, the possibility of using the upper jaw for the immobilisation of the lower had vanished. When, however, the treatment of the fractured upper jaw had been placed on a satisfactory footing (by a combination of intermaxillary fixation and plaster headcap) and the Kingsley splint discarded, then it became possible to utilise the upper, even though fractured, as the splint for the lower and vice versa. The only time when this is not very effective is when the fractures in both jaws are in the same region, e.g. fracture through the symphysis in the lower and longitudinally through the palate in the upper. So far these cases have been dealt with by first immobilising the upper fragments to each other by means of a screw connecting bar, and then reducing the lower fragments into occlusion against the upper. The difficulty which has arisen is that the reduction of the two upper fragments has been arbitrary and sometimes wrong, necessitating duplication of work. It is for these cases that it is thought that the rapidly made screw connecting bar (Toomey, 1944) may prove valuable, the procedure being to reduce and fix the upper and lower fragments manually under anaesthesia, and make the connecting bar there and then while holding the fragments in correct alignment.

EDENTULOUS POSTERIOR FRAGMENT OF THE MANDIBLE

The control of the edentulous posterior fragment offered very considerable difficulty in 1939. The methods then in general use were:

(*a*) Control by fixation of the anterior fragment.
(*b*) Control by an intra-oral horizontal saddle or upper tooth.
(*c*) Control by traction on an external wire through the angle of the mandible (Darcissac method).
(*d*) Surgical wiring of the bone ends at open operation (not commonly used).

Methods (*a*) and (*b*) are still widely and effectively used where indicated. As described in the textbooks, method (*c*) consisted of passing a wire through the bone at the posterior border of the posterior fragment, and exerting traction in a downward and backward direction to overcome the upward and forward displacement. The disadvantage of so doing was that the bone ends were separated and use was not made of the anterior fragment to control the posterior (Lenormant and Darcissac, 1927). It has been found that the traction can be so arranged as both to control the upward and forward displacement and at the same time bring the posterior fragment into firm contact with the anterior. This is done by having the traction downwards only, not backwards.

As described, the point of attachment for the traction was a rod from a plaster headcap, passing behind the ear. If an extension from the lower cap splint be used instead, the stability of the whole appliance is greatly enhanced, as it eliminates the movement inseparable from a plaster headcap.

ROGER ANDERSON PINS

The introduction of the Roger Anderson pin (Clouston and Walker, 1943) method has to a large extent eclipsed the Darcissac method, for it is no more difficult to apply and provides better fixation.

The Roger Anderson pin appliance was originally devised for the treatment of long bone fractures, modified for fingers and finally adapted to jaws. It is the appliance of choice for the control of the edentulous posterior fragment when methods (*a*) and (*b*) are inadequate. It has not been found as useful for the treatment of other types of edentulous fragments, as many people at first thought it would be; and as is usual with new appliances it was enthusiastically over-used. That phase is now passing and it is gradually falling into its proper place in the treatment of jaw fractures.

In the original design of the appliance the pairs of pins were driven into the bone, at a relative angle of 60°, through a block, the holes of which had already been drilled at 60° (Plate V). This was not found very convenient as it is difficult to start the point of a pin at other than 90° to the bone surface. With the introduction of the apparatus (Clouston and Walker, 1943) in which the pairs of pins may be inserted at any angle and in any plane, then jointed together by a rod and two universal joints, this difficulty has vanished. This arrangement has been so satisfactory that it seems likely that it will prove permanent (Plate VI).

The next defect in the apparatus which became apparent was lack of stability or stiffness. Using the original 2 mm. diameter pins and $\frac{1}{8}$ in. diameter connecting rods, a comparatively small force applied to the posterior fragment resulted in appreciable movement, especially if the rod connecting the pairs of pins together had to be long. Tests carried out to measure this movement showed that a weight of 2 lb. created a movement of as much as 5 mm. at the fracture.

The substitution of 3 mm. diameter pins and $\frac{3}{16}$ in. duraluminium connecting rods has decreased this movement by 50 per cent. (Fry, *et al.*, 1942). Whether this degree of rigidity is sufficient has not yet been determined clinically, but it seems likely that further improvement is still required (Plate VII).

There are two methods of fixing the posterior fragment with pins: first to place pairs of pins in the posterior and anterior fragments (Plate V) secondly, to use an extra-oral extension from the lower cap splint instead of the anterior pair of pins (Plate VIII). This latter method has some advantage inasmuch as two wounds down to the bone are avoided. This is especially important near the lips, for in that area the soft tissues are more mobile, and food, liquid, etc. are liable to be spilt over the pins, both factors tending to cause infection of the pin track and bone. When using such an extra-oral extension it has been found very advantageous to have a pair of rods fixed to the cap splint rather than one only, so as to increase rigidity (Plate VII).

The use of plain parallel-sided 2 mm. pins without any sort of guard is dangerous. On a number of occasions while driving such a pin into the thin posterior border of the ascending ramus, it penetrated the bone suddenly and the operator losing control, plunged the pin deeply into the soft tissues of the pharynx. Fortunately no disasters occurred. The first step to prevent this danger was the use of safety sleeves (Fig. 1B) but these have been rendered obsolete by the use of the 3 mm. pin, which has the part which is to enter the bone reduced in diameter to 1½ mm. leaving a shoulder which serves as a safety guard and prevents the pin from being driven in too far (Fig. 1F). (See also Plate IX.)

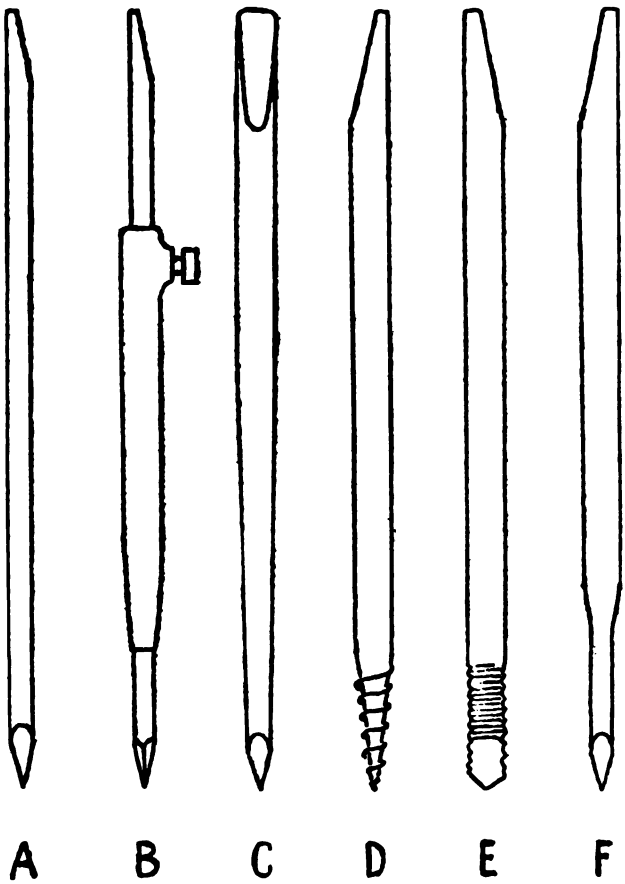

Fig. 1.—Various types of Pins.

Some operators prefer to use screw threads (Rushton, 1943) cut on that part of the pin which enters the bone (Fig. 1D, E). Results from both the smooth-shouldered pin and the threaded pin seem to be comparable.

A great advantage claimed for the Roger Anderson pin device in its early days was that intermaxillary fixation could be dispensed with and the patient permitted to eat as soon as the apparatus had been applied. In view of the mechanical weakness of the appliance and the strength of the elevator muscles of the mandible (capable of exerting a force of at least 100 lb. at their attachment) this does not seem a very desirable practice, and it would appear to be less risky to apply intermaxillary fixation in order to reduce the strain upon the pins and to discourage the patient from using the mandible. Nevertheless it must be placed on record that many cases have been successfully treated without intermaxillary fixation.

The main difficulty so far encountered, and one which remains unsolved, is that of infection of the bone around the pins. Complete asepsis is necessary for their insertion; but in spite of it a proportion exhibit bone infection after 2–3 weeks. Whether it is carried in at operation from the skin surface, or whether it is carried down the pin tract by tissue movement, is not known. Once such infection and bone absorption have occurred, the pin becomes loose and valueless as a fixation appliance. At first, spreading osteomyelitis from such infection was feared, but so far none has occurred; yet it always remains a possibility which should be borne in mind in deciding to use pins.

Electrolysis. When an extra-oral extension is used as one anchorage and Roger Anderson pins as the other, electrolytic action occurs between the tissues and the pins (Macgregor and Fickling, 1943), resulting in ulceration of the tissues and pitting of the pins. This electrolytic action is especially damaging to the bone, Fe ions being spread into the bony tissue causing chemical necrosis which is very slow to resolve. Cases have occurred where the fracture has united in six weeks but the necrosis has not cleared up for six months. Electrolytic action is at its maximum with ordinary steel pins, and is greatly reduced with stainless steel or vitallium ones. All electrolytic action can be avoided if an electrical insulator is placed between the pins and the cap splints. Similar electrolytic action can be seen between brass screw connecting bars and the adjoining mucous membrane. This can be prevented either by coating the brass parts with a non-conductor such as wax or shellac, or better, by plating all metal parts with rhodium or gold before placing in the mouth.

Surgical Wiring of the Bone Ends. This practice, used without much success in the War of 1914–18, has been revived to a certain extent not only for the control of an edentulous posterior fragment, but also for other fractures as well. This has been made a more practical proposition now that stainless steel wire is available (Gordon, 1943). Generally speaking it should be confined to those civilian cases which are not compound, but it has been used successfully in cases which are compound, provided that the operation is done early and one of the sulphonamides is used. Surgical wiring does not of itself provide good immobilisation; its chief purpose is to secure good apposition; immobilisation is then attained by intermaxillary fixation or other appropriate means.

Edentulous Patients. In 1939 the treatment of the more severe fractures of the edentulous jaws presented many unsolved problems. There were two methods available; the double Gunning splint and elastic chin strap; and fixation of an appliance to the mandible by circumferential wires. Fortunately the Gunning splint and chin strap serves for the treatment of the majority of the less severe fractures of the edentulous jaws and is to-day extensively used with satisfaction. Appliances wired to the mandible alone fail to provide very satisfactory immobilisation; and for the really severe cases there was no satisfactory treatment extant. It was only with the introduction of a means of fastening an appliance to the upper jaw that the solution to these problems was found. An upper appliance, made without a palatal portion, may be secured to the upper jaw by passing wires through the alveolar bone, and twisting them over the appliance (Fry, *et al.*, 1942). For the boring of the hole and the passing of the wire a convenient instrument is the 'wire passing awl'. The hole near the point is used as a means of withdrawing the wire through the alveolus. It might be thought that fixing appliances to the jaws in this fashion would result in septic absorption and ulceration; but in practice, provided the technique is good, they do not occur, the mucous membrane remaining remarkably healthy even over periods of several months. The main disadvantage of alveolar wiring is that after a variable period the wires tend to 'cut out' of the bone owing to infection. This can be minimised by so arranging the wires that they are stretched tightly over the edges of the plate. Where it is not possible to have special appliances made for the individual patient, there are two alternatives: either to use stock appliances lined with black gutta percha, which is quite satisfactory; or use the wires without any appliance at all—this is not quite so good, but will serve excellently as first-aid treatment. With availability of means to fix the upper and lower edentulous jaws securely together, most of the difficulties hitherto associated with fractures of the edentulous jaws have disappeared, treatment being carried along parallel lines to that of patients with natural teeth.

Overclosed Bite for Bilateral Fractures of the Edentulous Mandible. One type of case remained a problem, namely the bilateral fracture of the edentulous mandible, with the typical downward and backward displacement of the anterior fragment, and upward and forward displacement of the two posterior fragments. The anterior fragment can be reduced and fixed in normal position easily enough by means of circumferential and alveolar wires; the problem is the control of the two posterior. Various means were tried, such as wire traction on the angles, Roger Anderson pins, etc., but without great success for one reason or another. It was only when it was decided to place the anterior fragment in the closed bite position that the simple effective treatment was found. When the two posterior fragments become displaced upwards and forwards, they are moved to a closed bite position; what was simpler then than to place the anterior fragment in a similar position, thus eliminating the need for any reduction of the difficult posterior fragments? For these cases this treatment was found most effective; but only when the soft tissues held the fractured surfaces in good apposition. If there was much tearing and the bone ends were seriously out of apposition, it was found desirable to resort to surgical wiring of the fragments as well. Such was only possible of course if the fractures were not infected. If they were infected, then Roger Anderson pins would probably be used.

Unilateral Fractures of the Condylar Neck. No particular advance in the treatment of these cases has been made. There is one point of interest, however, which may be worth noting. It would appear that fracture combined with dislocation of the head is very much less common than was at one time supposed; even when the head of the condyle is markedly displaced forwards it would seem, judging by the functional efficiency of the joint after healing, that the head remains within the joint capsule. It is very difficult to believe, in these cases, that a fibrous joint in the soft tissues could permit so much movement and provide such effective masticatory efficiency.

Bilateral Fractures of the Condylar Necks. Following treatment (Fry, *et al.*, 1942) of these cases by the usual intermaxillary fixation, a certain number exhibited a recurrence of the deformity of 'open bite', i.e. the incisors were separated when the molars were in contact. This is a serious matter as the deformity interferes much with function and is not easily corrected. The reasons for such relapses were narrowed down to two possibilities. Either the repair callus was bending under the premature strain of the masticatory muscles, or the condylar head was displaced away from the base of the skull and was permitted to unite in that position, the teeth meanwhile being fixed in normal occlusion. Whichever the cause operative, a shortening of the ramus had obviously occurred. It seemed reasonable therefore to over-reduce these fractures by fixing the mandible in the normal occlusal plane, but with the teeth separated by $\frac{1}{8}$ in. to $\frac{1}{4}$ in. in both the molar and incisor regions, thus ensuring an over-reduction (i.e. over-lengthening) of the ramus of this amount. If, however, care is not taken when using this method, a malocclusion is likely to result, as the mandible is now in an arbitrary position; so that it is essential not to prolong the over-reduction beyond that stage where the callus is still soft and mouldable. Calcification of osteoid tissue starts ten to fourteen days after simple fracture, so it was decided that it was unwise to maintain the mandible in its arbitrary position for longer than this period, after which it was placed and fixed with the teeth in normal occlusion. In the comparatively few cases treated, this modification of the normal procedure has been found effective, no relapses having occurred.

First-Aid Wiring. Certain modifications in the eyelet-wiring technique have been found very valuable. The eyelet depends for its retention to a great extent upon the contact point between the pair of teeth on which it is placed. Therefore its bulk should be a maximum at this point. One way of achieving this is to use thick wire, 0·55 mm. soft stainless steel, or 0·7 soft brass. The disadvantage of the thick wire is the difficulty of applying it. This may be overcome by using 0·5 mm. brass wire for the eyelets and increasing the bulk at the contact point by soft soldering the twisted portion. If further increase in bulk is desired, the twisted portion may be whipped with thin copper wire (fuse wire) before being soldered. Additional security may be gained by passing the 'tails' of the eyelets round the pairs of teeth twice instead of the usual once, thus binding the pair of teeth more securely together and preventing the contact point from being opened. Another difficulty apparent with the eyelet method was that the intermaxillary connexions of wire tended to loosen very readily. The use of ligature silk (not floss silk) or several strands of thin stainless steel wire, in place of the usual thick wire, to a large extent overcame the trouble. The introduction of small rings has simplified intermaxillary fixation, especially where the teeth are unsuitable for eyelet wires, e.g. when there are spaces between them. The advantages and disadvantages of stainless steel versus brass wire have been much discussed. The relevant point would appear to be that the operator is much less likely to prick his finger with brass wire; and a pricked finger while working in a mouth with an infected gunshot type of injury may be a very serious matter, spreading infection of the finger and arm being not unknown.

B. SURGERY

BONE INFECTION

With one exception, no significant change in principle has been made since the War of 1914–18 in the treatment of bone infection. Adequate immobilisation and dependent drainage are still the mainstays of treatment. This treatment has been afforded to all casualties very much earlier during the War of 1939–45, as a result of better organisation and fewer cases, with the pleasing result that infection has been under better control, and avoidable bone loss very greatly reduced.

The Continuous Drip Method (Shepherd, 1940) of promoting drainage, used in the War of 1914–18 for the treatment of other wounds, has been used for infected comminuted fractures of the mandible. The continuous drip is not so practical in the face as in other parts of the body, but it can be used intermittently for several hours during the day. The method has proved effective and would undoubtedly be used widely if less attention were required. Hypertonic saline solution is employed.

Application of Heat has also continued to prove a useful auxiliary treatment, its value depending upon the continuous slight raising of the temperature of the deeper tissues rather than its mode of application.

Chemotherapy. The one new principle in the treatment of infection was the introduction of the sulphonamides and penicillin.

The Sulphonamides administered orally, have proved useful to prevent and abort the spread of infection from the local wound into the body as a whole, but hopes that they would prove valuable in the local treatment of fractures have been disappointed. This is no more than might be expected, for the drug is conveyed to the site of injury via the blood circulation. Therefore it is idle to expect them to reach necrotic areas. In addition, fractures of the jaws, if compound into the mouth, are subject to constant reinfection. The application of the sulphonamides locally in the fracture has not been attended by any noticeable benefit. The real use of sulphonamides in the treatment of jaw injuries is, first, to abort the acute exacerbation which occasionally occurs (usually due to ineffective surgery), and secondly, to treat the occasional pneumonia caused by the inhalation of débris from the mouth.

Penicillin is a useful aid in maxillo-facial practice. It can prevent a local infection becoming generalised, and it can postpone the inevitable surgery, but it must be an adjuvant to normal surgery and should never replace it. When first introduced, penicillin was so difficult to obtain that minimal doses were used to produce the required effect. Two methods were used: (*a*) parenteral injection 10,000 units 3-hourly, and (*b*) intra-muscular drip, which had the advantage that the blood concentration was kept at a continuous optimum—100,000 units of penicillin in 240 c.cm. of saline per twenty-four hours were used. Penicillin is now available in quantity and minimal dosage is no longer necessary. The bactericidal blood-penicillin level falls rapidly after two hours, and to maintain it 3-hourly parenteral injections were given. Lady Florey demonstrated that with massive parenteral therapy—i.e. 250,000 units —a sufficient plasma bactericidal penicillin level could be demonstrated eleven hours after injection. In maxillo-facial work the plasma level is the potent factor and massive dosage—i.e. 250,000 units 6-hourly or 500,000 units 12-hourly—is recommended. There is a risk in using a smaller dosage, as the normal bacterial balance in the mouth can be upset. It is not good practice to eliminate the pyogenic organisms and let the mycotic group flourish. Penicillin 1,000,000 units a day is bactericidal to the mycotic group as well as the pyogenic group and therefore that is the suggested dose. With adequate systemic penicillin, there is no necessity for its local use.

Chemotherapy has undoubtedly proved its usefulness in the treatment of generalised infections; its value locally is not so apparent, but more experience is necessary before results can be assessed. Chemotherapy is not a substitute for diagnosis or surgery; reliance upon it for these purposes invariably ends in disaster. The above remarks apply only to fractures of the jaws and should not be read as applying to soft tissue wounds or bony injuries elsewhere in the body. It must be appreciated that the proximity of the jaw bones to the oral cavity with the constant danger of infection and re-infection introduces an unusual factor into the problem.

CIVILIAN TYPE FRACTURES

Mention ought to be made at this point of infection in civilian type fractures, a complication which occurs in a small percentage of cases, and which has proved very troublesome, the fractures taking a long time to unite and even in some cases requiring a bone-graft. It appears that at an early stage the bone-ends lose their protective blood clot, the surfaces of the fractured bone-ends become exposed to the mouth and are infected. During the slow process of separation of the necrotic surface in the course of the succeeding four to six weeks, not only is no new repair tissue laid down, but bone loss is all the time occurring, so that it is only when the sequestra have been exfoliated or removed that repair across a wide gap can start.

The *prevention* of this complication was by guarding against the loss of the blood clot in the early stages, and it could only be accomplished by really early immobilisation. The *cure* lay in adequate drainage; frequently in these cases no acute signs of infection occurred owing to a minute sinus into the mouth which acted as a safety valve against the formation of pus under pressure. It was often missed at examination, for unlike an external sinus, the pus coming from it was washed away in the mouth. While acting as a safety valve it did not act as an adequate drain; dependent submandibular drainage and possibly débridement of the fracture area was the best line of treatment for these complications.

Débridement of Comminuted Fractures

Following a gunshot wound of the mandible, a patient might present one of two types of injury: (*a*) a compound comminuted fracture with little or no loss of bone; (*b*) one with a loss so big that a bone graft was an obvious necessity. In the borderline between these two types of cases, there was the type which was difficult to classify and about which there was considerable divergence of opinion as regards treatment. One school of thought treated these borderline cases by a minimum of interference with the comminuted fragments and adequate drainage, the other (Cuthbert, 1944) preferred to do a complete débridement of all comminuted and damaged bone, to cut the period of suppuration to a minimum, followed by an early bone-graft. It was difficult to assess the relative merits of the two methods; suffice to say that both produced good results. The decision as to which method to use in any particular case was not easy and certainly was not to be taken until the patient reached a static hospital, where time and facilities for an adequate investigation were available.

Soft Tissues. Soft tissue wounds of the face were not dental problems, so their treatment need not be discussed here, except in so far as it affected the treatment of the jaw fracture. The cardinal mistake which can be made is to suture the wounds of the face, leaving a compound comminuted fracture both undrained and not immobilised; the result is gross infection and loss of bone in the fracture, and a breakdown of the suturing as well. With the formation of maxillo-facial units in the Army mistakes of this nature disappeared, but in civil life too few people appreciate that the correct order of procedure in the treatment of facial injuries is: (1) reduction and fixation of the fractures; (2) drainage of the fractures (if necessary); (3) soft tissue surgery.

Chip Bone Grafts. Mention must be made of the chip bone-graft (Mowlem, 1944) developed in the last two or three years for use in restoring bony loss about the face. The block bone-graft which had been used hitherto took some three months to unite, and was very susceptible to infection. Chip grafts united in less than half this time, and a moderate degree of infection, while obviously undesirable, was not usually disastrous. This lessened period of healing made the immobilisation of the fragments the simpler. Such appliances as the Roger Anderson pins and alveolar wiring may be relied upon for 4–6 weeks, but are liable to give way before three months have elapsed.

Radiographic Interpretation. Several steps forward in radiographic interpretation were made; certain X-ray appearances which simulated fractures or gave the impression of comminution of the bone have been satisfactorily explained and described. The absence of callus in a mandibular fracture long after bony union has occurred has been shown to be apparent and not real; for the callus has been demonstrated by suitable technique.

TEACHING

One of the tragedies of the War of 1914–18 was that the knowledge of the principles and practice of the treatment of facial injuries was concentrated into few hands, with the inevitable result that unless the wounds fell into those hands, not only were they badly treated or not treated at all, but many of the patients died, quite unnecessarily, from asphyxia.

Experience in the treatment of battle casualties is obviously not acquired in ordinary peace-time dental practice; indeed few had any great experience of treating even simple fractures. In order to remedy this state of affairs when the War of 1939–45 started, a post-graduate school was formed. In all, about 1,000 dental surgeons from the Royal Navy, Army, R.A.F., Ministry of Health, Canadian Army, the United States Army, and many of the Allied Services passed through the school, taking the 'short course' of about ten days. Owing to the numbers it was not possible to permit members of these courses to gain actual experience on patients, but the lectures were supplemented by demonstrations by the staff on suitable clinical material, and by ciné films. It should be remarked that these latter were invaluable means of illustration and remarkably instructive to the inexperienced surgeon. In this short course emphasis was laid on two major points; the principles upon which treatment was based, and the first-aid treatment from the time of injury to evacuation from the casualty clearing station.

Lectures, however helpful they may be, are no substitute for experience, and for those few who were going to be stationed at a maxillo-facial surgical unit or maxillo-facial centre, an extended course of three to six months was arranged, in which they treated cases under the supervision of the teaching staff. Such supervision was kept down to a minimum so that each man could, within reason, profit by his own mistakes.

It is very gratifying to those who initiated and gave the courses to be able to record that the treatment afforded to battle casualties of the War of 1939–45 in the earlier stages was incomparably better than that of the War of 1914–18. While minor mistakes still occurred, the major mistakes of the earlier war were avoided and the wounded were evacuated to home base hospitals in excellent condition.

Experience has shown that air evacuation, apart altogether from the greater rapidity, is by far the most comfortable form of transport for maxillo-facial cases.

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PLATE I. Precision lock between upper and lower cap splints.

PLATE II. Vertical training flange screwed to lower splint ; as used for the treatment of a unilateral fracture of the condylar neck.

PLATE III. Plastic headcap, rods and universal joints to stabilise a fractured upper jaw.

[Facing page 376

Plate IV. Weight traction used for slow reduction of fracture of upper jaw.

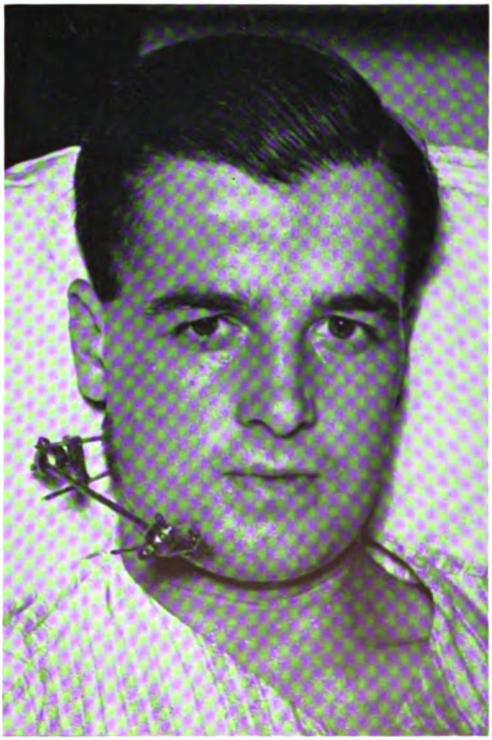

Plate V. The original Roger Anderson pin apparatus in which the pins are drilled into place through the prepared blocks.

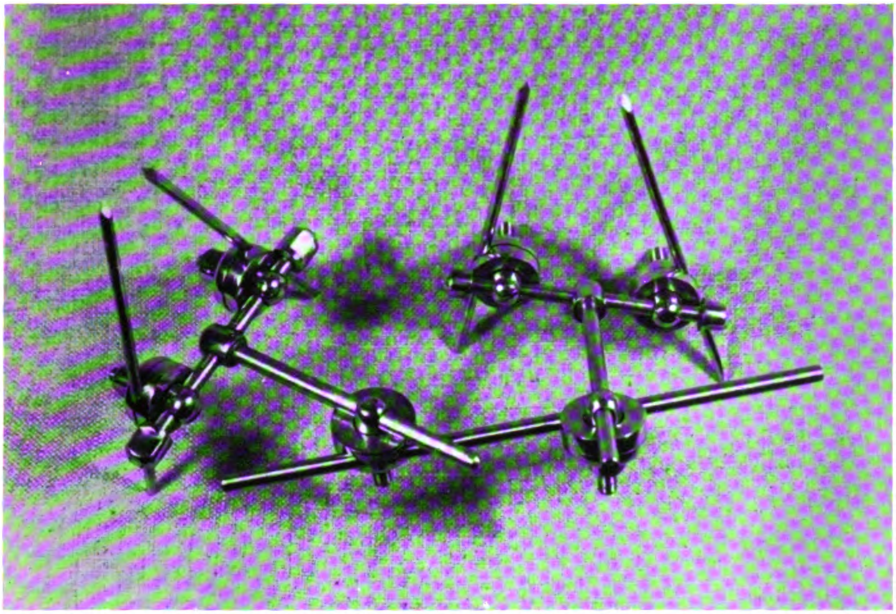

PLATE VI. The Clouston-Walker pattern Roger Anderson pins assembled for 2-pair fixation.

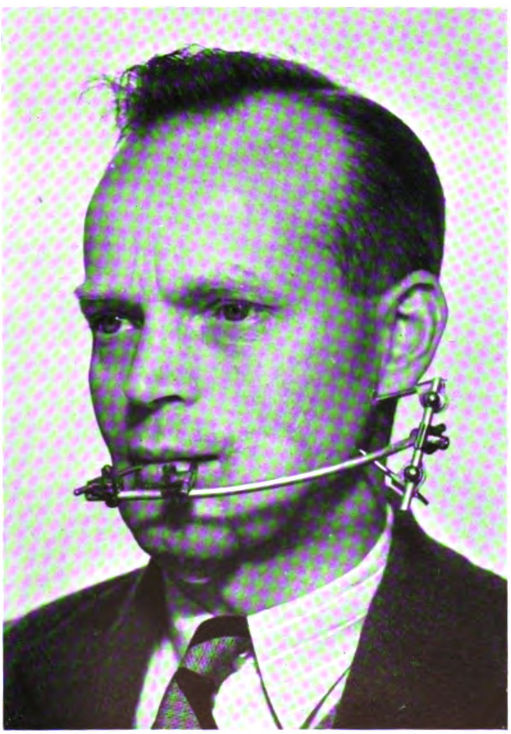

PLATE VII. 3 mm. Roger Anderson pins controlling edentulous posterior fragment for bone graft, with $\frac{3}{16}$ in. diam. duralumin connecting rod and two extensions from the mouth.

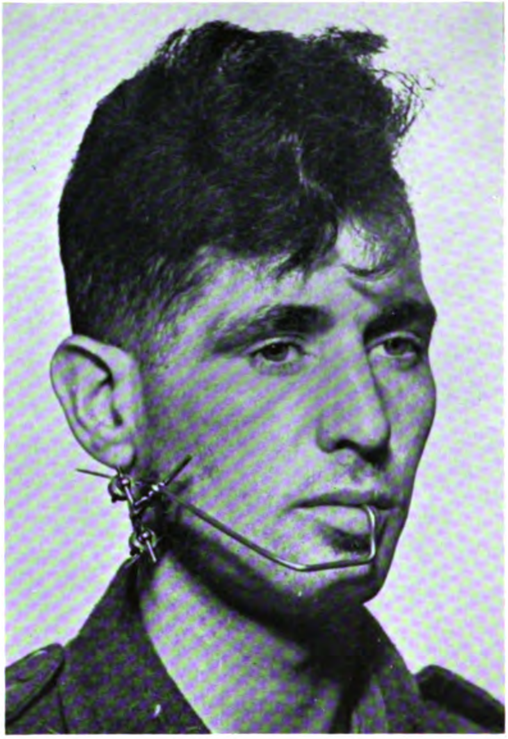

PLATE VIII. Clouston-Walker Roger Anderson pins used to control an edentulous posterior fragment. Note the single extension from the mouth.

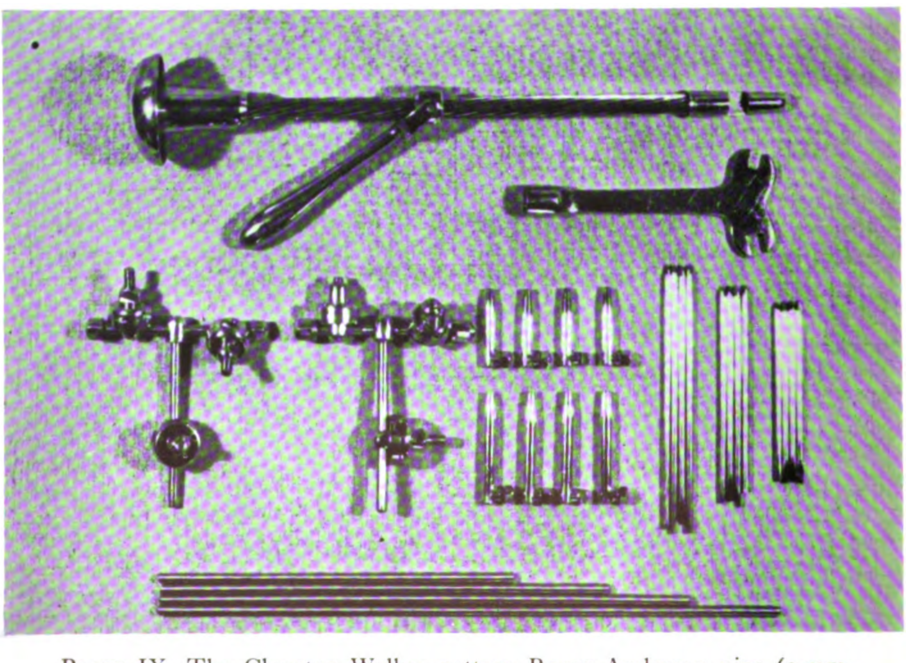

PLATE IX. The Clouston-Walker pattern Roger Anderson pins (2 mm. diam.) and safety sleeves.

CHAPTER 10
NEUROSURGERY
(i)
The Skull and Brain

By SIR ZACHARY COPE
B.A., M.D., M.S., F.R.C.S.

THE story of the great advances in the treatment of wounds of the head in the War of 1939–45 makes very encouraging reading. The following account has been put together after a general review of the available literature, but it has been chiefly derived from the writings of Professor Sir Geoffrey Jefferson, F.R.S. and Professor Sir Hugh Cairns and his colleagues; to those two outstanding figures in the neurosurgery of our generation, who more than any others made these improvements possible, we wish to express our great indebtedness and gratitude. We also wish to thank the Editor and publishers of the *British Journal of Surgery* for permitting us to make full use of the material in their excellent special supplement on Wounds of the Head.

In the War of 1914–18 it was felt that more should be done for head wounds than had been done in the past and a start was made to study the best way to collect and treat patients with head injury. This work will always be associated with the name of Harvey Cushing (1918*a*; 1918*b*). In that war it was estimated that 50 per cent. of those who died on the battlefield had been shot in the region of the head and neck, and that 15 per cent. of all cases passing through first-aid posts had head injuries. It was further shown that the greatest risk was infection; if there were already meningitis confirmed by lumbar puncture it was considered a waste of time to operate (Olivecrona, 1940). There was no official segregation of head wounds and there were no designated neurological surgeons, though in some forward units it became the practice for one surgeon in particular to deal with the head cases. Towards the close of that war there was a special segregation of head wounds at Wimereux under the care of Jefferson, and, as is well known, Harvey Cushing organised a unit which was run by Gilbert Horrax (1919).

In England, neurosurgical cases were collected largely at one or two hospitals in London. There were no units elsewhere. In spite of technical skill, the results of the treatment of head injuries in that war were very discouraging. Wounds with dural penetration gave a mortality of about 40 per cent. One operator gave a mortality of 9·3 per cent. for such cases, but this was at a base hospital, which cases with overwhelming injuries would hardly reach. It was pointed out by Jefferson in 1919 that death was nearly always due to infection; he estimated that of 28 fatal cases only 4 had died because of the irrecoverable nature of the brain injury. In the treatment of this infection, asepsis was unattainable while the local application of antiseptics proved a failure. The wound was excised, irrigated with antiseptics and then usually left open, with almost inevitable resulting infection. Nevertheless, there emerged the encouraging fact that the brain and meninges were able to resist infection to a remarkable degree, and it became clear that the problem was, not to make the brain do something it had never done before, but to assist its very considerable powers of resistance by wise handling, and, if possible, by new agents. As will be shown in the sequel, both these agents came to the surgeon's assistance in the Second World War, and enabled him to obtain much better results, so that there was a greatly increased survival rate, and a rate of 85 per cent. in which primary healing of head wounds was obtained. The wiser handling included segregation of cases, the provision of specially trained units, the technical improvements such as more efficient suction and better use of lighted retractors, and other such methods; the new agents included the sulphonamides and the wonderful antibiotic penicillin. Added to these factors one should mention the great value of close co-operation between the neurosurgeon, the oto-laryngologist and the plastic surgeon, that trinity which worked together for the good of the soldier with a head wound. The years between the wars witnessed notable advances in the realm of neurosurgery and it was significant that during this time the War Office appointed Professor Hugh Cairns, the Nuffield Professor of Surgery at Oxford, to be consultant in neurosurgery to the Queen Alexandra's Military Hospital at Millbank.

SEGREGATION OF PATIENTS WITH HEAD INJURY

The War of 1939–45 was the first war in which any military force developed an effective organisation for the segregation of patients with wounds of the head. Though this was most notable in Britain and with the British and American Forces, the same needs were felt by other countries. In the Finnish Campaign of 1939–40, Babtchine (1940), who was with the Russian Army, advised the extension of the principle of neurosurgical teams operating as near the line of battle as possible, the training of younger men in special neurosurgical technique, and the teaching of the elements of cranial surgery to general army surgeons. Similarly, the German, Tönnis (1940), who took part in the Polish Campaign, noted that patients who were operated upon under unfavourable conditions did badly, and only those quickly transported to a base hospital did well. Tönnis also recommended air transport for patients with head injury.

Britain made use of all available neurosurgical resources in order to treat head injuries efficiently. The Royal Navy had its own neurosurgical service which was on a smaller scale than that of the Army and that of the E.M.S., since the war risks of naval personnel are of a different kind.

In Britain the Emergency Medical Services of the Ministry of Health and of the Scottish Board of Health had the important rôle of treating many head injuries in bombed civilians and in wounded soldiers and some airmen from oversea, while still attending to the usual neurosurgical needs of the civilian population.

In the Army the outstanding feature of the new Head Injury Service was the creation of Mobile Neurosurgical Units. These units, raised and taught at the parent hospital in Oxford, provided highly trained and fully equipped teams fit to take the field and co-operate with and supplement the regular medical formations. There were eight such units which, particularly at and after Alamein, showed great dash and initiative in the various theatres of war and well proved their worth. The R.A.F. had no special Neurosurgical Service, but made use of the centres, particularly those provided by the Army.

It will be convenient to deal first with the organisation of the Emergency Medical Services and then to consider the provision made by the Army. Following that a section will be devoted to a brief account of the advances made in knowledge and technique during the course of the war.

THE EMERGENCY MEDICAL SERVICES

Before the war started there had arisen in Britain a number of neurosurgical centres based on the university medical schools. This recognition that neurosurgery was a whole-time, indeed a life-time's job was in advance of the Continental views and practice, and when war came there was a great deal of anticipatory interest as to the part the neurosurgeon would contribute to the care of battle casualties. The expectation was the greater because in the War of 1914–18 there had been no such ordered establishment, although there had been two or three centres in operation at the end of the war.

SPECIAL NEUROSURGICAL CENTRES

Before the outbreak of war in 1939 it was obvious that special conditions of medical work would be created by air attacks on civilians. Nor were hospitals and their staffs likely to be in any way immune from the same danger as the rest of the populace. It would clearly be unsafe to carry out work in the hospitals in the great cities, certainly not in London, which was expected to be the principal and earliest target. Innovations were therefore planned at Cabinet direction for a new division of the Ministry of Health—The Emergency Medical Services (E.M.S.) which drew up a scheme that worked well. By this plan, London was divided into radial Sectors each derived from a teaching hospital. The rest of the country was divided into Regions. Specialist advice was sought for different branches of medicine and surgery. In the first instance Prof. H. Cairns was neurosurgical adviser to the E.M.S. At the outbreak of war Professor G. Jefferson and he divided

England between them, but when Cairns went to the Army in February 1940, Jefferson took over England and Wales. Two neurosurgical centres were first established north and south of London and a third in the north-west of England. The National Hospital, Queen Square, was closed for surgery, and its surgical division moved into the country. One ward at Queen Square was later burned by an incendiary bomb, and the hospital was hit by a bomb that luckily did not explode, but otherwise it remained intact and its staff unhurt. The other two London neurological hospitals (Maida Vale and the West End) were also much modified in their working; one in fact, was eventually destroyed, the other badly damaged.

During the first nine months of the war, London continued to be regarded as the most vulnerable of British targets because of its size and its nearness to the Continent. But after the fall not only of France but of most of Europe, it became plain that the new bases that the enemy now possessed made the whole country vulnerable. This possibility was soon turned into reality. To meet the needs of the population the country had already been divided up into Regions with a great number of new hospital beds, mainly outside the great cities. Some of these were designated Special Centres, and stage by stage, 10 Special Head Centres were set up in England and 2 in Scotland (the latter under the Scottish Board of Health). Most of them were originally replacements of the peace-time centres moved to safer places, but some were new. These 12 centres did not all come into being at once; they were developed to meet needs. The latest was added only in the summer of 1944 for the invasion of Europe, when 3 temporary centres were created to deal with gun-shot wounds of the head arriving from the Normandy battles. Circumstances caused all of these centres to become extremely important to their Sectors (London) or Regions (the rest of Britain, i.e. the larger part). The centres varied in size with from 60 to 80, or even 120 active beds in each. The staff consisted of 1 neurosurgeon, 1 chief assistant, 2 house surgeons, 1 anaesthetist, 1 pathologist, 1 electro-encephalographer, and 2 secretaries. There were rehabilitation beds either in an affiliated or in the same hospital.

The centres dealt only with the cranial, and usually the spinal, wounds within the field allotted to them, but they had also to care for the neurological maladies of the civilian populations of their proper district—sometimes areas of many hundred square miles. This double burden of peace and war proved to be extremely onerous, especially so because the Army had no neurosurgeons but those that it could get from civilian life. The Armed Services very rightly required all that they could get, and the E.M.S. did not fail them. Not only did the centres deal with civilian and more rarely military air-raid casualties, but they played a major rôle in the neurosurgical treatment of soldiers, for it was their duty to help the Military. The Military also had their own hospitals, but in neurosurgery the work was widely shared with the E.M.S.

An idea of the work that these centres did can be gained from the table below, which appertains to 6 centres and covers the first two years of the war:

Analysis of 3,045 *Admissions to* 6 *Neurosurgical Centres*

Head injuries	1,509
Brain tumours	593
Brain abscesses	50
Epilepsy	125
Spinal tumours and injuries	219
Peripheral nerve lesions	102
Other conditions	447

By the middle of 1943, the total admissions had risen to 5,638, of which 46·8 per cent. were military personnel, the rest civilians. The reason why there were so few peripheral nerve injuries was chiefly that such cases were collected into three other special centres designated for that purpose and described in a separate chapter. Britain followed the pattern laid down in the previous war whereby the nerve injuries were in the hands of certain special orthopaedists, assisted by medical and sometimes surgical neurologists, because of the frequency with which fractures and severe soft-tissue injury complicated the cases. Only one of the special head centres (Winwick) was also a designated peripheral nerve injury centre.

Nevertheless, some of the centres did good work on uncomplicated peripheral nerve injuries. Spinal injuries also tended to become more and more segregated into special centres, not always neurosurgical and not orthopaedic either. Gun-shot injuries of the spine did not require immobilisation in plaster, as the stability of the spine was not much endangered by a shell fragment. In this war, the fragmentation of the missiles was such that small pieces of metal moving at high velocity were the usual wounding agents. These did damage by penetration or by traversing the body, but they did not very often shatter a spine. It was gratifying to find that by no means all of these wounds appeared to result in total and lasting paraplegia. Recovery seemed to be possible in about 25–30 per cent. of cases (Jefferson, 1945).

DISPOSAL OF HEAD-INJURED

Before the war it was not the custom anywhere for closed or blunt head injuries to be admitted only to neurosurgical centres. Neither Sir Victor Horsley nor Harvey Cushing had insisted on this. However, war imposes its own special necessities, and, in relation to head injuries, not the least was the Army's requirement that the soldier should be returned to duty quickly, and in as high a category of physical fitness as possible. This was true in little less degree for the civilian, a man or woman more often than not engaged in some form of duty relating to the war effort. The handling of the head-injured by the general surgeon and practitioner in peace-time left much to be desired; too often the injury was followed by a long period of invalidism, mainly because the patient developed a neurosis. Notwithstanding Wilfred Trotter's teaching that the patient should begin to get up within a few days of recovering consciousness (See Choyce's *System of Surgery*), most patients were treated on the old rule that three weeks in bed will prevent post-traumatic headaches, and there was little attempt to promote physical fitness by graduated exercise before return to work. In the early stages of the war, soldiers with recent head injuries were being sent on long train journeys immediately after being in bed for three weeks; they developed headaches or vertigo, became alarmed at what to them seemed evidence of unhealed brain damage, and were thus rendered unfit for further service. In pre-war days such patients were treated on the assumption that their post-traumatic headaches were directly due to unresolved bruising (persistent cerebral contusion), to raised intracranial pressure, or to adhesions between the injured brain and meninges: the brain was explored by operation at the site of maximum headache, the patient was 'dehydrated' by hypertonic salts, or air was injected into the cerebrospinal pathways to break down hypothetical adhesions. The emphasis had been indeed almost solely on the organic brain damage with little thought for the kind of brain which was injured, that is to say, for the personality of the patient. Teaching on the subject of post-traumatic headaches was not clear, and not unnaturally medical practitioners were disinclined to make prompt decisions on individual cases; patients were passed from doctor to doctor, from one form of treatment to another, and in the process their symptoms, often aggravated by the question of compensation, became more intense and fixed.

To C. P. Symonds (1928, 1945) was due most credit for the prompt and satisfactory manner in which this aspect of the nation's head injury problem was dealt with from the outbreak of war. Between the wars he had studied post-concussional syndromes and had recognised the importance of individual psychological factors. He foresaw the need to study systematically the patient's personality as soon as full consciousness had returned, and he also stressed the point that indecision or delay in arranging for convalescence and disposal of the patient would increase the likelihood of post-traumatic disability. During the war, Symonds's teaching was systematically applied in the head centres, in particular by the medical neurologists who dealt with the patients after their wounds had healed and their acute symptoms had subsided.

The study of the patient's personality was on common-sense psychological lines: his family history and past history, especially in regard to nervous breakdown; his record at school and at work; his hobbies; his adjustment to life in the Fighting Services; the present circumstances of his family; his general level of intelligence, and so on. It was soon shown that after a head injury individuals with an unstable pre-traumatic personality readjusted poorly to life in the Fighting Services; they had a better chance of avoiding a neurotic aftermath and were of more use to their country in its struggle if they were promptly returned to civil life. In the more stable types, systematic study of personality revealed a variety of additional causes, over and above the brain damage, for anxiety and persistent headaches after head injury, and many of these cases could be promptly dealt with. Some were worried from fear of permanent brain damage and incapacity, others because the head injury had interrupted their discharge of domestic responsibilities, fighting men feared that the head injury had lost them their own particular unit and comrades, and so on. Most serious were those cases, fortunately a minority, in which as a result of gross brain damage, the patient's mental powers were so impaired as to interfere with his prospect of returning to his former occupation, but not sufficiently impaired to prevent him being anxious about his disability. There was very little malingering.

The great improvements in the treatment of head injuries were made possible by the segregation into special neurosurgical centres of all patients with such injuries occurring among military personnel or civilians engaged in special work.

The first essential was to discover how many head injuries there were. It was found that industrial head injuries were not very common, the majority occurring as a result of traffic accidents in town and countryside. The only means of tracing such injuries was by instituting notification, by which any case admitted to a hospital in a given district should be notified to the neurosurgical centre proper to its region. At Professor Jefferson's suggestion and with the help of the Director-General, E.M.S., notification was introduced and in this way it became possible, as in the case of an infectious fever, to follow the history of a head injury. Usually these patients were removed to the special head centre, not always immediately, but always within a week or two. In one Region alone, 1,000 head injuries were thus notified, of which 178 had been caused by air raids.

In head injuries there are two danger periods; first, the immediate danger to life, which rarely extends beyond a week; second, the danger to morale, which begins when a patient nominally leaves hospital. It was in this second period that the worst failures occurred. However, it was possible by getting the patients into the special centres to help them in the first period and to apply preventive measures to avoid the second danger. Much was done for these patients by reassurance, and by occupational therapy in the early stages of convalescence, followed later by graduated physical training. Moreover, a follow-up was carried out so far as possible, one centre sending reports to others if the patient normally lived in a different area. The Ministry of Labour was of great help in finding suitable work for the injured, and the head-injured were better and more sympathetically treated by those who managed the great industries than was the case in the days of peace.

ABILITY OF HEAD-INJURED TO TRAVEL

It had been objected that, however desirable it is to get a person who has a head injury into a special centre, transportation would make the patient worse. That dogma was true only of those who were so badly injured that they would not recover in any case, or of those who had additional severe injuries elsewhere (e.g. fractures of the femur, ribs or pelvis). It was one of the outstanding lessons learned in the war that the head-injured could be moved without any decline in condition. On behalf of the Medical Research Council, Jefferson undertook to report on the pulse-rate, blood-pressure and temperature of patients before and after a journey of three hours or so by road; and though it was very difficult to obtain sufficient information, he was able to say that no significant alteration took place. This removed the greatest bar to transfer and segregation, for it was a matter of common knowledge that the head-injured were often most wisely taken to the hospital, great or small, nearest to the scene of the accident. Few doctors at first would take the responsibility for moving these patients from the first receiving hospital to a special centre, but experience taught them that it was not dangerous. Alternatively, a neurosurgeon from the nearest centre visited the patient and gave advice. In this way the first danger period was circumvented, while eventual transfer, if not in the first day or two, did much to mitigate the dangers of the second period—that of unnecessary illness. When the battles began in Europe these lessons were applied and many hundreds with head wounds were flown home for their definitive treatment in conditions much better than the battle-field provides. It was learned thus that journeys of much longer duration than two to three hours were well tolerated, and that such journeys should be undertaken if better treatment could thereby be ensured.

A special committee of the Medical Research Council, under the chairmanship of Professor E. D. Adrian, F.R.S., was set up to consider head injuries. It did much valuable work, for the committee was made up not only of surgeons but also of neurological physicians and psychiatrists. The committee published a glossary on the meaning of terms used in recording head injuries (1941), giving definitions—for example, of stupor and traumatic delirium—that proved useful. Projected experimental work could not be carried out, for the improvised hospitals of the E.M.S. were short of laboratory facilities of the right kind, had not sufficient trained personnel, and were often distant from the laboratories in which their staff had worked in peace-time. Some laboratories were destroyed by bombs. But the committee was helpful in advising on grants-in-aid of work, and in developing electro-encephalography.

AIR-RAID CASUALTIES AND TRAFFIC ACCIDENTS

The number of head injuries caused by bombing proved to be much fewer than the pessimists had foretold. It was found possible to group together head injuries inflicted by motor-cars and by enemy bombs. Penetrating wounds of the head, with head-laceration by portions of bomb-casing, were much less frequent than were blunt injuries caused by masonry when houses fell on their inmates. From a quarter to a third of those injured in air raids had a head injury, but it was often of a minor kind; the high incidence was due to the number of civilians whose houses had collapsed upon them. There was a high proportion of eye injuries. Glass, in small jewel-like fragments, propelled with great force by blast, proved to be a serious and dangerous form of missile which on one occasion actually penetrated to the hypothalamus. The wounds were nearly all dirty with fine particles blasted into the tissues. Most of them were crushed and contused from blunt violence which often, by lateral movements, caused irregular tears and, by rotation, complete removal of tissue. Deep contusion was common and blood was found in the cerebrospinal fluid in a fifth of the cases of apparently pure scalp wounds. Depressed fractures might be unsuspected and missed, and if the wound became septic future management of the fracture was hazardous owing to the risk of osteomyelitis and meningitis; if the signs of deep infection were delayed, it might happen that the original operator never learnt of the subsequent complication.

The congregation of all these injuries in the different centres allowed the neurosurgeon to see head injuries for the first time in the mass. His most immediate and striking impression, which experience confirmed, was that a very large proportion were not very serious. It is necessary not to confine thought upon the worst cases alone, because a planned system of treatment must take account of only the few severe cases in every hundred. The mortality of such congregations of head-injured was low, not more than 2 to 4 per cent. It is well known that in some sets of figures in the literature the mortality has been as high as 38 per cent., while in many where the patients have been very well looked after it has been 20 per cent. or a little less. The disparity between these percentages is due, not so much to differences in surgical treatment, as to differences in the material itself, to the fact that in some hospitals head injuries of all grades were admitted, while in others none but the worst were accepted.

It is well in speaking of the care of head injuries to use the word 'management' rather than 'treatment' for this emphasises the fact that the treatment of the patient in a bed is only a phase of longer-sighted policy, linked up with his rehabilitation and early return to duty, whatever that may be.

THE FUTURE

A point has been reached when it is useful to enquire whether the plans made and put into action for the care of head-injured in war-time were so beneficial that they should be prolonged and improved in time of peace. It does not seem possible for every head injury to receive primary treatment in a neurosurgical centre, at least not in the immediate future. The difficulty is with the smaller places, and especially with country districts. Very many injuries occur in places far removed from highly-skilled help and it says much for the recuperative powers of the brain that so many survive if they are placed in even the smallest hospital. The danger is that, the smaller the hospital, the longer does it retain such a patient and the more unnecessary the attentions he receives from its staff—too often leading him to believe that he is a wonderful man to have survived. There will perhaps always be some such instances even with the best of organisations.

However, there is a clear possibility that, under the new National Health Service, regionalised schemes for the care of designated categories of illnesses and accidents will be established. The plan would be to have an accident service that would include head injuries, with a neurosurgical consultant to advise. This at least would be the plan in the university city, or greatest industrial cities. In some centres it might be preferred to admit the head-injured to an enlarged neurosurgical centre, but a considerable proportion of them have also fractures of long bones and other injuries. Head injuries in the smaller surrounding towns should be attended by general surgeons, who have undergone a training at their parent university centre in the methods of neurosurgery and in the meaning and interpretation of the clinical signs of head injuries, with a good background of neurophysiology. Surgeons without such knowledge should not be allowed to handle these cases. Furthermore, the general practitioner still needs instruction in the prognosis of the head-injured; his sense of values requires reformation.

Proper management can be achieved only by planning on a national basis. The experiences of the war showed that a planned scheme has great advantages for the injured, and it will be one of the more important of the duties of the neurosurgeon in the future to ensure that head injuries shall be better cared for—not merely at the bedside, but in their convalescence (Jefferson, 1945).

NEUROSURGERY IN THE BRITISH ARMY, 1939–45

The treatment of head injuries during the war was a large and difficult problem. Such limited surveys as were made of battle casualties in forward areas indicated that the true incidence of head wounds on the battlefield was about 10 per cent. This major problem had never been seriously tackled in the War of 1914–18, but between the two great wars the British Army, as mentioned above, had recognised neurosurgery as a specialty and appointed a consultant neurosurgeon to Queen Alexandra's Military Hospital at Millbank, and in 1938–9 formulated plans for utilising the limited numbers of neurosurgeons available to the Army. Though it took some time to perfect the arrangements and to train more surgeons and staff there is no doubt that during the major part of the serious fighting the neurosurgical problems of the British Armed Forces were overcome to an extent scarcely hoped for in 1939. Full success depended largely upon prompt segregation and was achieved with an increasing efficiency from the time of the battle of the First Army in North Africa, through the campaigns of Alamein, Italy, Normandy and North-west Europe; it was even achieved in the difficult Far East campaign of the Fourteenth Army in Burma.

In all campaigns it became clear that effective segregation of head cases depended to a very great extent on air evacuation. Sooner or later in all major theatres of war, 90 per cent. of patients with head wounds were in the hands of expert, fully equipped neurosurgeons, at distances varying from 10 to 1,000 miles from the front, in time to have their wounds completely closed after excision and cleaning; the majority were operated on within forty-eight hours of injury. In over 80 per cent. of those who survived the initial brain damage, wounds healed by first intention. Brain fungus became a rare event and the death rate from infection in penetrating brain wounds was reduced to 5 per cent. or less. In non-penetrating wounds the death rate was under 1 per cent., and when there were no neurological signs the patients returned to duty, often without leaving the Army area.

Such results as these—unparalleled and even unapproached in any previous war—call for a more detailed record of this new system of organisation for the treatment of neurosurgical cases.

The Consultant Neurosurgeon to the Army, Professor (and later Sir) H. Cairns, had his headquarters at Oxford in the newly established Military Hospital for head injuries at St. Hugh's College. Between 1940 and 1945 in this hospital of 300 beds, there were treated some 13,000 patients from the Army, R.A.F. and Royal Navy (in addition to patients from the Allies), and here was provided an excellent training ground for neurologists, neurosurgeons, nurses and orderlies. A British Red Cross Hospital at Middleton Park and another at Tusmore Park provided centres for convalescence and rehabilitation of patients from the Oxford hospital. These dispositions were closely co-ordinated with those of the Canadian Neurological Hospital at Hackwood Park, Basingstoke and the various neurosurgical centres of the Emergency Medical Services, and there was the freest interchange between these services. No account of the neurosurgery in the British Army would be complete without grateful acknowledgement to the neurosurgeons in the Emergency Medical Services and in the Canadian Hospital.

In the oversea theatres the organisation of neurosurgery was planned with the advice of the Consultant Surgeon or the Consultant Neurologist of the Force, at times assisted by a part-time Neurosurgical Adviser. At all levels there was the closest co-operation between the neurosurgeon and the neurologist. With the armies oversea there were mobile neurosurgical units (M.N.S.U.) and a few static head units, all of which had been trained and equipped at the parent hospital at Oxford. The original establishment of the unit consisted of 1 neurosurgeon, 1 neurologist, 1 anaesthetist, 2 general duty medical officers, 2 nursing sisters, 4 R.A.M.C. O.Rs. and 2 R.A.S.C. drivers, but the team was often split up or modified for brief periods to form two or even three smaller teams to meet a special circumstance. Each unit was equipped with 2 sets of neurosurgical and 1 set of general surgical instruments, 2 operating tables (electrically heated), surgical diathermy, motor suction, and material and equipment for 200 neurosurgical operations. It had its own vehicles, with a petrol engine and generator to supply power for diathermy, suction, theatre lighting, etc., its own water-tank and sterilisers for instruments, bowls and lotions, heated by 4-burner primuses. It depended on a host unit, usually a general hospital, for beds and arrangements for nursing, X-ray and pathological services and sterilisation of linen.

No. 1 Neurosurgical Unit was captured at Dunkirk, where its special personnel were taken prisoners, but was re-constituted and took part in the North African Campaign of 1941–2, demonstrating clearly that a modern surgical service could be taken to the wounded even in the difficult conditions of the desert; this unit afterwards worked in Cairo where it did much good work.

No. 4 M.N.S.U. was sent out to North Africa and took its place in the Eighth Army's advance after Alamein. It crossed Cyrenaica, Tripolitania, and Tunisia, and in a narrow and particularly favourable line of communication brilliantly demonstrated what effectiveness and flexibility could be achieved by a mobile neurosurgical unit in the forward area. Most of the head wounds were operated on within 24 hours of wounding, the incidence of brain abscess as a complication of penetrating wounds was reduced from 27 per cent. to less than 5 per cent. and primary healing of excised wounds was more common. By splitting of the unit into a forward section, working usually with the most forward C.C.S. and a rear section on the lines of communication at Tripoli, and with adequate air evacuation, a specialised head service was provided from the forward C.C.S. to the base at Cairo—a distance of 2,000 miles—with great economy of personnel.

No. 5 Unit did similar valuable work with the First Army, and though the front was wider, the lines of communication less favourable, and air evacuation not so well developed as in the Eighth Army, about 70 per cent. of the brain wounds of the First Army passed through its hands.

No. 6 Unit followed the 21st Army Group in Normandy and Germany, and did excellent work; No. 2 Unit which went to India and Burma did not get much experience, but No. 3 Unit which served in Assam and Eastern Bengal did valiant service under very difficult conditions. The moist heat was often so intolerable that operations could only be done at night, and always under general anaesthesia, because no conscious patient could manage to keep perfectly still under drapings on the operating table.

The outstanding achievements of the neurosurgical units depended upon several factors. Trained personnel, suitable and up-to-date equipment, sympathetic co-operation of the administrative officers of the regular R.A.M.C., and adequate air transport were all necessary and available for their success. Experience with the equipment of the units showed the prime importance to any organised medical service of an expert staff, including doctors and those with experience of pharmacy and mechanical and electrical engineering, to deal with the question of supplies and equipment. One reason why the equipment of neurosurgical units was so satisfactory was that practically all of it was bespoken at the outbreak of war, before the industry of the country became geared to war-time mass production.

The units were sufficiently flexible to meet the changing conditions of warfare and to provide continuity of treatment. When, as often happened, the unit was split into two sections, the personnel could be transferred from one section to the other as occasion and pressure of work required, and often the patient was passed from the forward section to the rear section of the unit. In some ways special units must have been a nuisance from the administrative point of view, but the task of looking after them was accepted by the R.A.M.C. and other branches of the Service without complaint but rather with helpful co-operation.

Considering this was the first war in which it was used on a large scale, air evacuation of the wounded was carried out remarkably well. Certainly head cases travelled well by air both before and after operation, and they were given high priority for air evacuation. The prompt evacuation by air had a lot to do with the improved results of the treatment of head wounds.

EVOLUTION OF THE TREATMENT OF SIMPLE BRAIN WOUNDS

In the first years of the war the principles of excision and primary suture which had been elaborated for head wounds by Cushing were applied, when opportunity presented, to recent uncomplicated brain wounds, with the aid of sulphonamide therapy and all the modern apparatus of neurosurgery, such as motor suction and diathermy, which had not been available in the War of 1914–18, but there was no generally accepted line of treatment for the later cases. Many head wounds, partly excised in the forward area, were only seen late (more than one week after injury) at the neurosurgical units, often suppurating and plugged with vaseline gauze; many of these developed brain abscess and required further operations. At this time drainage was considered essential after primary excision and suture, and when there was difficulty in approximating the edges of the scalp the wound was left open. By 1943, when the neurosurgical units began to receive their cases early and were able to excise and close fresh wounds with regularity, the incidence of post-operative infection fell. In the early stages of the war up to the latter part of 1943, it was customary to apply sulphonamide powders to débrided brain wounds, but no clear evidence of their value in head wounds was obtained, though the general impression remained that they were helpful. Moreover, it was demonstrated by Watt and Alexander (1942) and confirmed by Cairns (1947) and his colleagues that when sulphathiazole had free access to the cerebro-spinal pathways it could give rise to fits and rapid death. Fortunately sulphamezathine was not so toxic.

It was also in 1943 that penicillin became available for the treatment of wounds, when the special mission of Florey and Cairns (1943) to North Africa demonstrated its value in any kind of war wound. The early stages of the Italian Campaign quickly confirmed the impressions of the Sicilian Campaign that adequate local use of penicillin provided a measure of control of the severe infected head wound never before attained, with significant improvement in the over-all results. It was established (by Cairns, Eden and others) that penicillin intrathecally (4,000 units)* was curative in meningitis from susceptible organisms, provided there was no blockage of the cerebro-spinal pathway and that the primary focus had been adequately treated; that in grossly infected wounds with superficial suppuration, cellulitis of the scalp and osteomyelitis, and in cases of infected brain fungus, systemic penicillin was of great value; and that, injected locally, penicillin solution (10,000 units per c.cm.) was useful for sterilising abscesses when these were being treated by repeated aspiration or drainage as a preliminary to enucleation. There was a difference of opinion as to the relative value of local and systemic penicillin in prevention of infection with Gram-positive organisms after excision and suture of brain wounds. In Burma, virulent Gram-negative infections were so prevalent that penicillin was not used locally on brain wounds in which there was clinical evidence of this type of infection, and never intrathecally save in proved infection with susceptible organisms. Intrathecal penicillin was instrumental in saving the lives of several patients suffering from pneumococcal meningitis following operation and manipulation of maxillo-facial wounds. Nevertheless, the injection of penicillin or any other drug into the theca needed accurate knowledge of the dosage and great care in technique.

* This was the minimal effective intrathecal dose, worked out at a time when the impurity of preparations of penicillin rendered any considerable increase above that dose dangerous to the patient. Later when purer and finally crystalline penicillin became available the optimum intrathecal dose was found to be 10–20,000 units once or twice daily.

In 1943–4 was developed that very useful co-operation between the neurosurgical units, the ophthalmologists, and the plastic surgeons who all worked together for the benefit of the patient with head wounds. In North Africa the association had begun and in Italy it was continued to such an extent that all wounds above the clavicle were sometimes sent to one hospital in which all the specialists were working. The plastic surgeons showed the neurosurgeons how to make good scalp defects by the use of sliding or rotation flaps. By this means the incidence of brain fungus was diminished and the percentage of complete primary healing increased.

A further improvement in 1944 was the use of fibrin foam (sent from Harvard), to stop bleeding from brain cavities, large venous sinuses or other source of bleeding. The foam seemed to be less often followed by infection than the muscle graft which had been previously used.

By the year 1944 technique was well established. Opportunities for excision and primary closure were greater owing to improved segregation and better transport. There was increasing thoroughness and skill in cleaning or débriding the brain track, and an increasing confidence in closure of the scalp and dura, owing to the adoption of the principles of plastic surgery. Débridement of the brain track by syringing had been discarded in favour of suction under direct vision. The neurosurgeon realised the serious risk of leaving brain pulp, clot and foreign material in pockets of the wound track. Heavily contaminated wounds and other wounds three days old or older were closed after thorough débridement; purulent wounds were also closed almost completely, a small tube being left for installation of penicillin. The results were exceptionally good. For example, Small and Turner, dealing with 182 cases of uncomplicated brain wound, recorded that eleven died within a few days, but 161 were evacuated to the United Kingdom and all but one were alive three months later; in all varieties of brain wound, both simple and complicated, they obtained primary healing after operation in 86 per cent. of cases. Considerable factors in success were the methods of sorting and resuscitation, and the skilful and improved methods of anaesthesia. Special 'head' cards were provided in the forward area, and at the unit it became the neurologist's function to select cases for operation in an agreed order of priority, to record the physical signs, to evacuate suitable cases by air to the base without operation, and thus to maintain a steady stream of cases into the operating theatre while preventing the surgeons of the unit from being overwhelmed. The wounded arrived at the unit dehydrated and in need of fluid. If at operation blood was not given, the severely wounded underwent a greatly increased risk. Blood transfusion as a pre-operative measure was required in those patients who had lost blood, those whose wounds were already infected, those with multiple wounds and those who had been unduly exposed. At the battle of Cassino blood was given to 15 per cent. of all patients with head and face wounds, with an average of 2·5 bottles per patient (Technique, Plates I–V, Schorstein).

Most neurosurgeons on active service preferred general anaesthesia for all their patients, except those in coma or in such a state that they were likely to be jeopardised by general anaesthesia. Continuous pentothal in an intravenous drip, or induction by pentothal followed by intra-tracheal gas, oxygen and ether, or by cyclopropane, were the methods of choice. Tracheal intubation was usually necessary, and packing whenever there was blood in the pharynx. The essential was an absolutely clear airway, and even minor degrees of obstruction from mucus or kinking of the tube would so raise the cerebral venous pressure as to increase greatly the brain-swelling and bleeding from the operative field. Suction through the tracheal tube was often required before, during or after operation.

It was by no means uncommon for soldiers to have multiple wounds of which at least one affected the head. If these were dealt with in a purely neurosurgical unit, or by a general surgeon without neurological experience, there was the danger that either the head injury or the other wounds might not receive the best possible attention. This problem was solved in one of two ways. Those patients who could not be moved back to a mobile neurosurgical unit were sometimes dealt with by sending forward a section of the unit to work at the C.C.S. in co-operation with the general surgeons there. On the other hand at the base, where there were large numbers of patients with head wounds, the care of the wounds in other parts of the body was placed in the hands of a general surgeon specially attached to the unit. This arrangement worked well at Naples during the battle of Cassino, and at Oxford during the invasion of Normandy. In any case the surgeons concerned in combined operations needed to give very special care to the general condition of the patient.

PROGNOSIS

The immediate prognosis of penetrating wounds can be judged by the figures already given in the text.

The remoter prognosis of head injuries with dural penetration was considered after a careful follow-up of 200 cases by Dr. Ritchie Russell (1947). All the cases were admitted to the Military Hospital for Head Injuries from the battle of Europe during the period of three months from June 15, 1944 and the follow-up extended to 14–18 months after wounding.

Of the 200 cases, 24 were still in the Army (4 in category A; 4 in category B; 16 in category C); 121 had resumed civilian employment, but 55 had done no profitable work. Of those in civilian employment, 84 were doing light manual work, 18 clerical work; 16 in professional or technical occupation but only 3 were doing heavy manual work.

PLATE I. Through-and-through frontal gun-shot wound with involvement of the frontal sinus:
Scalp shaved. Entry and exit wounds shown. Brain debris extruding from exit wound.

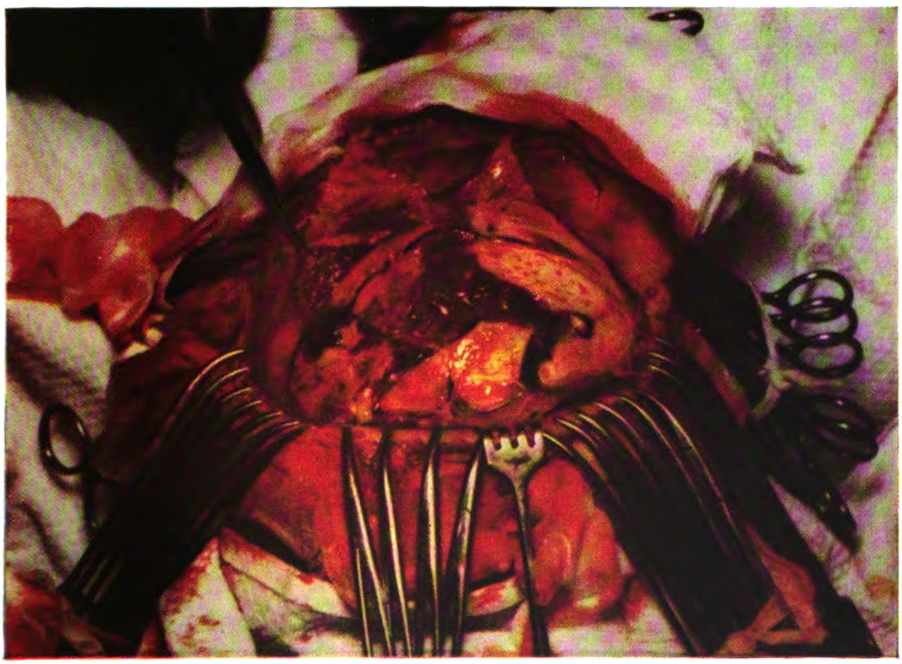

PLATE II. The skin has been excised, and the flaps retracted. Frontal sinus exposed at top part of the bone-injury.

Colour photographs by Hennell of the Metal Box Company, Ltd

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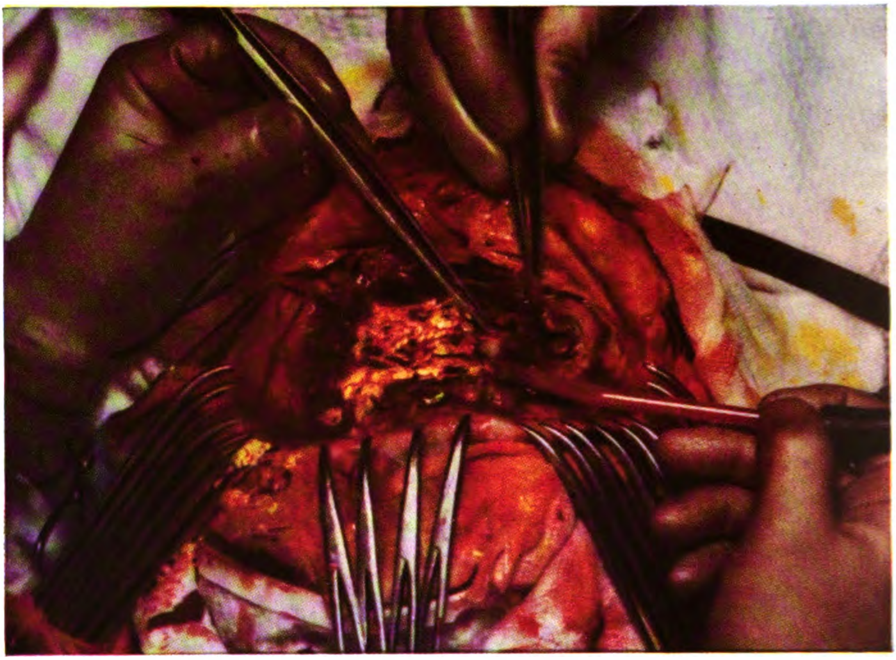


PLATE III. The shattered bone has been removed, and the cerebral tissue cleaned by suction.

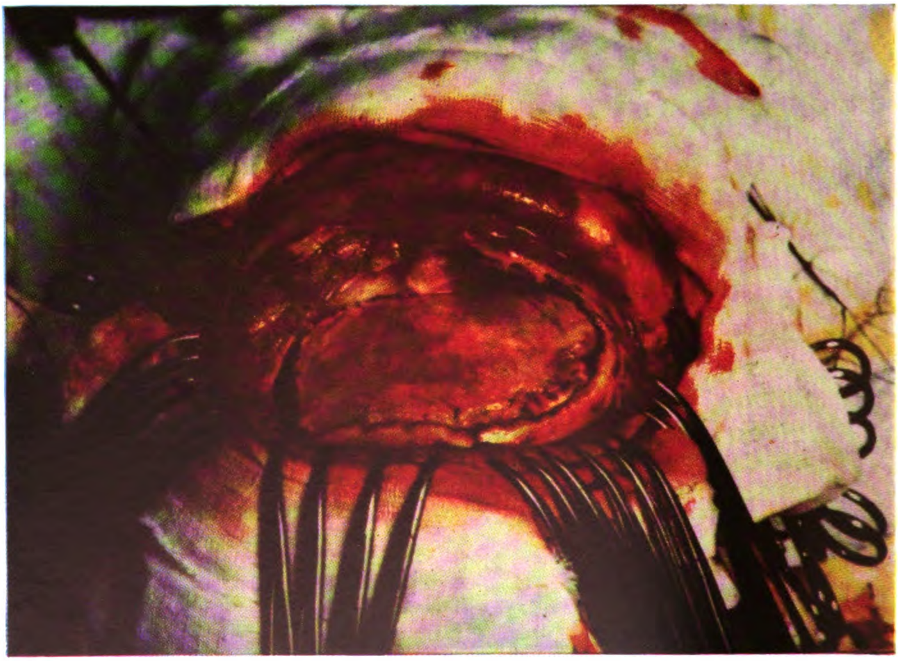


PLATE IV. A piece of fascia lata has been sutured to the edges of the dural defect.

Colour photographs by Hennell of the Metal Box Company, Ltd.

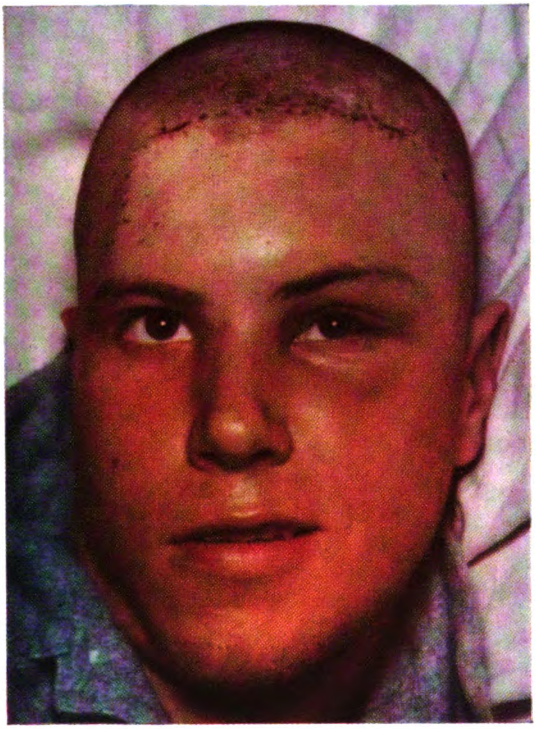


PLATE V. Patient on the tenth post-operative day. He was still mentally confused, had slight right-sided weakness but was otherwise well. His bone defect was subsequently repaired and he returned to duty.

Colour photograph by Hennell of the Metal Box Company, Ltd.

It was interesting to note the nature of some of the occupations, which included messenger, garage attendant, traveller, van driver, bus conductor, insurance broker, packer, porter, student, chartered accountant, cooper, carpenter, painter, fitter, printer, shoemaker, cycle repairer and surgeon.

Some were content with their occupation, but others complained of the strain and fatigue; for many of them it was hard to get pleasure from their recreation or satisfaction from their efficiency at work. Nevertheless the patients adapted themselves to their handicaps and after the first year the general health and later the working capacity improved greatly.

Note was made by Russell as to the relation between the site of injury in the brain and the capability of resuming work. The result can be seen in the following table:

Site of Wound	*Total Number of Cases*	*Number of Cases in which no Work Attempted*
Frontal	72	16
Parietal	81	30
Temporal	26	5
Occipital	19	4
Cerebellar	2	—
	200	55

SPECIAL TYPES OF WOUNDS

Warfare gives the surgeon the opportunity to study groups of cases which in ordinary peaceful times occur rarely and in too small number to enable him to form definite judgments upon the best mode of treatment. The War of 1939–45 certainly advanced our knowledge on the treatment of certain types of head wound.

CRANIO-FACIAL-ORBITAL WOUNDS INVOLVING PARANASAL AIR SINUSES

In any battle-wound the surgeon is concerned with scalp and skull as well as brain, but in facial or forehead wounds the skull architecture is complicated by the presence of the paranasal sinuses. Dangers, therefore, of cerebro-spinal fluid rhinorrhoea, aerocele or deep infection are greatly enhanced, but of course the same is true in blunt injuries low on the forehead. No essential difference in surgical principles is involved in any sort of injury that fractures the paranasal sinuses and tears the dura at the same time. The real point is that these are compound fractures and open to the dangers that belong naturally to that type. They have the additional disadvantage of being not only compound, but that the exterior is put into communication with the meningeal spaces and the brain. Although, therefore, during the first day or so the patient may appear to be little the worse for this happening, except that there is an escape of cerebro-spinal fluid into the nose, the picture in another two or three days may change into one of acute meningitis. It is important that the dural tear should be closed. Even in those cases where for some reason or another an operative repair has not been done, but in spite of it the patient recovers (and that sometimes happens), the patient lives in constant danger of late meningitis from an infection finding its way from the nasal passages through the scar tissue of the meninges, since the thin bones of the nasal roof rarely heal by osseous union. But in penetrating wounds, such as deep stab or gunshot wounds, there is in addition a brain injury, usually much deeper than in blunt injuries, for the projectile may traverse in any of many directions and to variable depths, and as a consequence possible complications are more numerous. A missile wound, moreover, may be at a distance (from the sinus), traverse across the face just below the brain and lift the sinus roof and open the dura by indirect violence. So it is that surgery has to take into account two things: (*a*) the surgery of the brain injury, and (*b*) the surgery of the dura-sinus injury. These may be closely related or entirely separate problems. This is to some extent true in blunt injuries of the air sinuses, but there is just enough difference to make it desirable to deal separately with the two varieties. Long before missile wounds became numerous great strides had been made in the diagnosis and treatment of sinus fractures associated with blunt injuries, so that the lessons learned were quickly applied to the gunshot wounds with success from the start.

BLUNT HEAD INJURIES AND DURAL TEARS

In the early years of the war Cairns and Calvert (1942) had drawn attention to this important and dangerous complication of a head injury, and had pointed out that, although Cushing's method of dural closure by application of a patch of fascia lata was successful in preventing the spread of infection, there were many difficulties. Some were technical, for the operation was extensive and carried some risk, but there were also problems of diagnosis in deciding whether there were one or more communications and their exact position, for some of these defects were notoriously difficult to find at operation. Aerocele or cerebro-spinal fluid rhinorrhoea had been the original indications for operation, but even in their absence there might be a defect with the risk of meningitis and brain abscess, and these authors showed the importance of radiological studies and of varying degrees of anosmia in the diagnosis of a dura-sinus defect. As experience was gained results improved, and finally, with the introduction of effective and yet safe sulphonamide compounds such as sulphadiazine and sulphamezathine, and the use, for the more difficult cases, of the intradural approach advocated by Julian Taylor, the procedure became relatively safe and accurate. The operation, nevertheless, is an extensive one and perhaps now that we have such effective antibiotics as penicillin and streptomycin the indications for it as a prophylactic measure are not so pressing, and in fact will depend to some degree on the relative incidence of infection by resistant organisms (a matter still to be decided by experience), and of course on the extent of the injury.

Cone and Stewart developed a technique of treatment for compound blunt injuries of the frontal region which was largely followed by Stewart and Botterell (1947) in their treatment of open wounds of this region. The latter recommended that these wounds should be treated completely and finally at the first operation as early as possible after wounding. With penicillin and sulphonamides administered at all levels of evacuation, as well as post-operatively, a delay of one, two or even three days was considered of less consequence than the danger of earlier but incomplete operation.

The four main principles guiding the operation and necessary to obtain success were—(1) radical débridement of the cranial and cerebral wounds; (2) débridement of damaged paranasal sinuses with the establishment of adequate drainage through the nose; (3) sealing of the subdural and subarachnoid spaces and (4) closure of the scalp without tension and without drainage. The frontal sinus was most often involved, next in frequency the ethmoid cells, and more rarely the maxillary antrum and the sphenoidal sinus. Damaged parts of the air cells were removed, the remaining parts cleansed and unobstructed drainage into the nose effected. (The Canadians at that time advocated a wider exenteration of the paranasal sinuses than United Kingdom surgeons later found to be necessary.) Sometimes the dura could be sutured, but in many cases it was necessary either to make a plastic repair with fascia lata or temporal fascia, with or without the additional aid of the orbital soft tissues, which could be made available by unroofing part of the orbit and incising the orbital fascia. If there were purulent infection the wound was cleansed, drained into the nose and loose packing put into the cranial cavity in the extradural plane. If the wound could not be easily closed without tension, it was necessary to make use of some plastic procedure such as a rotating skin-flap of the single or double 'S' type. Fascial grafts for dural repair were unsuitable when the wound was incompletely closed or packed.

In the foregoing account emphasis has been laid upon the serious import of dural laceration and the necessity of repairing such defects if aerocele, cerebral abscess or meningitis were to be prevented. R. T. Johnson and P. Dutt (1947) made a special study of the causation and diagnosis of these lacerations which was of great value. These writers did a considerable service by establishing new tangents for X-ray projection that would show the state of the roofs of the ethmoid sinuses. They pointed out, further, that the dural tear might result from the effect of a direct injury by the missile, or by a bony fragment impelled by such missile, or it might be caused by a fissured fracture sometimes at one or two separated points only. It was from the smallest of fractures, often unsuspected, that infective complications might arise and Johnson and Dutt emphasised the great importance of a careful radiological examination in any suspected case, and discussed the best methods of obtaining a clear view of the ethmoidal region. Fractures anterior to the groove for the anterior ethmoidal vessels and nerve were usually relatively easy to diagnose by radiography, but those posterior to this groove, i.e., the middle and posterior ethmoidal and sphenoidal group, required a high standard of radiology, and considerable co-operation on the part of the patient, for diagnosis. They emphasised the irregular thickness of the roof of the ethmoid cells and found that it was extremely rare for a fracture-fissure to cross ethmoidal roofs without producing a defect in the bone and a tear of the dura. Furthermore they recorded cases in which dural tear had resulted from a discrete fracture and displacement of what they called the ethmoidal shelf (i.e. the raised lateral edge of the olfactory groove), which had resulted from violence applied to a distant part of the skull.

Fractures of the middle cranial fossa were not so likely to be accompanied by dangerous dural tears, for in this region fractures compatible with life are rarely subject to such wide separation as those in the anterior fossa; displaced flakes of bone are usually smaller and are not of necessity situated directly over the tegmen. The smaller dural defects tend to heal soundly.

The high incidence in the Far Eastern theatre of war of a virulent form of meningitis, thought to be due to a variant of *E. coli*, and to the common appearance of this organism in sinus and ear infections, gave added and disproportionate weight to the importance of early and definitive closures of the dura-sinus communication. As had been pointed out by Cairns, however, the danger of conservatism, of leaving alone an unrepaired dural tear, persists and might result in serious infective complication at a much later date.

MISSILE WOUNDS OF THE AIR SINUSES AND DURA

At the end of the war, Calvert (1947), in a careful and detailed analysis, summarised his experience in a series of 57 cases of missile wounds, in which there was the remarkably low mortality of 4 per cent. He classified them in five groups:

(1) *Fronto-cranio-paranasal sinus.* The missile entered the skull in the frontal region, traversed one or both frontal lobes and made its exit from the cranium either via the orbital roof or by way of the paranasal sinuses.

(2) *Transorbito-nasal.* In this there was a severe tangential gutter wound of the floor of the anterior fossa. These wounds sometimes presented a fearful appearance, giving the impression that they would be almost impossible to repair and hardly worth repairing, in view of the loss of sight and possible deterioration of intellect

through injury to the frontal lobes. Experience showed, however, that these patients after their wounds were healed frequently showed little or no disturbance of intellect, and when the sight of one eye was preserved, the recovery after surgical treatment and re-settlement in civil life took a satisfactory course.

(3) *Facio-orbital frontal.* In this the missile entered somewhere in the face and passed upward and backward and often deeply into various parts of the brain.

(4) *Frontal sinus penetrating wound.* In this the missile entered low down the central frontal region, penetrated the frontal sinus and entered the skull, but kept above the level of the skull base.

(5) *Orbito-facial.* In this the missile entered the orbit and travelled backwards sometimes injuring the dura and less commonly opening the paranasal sinuses, so that there was rarely need for an intracranial exploration.

These groups were not always clear and distinct as regards treatment or prognosis, but it is important to emphasise that defects might be unsuspected in Groups (3) and (5), especially if the missile were small and the cases evacuated labelled 'maxillo-facial' or 'ophthalmological'.

Treatment of the missile-wound group varied. Many of these wounds often needed the co-operation of the maxillo-facial, the dental and the plastic surgeons. Far forward, the great problem was always how much should be done in the acute stage, for the early treatment of the missile entry wound, especially if it were cranial rather than facial or orbital, was as important as it was in cases uncomplicated by sinus fractures. The condition of the patient, the amount of skin loss, the possible presence of superficial infection and the extent of the operation necessary for repair, determined when this should be carried out. Sometimes the dura-sinus communication was simply and readily accessible and could even be repaired via the sinus. Sometimes it was anterior and could be repaired extra-durally, either through the bony defect or by making a small frontal bone flap. Often the fractures were extensive and a bilateral flap with an intradural inspection of the sinus roofs (preceded, of course, by careful radiological studies) would be necessary. It was rarely found wise to undertake this type of procedure in the acute stage. It is interesting to note, in conclusion, that in all Calvert's 57 cases the removal of completely loose or contaminated bone fragments alone was found to be all that was necessary to avoid all complications from faulty drainage of damaged air sinuses; the somewhat unexpected absence of late sinusitis was a feature of this type of injury.

POSTERIOR FOSSA WOUNDS

No one has ever had a large experience of these wounds, because if the missile penetrates to a depth of 5·0 cm. or so fatal injury in the medulla or pons occurs.

Small and Turner (1947) observed that patients with a wound in the posterior fossa, either penetrating from the suboccipital region or from above the tentorium, tended to be lethargic, but as intracranial pressure increased they became extremely restless. The reason in all likelihood was that rises of pressure in the posterior fossa cause more pain than similar rises above the tentorium. Excision of the wound track alone did not give satisfactory results and it was found necessary to perform a bony suboccipital decompression and to open the dura. Tapping of the lateral ventricle through a posterior burr hole was frequently necessary to relieve intracranial pressure.

WOUNDS OF THE VENOUS SINUSES

Small and Turner found that major haemorrhage occurred from the venous sinuses in 7 per cent. of their 500 cases. The sagittal was more frequently involved than the lateral sinus. They could be injured either directly by the missile or indriven bone fragments, or indirectly by traction by fragments of the vertex being torn away from the underlying sinus. The bleeding could be torrential but was reduced if the patient were in a reclining position. Immediate control of the bleeding was obtained by finger pressure, and, when the tear was completely exposed, artery forceps were clipped on to the torn dural margin and allowed to hang over so as to occlude the sinus. Fibrin foam or muscle was then placed over the tear and made to adhere by pressure; sutures in the dura might reinforce this but it was best not to allow them to pass through the lumen of the sagittal sinus to such a degree that they obliterated it, at least in the posterior half of its course.

Table (Small and Turner) analysing 310 cases of penetrating Brain Wounds (in a total series of 500)

Structure involved	500 in unit			330 of 500 followed up in U.K.			Total mortality
	No. of cases	Deaths	Per cent.	No. of cases	Deaths	Per cent.	
Paranasal sinuses	109	5	4·6	70	7	10	
Venous sinuses .	36	7	20	14	7	14	30 per cent. (calculated)
Lateral ventricles	87	15	17	47	8	17	31 per cent. (calculated)
Posterior fossa .	13	4	31	9	0	0	31 per cent.
Low temporal region . .	44	8	18	14	1	7	25 per cent.
Large blood-clot in track .	21	6	29	4	3	75	

INFECTION IN HEAD WOUNDS

A most important investigation into the infective complication of head wounds was made by Cairns, Calvert, Daniel and Northcroft (1947), who pointed out that, though with standard treatment infection became a rarity in the less severe penetrating wounds, yet in the gross or deep wounds it often persisted in a modified form.

Rapidly fatal septic encephalitis and consequent ventricular infection with meningitis, so common in the War of 1914–18, was in this war largely controlled by chemotherapy, but instead, and largely because of this, there were various delayed manifestations of infection. The immediate results of brain wounds were remarkably good. In a series of 354 cases from Normandy, healing was by first intention, or was linear and complete after a small gap or sinus in 87 per cent. of the recovered cases, and brain fungus after operation was observed in only 17 cases. It was the rule to give a sulphonamide by mouth or intravenously from the moment of wounding, and the majority also received systemic penicillin. Local application of the antibiotics to the wound was also the rule. The addition of penicillin to the local application made for greater security against sepsis.

Before operation, wounds were frequently found to be contaminated by various organisms—streptococci, coliform bacilli or even clostridia—but detailed study of recent war wounds was not a sure guide as to the organism which might eventually prove pathogenic, and examination of a smear of the discharge by the surgeon himself might prove of almost as much practical value as a full bacteriological examination.

Non-penetrating wounds. In a few cases mild suppuration of a head wound with an uninjured dura occurred with lymphadenitis and lymphangitis, and in one case a low-grade pyaemia occurred which was controlled by penicillin. In two cases infection spread through the intact dura and in one case a fatal septicaemia resulted. Such instances were very rare, the dura proving a barrier to infection.

Cairns and his colleagues carefully investigated 18 cases of clostridial infection with a view to clearing up some of the problems concerning the behaviour of this organism in cerebral tissue. The organisms isolated from the wound or cerebro-spinal fluid were *Cl. sporogenes* in 12 cases, *Cl. Welchii* in 11 cases, *Cl. bifermentans* in 2 cases. *Cl. capitovale* and *Cl. hastiforme* in one case each. Usually they were mixed with aerobic organisms, especially *strep. viridans*, but in some abscesses only *Cl. Welchii* was found. The intensity of the infection did not vary with the species of organisms, but appeared to be correlated with the size of the wound. The intense infections were all in very large brain wounds, while the mild infections were in small wounds. In no case in this series was a generalised toxaemia encountered such as is met with in gas gangrene of muscles, though other neurosurgeons found such symptoms when the temporal muscle was involved. The power of the brain to localise the clostridial infection seemed to be considerable. The types of case varied. Sometimes there was a mild superficial infection, sometimes an acute abscess, while in other cases there were large dirty suppurating wounds. In 4 cases the clostridia were found in the cerebro-spinal fluid. Of the 18 cases infected with clostridia, 5 died from infection and one from other causes. Cairns concluded that *Cl. Welchii* could be the sole pathogenic organism in brain abscess, and this infection, though it tended to become established early after wounding, was remarkably benign—much less virulent and more easy to treat than the cerebral abscess due to *staph. aureus*. When in the cerebro-spinal fluid they did not give rise to serious symptoms, unless accompanied by other organisms. There was no evidence that the presence of clostridia resulted in infection of a fulminating intensity, but it appeared probable that they conduced to earlier suppuration and to a tendency to diffuse haemorrhage. All the infecting clostridia were sensitive to penicillin and Cairns did not recommend anti-serum, but placed confidence in adequate treatment of the wound and chemotherapy.

Cerebral Abscess. In the 354 cases of brain wound there resulted 23 cases of acute intracranial abscess, of which 14 were probably clostridial; 8 cases were due to staphylococci or streptococci and 1 to *Ps. pyocyanea*. The recognition of brain abscess was not always easy. When there was local pain and swelling and the X-ray showed indriven bone chips still present in the brain, an abscess could be suspected. Also recurrence of focal signs relating to the injured part of the brain was suggestive (but not proof) of abscess or delayed haemorrhage. Several of the abscesses discharged spontaneously. One case recovered even though it was accompanied by lateral and cavernous sinus thrombosis—a remarkable testimony to the efficacy of penicillin. There were four deaths in the series.

It was fortunate that the common infecting organisms in cerebral wounds proved to be sensitive to penicillin, for when infection happened to be due to bacteria insensitive to penicillin the neurosurgeon could do little to combat it.

Meningitis. In the series of 354 brain wounds there were only 35 cases with meningitis, of which 18 were fatal. In most cases, though not in all, the meningitis was associated with ventriculitis, often also with a small brain abscess or a collection of necrotic brain-pulp which was the precursor of an abscess. The greatest risk accompanied trans- or paraventricular wounds, of which 1 in 4 developed meningitis. Among the 17 cases of brain-fungus there were 8 cases of meningitis, which was of better prognosis when there was no accompanying abscess. Twenty-two cases developed the meningitis within a fortnight of wounding; the latest onset (a recurrent attack) was 127 days after infliction of the wound. All the patients had sulphadiazine, and many had systemic penicillin during the first week after wounding, and intrathecal penicillin was given to all diagnosed cases (except gram-negative infections) during definitive treatment. In one case, in a wound penetrating the ventricle, the making of a cisternal encephalogram after the subsidence of a moderately severe attack of meningitis was followed by a fulminating and fatal recrudescence of the meningitis. The most common cause of late meningitis was the spread of bacteria, usually pneumococci, from the paranasal sinuses through an overlying dural tear.

Brain-Fungus. As stated above there were 17 cases of brain-fungus in the series. By post-operative fungus is meant brain tissue exposed in part or whole of an open wound after operation. The fungus developed either because the wound had been left open or had been closed under too much tension, or the intracranial pressure had been unduly raised by some pathological cause. This cause was either lateral sinus thrombosis, subdural abscess, meningitis, subdural haematoma, intra-cerebral abscess or hydrocephalus. All that was required for the formation of a fungus was the protrusion of brain through a hole in the dura, but as a generalisation it can be said that a fungus always meant infection. The size of the fungus depended directly upon the height of intracranial pressure. The essential changes in its formation were local cerebritis with the death of the neuronal tissues, and their replacement, first by neuroglia and fibroblasts, and ultimately, as retraction and healing occurred, by collagenous fibrous tissue. It was found that when once collagen had been deposited on the surface of the fungus it did not enlarge, even though the intracranial pressure were suddenly increased by an attack of meningitis. The death of the brain-tissue was the result of shearing stress and not strangulation (Holbourn, 1944a); the infected area was not limited to the protruding portion alone but also involved a funnel-shaped area of the underlying white matter, which might become separated from the adjacent healthy white matter by one or more cystic spaces which might contain an abscess or a blood clot. In brain wounds after débridement the only way to avoid further brain-necrosis from fungation was by reconstitution of the dura, since closure of the skin alone did not ensure against it. None the less a great many brain wounds did actually heal, even though the dura were not closed because too much of that inelastic membrane had been lost. However, towards the end of the war when the remarkable powers of penicillin had become finally established many neurosurgical groups were securing complete dural closure by the use of grafts of the pericranium or fascia lata, with promising results. The treatment which was as a rule adopted for cerebral fungus was both systemic and local. From the start sulphadiazine and penicillin were given systemically. Débridement of the wound was performed if there were evidence that it had not been adequately performed initially. With suspicion of an abscess, the taking of a ventriculogram was preferred to needling the fungus. Otherwise conservative treatment was adopted, and in the early stages débris was removed by low-pressure suction, and at each dressing the surface was frosted with penicillin-sulphamezathine powder (never with sulphathiazole). Lumbar puncture was useful in the early stages. When the fungus was covered with granulations the head was sometimes encased in a plaster-of-paris cap. Carmichael (1945) recommended excision and primary closure of brain fungus with tantalum repair of the skull defect, but this method did not meet with general acceptance, for even large fungi disappeared under more conservative treatment.

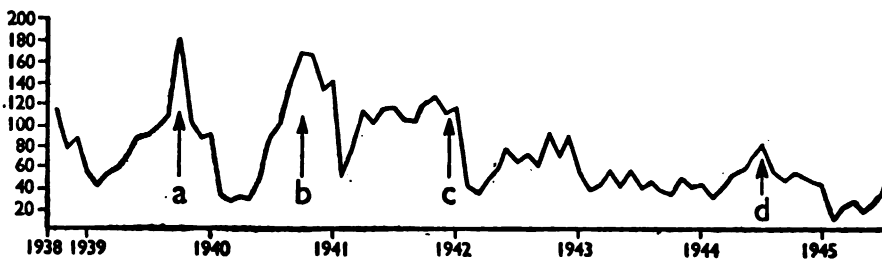
Cerebro-spinal fluid fistulae. As the fungus began to diminish in size it was the rule for a cerebro-spinal fistula to form; the fluid might come from the ventricle, from cysts in the deeper part of the fungus or from persisting cerebral sulci. Cerebro-spinal fluid fistula might also follow incomplete operations on wounds involving the paranasal sinuses, and petromastoid wounds. Fistulae through mastoid wounds tended to close spontaneously, but those in wounds of the vertex more often required treatment.

Chronic Abscess sometimes resulted from a wound of the brain and might develop months or even years after the wound had healed. As a rule the healing of the original wound had been unsatisfactory and either a discharging sinus had persisted for some time, or a brain-fungus had been a feature of the case. In most cases it was the retained bone fragments, very rarely the missile, which caused the abscess. Staphylococci and streptococci were the usual organisms found in the abscess. In several cases there was evidence that bacteria might remain latent in a tiny chronic abscess, or even in a scar which for long periods had given rise to no symptoms. The abscesses usually formed in one or several parts of the wound track. The coalescing of several small abscesses sometimes formed a mass of irregular shape which was often tethered to the neighbouring nerve tissue by fibrous cords formed from resolution of uninfected parts of the track. When the abscess was excised the resulting cavity was usually larger than the size of the mass removed and the fibrous capsule of the abscess might be very thick. These chronic abscesses sometimes gave rise to no symptoms other than occasional slight purulent discharge from the old wound, though it was noted that the cerebro-spinal pressure, as ascertained by lumbar puncture, was sometimes higher than normal, and there might be a rise in the cerebro-spinal fluid protein. Occasional paroxysms of severe headache due to recurrent mild meningitis were sometimes for months the only symptom, and only later were realised to have been significant. Sooner or later, however, the patient either had an epileptic fit, or attacks of headache or vomiting (or both), with focal signs corresponding to that part of the brain involved; or the first serious symptom might even be fulminating and sometimes fatal meningitis, due to rupture of the abscess into the ventricle or one of the larger cisterns. In diagnosis the surgeon had to beware of too readily assuming a discharging sinus to be due to local osteomyelitis of the skull; ventriculography rather than encephalography was of value in showing deformity of the affected part. Brain abscess had to be suspected in any case of old brain wound in which radiography showed a cluster of bone fragments still in the brain; and it had to be considered in cases of post-traumatic epilepsy in which bone fragments remained in the brain. The most satisfactory treatment of a chronic traumatic brain abscess was total removal, together with its capsule. Sulphadiazine was given before operation in amounts sufficient to secure an adequate concentration of the drug in the cerebro-spinal fluid, and penicillin was instilled into the ventricle or lumbar sub-arachnoid space before, during or after operation. It was necessary to make a wide exposure, to keep a sharp look-out for separate loculi and to investigate any fibrous mass with a spherical contour by means of a blunt-ended brain needle or by further dissection. Any large dural gap needed to be repaired and sometimes the skull loss was made good by a tantalum plate.

A consideration of the material surveyed showed that there were 49 cases of major infection in 354 cases, i.e. an incidence of 14 per cent.; 19, or 5 per cent., of the total cases died from infection, while 2 died from other causes. Now that the incidence of infection has been considerably reduced by the combination of good surgery and the use of antibiotics, the danger in the future will most likely come from those organisms less sensitive to penicillin, e.g. non-β-haemolytic streptococci. The standard dose of penicillin will probably have to be increased, and regular daily intrathecal injection given during the first week of treatment of brain wounds.

PREVENTION OF HEAD INJURIES

There can be little doubt that the wearing of steel helmets considerably diminished the damage done to the brain when the head was wounded, even though the high velocity of the missile enabled it to penetrate the helmet. At the beginning of the war, in the United Kingdom, it was not customary for all motor cyclists in the Army to wear protective helmets, and the large number of motor cyclists with serious head injuries who were referred to the Oxford Head Centre caused Sir Hugh Cairns (1941a) to consider whether the wearing of a protective helmet might reduce the incidence of head injuries and the severity of those which did occur. At that time (1940) the death-rate from motor-cycle accidents was rising. In the first twenty-one months of the war, 2,279 motor cyclists and pillion passengers were killed on the road, and calculations showed that to this death-roll the Army contributed about two thirds. Inquiries elicited the fact that head injury was present in 92 per cent. of a series of 111 fatal cases and though not the sole cause of death, it was clearly a major factor in most. In 1940 the Army already had some crash helmets. These were issued only to certain types of motor cyclists, and some were of canvas and others meant for use in armoured vehicles. Some motor cyclists wore the ordinary steel battle helmet. In 1940–1 only 1 in 20 of the motor cyclist patients had been wearing crash helmets at the time of the accident, but in these the relative mildness of the symptoms was impressive enough to justify a report to the Director-General of the Army Medical Services, and to the Military Personnel Research Committee of the Medical Research Council, who were at that time considering helmets. In November 1941, the Army Council, on Sir Hugh Cairns' recommendation, made the use of crash helmets compulsory for all motor cyclists. The R.A.F. followed suit in 1942 and there were similar instructions to motor cyclists in the R.N. By the end of 1942 Cairns and Holbourn had collected sufficient evidence to prove that crash helmets were really very effective in diminishing the



Graph showing monthly totals of motor-cyclist fatalities (Service and civilian motor-cyclists) in Great Britain from 1939 to 1945, from figures issued by the Ministry of War Transport. Events influencing the death rate are: (*a*) outbreak of war; (*b*) preparation for German invasion; (*c*) crash helmet made compulsory for Army motor-cyclists; (*d*) preparation for invasion of Normandy. In addition there is a low peak during each winter, corresponding to bad weather, when little motor-cycling was done.

severity of injuries and in saving life. In 1943 the same authors published statistics from which they concluded that the incidence of fractured skull was reduced to one quarter by the use of the pulp helmet, and the severity of such fractures as occurred was demonstrably less. The effects of concussion were also modified by crash helmets, for the incidence of prolonged amnesia after injury was only one third of its incidence among those who had not worn a crash helmet. In non-lethal accidents, the pulp helmets so alleviated the injury as to halve the incidence of admission to hospital. To what extent the helmets were life-saving it was impossible to determine, but it was probably of significance that after the crash helmet was made compulsory in the Army, there was a considerable sustained fall in the total death-rate of motor cyclists in Britain. (See graph which also includes civilians—Cairns, 1946.)

The components of the crash helmet were a firm outer shell and an inner sling and hat-band which acted as buffers. The two main types of helmet used by Army motor cyclists were the vulcanised rubber helmet and the pulp helmet. The pulp helmet was at least twice as good as the rubber helmet. The importance of adjusting the fit so as to obtain maximum protection of the forehead and sides of the head, the need to have the chin-strap buckled and to maintain all parts of the helmet in serviceable condition, were emphasised in Army Council Instruction and Training Memoranda.

In addition there were the Army steel crash helmet and the leather helmet used by motor cyclists of the National Fire Service. The steel crash helmet was eventually good, and the leather helmet appeared to answer well for the N.F.S. whose motor cycling was done in built-up areas, presumably at low speeds.

The mechanism of head injuries was examined by Holbourn (1943, 1944b, 1945) who described two effects of the blow inflicted in a blunt head injury: (1) the local injury beneath the site of the blow; (2) distortion in parts of the brain remote from the blow which depends on sudden change of velocity of the head. At the site of the blow the scalp might be torn, the skull might bend and break, and fragments of it might be bruised as well as torn. When the head rotated suddenly as the result of a blow from a moving object, or against a stationary one, the brain, not being a rigid structure, lagged behind. The brain made the only kind of movement possible to a highly incompressible substance in an enclosed space—namely a swirling movement—and the surface of the brain slid along inside the cranial cavity. These sliding movements of the surface of the brain were later observed by the U.S. Naval Medical Research Unit by means of a high-speed camera and a perspex artificial skull (using the technique of Shelden). The movements set up shearing stresses in various parts of the brain; they were most severe where the lesser wing of the sphenoid jutted into the cranial cavity, and it was in this region that bruising and laceration of the brain were so often seen, no matter where the blow was struck. Given the precise details as to how the head was struck, it was possible to predict the likely damage to the brain with reasonable mathematical accuracy. The clinical state of concussion was clearly due to remote effects, since it did not arise from the local brain injury of many gunshot wounds or surgical operations.

The crash helmet modified both the local and the remote effects. Locally the shell of the helmet spread the blow over a wide area and protected the scalp and skull from the pointed pieces of road metal or whatever object was struck. In some cases it prevented fracture of the skull; in others, where a fracture was produced, it prevented the fracture from becoming depressed. The shell lessened the bending of the skull and therefore the local bruising of the brain. The shell also lengthened the blow, i.e. spread it over a longer period of time. It did this by sliding over the surface struck, instead of stopping more abruptly (as the unprotected head would do, owing to its greater co-efficient of friction), and the buffering action of the slings and hat band. The blow was also lengthened to some extent by rotation of the helmet relative to the head. So far as the remote injury was concerned, spreading the blow over a larger area did not diminish the rotational velocity, but spreading the blow over a longer interval of time reduced the total force at any instant and thus lessened the remote effects.

There can be little doubt that the adoption of a crash helmet as standard wear by all civilian motor cyclists would result in considerable saving of life, of working time, and of time of the hospitals, so that it can be regarded as one mode of prophylaxis against head wounds.

OTHER COMPLICATIONS OF HEAD INJURIES

Infection was not the only complication which followed in the train of penetrating wounds of the head, for even in non-infected cases thrombosis of the cerebral venous sinuses and blood vessels might occur. Cairns and his colleagues made an investigation into the problem. They found that, though cortical blood vessels were often divided by missiles and indriven bone fragments, they were the most resistant structures inside the dura. A certain amount of intravascular thrombosis was inevitable in any brain wound, but in addition necropsy studies showed a high incidence of thrombosis of the cerebral venous sinuses and large cerebral veins at a distance from the wound. In 28 necropsies of penetrating brain wounds there were 11 showing ante-mortem thrombosis; in 8 of these the thrombosis was in one of the major venous sinuses, with or without thrombosis in the cerebral veins. In 6 of the 11 the thrombosis was at a considerable distance from the site of injury; in 5 it was at the site of injury. In all these cases the thrombosis was firm and not infected. In 6 of the 11 cases death took place between the fifth and seventh days. No adequate explanation for the distant thrombosis was forthcoming. The interesting observation was made that thrombosis of the lateral sinus following traumatic laceration did not always persist, for a rapid re-establishment of circulation in the sinus was observed on several occasions.

Movement of Missiles in the Cranium. Brain substance is soft and it would not have been surprising if the hard metallic missiles had frequently moved in position within the cranium. This, however, seldom happened, though in the first days after injury missiles sometimes moved about if they lay in large lacerated areas or in intra-cerebral clots. At a later stage movement of missiles betokened abscess formation, and even then the movement was of small range, often no more than a rotation. The commonest cause of movement of missiles within the cranial cavity was lodgement of the missile in or near a ventricle. A missile which at the first X-ray examination was in a paraventricular frontal wound might subsequently be found in the posterior horn of the corresponding lateral ventricle, and in a remarkable case reported by

Taverner and Phillips (1947) a missile at first in the vicinity of the posterior horn later moved into the third ventricle. Perhaps the most interesting of all was that case in which a bullet which was at first in the right frontal region migrated within four days in the subdural space to a position below the left frontal lobe; in this case the track from right to left had been in front of the optic chiasma through that gap which is the only communication between the right and left subdural spaces above the tentorium. Another case recorded by Cairns, Calvert, *et al.* (1947) deserves record. A grenade fragment which lodged in the third ventricle moved backwards and downwards (in the course of a few weeks) to the opening of the aqueduct of Sylvius, which it blocked. In view of the patient's drowsiness and disorientation and the failure of postural treatment the lateral ventricle was drained and later still Torkildsen's operation—the insertion of an indwelling rubber tube between the lateral ventricle and the cisterna magna—was performed with considerable improvement in the patient's condition.

Pulmonary Complications. Very few patients with mild or moderately severe brain wounds were lost through pulmonary complications, but a few of those who died from severe wounds might have lived but for the onset of pulmonary collapse. Of 142 cases of penetrating brain wounds evacuated from Normandy to Oxford in 1944, 17 cases (i.e. 12 per cent.) had pulmonary complications. These included massive collapse of the lung, fatal pulmonary embolism and pulmonary infarction—a small incidence of embolic manifestations considering the frequency of thrombosis in the cerebral veins and venous sinuses—pulmonary fat embolism, pulmonary oedema, and aspiration broncho-pneumonia. Massive collapse of the lung was the most common variety and occurred as a rule in the first week after operation. The condition was not limited to post-operative cases and had no relation to early air evacuation. It was most common in the hemiplegic. That had a clear physiological meaning. Whenever possible, attempts were made to reduce the incidence of pulmonary collapse by instituting breathing exercises, altering the position of the patient and performing intra-tracheal suction before and at the conclusion of operation whenever inhalation anæsthesia had been employed.

Anosmia. Many head injuries resulted in a defect of smell, and laceration of the olfactory nerves is now established as the commonest injury of the cranial nerves. In a study of 1,000 cases of head injury, A. D. Leigh (1943) found that 72 patients had defects of smell. Seventy had suffered blunt head injuries, 30 in the frontal and 18 in the occipital regions. Of the former, 14 involved the frontal sinuses and there was cerebro-spinal rhinorrhoea in five; two of the patients died of meningitis. The violence that produced the anosmia was usually severe, post-traumatic amnesia being measured in days in all but six cases, and 26 patients were so incapacitated that they were discharged from the

Army. Perversions of smell were found in 12 of the 72 cases and were always of an unpleasant nature. In only 6 of the 41 cases with complete anosmia was there loss of the sensation of taste.

BLUNT OR NON-PENETRATING HEAD INJURIES (CLOSED HEAD INJURIES)

A closed head injury is one caused by the impact of a blunt object which does not lead to a penetration of the dura mater. The acute stage is regarded as lasting until the patient has recovered clear consciousness and become properly orientated, or, when consciousness has not been disturbed, until an arbitrary period of twenty-four hours has elapsed (Symonds, 1945).

CONCUSSION

During the course of the war a new view, or rather a new presentation of an older view, on the nature of concussion was put forward by Jefferson (1944). The nature of the changes responsible for that state of impaired consciousness following cerebral injury, and generally known as concussion, has been the subject of experiment and speculation for many years. Most authorities at one time regarded it as due to dysfunction of the higher cerebral centres or their interconnexions, either produced by excessive vibratory influence or possibly due to vaso-paralysis. Then followed the view of Strohmeyer and later Trotter (1932) who taught that the cause of concussion was cerebral anaemia induced by the instantaneous rise of intracranial pressure at the moment of injury. Duret and others, however, pointed out that a blow on the vertex causing concussion affected the vital bulbar centres, and invoked the movement downwards of the cerebro-spinal fluid to account for this. In 1941 Cairns raised the question of the cause of unconsciousness in penetrating head wounds (Cairns, 1941b). He noted that frontal and parietal wounds were not necessarily accompanied by loss of consciousness, while the penetration of a missile through the petrous bone into the cerebellar vermis was accompanied by unconsciousness. He put the query—was the unconsciousness of a closed head injury due to commotion of the whole brain or to damage of some part of it—such as the brain stem ? In the same year Denny-Brown and Ritchie Russell (1941) published their conclusions that concussion could more easily be produced if the head were free to move when it was struck, and that the essential factor was not a deformation of the skull, but the suddenness of the acceleration of the head. The fundamental fact appeared to be that the injury or contusion paralysed nervous actions without necessarily leaving microscopic or macroscopic evidence. Following these experiments and basing his arguments on some remarkable clinical data, Jefferson concluded that unconsciousness, or as he preferred to say, the traumatic stupor of concussion, was produced by a low level lesion—hypothalamic and brain-stem, and he coined a new word 'parasomnia' to indicate the condition. In his own words: 'we approach closer to the facts of clinical observations if we speak of unnatural or, in the case of concussion, of traumatic sleep rather than unconsciousness. Traumatic stupor is a better term than unconsciousness because it has, for most of us, a certain sleep connotation. There is an advantage in inventing a new term to overcome these difficulties. Something is needed with a sleep meaning but indicative of a condition different from ordinary sleep'. Jefferson defined the word 'parasomnia' as a state following injury in which there are no responses to stimuli, verbal or mechanical, except those of a reflex nature. He pointed out that the tossings, nose and body rubbings, mutterings and unruliness occurring with some head injuries showed that cortical actions continue, though there was no doubt a disturbance of high level function. He compared this condition (parasomnia) with the state of akinetic mutism which was described by Cairns and his colleagues as resulting from pressure of a cyst on the third ventricle, but he pointed out that there was a difference between the two in that sleep propensities were the dominant factor in parasomnia but not in akinetic mutism.

From a study of 100 consecutive cases with a fatality of 20 per cent. Jefferson (1942) confirmed that the chance of survival of those admitted in coma was lower than in others, and that unconsciousness was in itself the most serious single sign. Rapid death was due to deep brain stem contusion. Considerable laceration and destruction of the hemispheres could be present without causing death or even unconsciousness. Experience showed that when there was no permanent damage to the brain stem, the patient recovered.

Jefferson also raised the question of how an initial lesion severe enough to cause neural paralysis could be survived, though death occurred hours or days afterwards. He thought the answer to the question was that the injury set going a self-propagating chain of events that ultimately led to death. He believed that the level at which these events occurred was in the more primitive but still extremely complex and integrated neural mechanisms considerably below cortical level.

TREATMENT AND PROGNOSIS OF BLUNT HEAD INJURIES

Before 1939 the treatment of blunt head injuries was based upon the accepted but unproved view that injury to the delicate nerve substance must require prolonged rest. This view appeared to be supported by the frequency with which these injuries were followed by headache and other disabilities. During the course of the War of 1939–45, several careful investigations were made to ascertain whether such prolonged rest is necessary and whether one could not obtain better results by early attempts to rehabilitate the patient. One of the surprises of the war was the proof provided that the prognosis of this class of injury need not be so bad as it had previously been thought to be. Thus Symonds and Russell (1943) found that of 242 acute cases only 22 were invalided, while as many as 215 returned to duty. Their figures also brought out the interesting fact that the prognosis became worse as the length of the amnesia following the accident increased. There was a rise in the proportion of those invalided when the post-traumatic amnesia (P.T.A.) exceeded one day, and a further significant rise when the P.T.A. was longer than seven days. Of the remainder, 193 were followed up and it was ascertained that 11 per cent. broke down. Prolonged periods of rest in bed gave no better results than when patients got on their feet early and were encouraged to return to duty.

With rare exceptions the policy of dehydration as a routine treatment was abandoned. Dandy once said that he did not believe that anybody's life had ever been saved by it, and it is quite certain that death can be caused by abuse of this treatment. The trouble with the more severely wounded who remained unconscious for a long time—a state that some believed to be caused by a disturbance of the autonomic centres in the brain stem, or hypothalamus, rather than in the cerebral cortex—was that they involuntarily dehydrated themselves and became uraemic, unless they were fed by nasal intubation. Care of this kind, the general nursing rather than skill in making holes in the patient's skull, was of the greatest use to the greatest number. The old-fashioned practice of nursing these patients on their backs with the head low was also abandoned. The head was kept high if the patient swallowed well, or was kept low and the patient nursed on his side or semi-prone if the patient was 'chesty'. Every head injury was a potential cause of an intra- or extra-dural clot, the diagnosis of which, by bedside observation, might be so difficult as to lead to dangerous delay.

It is curious that ventriculography should have had so enthusiastic a reception, so wide a usage, and yet have been so little used for head injuries until Jefferson showed its value in 1942. After that time, the use of pneumography steadily grew. Sometimes a massive clot was discovered while the drill hole was being made. The use of inspection burr-holes became a commonplace in treatment, but only the minority required even that. Lumbar encephalography, too, was used on the recovering cases, leading to the discovery of a puzzling post-traumatic internal hydrocephalus in a number of the severer injuries. Electro-encephalography (EEG) also became of great interest. The information gained was an important help in giving a measured background to clinical judgment. It is quite likely that, with the use of portable EEG equipment, more practical information will be forthcoming. All but one or two of the neurosurgical centres used electro-encephalography, and studies on it were very greatly advanced by Grey Walter (1944a, b) at Bristol, and by Denis Williams (1945), then at the Manchester Centre.

One lesson learned very fully was what to expect in the way of knowledge from lumbar puncture. The high pressures that many general surgeons had reported in large series of head injuries were not confirmed by the more meticulous standards of the neurosurgeon. A struggling patient, or one whose breathing is embarrassed by the posture in which he has been placed, will always have a high pressure—a pressure bearing no relation to the neurological condition. The majority of unconscious patients had no more than a normal (80–100 mm. water) or high normal (up to 180 mm.) pressure. Only rarely was the pressure above 250 mm. The result of a very large experience was to relegate the lumbar intrathecal pressure to a lower degree of importance than it formerly had. It had to be considered in relation to the general clinical picture. Even when it was high, it was no indication by itself that surgery was needed; it usually fell in two to five days to normal levels.

Of equal importance was the erythrocyte count of the cerebro-spinal fluid (CSF). Often there was no blood in the CSF in cases of concussion, and, indeed, blood is always a sign of contusion or laceration. This was an important fact for record in the notes of a patient who might in the future claim a disablement pension, for if there were no bleeding and if traumatic stupor were very brief, one could be reasonably sure that no serious brain laceration had occurred.

One of the commonest complaints after blunt head injury has always been headache. Gutmann (1943a, b) made a study of this question and came to the significant conclusion that the psychological were as important as the physical factors—perhaps more important—in causing these headaches. He found that there was a higher incidence of headaches among the milder than among the severe cases; and that while less than half the patients complained of headache when awakening from unconsciousness, the proportion grew smaller the longer the unconsciousness lasted. The great part played by psychological factors in causing disability following these head injuries led to an altered method of treatment. The patient, after he had recovered consciousness and while in bed, was allowed to assume the position which suited him best, and was allowed to converse and read as much as he felt inclined. Graduated physical exercises were begun while he was still in bed and a policy of encouragement and reassurance was followed. The rate of progress was determined by the symptoms of the individual. When the patient was able to walk about he was transferred to a convalescent hospital where he was given physical training and suitable mental occupation until judged fit to return to duty. This method of treatment proved most encouraging. Symonds and Russell (1943) showed that 92 per cent. of their cases were treated for less than three months, while about 80 per cent. of those who survived the acute stage returned to useful duty within a few months. Many did so in spite of complications, among which were: X-ray evidence of fracture of the skull, depressed fracture, injury to cranial nerves I, II, III, IV, VI or VIII, and even intracranial haematoma. These figures corrected the old belief that, for cases of head injury or skull fracture, very long rest and convalescence were necessary for recovery.

As Cairns (1943) pointed out, in civilian head injuries (which were mostly of the closed or blunt type) it was an uncommon event for permanent incapacity to result from the damage to the brain. In Gutmann's (1943b) series the average working time lost by wage-earners was roughly eight weeks, while only 2 out of 158 patients became permanently incapacitated. These results indicate that the new and almost revolutionary change in treatment was well justified.

INTRACRANIAL AND INTRACEREBRAL HAEMATOMA

The experience gained by treatment of large numbers of injuries of the head, seen and treated at a special neurosurgical centre, enabled neurosurgeons to acquire certain knowledge that could hardly ever be gained in a peace-time clinic. As an example may be cited the subject of intracranial haematoma, by which is meant a collection of blood (outside the vessels) which of itself adds to the neural damage inflicted by the injury. This subject was considered by Schorstein (1947) in connexion with a series of 2,000 missile wounds of the head seen in oversea theatres of war during a period of two years. Among these cases there were 83 cases of intracranial haematoma. Only in 3 cases was the haematoma outside the dura. In 11 cases the bleeding occurred under the dura which in 7 cases remained intact with a depressed fracture. In these cases there was the problem as to whether or not the dura should be opened at the operation done for treatment of the wound. Schorstein came to the conclusion that it was inadvisable to follow the advice given by Cushing that, given reasonable working conditions, one should incise the dura in patients who had depressed skull fractures and focal neurological signs. He recommended that the dura should only be opened in patients who showed evidence of widespread inhibition of cerebral function, and considered that a delayed but progressive depression of the stage of responsiveness was sufficient indication for this procedure. If the surgeon found himself in doubt whether or not to open the dura, then it was better to operate under local anaesthesia, leave the dura intact and watch the patient carefully for another day or two. Linear incision of the dura was recommended. Of the 63 cases of intracerebral haematoma, in 14 cases the clot was fairly superficial; in 37 instances it was in the deep course of the track of the missile, while in 12 cases the blood apparently coming from the track of the missile had collected chiefly under the dura, in several instances at the opposite side of the brain from the point of entry. In 6 cases the intracranial haemorrhage occurred some time (five to nineteen days) after wounding, and all these cases were fatal. It was noteworthy that among 900 penetrating missile wounds of the brain there were 42 instances of particularly deep penetration by small fragments of missile (average weight 0·1 g.), and 32 of these had intracerebral haematomas.

In considering the diagnosis of an intracranial haematoma, Schorstein pointed out that the severity of the original brain lesion often masked any lucid interval and made it difficult to estimate the progress of neurological dysfunction. A slow pulse and a raised blood-pressure were not of much value in diagnosis, but consideration of the type of wound was valuable, for the small penetrating or perforating missile wound was most commonly associated with an intra-cerebral clot. Small and Turner (1947) pointed out that retention of blood clot within the track of the missile could sometimes be diagnosed by the radiological appearance; usually indriven bony fragments appeared rather like a comet's tail, but when the track was expanded by clot the fragments often assumed a circular arrangement, owing to the displacement. When haemorrhage was suspected prompt operation was recommended. A summary of Schorstein's cases is appended.

Type of Haematoma	*Number of Cases*	*Number of Deaths*
(1) Immediate		
Extradural . .	3	1
Subdural . .	11	1
Intra-cerebral		
Superficial . .	14	1
In track . . .	37	14
Subdural and in track	12	3
(2) Delayed . . .	6	6
	83	26

NEUROSURGERY IN THE NAVY

During the course of the war there was only one neurosurgical unit in the Royal Navy, and this was under the general supervision of the neurosurgical consultant, Surgeon Captain Lambert Rogers. In the early part of the war the unit worked at the Royal Naval Hospital, Plymouth, but after that building had been damaged in 1941 the work could not be continued there. The facilities at Barrow Gurney were not adequate, and though for a time there was the possibility of acquiring the Burden Neurological Institute for the Navy, negotiations fell through, and in April 1942 the neurosurgical unit was finally established at the new naval hospital at Sherborne, where it was in close proximity to an orthopaedic unit. Here it functioned for the rest of the war with Lieut. Commander Langmaid as surgeon-specialist (Lambert Rogers, 1947).

The work done by the unit varied from time to time. At Plymouth many closed and open head injuries were dealt with at the time of the bombing attack on that city. At Sherborne the work included traumatic, neoplastic and inflammatory conditions of the cranium and spinal column. More than a hundred operations were done for sciatica due to displacement of an intervertebral disk (usually the lumbo-sacral). A trial was given to aminoplastin in nerve suture, but this proved ineffective in preventing adhesions to the nerve.

ELECTRO-ENCEPHALOGRAPHY IN THE DIAGNOSIS OF HEAD INJURIES

During the course of the war attempts were made to add precision to the diagnosis of injuries of the head by utilising evidence furnished by electro-encephalography. Jasper, Kershmann and Elvidge in Canada (1940), and Denis Williams (1945) in this country made important clinical investigations, and Williams and Denny-Brown carried out experimental work on the subject.

In 1941 Denis Williams published the results of his examination of 74 cases of head injury investigated within 20 days of injury. He found that in the acute stage there were widespread abnormalities which affected all parts of the cortex, but later, in cases of gross brain injury some local abnormalities often persisted. The irregularities consisted of widespread abnormally slow waves whose frequency varied from less than ½ per second up to 7 per second, a suppression of the normal dominant frequencies of 8–12 per second, and clear-cut outbursts of high-voltage sine waves of 2–3 per second.

Slow waves of the first type were invariably present when there was impairment of consciousness as the result of head injury, and their persistence, size, and period were related to the depth of unconsciousness. Coma was associated with high-voltage abnormally slow waves, with period 1–2 seconds, and always generalised. One of the outstanding features of EEGs recorded within a few hours of a head injury was the appearance of the intermittent outbursts of high-voltage sine waves mentioned above. These outbursts usually occurred in all leads simultaneously, but occasionally they appeared in leads from different lobes independently. They were found when an EEG was obtained within a few hours after a head injury. They were usually associated with a change in the state of consciousness of the patient, always subsided completely, and seemed to be unrelated to the onset of immediate post-traumatic convulsions. Their presence bore no apparent relationship to the subsequent incidence of post-traumatic epilepsy.

There was a positive relationship between the degree of severity of head injury and the amount of generalised abnormality in the EEG. Skull fractures and dural defects did not of themselves affect the normal cortical rhythms.

The clinical recovery of the patient often corresponded closely with the improvement in the electrical record, but in severe injuries local abnormalities were often persistent. Even when clinical examination showed no abnormality the persistence of an abnormal EEG might correspond to a defect, which would only make itself evident when the patient was submitted to a more rigorous mental or physical strain.

Williams pointed out that the practical value of the EEG was greatest when the clinical evidence of damage was slight; that a normal EEG obtained shortly after a head injury indicated that no gross cerebral damage had occurred, while a normal record in a patient with stupor or confusion attributed to head injury threw doubt on the diagnosis of trauma. On the other hand an abnormal EEG after an apparently trivial head injury might indicate active cerebral change as the result of the injury, or an abnormal pre-traumatic record.

Denis Williams also investigated a series of 325 cases of head injury in which the trauma had occurred some weeks or years previously, with a view to seeing if milder degrees of cerebral dysfunction could be demonstrated by the electro-encephalogram after all clinical signs had subsided. The ages of the patients ranged from 18 to 60 years, but over 90 per cent. were under 35 years of age. An attempt was made to relate the results to those often vague but well-known symptoms which may persist—headache, giddiness, defects of memory, lack of concentration, fatigue, irritability and changes in mood. The records were divided into normal and abnormal groups, as compared with 160 controls taken from healthy personnel. It was found that 50 per cent. of patients who had suffered head injuries had an abnormal EEG, though in some cases the injury had occurred years previously. The disturbance was almost always generalised and consisted of low-voltage, 2 to 7 a second waves underlying the normal dominant frequencies of 8 to 12 and 15 to 25 a second. Slow waves of high voltage were not encountered. Abnormality was still present in 47 per cent. of the cases investigated more than two years after the injury. The high percentage of abnormals may to some extent be due to the fact that cases were referred to the hospitals because of persistence of symptoms. There was a direct correlation between the duration of post-traumatic amnesia (and therefore the severity of cerebral damage), and the percentage of abnormality. The percentage of abnormality was not influenced by fracture of the skull, apart from cerebral trauma, nor was it higher in those with a morbid personality. The fact that a considerable proportion of patients who have had an injury to the head show an abnormal EEG for long periods afterwards, places a syndrome which has often been regarded as functional upon an organic basis, and explains the recurrence of symptoms in some patients after an apparently satisfactory clinical recovery.

Williams and Denny-Brown (1941) carried out some experimental work on cats, under light anaesthesia which showed that clinical concussion caused an immediate diminution of electrical activity in the brain. During recovery abnormal slow waves appeared, of the type which appeared after injury in man. Clinical application of electro-encephalography was made in 1940 by Rendle Short and Dunster (1940), who were for the first time by this means able accurately to locate an extra-dural clot over the lower right Rolandic area, in a case where the neurological signs pointed to a lesion in the upper part of the area; the affected area gave rise to well-defined slow delta waves. In a similar manner, Lambert Rogers (1941) diagnosed a subdural haematoma with the aid of an electro-encephalogram which showed a low potential discharge at varying frequencies, most definite in the region of the Sylvian point, where the haematoma was actually found at operation; in this case various diagnoses had been suggested, among which were tuberculous meningitis, intracranial tumour, and sub-dural or subarachnoid haemorrhage, and there was a doubt as to whether the lesions were in the right frontal region or in the posterior fossa.

Other observers also recorded cases in which the EEG was of assistance in diagnosing subdural haemorrhage, so that this method of examination proved its worth as an ancillary means of diagnosis, and at the present day its value and accuracy leave no room for doubt. In connexion with the epileptiform fits which may occur some time after a head injury, Garland (1942) showed that these post-traumatic fits rarely if ever gave an electro-encephalogram similar to that which is characteristic of petit mal or psychomotor epilepsy.

Electro-encephalography in the Diagnosis of Epilepsy. Before the war it had been found that a considerable proportion of epileptics showed abnormal tracings in between the attacks—usually large slow waves (delta waves).

In the Services, particularly in the Navy, where the epileptic afloat was a constant source of possible danger, it was important to make a diagnosis as soon as possible. In the early years of the war many suspected epileptics were admitted to the R.N. Auxiliary Hospital, Barrow Gurney, for investigation of faints, fits, vertigo, and other paroxysmal disorders. They were specially investigated by encephalography to see if, by any variations in electrical potential, a diagnosis of epilepsy could be demonstrated. At Barrow Gurney in a series of 125 naval cases clinically considered to be idiopathic epilepsy, 62 showed abnormal and 63 normal or doubtful EEGs. Only one patient over 35 showed an abnormal tracing. Electro-encephalography was thus shown to be no short cut to diagnosis, but a useful aid to be taken together with the clinical findings.

REHABILITATION FOLLOWING HEAD INJURIES (IN THE E.M.S.)

In a memorandum prepared early in the war Professor Jefferson and Brigadier Riddoch set out their views on rehabilitation in general, and more particularly as it concerned those with head injuries. Certain plans were formulated and their definition of rehabilitation bears quotation: 'the planned attempt under skilled direction by the use of all available means to restore or improve the health, usefulness and happiness of those who have suffered an injury, or are recovering from a disease. Its further object is to return them to the service of the community in the shortest time. Although it is a new word, rehabilitation is an old purpose.' (See *Proceedings of the Royal Society of Medicine*, 1942, 35, 295.)

In order to deal more effectively with the after-care of head injuries, the E.M.S. made arrangements for rehabilitation at all its special head centres. This, following the general plan, took the form of (*a*) occupational therapy, (*b*) physical therapy—massage, drill, organised games and so forth, and (*c*) in two centres only, speech therapy for the relieving of those with dysphasias resulting from local injury to the brain. The full service was only provided at one (Hill End) of the centres based on a London teaching school or parent hospital, and only at two others in the rest of England (Sheffield and Winwick, near Warrington, Lancs.) was it complete. In one or other respect all the remaining centres lacked something or other.

In the first place stress must be laid on the psychological side, an aspect which Jefferson and Riddoch threw into high light in their joint report. It was pointed out that the great defect in method heretofore had been over-stressing of massage and electro-therapy, which, though important in their way and in special circumstances, did not by themselves sufficiently occupy the patient's time, nor fully enough engage his mind, nor call upon his own volition. This turned out to be particularly true of head injuries and head wounds. Jefferson in 1942 made some inquiries on the degree to which massage had been utilised on these patients, and in comparison with limb fractures the skull fracture was low in the scale.

Analysis of the cases treated at four centres showed that very few indeed were head injuries. The highest incidence was (*a*) peripheral nerve injuries, (*b*) spinal injuries, and (*c*) coincident-fractures or severe injuries to the limbs. The proportion of hemiplegics, per hundred head injuries of all kinds admitted, seemed to be no more than 5 per cent. or so. It proved to be higher in battle casualties. Since most of these centres were treating brain and spinal tumours as well as casualties a good deal of massage had been done on these cases, but that is beside the present point. These figures cleared up the question of the extent to which massage was needed in rehabilitating head injuries. Though it was a desirable adjunct to the centres, in effect it played but a relatively small part in the after-care of head injuries.

The purpose of rehabilitation was to give the patients an interest in getting themselves better by means of interesting pursuits of widely different kinds. The method of application to head injuries is illustrated by the following account, based upon experience at Winwick. At this hospital 88 per cent. of the patients treated by the E.M.S. were Service cases.

OCCUPATIONAL THERAPY

Mention has been made of the Army Centres at Tusmore Park and Middleton.

The actual schedule of the work done at Winwick has been set out separately by Miss Turner (Occupational Therapist at Winwick), Allan Kerr and Jefferson. Practically every type of occupation was employed, according to the capabilities and interest of each individual patient.

Bed Patients: These patients, unless suffering from other injuries to the body were not encouraged to do occupations in bed; better results were obtained in the workshops, where the patient got away from the hospital atmosphere and from discussing with his 'ward pals' his special case-history.

In Lesions of the Upper Motor Neurons

(1) Beginning with simple movement in whatever the patient can cover:

Adults	*Children*
Basketry, rug weaving, weaving on treadle loom	Sand trays, finger painting, bicycles, etc.

(2) Encouraging independence and rhythm action, avoiding jerks:

Adults	*Children*
Painting large surfaces, knitting, typing, bicycle, saw and treadle saw when strong enough	Plasticine, clay modelling, glove puppets, cycling when sufficiently strong

(3) Bilateral movements to balance power:

Adults	*Children*
Knotted dog leads, net making, etc.	Games with two hands, cord knotting for older children.

In these cases work was graded carefully and progressively, avoiding fatigue, and with a view to psychological as well as physical effect, taking care the patient knew what was expected of him.

Post-concussion Syndrome. These patients were treated in the curative workshops and employed to the limit of their capacity.

Assisting concentration. At first simple scale drawing for woodwork models. Stencil cutting, sign writing, cord knotting, weaving, basketry, etc. These were all the quieter types of occupation given.

Accuracy and decision. Leatherwork, book-binding, simple types, and where a little more noise could be tolerated, art metal work, shoe repairing, model building, bicycle and radio repairing.

For those who were showing marked signs of recovery. Carpentry and the heavier types of woodwork construction were employed; gardening except in bright sunshine. In a hospital where there was no physical training instructor, Army education officer, or entertainments personnel on the staff, then such social activities would be arranged by the occupational therapist as part of the patient's daily treatment, leaving the patient only the minimum of time to brood over his particular injury. Gardening was a failure. The men were liable to down tools and fade away at the first opportunity—save for the rare fellow who knew how to handle the land and growing things, and admired them. Probably age had a good deal to do with this; gardening has a greater appeal to maturity than to youth. Service personnel fall into the youthful group who dislike botanical pursuits. The most popular types of occupational therapy were the fabrication of small things which could be bought or taken away. Money could be made by a shrewd choice of article by those of the congenitally acquisitive group, and this gave a warning that rehabilitation might be prolonged because there could be considerable profit in it. Certainly the least sought-after occupation was the making of large rugs or carpets of cloth where, in a communal spirit, successive workers added a piece towards some not quickly realisable end.

There is one side of the work in the occupational workshops which Professor Norman Dott pointed out was peculiar to the head injury centres. It was this: that after some injuries to the brain (those of the left temporal and parietal area, and perhaps the deeper commissural fibres) there was some loss of skill of an apractic kind. A man may find that when he comes to work he knows what to do but that his hands will not do exactly what he wishes, that he has lost his aptitude. This was, as it were (and to mix terms), a dysphasia of the fingers. It was different from the effects of a mild paresis or cortical anaesthesia. This has long been known as a clinical entity, but the point was that work in an occupational workshop might perform a diagnostic service by revealing a disability unsuspected from the patient's general conduct in the wards and unrealised by him until he tried something that required craftsmanship. Once discovered, a little observation and explanation and training in easy things could teach him to overcome it. Left to himself he might have given up and remained off work for a long time.

Speech Therapy: Much valuable work was done in speech re-education of dysphasia, notably at the two Scottish centres and in the Army Hospital at Oxford.

PHYSICAL TRAINING

Physical training was of the greatest advantage in helping the patient with a head injury back to normality, but there were several prerequisites for its success. First the patient had to possess the will to be made fit, and this meant the inculcation of hope from the very beginning of treatment. Moreover, there was need for the closest co-operation between the medical officer and the instructor in physical training. It was essential that the instructor should be sympathetic and not overdose his pupil with exercise. The training had to be systematic and progressive, with a definite scheme for each patient to which he must adjust himself. Grading of activities had to be as fine as possible and the continuity sustained. Though game forms were more palatable to the patient, each set period of instruction needed to have a table of graded exercises having a definite function. Recreational training was also important and sessions were set aside when patients could play table tennis, badminton and quoit tennis, but these sessions should be called 'free activity periods', for some patients will indulge in informal activities which they would regard as too strenuous when forming part of a formal course. (In the 1st Canadian Neurological Hospital it was the routine for all patients with head injuries to start doing leg and arm exercises in bed prior to being allowed up.)

There was no real contest between occupational versus physical training; each had its great uses.

REHABILITATION AND PSYCHOLOGY

All patients who did not make progress, who got so far and then stuck, or who relapsed, were referred back for neurological opinion. If no physical cause was discernible the patients were sent for psychological study. The question of the will to recover and to return again to full pre-trauma efficiency varied in individuals. Latent neurosis was a common factor, and it was easily predictable that a proportion of those injured would be of this type.

The assistance of the psychologist was of particular importance in the head injury group because in a proportion of cases there was some damage to the mind. In those who had been unconscious for several days, in those who had no recollection of any events during the first week, and, more pronouncedly still, when the periods of unconsciousness or post-traumatic amnesia were even longer, there was almost invariably some difficulty in thinking, in concentrating, in conversing with more than one person at a time, in doing anything mental without rapid fatigue. This cleared up in all but the most severely injured, but it was a state that only actual psychological testing could correctly dissect and assess. So that while it was true that a psychologist was a valuable member of any rehabilitation team, he was particularly useful (*a*) to discover whether at the outset there was any mental disability, (*b*) to discover whether the reason for a lack of improvement during rehabilitation was due to that cause. Only careful tests could bring these facts correctly to the light. Ritchie Russell's (1942) studies showed that 80 per cent. of patients with head injuries go back to work in six months, so that the severely damaged category is not very large, though it is large enough. His studies showed how much personality before the accident conditioned the results, which is another way of saying how important heredity was; to make a good recovery one needed to be born into the right family. These conclusions were applicable to injuries of other systems than the nervous, but there remained this special characteristic of head injury (not to be laboured overmuch) that the mental apparatus which controlled the individual's behaviour had sometimes been deranged, both in its intellectual and emotional actions.

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(ii)

THE TREATMENT AND REHABILITATION OF PATIENTS WITH INJURIES OF THE SPINAL CORD*

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HISTORICAL INTRODUCTION

Recollections of casualties with spinal cord injuries from the First World War and the after-war period have left depressing memories of hopelessness and helplessness. The literature of that time in every country, though containing many excellent publications on problems of neuro-physiology, pathology or special surgical problems, reveals a profound defeatist attitude of the medical profession towards these

* This article was already delivered in 1950 and describes the experience gained up to that date only.

unfortunate sufferers, when dealing with the problem of prognosis and rehabilitation. In 1927, Harvey Cushing, the Consultant in Neurosurgery in the American Army during the War of 1914–18, gave a vivid description of the pitiable fate of battle casualties with spinal cord injuries, 80 per cent. of whom died in the first two weeks. 'The conditions were such', he writes, 'owing to pressure of work as to make it almost impossible to give these unfortunate men the care their conditions required. No water beds were available, and each case demands undivided attention of a nurse trained in the care of paraplegics. Only those cases survived in which the spinal lesion was a partial one'.

The mortality of traumatic paraplegics in the British Army was similar. The early mortality (death within the first few weeks or months) varied from 47 to 65 per cent. (Vellacott and Webb-Johnson, 1919), and the overall mortality after three years was estimated at 80 per cent. (Thompson-Walker, 1937). Most of those men who managed to survive dragged out their lives as useless and hopeless cripples, unemployable and unwanted. They were doomed to spend the rest of their lives at home or in institutions, dependent on other people's assistance and, as a rule, with no incentive or encouragement to return to a useful life. In 1934 Gowlland gave the following account of the conditions of these pathetic human wrecks treated at the Star and Garter Home:

'Two or three times a week, the patient is bathed: this means he must be lifted from his bed to his ward chair and wheeled into the bathroom, where his pyjamas and night-clothes are removed, and he is placed in a very warm bath and washed by an orderly.' In discussing the problem of painful, reflex spasms and contractures, he points out: 'The position is often terrible. I suppose there is more morphia, atropine and hyoscine used in this Home, which I look after, than in any other place of the same size in the country.'

Even in the early years of the Second World War, a defeatist attitude of most members of the medical profession towards spinal paraplegics in this and other countries was still prevalent. It is, therefore, not surprising that, in all discussions on rehabilitation during the years 1939–42, the subject of spinal paraplegia was hardly mentioned (see 'Discussion on Rehabilitation of Injuries to the Central Nervous System', 1941). However, a fundamental step forwards in a new approach to the problem of rehabilitation of paraplegics was taken by the Peripheral Nerve Committee of the Medical Research Council, under the leadership of Dr. George Riddoch, Neurological Consultant to the British Army, who decided to segregate spinal cord casualties in special hospitals or units, for it was anticipated that the number of war casualties with spinal cord injuries would be considerably increased by air raid casualties among civilians. Other measures taken in the Second World War, which contributed to increasing the early survival rate of traumatic paraplegics, can be summarised as follows. (1) Improved methods of combating traumatic shock—in particular, the use of blood transfusions. (2) Better facilities for the early transport of wounded men from the battle-front to the rear. In fact, in later stages of the war, this factor became of vital importance for the better prognosis of traumatic paraplegics, when high priority for evacuation by air was granted. (3) A more conservative attitude by neurosurgeons and surgeons towards immediate and early laminectomies. (4) The introduction of sulphonamides, and later on of penicillin, in the early treatment of war wounds. (5) The employment of suprapubic cystostomy as an emergency method in the early management of the paralysed bladder under battlefield conditions. Although this method has not proved to be a safeguard against ascending urinary infection in later stages of paraplegia—and, indeed, represents an undesirable method for the permanent management of the bladder in lesions of the cord or cauda equina—it has, in the immediate management of the paralysed bladder, at least greatly diminished the incidence of unskilled urethral catheterisation by inexperienced medical officers and orderlies which, in the War of 1914–18, had such dreadful effects on the paralysed urinary tract.

During the course of the war, ten spinal units were gradually set up in various parts of this country, where most of the 650 or more casualties with spinal cord lesions were collected. However, it was not generally recognised that, in order to prevent their becoming merely an accumulation of doomed cripples, the provision of certain arrangements was indispensable:—

(1) Adequate technical facilities for the specialised care and rehabilitation of these long-term patients, including pre-vocational training.
(2) Nursing and auxiliary staff sufficient in number to cope with the many details involved in the work, and avoidance of the usual practice of changing the nursing staff from one department to another at short intervals.
(3) Supervision of such a unit by an experienced physician or surgeon, who was prepared to devote his full time to the work, which demands scrupulous attention to detail, to organise the many details of treatment and to correlate the sometimes conflicting interests of the various medical specialists concerned with the rehabilitation of paraplegics.

In fact, it can now be concluded that, if the principles underlying the treatment and rehabilitation applied to the unfortunate victims of the war, to prevent their being cast on the human scrap-heap, were generally applied to spinal cord injuries in peace-time, the present still unsatisfactory conditions regarding rehabilitation of civilian paraplegics could be vastly improved.

In the following account there is presented the experience gained in the treatment of injuries to the spinal cord and cauda equina at the Spinal Injuries Centre of the Ministry of Pensions Hospital, Stoke Mandeville, where the majority of these casualties were treated during and after the War of 1939–45. This unit, starting from scratch with two patients on February 1, 1944, has gradually developed into the largest spinal centre of its kind in the British Commonwealth and Europe. It consists at present of one female and five male wards, totalling 120 beds, where Service personnel and pensioners, as well as civilians, suffering from spinal cord lesions are treated. Closely affiliated to and medically guided by this centre are three other spinal units set up by the Ministry of Pensions in recent years as auxiliary units, where paraplegics can continue their rehabilitation, pending discharge to their own homes or permanent settlements, and where some can remain as residents—Chaseley Convalescent Home at Eastbourne, the Paraplegic Unit at the Star and Garter Home, Richmond, and the Duchess of Gloucester House, Isleworth. There are also two settlements for paraplegic ex-Servicemen set up in recent years by the Red Cross and St. John's Organisation, which work in close contact with this centre—Lyme Green Settlement at Macclesfield and Kytes at Watford. Such a uniform scheme of treatment and rehabilitation of spinal paraplegics has already proved invaluable for achieving most gratifying results, from both a medical and a social point of view, and has formed a sound basis for the satisfactory solution of a problem, which, throughout the centuries, has been one of the most neglected and depressing in medicine.

GENERAL STATISTICS

Table I gives a statistical survey of the whole material of 570 spinal cord lesions treated during the period February 1944 to July 1950.

TABLE I

Total Material

		Injuries	Transverse myelitis	Polio-myelitis	Miscellaneous	Totals
Cervical	Complete	11	1	—	1	13
	Incomplete	30	—	11	13	54
Thoracic 1–5	Complete	34	2	—	2	38
	Incomplete	10	2	—	2	14
Thoracic 6–12	Complete	209	13	10	10	242
	Incomplete	35	13	12	18	78
Cauda equina	L1/5	101	—	—	2	103
	S1/5	28	—	—	—	28
		458	31	33	48	570

It demonstrates the segmental level, the type of lesion and the various aetiologies. Although priority has always been given to traumatic lesions (as shown in the table by the high figure of 458), spinal cord lesions of the other aetiologies were also admitted, especially those suffering from ascending urinary infection and pressure-sores. The aetiologies tabled as 'Miscellaneous' include osteomyelitis of the spine, epidural abscess, Pott's disease, meningitis, tumour, haemangioma, lymphogranulomatosis, amyotrophic lateral sclerosis, syringomyelia, avitaminosis, combined sub-acute degeneration, and selected cases of disseminated sclerosis; 461 out of a total number of 570 were Service patients or pensioners, the remaining 109 being civilians.

Table II gives a detailed classification of the spinal injuries and demonstrates the relationship between war casualties and civilian casualties in peace-time.

TABLE II

Traumatic Lesions

		Service Cases and Pensioners		*Civilians*	
Cervical	Complete	8	35	3	6
	Incomplete	27		3	
Thoracic 1–5	Complete	29	36	4	7
	Incomplete	7		3	
Thoracic 6–12	Complete	162	195	48	50
	Incomplete	33		2	
Cauda equina	L1/5	94	122	5	7
	S1/5	28		2	
	Total	388		70	
			458		

The preponderance of lesions of the distal part of the spinal cord is obvious in both Service and Civilian cases, and the figures are in accordance with statistics of other authors and the writer's own statistics published previously elsewhere (Guttmann, 1947).

The overall figure of 388 Service injuries of this Centre shown in Table II includes 14 cases from the First World War, 351 from the War of 1939–45 and 23 from the after-war period. Among the latter group are battle casualties from Malaya, Palestine and the Yangtse River. In the following statistics, only the 351 war casualties of the Second World War are considered. Their injuries were caused by gunshot wounds, fractures and stab wounds.

MORTALITY OF SPINAL INJURIES

The death rate of the 351 spinal casualties of the Second World War is at present 9·3 per cent. representing 33 deaths. This figure includes paraplegics who died after their discharge home or to other institutions. It also includes 7 cases in which death was obviously due to causes other than the spinal injury—such as perforated duodenal ulcer, empyema, coronary thrombosis, pneumonia, tuberculosis, cerebral haemorrhage, and street accident. Excluding these cases, the corrected mortality rate due to spinal injury is at present 7·4 per cent. The writer's previous statistics given on 177 war casualties in 1947 was 7·3 per cent. (corrected figure 5·6 per cent.). This decrease in the mortality rate of war casualties during the last few years is dramatically lower than one would have expected only a few years ago.

Although no up-to-date figures on the death rate of paraplegic patients of the Second World War are available from all the other countries involved in that war—in particular, Germany and Russia—a few statistics have been published in the U.S.A. and Canada. Jousse and Botterell (1947) published a mortality of 7·8 per cent. among 103 patients. Prather (U.S.A., 1947) gave 3·8 per cent. among 61 patients, and the Framingham V.A. Hospital, Van Nuys, California (1948) statistics show 2·2 per cent. out of 458 patients. There are, however, no detailed data available of these statistics, especially as to whether these were all injuries or whether cases of transverse myelitis, etc., have also been included; furthermore, there is no indication whether these statistics also include patients who died after discharge from hospital, or whether the figures given are already the corrected statistics, excluding the cases where death was not related to the spinal injury. The writer feels that there is a great need for international agreement about statistical work on paraplegics, to ensure proper comparison in future.

Table III demonstrates the time lapse between injury and death, in our series of war casualties of the War of 1939–45.

TABLE III

Death after Injury

Within 1 year	8 (5 within the first 6 months)
2 years	3
3 "	6
4 "	5
5 "	5
6 "	1
7 "	4
8½ "	1
	33

FACTORS DETERMINING DEATH AFTER SPINAL INJURY

The old teaching that the lower the spinal injury the better the prognosis is only true in so far as high cervical injuries have, as a rule, little prospect of surviving, due to the involvement of the respiratory mechanisms. However, in our series of 33 deaths, neither the severity—i.e. the completeness—nor the level of the spinal cord injury has proved to be an essential factor in determining the late prognosis after injury: 4 were cervical, 7 upper thoracic (T.1 to 5), 6 mid-thoracic (T.6 to 9), 9 lower thoracic (T.10 to 12), and 7 cauda equina lesions, and no relationship was found between the level of the lesion and the date of death after injury. The vital factor determining the prognosis of traumatic paraplegics is the degree of care and attention to all the details of immediate and early treatment—in particular, the prevention and combat of the two main complications, urinary infection and pressure-sores. This conclusion, already drawn by the Committee of the Medical Research Council (1924) on Injuries of the Nervous System, from experience on spinal cord injuries of the First World War, has been fully confirmed by the experience gained in the Second World War.

PATHOLOGY

In 20 of the 26 patients of our series, whose deaths were due to spinal injuries, the only or main cause was the urinary infection, resulting in renal deficiency. In 5 others, the sepsis from extensive pressure sores was either the only cause or an additional cause to the infection of the urinary tract. One patient with a lesion of the distal cauda equina died of meningitis originating from multiple shell fragments in the pelvis and in the lumbar spine, and frightful sores of the sacrum and lumbar spine, resulting from a plaster cast. Nineteen out of the twenty-six patients who died of urinary infection and sores had suprapubic drainage at the time of death; in most of these cases, suprapubic drainage was instituted either on the day of injury or within the first few days following injury. In 5 cases, the suprapubic drainage had been closed at varying periods before death, while only 2 cases had never had suprapubic drainage.

The pathological findings of the urinary tract in all these cases where post-mortem was possible (19) were uniform. The bladder, showing all the signs of chronic infection, was contracted and adherent to the pelvis, being surrounded by a thick wall of fibrous tissue. The ureters were dilated, tortuous and adherent to the surrounding tissues and also embedded in dense fibrous tissue. The kidneys showed various degrees of hydro- or pyo-nephrosis and were also found to be embedded in a mass of fibrous tissue. Sometimes, one of the kidneys was found to be in an extreme degree of atrophy and very small. These findings were associated with those of amyloidosis of various organs, but were only occasionally accompanied by hepatomegaly. Mention may be made of one of the patients with spinal injury, whose death could not be attributed to the spinal injury, as he represented an interesting contribution to the problem of relationship between spinal injury and tuberculosis of the spine. An airman of 23 sustained a fracture of his 3rd thoracic vertebra, resulting in an incomplete transverse lesion of the spinal cord. The injury was associated with a compound fracture of the right femur. His condition markedly improved, the suprapubic drainage was successfully closed and the patient had already started walking exercises, when he developed an abscess over the left buttock. This was found to be of a tuberculous nature, connected with a tuberculosis of the 1st and 2nd lumbar vertebrae. At post-mortem, neither the old spinal fracture at T.3 nor the fractured femur revealed any signs of tuberculosis.

SURVIVAL RATE AFTER SPINAL INJURY

It is still too soon to make definite statements about the ultimate survival rate of traumatic paraplegics of the Second World War. So far, the survival time of the majority of the 318 survivors (namely, 255) lies between five and seven years, with over 50 per cent. (134) having already survived more than six years. There are 13 patients who have already survived ten or eleven years.

TYPE OF MATERIAL

The patients were admitted, at varying intervals after injury, from first-aid posts, military and E.M.S. hospitals and from home. In numerous cases, their condition was very serious. The cases admitted can conveniently be divided into the following groups:

(1) Cases admitted at an early date after injury, arriving with gaping wounds caused by bullets or shell fragments, with or without discharging cerebro-spinal fluid, or with associated injuries to other organs, such as lung, liver, kidney or fracture of extremities.
(2) Cases admitted at later dates with signs of septic absorption resulting from urinary infection and multiple pressure-sores. Many of this group showed signs of nutritional deficiency and some of them showed extreme degrees of malnutrition comparable with those found in inmates of concentration camps (Belsen type).
(3) Another group of late arrivals, where pain and intractable spasticity, overlaid by contractures, were found in the foreground of the clinical symptoms.
(4) A further group admitted at later dates, where the physical condition was not unsatisfactory but the mental condition was poor, due to prolonged and enforced inactivity in hospitals, institutions or at home.
(5) Ex-patients of this centre, discharged either to their own homes or resettlements, readmitted for check-up.

It is obvious that the great variety of symptoms observed in all these groups involve many problems of physiology, medicine and surgery. The following pages are concerned with a survey of the major physiological and clinical aspects encountered in the treatment and rehabilitation of paraplegics admitted to this centre. They will be reviewed in the light of experience of other authors.

MECHANISM OF INJURY

There is little to add to what has already been written on the mechanism of spinal cord injury, as the result of gunshot wound or fracture. The fractures of the spine were caused by a variety of accidents, such as direct trauma by a heavy load or from falling masonry, a fall from a height, motor car and motor cycle accidents, aeroplane crashes, and diving into shallow water. In accordance with the experience of previous authors, no relationship was found between the severity of the vertebral injury and the injury to the spinal cord. The writer's own observations on cervical fractures after diving into shallow water, and motor car accidents confirmed Jefferson's view (1927) that the predilection zone of cervical fractures is not the cervico-thoracic junction, as was previously thought, but at the level of the 5th and 6th cervical vertebrae.

Special mention may be made about the mechanism of spinal cord injuries in the upper thoracic region after air-crash landings, as they demonstrate the importance of the position of the body at the moment of injury as a factor determining the level of the lesion. According to Watson-Jones (1941), the special fixation of the pilot in the cockpit by his harness over the front of both shoulder-joints holds the pilot in his seat and thus eliminates the violent forward movement of the trunk, which would otherwise occur at the moment of the crash. Consequently, it raises the site of angulation from the thoracic lumbar junction to the upper thoracic level. Hence, the resulting fracture occurs not at the thoraco-lumbar junction, as commonly found in coal mine and other industrial injuries, but at the upper thoracic or cervical spine. Experience gained in this centre on spinal cord injuries following air-crash landings is in accordance with this conception. There is not a single case in our series of the shoveller type of injury (Watson-Jones, 1942), and it can therefore be assumed that, with this type of vertebral injury, the chance of injuring the spinal cord is very remote.

A blunt or penetrating force striking the vertebral column may result in a spinal cord damage in both transverse and vertical directions. Damage to the spinal cord in vertical direction, described already in the First World War by Collier (1916) under the heading 'remote lesions', may involve numerous spinal cord segments above and below the primary injury, and by damaging the anterior horn cells be responsible for the delayed recovery from the state of flaccidity and lost or diminished reflex activity below the level of the lesion, commonly termed rather loosely 'spinal shock'. If a definite destruction of the anterior horns has occurred over a considerable distance below the level of the lesion, this accounts for the persistent flaccid type of paraplegia associated with atonic or hypotonic bladder. This was found to be the mechanism in several cases admitted to this centre with lesions at the mid- and even the upper-thoracic cord, following both fractures and gunshot injuries. The muscles below the level of the lesions showed more or less pronounced degrees of a lower motor-neuron paralysis, with degenerative atrophy, and electrical examination revealed the reaction of degeneration. It may be noted that, from a rehabilitation point of view, the management of this type of injury is easier by far than the spastic type.

In the beginning of the War of 1939–45, it was expected, having regard to the probable great number of air raids, that the number of survivors with spinal cord injuries due to blast might be considerable. However, although the number of people exposed to blast was no doubt great, no statistics are available to prove that this expectation was justified.

PHYSIOLOGICAL AND NEUROLOGICAL ASPECTS

REFLEX ACTIVITY OF THE ISOLATED SPINAL CORD

In the light of the classical researches of Sherrington and his school on the integrative action of the nervous system, and their great development by Graham Brown, Magnus and his school, Holmes, Walshe, Riddoch, Foerster, *et al.*, the modern student of spinal spasticity can approach this subject with more precise conception of the factors involved in this mechanism than the investigator of the past. Moreover, in the light of experience acquired in recent years on so many paraplegics who survived from the War of 1939–45, it is now possible to resurvey earlier observations, with a view to clarifying some of the obscure phenomena and rectifying certain dogmatic views of the past.

CLINICAL SIGNIFICANCE OF PARAPLEGIA-IN-FLEXION OR -EXTENSION. FACTORS INFLUENCING REFLEX SYNERGIES

Riddoch's thesis (1917) that, by studying the activities of the flexor and extensor reflex arcs of the paralysed lower limbs, it is frequently possible to say whether conduction of the spinal cord has been completely destroyed or not, has led to the conception that paraplegia-in-flexion is pathognomonic of complete transection of the cord, while paraplegia-in-extension is pathognomonic of partial lesions. Moreover, Fulton, Liddell and Rioch's animal experiments (1930) indicate that extensor hypertonus depends on the transmission of postural reflexes along intact vestibulo-spinal and probably also ventro-reticulo-spinal pathways to the cord centres below the level of the lesion, and only destruction of these tracts results in a preponderance of the flexor reflexes or paraplegia-in-flexion. On the other hand, Sherrington found a variability in the order of recovery of the various spinal reflexes from spinal shock in the dog, following complete transection of the cord, and in some individuals a preponderance of extensor rigidity was evident: 'The limbs are kept extended at knee and ankle to a degree that it is difficult to break through by the inhibition accompanying elicitation of the flexion reflex stimulation of the foot'. Sherrington's explanation is that 'some incidental circumstance determining the preponderance of some passive attitude of the limb during the early days succeeding the lesion may, by its influence on the interaction of the recovering spinal arcs, impress an unwanted reflex habit upon the limb'.

Experience gained in this centre confirms Sherrington's views on the great influence the position of the paralysed limbs has in the development of the various patterns of reflex activity of the isolated cord in the spinal man during the early stages of paraplegia. Therefore, the doctrine taught for so many years by physiologists and neurologists that there is a characteristic reflex pattern which distinguishes a particular type of cord lesion has to be rectified. It was found that, in later stages of complete lesions of the spinal cord, the extensor reflex synergy prevails, especially in those paraplegics who have not developed flexion contractures during the early stages, whose general conditions are satisfactory and, in particular, who are free from sepsis. It may be remembered that Riddoch himself had already found that, in later stages of heightened reflex activity in complete lesions, the difference in the tone of the extensor and flexor groups (the latter being predominant in the early stages) becomes less marked. Foerster (1936) reported two cases of transection of the cord of over one year's duration, with preponderance of extension reflex synergy. In one of these cases, this extensor reflex could be elicited in both legs by stimuli applied to the ano-genital region.

Among the factors influencing the pattern of spasticity, the writer found attitudes and posture of the paraplegic (whether the lesion be complete or incomplete) most important in the early stages following injury. Attention has already been drawn to the fact that prolonged fixation of the paralysed limbs in adduction and semiflexion, as produced by placing pillows under the knees, invariably promotes flexor spasms and consequently paraplegia-in-flexion (Guttmann, 1946). The explanation is that the constant approximation of the insertion points of the flexor muscle in such cases causes facilitation (Bahnung) of their stretch reflex and at the same time the constant overstretching of their antagonists, the extensors of the knee and hip, causes a weakening of the stretch reflex of the latter. On the other hand factors which have proved effectual for facilitating extensor activity are:

(1) Placing of the paralysed limbs in abduction and extension of hips and knees, in supine position.

(2) Early passive movements.

(3) Placing the patient in prone position, which, particularly in high spinal cord lesions, as in children whose pyramidal tracts are not yet developed, sets up the extension reflex of the body.

(4) Restoration of the upright position—in particular, standing in parallel bars.

It is beyond the scope of this report to describe in detail the many varieties of reflex patterns of the lower limbs in complete lesions, described in the literature and found in paraplegics in this centre, but three varieties are worth mentioning:

(1) *Preponderance of the extensor hallucis longus in the reflex synergy*

In a few cases among our material, it showed a profound preponderance over any other muscle of the lower limbs. In one patient with a complete transverse lesion at T.4, it was found almost constantly present, finally resulting in subluxation of the terminal phalanx of the toes (Plate I).

(2) *Preponderance of plantar flexors of feet and toes*

In several patients with complete or incomplete lesions, resulting in marked spasticity of the paralysed legs, a large preponderance of the plantar flexors of the feet and toes was found. This may occur in one leg only, though it was repeatedly seen bilaterally. Neither the extensor hallucis longus nor any other of the dorsiflexors took part in reflex responses to intrinsic or extrinsic stimuli. The reason for the absence of the reflex activity of these muscles was found to be a superimposed external popliteal nerve lesion, which, in these cases, had occurred due to pressure against the head of the fibula by faulty position and care, especially in the early stages following injury. The peripheral type of this lesion can be diagnosed by the absence of any reflex response to cutaneous stimulation within the area of cutaneous distribution of the external popliteal nerve—for instance, by pricking or stroking with a pin. Reflex responses to nociceptive stimuli are obtained only at the border of the cutaneous distribution of the external popliteal nerve. Moreover, electrical examination of the muscles in question will reveal complete or incomplete R.D.

(3) *Synchronous rhythmic contractions*

Rhythmic, alternating flexion and extension contractions in the spinal man have repeatedly been described (Riddoch, 1917; Foerster, 1936), and special mention may be made of the coitus reflex described by Riddoch as an example of rhythmic, alternating flexion and extension synergy. One of the writer's patients, a young soldier with a complete lesion at T.3, whose paraplegia since his injury in 1944 gradually developed into one of extension, showed interesting, synchronous, rhythmic contractions occurring only in the tibialis posterior on both sides.

THE CONTROL OF POSTURE IN SPINAL MAN

(1) *Postural activity of the isolated cord*

The viewpoints from which investigators in the past approached the subject of postural control in the spinal man were mainly fixed on the part which the isolated portion of the spinal cord after transection plays as the only remaining central apparatus controlling postural reflexes. There is general agreement that, unlike the amphibia in which local reflex arcs in the spinal cord are capable of controlling the postural reflex, in the ascending phylogenetic scale the final common path has come more and more under the control of cerebral centres, which exert their influence either directly or indirectly through the cerebellum. Thus, the influence of the spinal cord as a central organ regulating posture becomes more and more negligible. Although, as Sherrington (1915) has shown, the cat with the spinal cord transected in the lower thoracic region is capable of maintaining standing posture, and supporting the weight of the hind quarters even for minutes, this spinal standing is liable to sudden complete lapses, and 'the spinal animal, although it has poorly developed stretch reflexes and fragmentary static reflexes in the form of extensor thrust, cannot stand' (Fulton 1943). The view that the isolated spinal cord is most ineffectual as a regulatory postural reflex centre, and that spinal tone lacks plasticity is even more generally accepted for the spinal man. However, experience gained in recent years on traumatic paraplegics indicates that the isolated spinal cord is capable of some readaptive metamorphosis. It has already been pointed out that, in later stages of spinal paraplegia, the preponderance of the flexor reflex may disappear and the extensor reflex may predominate, thus facilitating the maintenance of standing posture. These changes in tone pattern are produced by proprioceptive impulses arising from the extensors of the hips and knees and are influenced by extroceptive impulses. As pointed out, apart from early passive movements of the paralysed limbs, placing the patient in the prone position on a plinth, and regular gradual passive stretching of the hips and knees by pressure, using slings over the hips and fixed at the side of the plinth, have proved invaluable in overcoming the predominant flexor tone and promoting increase of extensor tone. Later on, standing in parallel bars with the knees kept in extension by light plaster splints, thus producing pressure against the plantar surface of the feet, was found most effective in promoting increase of extensor tone in hips and knees. Eventually, some paraplegics of this centre with complete lesions as high as T.7 were able, after training, to stand in parallel bars merely by supporting themselves on their arms, but without support by plaster splints or other appliances fitted to the paralysed lower limbs, for as long as ten minutes, without being interfered with by sudden flexor spasms. Therefore, it can now be concluded that, in the spinal man, the isolated spinal cord under the influence of appropriate impulses is adaptive to posture and can undergo such functional adaptation that local reflex arcs become strong enough to be capable of producing useful static reflexes. However variable and fragmentary the control of the postural reflex activity of the isolated spinal cord in many may be, it is trainable and can be utilised for the rehabilitation of paraplegics.

(2) *Postural re-adaptive activity of motor and sensory mechanisms in normal parts of the body*

In the past, a man with a complete lesion of the spinal cord at the level of the upper and even the middle thoracic region, let alone those with lesions of the cervical cord, was, as a rule, confined to bed or had to be transported in lying position in a spinal carriage. If the upright position in such cases was attempted, it was achieved by propping them up with artificial aids, such as heavy leather and steel corsets. Yet, nature has provided us with wonderful facilities for discarding these artificial aids, by mobilising and utilising certain muscle groups of the trunk which, by their attachment to the pelvis and spine, can restore upright position and standing, maintain postural control of the paraplegic, and even restore, to a certain extent, walking by pelvic tilting. In previous papers, attention has been drawn in particular to the great importance of the shoulder and trunk muscles, especially latissimus dorsi, in the restoration of postural control in high lesions, by stabilising the pelvis (Guttmann, 1945, 1946, 1949). The latissimus dorsi—that large muscle, with its segmental supply as high as C.6, 7 and 8—by-passes the spinal lesion in any transection of the spinal cord at any thoracic level and up to C.7, and thus connects the paralysed portion of the body with the remaining normal parts. In normal circumstances, the latissimus dorsi will adduct, retrovert and internally rotate the humerus. If, however, the shoulders are fixed by arm crutches or parallel bars, the mobilising part of this muscle is transferred to its insertion points on the thoracic and lumbar spine, the sacrum, and, most important of all, the postero-lateral rim of the ilium, and thus a pull is exerted on the pelvis which results in tilting the pelvis in an upward direction. Moreover, as the gluteus maximus, like the latissimus dorsi, also has its insertion on the lumbar fascia, the upward pull of the latissimus dorsi consequently results in extension of the hip by fascial stretch. It is possible, if not probable, that this stretch effect, set up by the action of the normal part of the body, in turn promotes reflexly the increase of the tone of the gluteus maximus, as the main extensor of the hip. It may be noted that the middle and upper portion of the trapezius acts as synergist to the latissimus dorsi in this upward movement, if the shoulders and scapulae are fixed, owing to its insertion of the 11th and 12th dorsal vertebrae. It is obvious that the more distal the spinal cord lesion, the greater the number of muscles available with attachment to the pelvis, especially rectus abdominis and obliquus externus, in order to co-operate in the team work to restore stabilisation of the pelvis, and thus postural adaptation in the spinal man.

The attachment of the latissimus dorsi to the pelvis is, however, also of the utmost importance for the re-orientation of the afferent system in the restoration of postural control in paraplegics with complete lesions at the mid- and upper-thoracic and cervical levels. Proprioceptive impulses arising from any movement of the pelvis are transmitted centrally along the afferent pathways in this muscle, and thus connect the insensitive part of the body to the various centres and pathways subserving postural control above the level of the spinal lesion, and in turn elicit appropriate efferent postural responses. Eventually, a new pattern of postural sensibility gradually develops, and this is accomplished by systematic training. The method employed by the writer in achieving this will be discussed later.

EFFECTS OF SPINAL CORD INJURIES ON THE AUTONOMIC SYSTEM

Effects of spinal cord lesions on the autonomic mechanisms have been the subject of systematic research in paraplegics from the Second World War, and the following is a survey of studies carried out by the writer and his research team. Emphasis is laid on the importance of the nervous system in the maintenance of a suitable internal environment in the spinal man. After a complete lesion of the spinal cord, this regulatory function becomes increasingly deficient the higher the lesion of the spinal cord. In particular, the failure to regulate blood-pressure, blood-flow and body temperature is not only responsible for imposing limitations on the activity of a paraplegic, but also results in the development of widespread abnormal reactions of autonomic mechanisms to visceral activity in the paralysed part of the body, especially the bladder. On the other hand, the study of the nature of the various components of these autonomic responses has resulted in a better understanding and utilisation of the forces of adaptation in the nervous system, in setting up regulatory mechanisms to restore suitable internal environment in the paralysed.

(1) *Significance of vasomotor control for postural readjustment in the spinal man*

Experimental work on the effects of postural changes on vasomotor control in spinal mammals was initiated in this country by Hill and Barnard in 1897, who demonstrated the profound effect of gravity, following change of posture, on the respiratory and skeletal mechanisms in the dog, due to loss of vasomotor control in the splanchnic area, after transection of the upper thoracic cord. Studies on this subject under normal and pathological conditions in man have been published (Gordt *et al.*, 1945), but little attention has been paid to the analysis of the effects of postural changes on the cardiovascular system in paraplegics (Guttmann, 1946; Jonason, 1947). The writer has since continued these studies in co-operation with Whitteridge. We studied the effects of rapid tilting from the horizontal to the vertical feet-down position, on systolic and diastolic blood-pressure, pulse rate, blood-flow, and the subjective sensations noticed by the patient, in paraplegics with complete lesions at various levels.

It was found that while paraplegics with lesions of the distal cord or cauda equina did not differ from other non-spinal convalescent patients in their cardiovascular responses to postural change, those with high thoracic and cervical lesions showed profound effects, owing to the lack of postural adaptation mechanisms resulting from the interruption of their splanchnic control. This maladaptation to the vertical position of paraplegics with lesions above T.5 results in rapid and uninhibited accumulation of blood in the abdominal area and lower limbs, with resultant decrease in the supply to the central veins and, consequently, insufficient cardiac output. The blood-pressure shows rapid and steep fall, the pulse rate is raised to the highest level, and syncope follows in a few seconds or minutes. The obvious explanation of this postural hypotension in paraplegics with lesions at or above T.5 is to be found in the inability of the blood vessels of the viscera to constrict, due to deprivation of control of the roots of the splanchnic nerve. In some cases, it was found that the pulse rate may slow down before syncope occurs. Moreover, swallowing cold water or ice, or deep inspiration, were also found to be stimuli which elicited vasoconstrictor responses (see later). However, it was found that the postural circulatory disturbances in paraplegics with high spinal lesions can be overcome by systematic exercises. It must be assumed that the carotid sinus and aortic nerves and other blood collectors act as 'emergency vasomotor adaptors', in order to compensate for the loss of the splanchnic control. Moreover, as will be shown in the following paragraph, in these spinal lesions the isolated cord itself may play a part in this adaptation mechanism by reflex activity.

(2) *Vasomotor response to deep inspiration*

It was pointed out in the foregoing paragraph that, in high lesions, deep inspiration elicits vasoconstriction, which can prevent or at least delay the fainting reaction due to postural hypotension in paraplegics. This clinical observation shows that paraplegics with high thoracic and lower cervical cord lesions, in spite of paralysis of their intercostal musculature, are able to increase the diameter of the chest sufficiently to take in enough air to elicit the necessary afferent stimulus for skin vasoconstriction. This shows that the paraplegic, if trained, can compensate for the paralysis of the intercostals to a certain extent, by utilising and overdeveloping other auxiliary inspiratory muscles, in particular the sterno-cleidomastoids, which, by pulling the sternum upwards, can thus increase the antero-posterior diameter of the chest.

We have studied ten paraplegics with complete lesions at levels ranging from C.6/7 to T.10/11, using the technique as described by Sturup, Bolton, Williams and Carmichael (1935) in normal subjects, to investigate the effect of deep inspiration in relation to extrinsic sensory stimuli (pin-prick, noise) (Gilliatt, Guttmann, Whitteridge, 1948). The most outstanding result of this study is the fact that paraplegics with high spinal cord lesions, resulting in complete interruption of functional continuity of the spinal cord, who had apparently no cerebral or medullary control of the sympathetic outflow to the limbs, showed a vasoconstrictor response in the fingers to deep inspiration. This indicates that, in these patients, vasoconstriction in the hand on deep inspiration is purely a spinal reflex through afferent fibres, which reach the cord in the upper thoracic region. The responses of the toes to deep inspiration were found to be more variable in these cases than those of the fingers. The reason for this defect in conduction is still obscure.

(3) *Disturbance of sweating*

This section deals with the disturbances of sudomotor function, as revealed by the thermo-regulatory sweat test, while reflex responses of sweat glands to the activity of the isolated cord will be discussed in connexion with the visceral distension. The quinizarin method (Guttmann, 1937, 1947) was used in all these cases as an indication of sweat-gland activity.

Lesions at and above the cervico-thoracic junction. In complete lesions of the cervical cord and of the cervico-thoracic junction, down to and including the second thoracic segment, no sweating in response to heat was found in any part of the body, apart from a few pin-points of sweat in face and neck, in upper thoracic lesions. Such patients, as a rule, could not stand heat well, they felt uncomfortable, and a few minutes after onset of heating, auxiliary heat regulatory mechanisms were readily mobilised, such as increased rate of respiration (panting), patchy vasodilatation and also increased renal function, resulting in distension of the bladder and detrusor action. The micturition reflex in turn elicited reflex sweating in these high lesions, and an outburst of sweating occurred, involving face, neck, both upper limbs, chest and trunk—gradually diminishing in intensity distally to the 10th thoracic dermatome.

In incomplete lesions of the cervical cord, two types of sudomotor abnormalities were found.

(1) Unilateral hypohidrosis, involving more or less the whole of one side of the body. Experience previously gained with unilateral cordotomy in the cervical region indicates that the descending thermo-regulatory fibres can be localised in the postero-medial part of the antero-lateral tract in closest relationship to the lateral pyramidal tract (Guttmann and List, 1928). Moreover, a cordotomy carried out in the upper cervical region—say, between C.2 and 3—may interrupt sweat fibres for specific areas subserving sweating for specific areas of the body only—for instance, the trunk or leg. This indicates that a somatotopic division exists of the sudomotor tract in the cervical region, as has been proved to

exist for the various modalities of sensation, mediated through the spinothalamic and posterior column tracts.

(2) This explains the occurrence of the second possibility of sweating disturbance, found in incomplete lesions of the cervical cord—namely the segmental type. Plate IV demonstrates the result of the quinizarin sweat test in a case of incomplete cervical lesion at the mid-cervical area, following fracture dislocation of the spine. This figure reveals the segmental disturbances of sweating over the right trunk and leg, which is quite dissociated from the areas of analgesia (interrupted line) and thermo-anaesthesia (crossed line).

Lesions of thoracic cord. Plate II shows the results in complete lesions at the levels of T.5, T.6, T.7/8 and T.10, clearly demonstrating how the dissociations between the areas of sensory loss and area of anhidrosis gradually diminishes the nearer the lesion to the 10th thoracic segment.

The significance of the phenomenon of border-zone activity at the level of a complete transverse lesion, characterised by an early onset of sweating and relative hyperhidrosis, will be discussed later. (See p. 460 *et seq.*)

Lesions of conus and cauda equina. As one might expect from the anatomical arrangements of the spinal sudomotor pathways subserving sweating in the lower limbs, a lesion below the second lumbar segment should show normal sweating, as sudomotor fibres for the lower limbs leave the cord between the 10th thoracic and second lumbar segments (thoraco-lumbar junction). This was verified in uncomplicated lesions of the cauda equina at any level in our material. In fact, sweating in the paralysed lower limbs in these cases can be particularly profuse in the distal parts, and it begins very early in these areas. In some cases, there can even be marked spontaneous sweating in the feet without any application of heat. It is not clear whether this increased sweat-gland activity is a release phenomenon, due to loss of inhibitory mechanisms, or whether this is a result of direct irritation of the distal part of the sudomotor centre situated at the thoracic-lumbar junction by post-traumatic changes within the spinal canal.

However, there are lesions of the cauda equina where the thermo-regulatory sweat test reveals sweat disturbances due to a lesion, either of the sympathetic chain or ganglia or peripheral nerves, especially the external popliteal nerve, superimposed on the lesion of the cauda equina. Evidence of the former possibility has previously been published elsewhere (Guttmann, 1931). Plate III shows an external popliteal palsy superimposed on a lesion of the cauda equina, caused by pressure against the head of the fibula (not the scar). The occurrence of such superimposed peripheral nerve injury, most often due to pressure of plaster or splints, was found to be not infrequent in paraplegics of the War of 1939–45. Cases previously investigated by the writer during that war have already been published by Lewin (1944).

EFFECTS OF ABDOMINAL VISCERAL ACTIVITY ON AUTONOMIC MECHANISMS

(1) *Reflex sweating*

The investigation of sweat-gland activity in spinal paraplegics is not only of interest from a heat-regulatory point of view, but it also represents an outstanding component of widespread reflex responses of autonomic mechanisms, which are elicited by any extrinsic and intrinsic stimulus in the paralysed part of the body, especially by distension of the bladder.

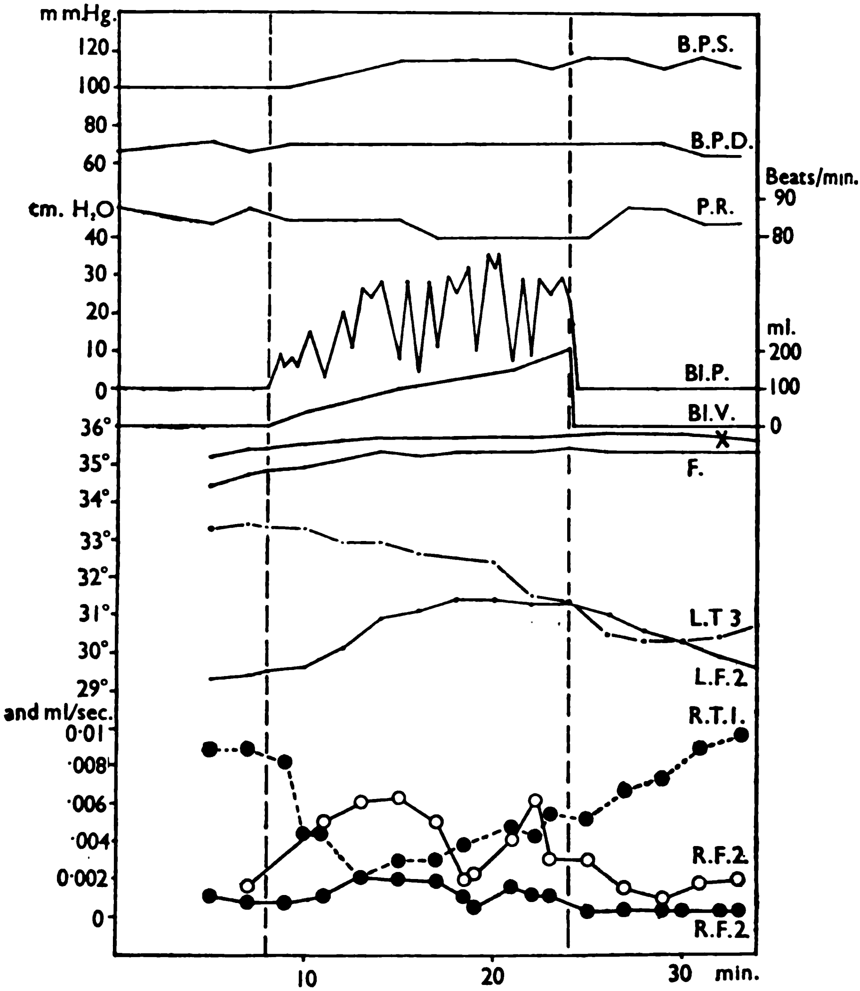
In upper thoracic and cervical lesions, reflex sweating due to distension of the bladder involves the face, neck, upper limbs and chest, and to a lesser degree the trunk. In none of these high lesions did sweating progress beyond the 10th or 11th thoracic dermatomes, and the lower limbs remained dry. In patients with mid-thoracic lesions, sweating was not so regularly elicited by distension as in high lesions. It was absent especially where the injury had caused, below the level of the transverse lesion, a vertical lesion of the cord, resulting in flaccid paraplegia of a lower motor-neurone type with an atonic or hypotonic bladder. However, if present, sweating involved the distal part of the trunk and the lower limbs. These findings suggest that the distribution of sweating due to visceral activity depends largely on the distance of the spinal lesion from the cervico-thoracic and thoraco-lumbar junctions respectively. In some cases, the part of these spinal sudomotor centres nearest to the lesion may show an especially marked degree of irritability resulting in a ready and exaggerated response to any intrinsic stimulus. This would explain the band-like area of hyperhidrosis found in certain dermatomes, as shown in Plate V in a case of transverse lesion at T.4, by the outburst of sweating at the level of the lesion. The black lines in face and neck represent the distribution of the patchy-vaso-dilatation—another effect of visceral distension which will be discussed later. Reflex sweating was even more pronounced in a case of complete lesion at T.7. While, in this case, the thermo-regulatory sweat test showed a complete anhidrosis below T.10, reflex sweating due to bladder activity was present below the level of the lesion and revealed a profuse band-like hyperhidrosis between T.10 and T.11. It may also be noted that, in certain cases, posture has played an important part in eliciting reflex sweating. There was one patient who became soaked in sweat when placed in the prone position—another when placed on his left side.

(2) *Cardiovascular reactions*

The immediate cause of this study was the following clinical observation:—On the occasion of a cystometrographic examination in April 1944, of three patients with complete lesions of the upper thoracic cord (T.3, T.4 and T.5), distension of the bladder gave rise to a clinical syndrome characterised by patchy flushing of the upper chest and shoulders, and especially the lateral aspect of the neck and face (see Plate V). In one of these cases, engorgement of the temporal and supraclavicular vessels was very striking. The vasodilatation in parts above the level of the lesion also involved the naso-pharyngeal mucosa, causing complete blockage of the nasal air-passage and, in one of these patients, a nasal voice. The pulse became slow and there were occasional extra systoles, and there was also an outburst of sweating, the details of which have already been described in the previous paragraph. Interesting subjective signs accompanied this vasomotor phenomenon, which will be discussed later, in the paragraph on the problem of pain. It was realised that these symptoms could not be explained merely as effects due to activity of the isolated cord, but that the distension of a visceral organ, such as the bladder, situated in the paralysed part of the body, had set up profound effects on the cardiovascular activity in parts of the body above the level of the spinal lesion. Following this observation, the detailed study of the various components of the cardiovascular mechanisms involved in this autonomic mass response was concerned with recording skin and rectal temperature, respiration, pulse rate, blood-pressure, pulse volume, blood-flow, and electrocardiogram, in relation to bladder activity (Guttmann and Whitteridge, 1947).

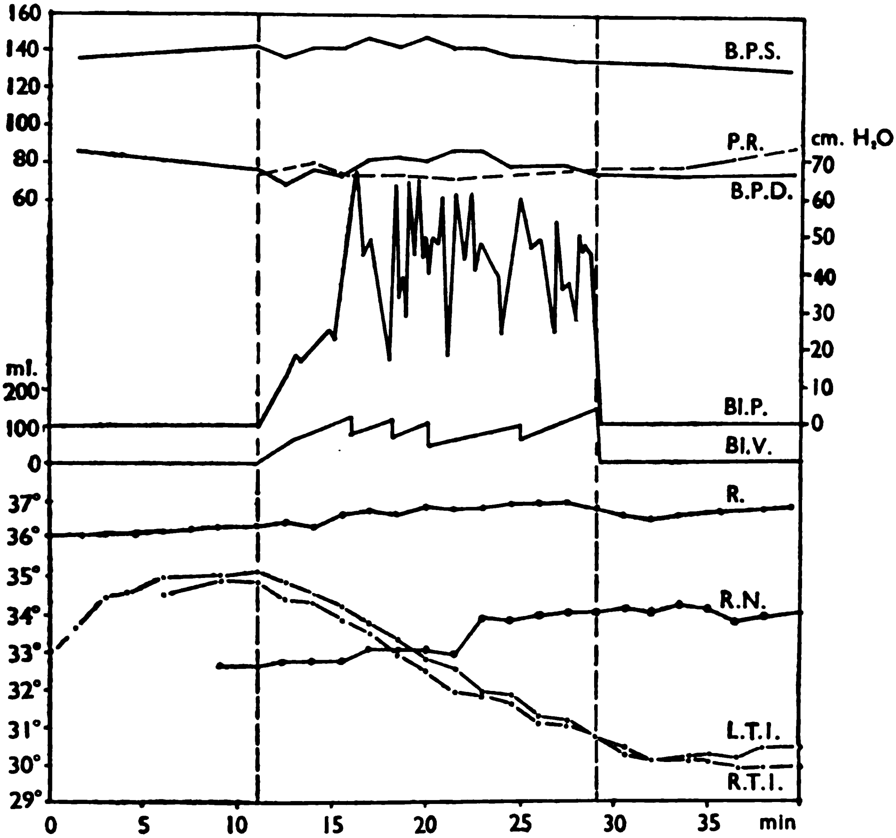
It was found that the constant basic reflex response to distension of the bladder, in all complete lesions above L.2 with intact isolated cord, is vasoconstriction of the toes, which is not limited to the skin, and is mediated by the lowest parts of the sympathetic outflow. Since, in these low lesions, there are large areas of the vascular bed left, which can be utilised for vasomotor regulation, the compensatory vasomotor response to the vasoconstriction in the toes is vasodilatation in parts above the level of the lesion, especially the fingers. Hence, in paraplegics with complete lesions below T.6, no, or only insignificant, changes of blood-pressure occur, as shown in graphs on pp. 442–3. Recent studies on blood-flow indicate that, in these cases, the increase of blood-flow occurring in the upper limbs, as the compensatory response to its decrease in the paralysed limbs, involves both skin and muscles (Cunningham, Guttmann, Whitteridge and Wyndham).

In paraplegics with lesions at or above T.5, conditions are different. In these cases, vasoconstriction in the toes, due to visceral activity, is accompanied by vasoconstriction in the fingers and a very large rise in blood-pressure. When the bladder was suddenly distended, vasoconstriction began in 5 or 6 seconds and was followed almost immediately by a rise in blood-pressure. The rise in systolic pressure was 70 to 160 mm. Hg, and the diastolic rise was 50 to 90 mm. Hg.



Graph 1.—(L.S.)—Complete lesion at T.7. The effect of bladder distension on blood flow in the finger, on pulse volume in finger and toe, on skin temperature, and on blood-pressure in a patient with a mid-thoracic lesion. B.P.S., systolic blood-pressure; B.P.D., diastolic blood-pressure; P.R., pulse-rate; Bl.P., bladder pressure; Bl.V., bladder volume; X., temperature of xiphisternum; F., temperature of forehead; L.T.3, temperature of left third toe; L.F.2, temperature of left index finger; R.T.1—●—pulse volume on right big toe; R.F.2—○—blood flow in right index finger; R.F.2—●—pulse volume in right index finger. (L. Guttmann and D. Whitteridge: *Brain*, 70, 1947.)

Moreover, in two patients with lesions above T.5, in whom venous pressure was recorded in the antecubital vein, a steep rise occurred, amounting in one case to 14 c.cm. of water, thus confirming the writer's



Graph 2.—(R.M.)—Complete lesion at T.10. B.P.S., systolic blood-pressure; P.R., pulse-rate; B.P.D., diastolic blood-pressure; Bl.P., bladder pressure; Bl.V., bladder volume; R., rectal temperature; R.N., right side of neck; L.T.1, left big toe; R.T.1, right big toe.

previous observation of the considerable engorgement of the veins of the neck seen in paraplegics with high lesions. The rise of venous pressure occurred at a time when the blood-pressure had only risen from 100 to 140 mm. Hg and the pulse rate was stationary. Later on, marked slowing of pulse rate and change of rhythm in the electrocardiogram—in particular, extra systoles—and increase in the size of the 'U' wave were observed. These findings indicate that an increase in the load on the heart must occur at the height of bladder activity due to distension, and this was proved by systematic X-ray studies of the chest, in correlation to cystometrograms (Guttmann and Jones). It was found that, at the height of visceral activity in these high lesions, the heart shadow may show an increase of several centimeters.

However, even in these high lesions, certain adaptive mechanisms are mobilised to counteract the effects of vasoconstriction of even so large an area of the vascular bed. The patchy vasodilatation in face and neck, associated with vasodilatation of the naso-pharyngeal mucosa, has already been mentioned as a regular and outstanding symptom. Furthermore, it has been found recently in patients with lesions at T.1 and C.7 that the blood-flow in the forearm greatly increased, although in the fingers the vasoconstriction was so prevalent that the flow through the skin of the fingers almost stopped (Cunningham, Guttmann, Whitteridge and Wyndham).

These are remarkable findings, which are not in accordance with the accepted views regarding the vasomotor innervation. In these high lesions, the sympathetic supply of the upper limbs, face and neck is derived from the cord below the level of the lesion. Therefore, one would expect vasoconstriction during the visceral distension not only in the fingers but also in the whole of the upper limbs, face and neck—the more as sweating occurred in face and neck. However, face neck and arms showed marked vasodilatation. The mechanisms involved in this vasodilator effect are not obvious. Although it is safe to assume that both the nasal congestion and also the headaches in these high lesions, resulting from visceral distension, are due to passive dilatation of the vessels following sudden increase in blood-flow from the raised blood-pressure, the mechanism of the patchy type of cutaneous vasodilatation in face, neck and upper chest is still obscure and needs further investigation.

From a clinical point of view, knowledge of all these reflex responses of autonomic mechanisms above the level of the spinal lesion is important, as they indicate abnormal activity of a viscus in the anaesthetic area below the level of the lesion. They can be diagnosed simply from facial appearance, and their recognition by medical and nursing staff will be a guide for immediate and correct action. Moreover, they explain why complaints of headaches and fullness in the head in paraplegics have always to be considered seriously, as they may be a warning of impending abdominal catastrophe.

MANAGEMENT

FIRST AID AND TRANSPORTATION

Although the importance of a sound knowledge of the fundamentals of first aid in spinal injuries and the need for standardised, simple instructions were readily recognised, there was controversy during the Second World War concerning various details, especially the position in which the patient should be transported. From all the discussions, the following conclusions may be drawn:

(1) The patient should be warned not to move. At least three, or better still, five people are necessary for first aid.

(2) Hard objects are to be removed from the patient's pockets at once, and areas with prominent bone padded. The simplest way to keep the heels and the head of the fibula from pressure is to place pillows or a blanket underneath the calves.

(3) The patient should be covered with blankets to preserve body heat and diminish general shock.

(4) If a doctor is not readily available and the patient is found in any position other than on his back, he should be gently turned on to his back 'in one piece' by at least three people. Most of the authors agree that all spinal injuries can be safely and comfortably transported in supine position, provided that no flexion or extreme hyperextension movements are allowed during lifting and transport. The patient should be carried on a rigid stretcher or, if this is not available, on a board. The contour of the spine should be maintained by placing cushions or other improvised soft supports under the natural hollows of the body, especially the small of the back and the nape of the neck. In suspected lesions of the dorsal, lumbar and sacral spine, turning the patient to the prone position has been suggested as the method of choice (Stinchfield, 1940; Watson-Jones, 1941; Shovell, 1942). It must be remembered, however, that the nature of the injury very often cannot be diagnosed, and if the spinal lesion is associated with fracture of pelvis, ribs, etc., or with collapse of a lung, the prone position may be quite harmful. It may be noted that, in 1943, the British Orthopaedic Association rejected any dogmatic view in the matter of transportation: 'Patients with suspected spinal fracture should be shifted and moved in such a way as not to be bent either backwards or forwards. The patient should be disturbed as little as possible, being transported as he lies.'

(5) Fluid should be restricted within the first twenty-four hours, to prevent over-distension of the paralysed bladder. General shock should be treated as soon as possible by blood transfusions to restore a good blood-pressure.

(6) Morphine should not be given indiscriminately and is indicated only in the presence of severe root pain. Its administration in cervical lesions and others with suspicion of lung collapse may be harmful and even disastrous.

(7) It is of vital importance to transfer acute cases of paraplegia as early as possible to a specially equipped and staffed spinal unit, as this is the best guarantee of reducing the complications after spinal injury to a minimum. Transportation of paraplegics by air is fundamentally superior to that by rail or water. In war-time casualties with spinal cord injuries need highest priority for evacuation by air.

NUTRITION

Nutritional deficiency was a relatively common finding in paraplegics admitted to this centre. The cause of malnutrition in these cases was the depletion of the body's protein reserve, due to infection from pressure-sores and from the urinary tract. It has been found that the daily loss of protein oozing from sores and escaping from the urinary tract varies between 5 and 50 g. (Poer, 1946). This can result in extreme degrees of malnutrition comparable to those found in inmates of concentration camps (Plate VI (a)). It may be noted that the assessment of plasma protein has not proved to be a reliable guide to the degree of malnutrition. Persons with such extreme emaciation, as seen in Plate VI (b) may show normal or only slightly diminished value, although the ratio globulin/albumin is invariably reversed.

Paraplegics with multiple bedsores and urinary infection also showed signs of anaemia, although, as vomiting is common in these cases, the exact degree might be clouded by haemoconcentration. The average value of haemoglobin varied from between 60 and 75 per cent., but in cases of longer standing 50 per cent. was not infrequently found. The number of erythrocytes varied from 3 to 3·8 million.

Of all the methods employed for combating nutritional deficiency and restoring and maintaining a satisfactory nutritional condition in paraplegics, blood transfusions proved to be the quickest and most effective (Guttmann, 1946, 1949). To try and counteract these changes at this stage by iron or liver injections, or by intravenous injection of protein hydrolysates, was waste of vital time and money. The writer agrees with Allan *et al.* (1948) that fear of excessive transfusion is unwarranted, and all the experience gained in this centre accords with the view that blood transfusion is preferable to plasma in paraplegics, because of the gain in oxygen-carrying cells and their possible utilisation for forming tissue proteins. Blood transfusions are not contra-indicated in paraplegics with renal deficiency and increased blood urea. On the contrary, it has been repeatedly found that blood transfusions have the effect of diminishing the amount of blood urea, especially in cases with marked degrees of anaemia. Whenever possible, fresh blood should be transfused.

One serious disadvantage found was that several paraplegics, after a variable number of whole-blood transfusions, showed undesirable reactions such as rigor, urticaria, etc., in spite of the fact that no incompatibility was demonstrable *in vitro*. Walsh, who carried out studies on this subject in this centre, found that the incidence of these reactions can be greatly decreased by transfusions of red-cells suspensions in saline, instead of full blood.

Once the acute stage of nutritional deficiency is past, a special diet, rich in protein and vitamins, supplemented in certain cases by hydrolysed protein, such as pronutrin, combined with liver extract or B.12 injections and iron, has proved effective. Constant attention must also be directed to the maintenance of good nutrition after the patient's discharge from hospital, when there are still signs of chronic infection of the urinary tract, and continuation of a high protein diet is recommended in these cases.

OSTEOPOROSIS AND SOFT-TISSUE-OSSIFICATION

Osteoporosis in the areas of the paralysed part of the body is one of the most common sequelae of spinal cord lesions, and in our material it was found in both spastic and flaccid types of paraplegia, especially if the patient, for one reason or another, was laid up inactive in bed for a considerable time. Although osteoporotic changes occur in any part of the skeletal system, they were most conspicuous in the femur. The osteoporosis is no doubt the cause of fractures from trivial causes. In all of our seven patients in whom fractures occurred, these involved the femur. The two places of predilection are the head or neck, and the most distal part of the shaft in the supracondylar region. With regard to the rate of healing of these fractures of osteoporotic bones, it is interesting to note that, as in cases of fragilitas ossium, the rate of consolidation was quite normal.

Soft-tissue-ossification, commonly called myositis ossificans or para-osteo-arthropathy, was found in our material most frequently around the hip-joints, and especially in the region of the insertion points of the adductor and inner hamstring muscles (Plate VII).

SURGICAL ASPECTS

REDUCTION OF FRACTURES

Although at the beginning of the war some surgeons (Albee, 1940; J. Taylor, 1941) emphasised the value of operative reduction in certain forms of fracture-dislocation, and L. Davis (1942) stressed the point that any manipulative method in the presence of a fracture may cause irreparable damage to the cord, which at the time of injury suffered only slight damage, most surgeons accept the non-operative reduction of dislocations and fractures with complete lesions of the spinal cord as the method of choice for the management of closed spinal injury. It is now more and more recognised that, in injuries of the thoraco-lumbar spine, hyper-extension in physiological position can be satisfactorily achieved by placing a blanket roll under the sorbo mattress and gradually increasing the extension. The writer has used a special bed, which can be folded up under the sorbo mattress according to the level of the lesion. There is no doubt that, by this management, even a badly displaced spine can be brought into satisfactory alignment to prevent a later kyphosis and ensure further weight-bearing of the spine. In cervical injuries, skull-traction by Crutchfield tongs or similar device was the accepted practice, and in fracture-dislocation with over-riding of the articular processes it was considered the safest method of reduction (Watson-Jones, 1942). As contra-indication to reduction by traction were considered foreign metallic bodies and bone fragments within the spinal canal, fracture dislocations with interlocking of facets, as well as an increase of the neurological symptoms.

IMMOBILISATION—PLASTER CASTS AND PLASTER BEDS

There is absolute agreement among those with experience of traumatic paraplegia that prolonged immobilisation and recumbency is detrimental in these cases, because of the tendency to encourage stagnation in the renal system, resulting in attacks of pyelitis, stone formation and hydronephrosis; furthermore, it leads to the development of pressure-sores and articular contractures. These dangers were greatly increased by plaster fixation, be it plaster jacket or plaster bed. The unsatisfactory results of fixation with plaster casts in traumatic paraplegics led to the movement for introduction of full-length plaster beds (Nissen, 1941), the idea being that pressure was then distributed more evenly. This conception did not prove to be correct. The volume of the paralysed limbs does not remain constant, because there are changes in the degree of vasodilatation as a result of interruption of the spinal vaso-motor centres. In fact, in patients with paraplegia who lay in plaster beds for months, even when those beds had been constructed by experts, not only did this method of fixation prove to be no better in the prevention and treatment of pressure-sores, but it greatly promoted the development of sores of the most frightful type. Moreover, this type of fixation, apart from the afore-mentioned disasters, caused profound fixed lordosis of the lumbar spine, distortion of the pelvis and atrophy of the normal back muscles, which are so vital for the physical readjustment and especially for the later maintenance of the patient's upright position. Plate VIII(*a*) and (*b*) shows the effect of prolonged immobilisation in a plaster bed in a soldier with a traumatic lesion of the cauda equina, which resulted in fixed hyper-extension of the lumbar spine, profound distortion of the pelvis, marked atrophy of back muscles, and pressure-sores over the sacrum and both tuberosities of the ischium. Plate VIII(*c*) shows the same patient two years later, before discharge from hospital: note the hypertrophy of the back muscles. The distortion of the pelvis was not completely overcome. In other cases admitted in plaster beds it took months or years to remedy or even to diminish the damage caused by this form of fixation. The conclusion drawn by the writer, who has already condemned this method of fixation (1945 and 1946), is that the use of plaster beds is contrary to the fundamentals of rehabilitation of patients with traumatic paraplegia. It should only be allowed, if at all, for the purpose of transport in cases of fracture-dislocation with incomplete lesion of the spinal cord. In particular, in most traumatic paraplegics following gunshot injuries,

PLATE I. Subluxation of terminal phalanges of big toes due to continuous spasms of extensor hallucis longus (Page 433).

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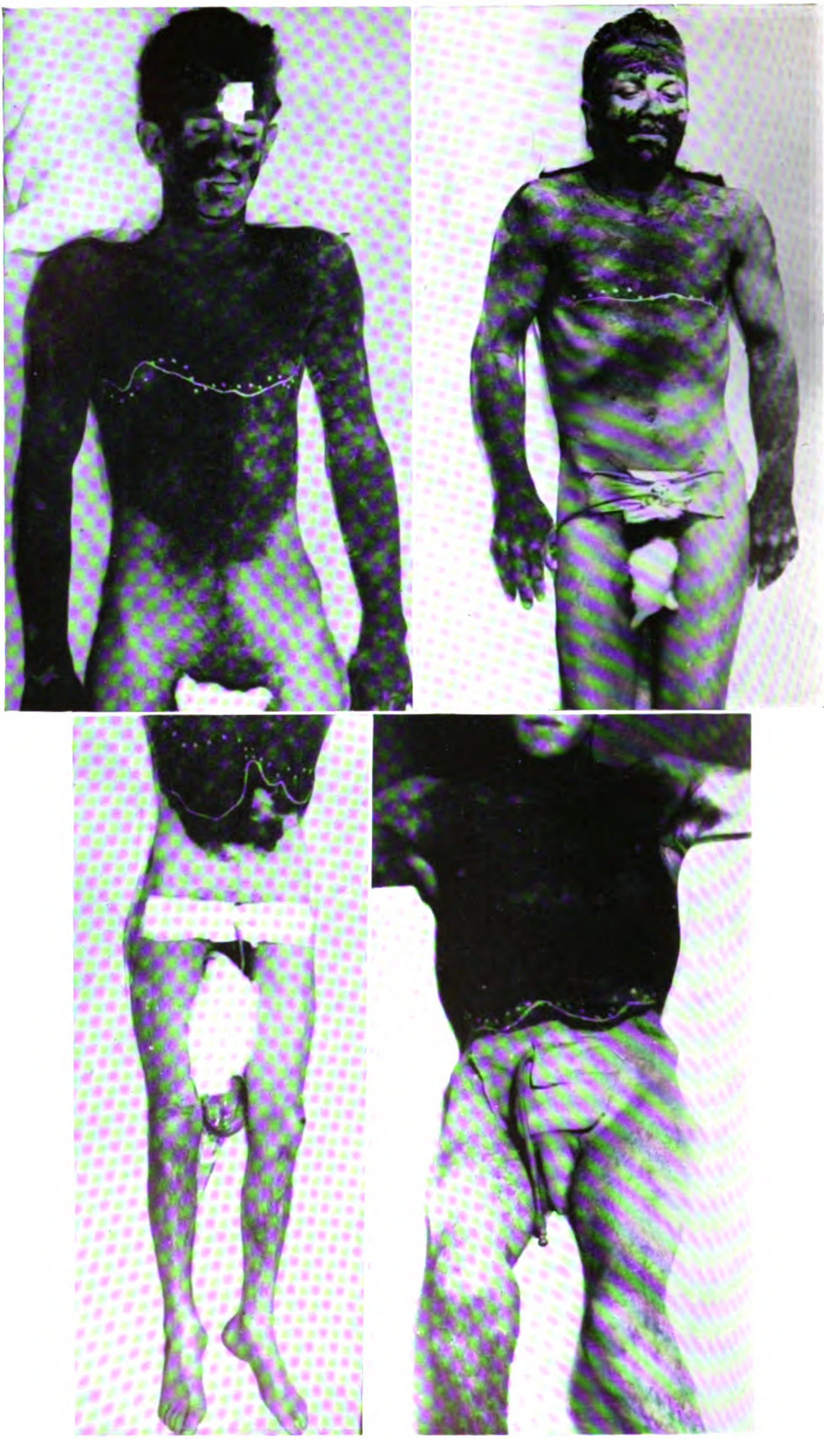
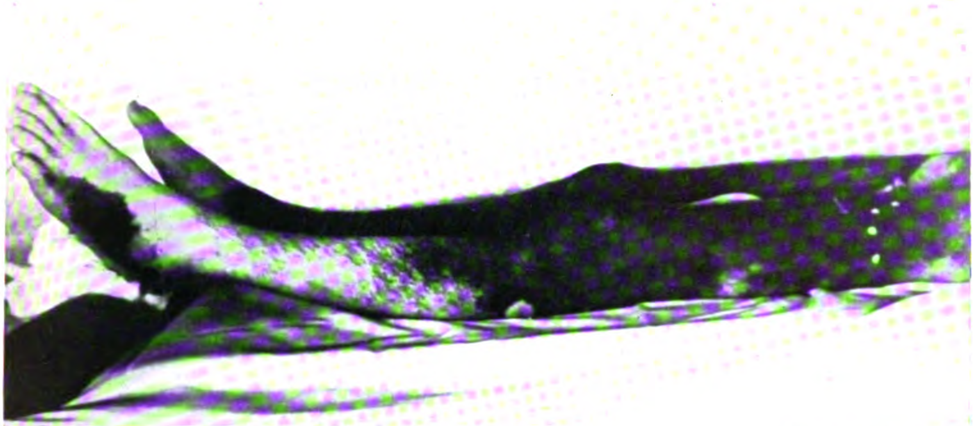


PLATE II. Results of thermo-regulatory sweat tests (Quinizarin method) in complete spinal cord lesions below T.5, T.6, T.7/8, and T.10, demonstrating the dissociation between areas of anhidrosis and sensory loss. Dotted line : level of analgesia ; uninterrupted line : level of anæsthesia (Page 439).



"British Surgical Practice"

PLATE III. External popliteal palsy caused by pressure sore against the head of the fibula superimposed on a cauda equina lesion, as demonstrated by the anhidrosis over the distribution of the external popliteal nerve and the scar over the head of the fibula. Dotted line showing level of sensory loss (Page 439).

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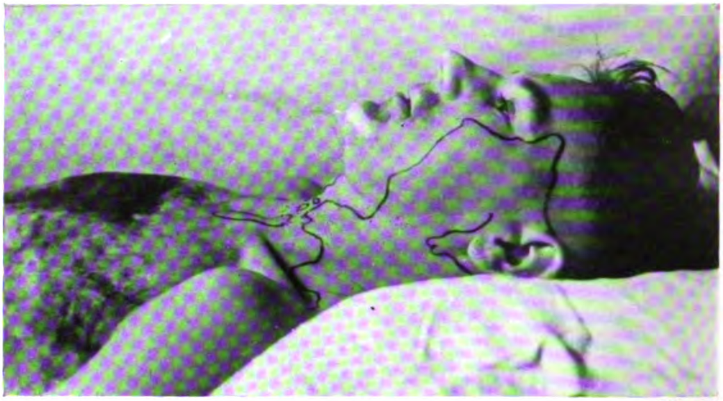
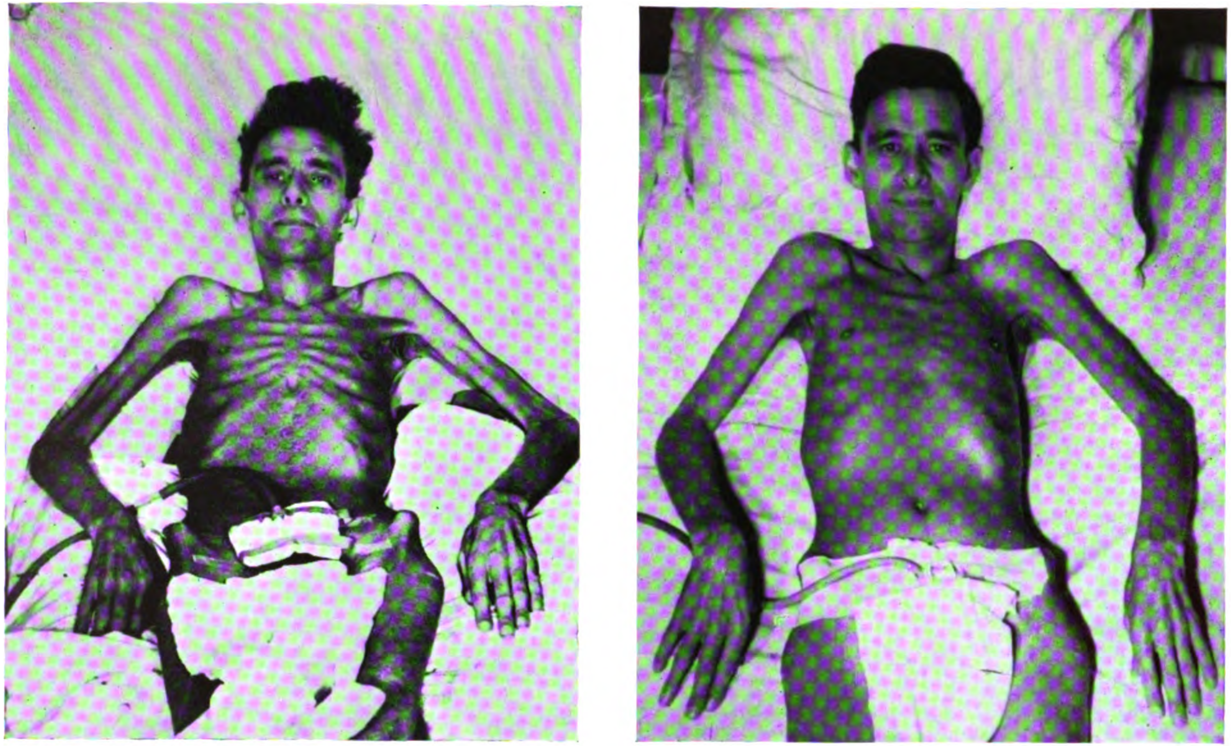
PLATE IV. Marked hypohidrosis of segmental type over right trunk and leg during thermo-regulatory sweat test in a case of incomplete mid-cervical lesion in correlation to disturbances of sensibility. The interrupted line demonstrates area of analgesia, the crossed and dotted line area of thermo-anæsthesia (Page 439).



"*Brain*"

"*Brain*"

PLATE V. Segmental reflex sweating with hyperhidrosis in T.4/5, due to bladder distension. Black lines in face and neck showing patchy area of vasodilatation at the height of raised blood pressure, as a result of bladder distension (L. Guttmann and D. Whitteridge: Brain 70, 361, 1947). (Pages 440–441).



"British Surgical Practice"

PLATE VI. Extreme degree of malnutrition due to profound protein loss, in a case of traumatic paraplegia (T.8) on admission to Stoke Mandeville Spinal Centre, 6 months after injury. Same patient 5 weeks later, greatly improved (Page 446).

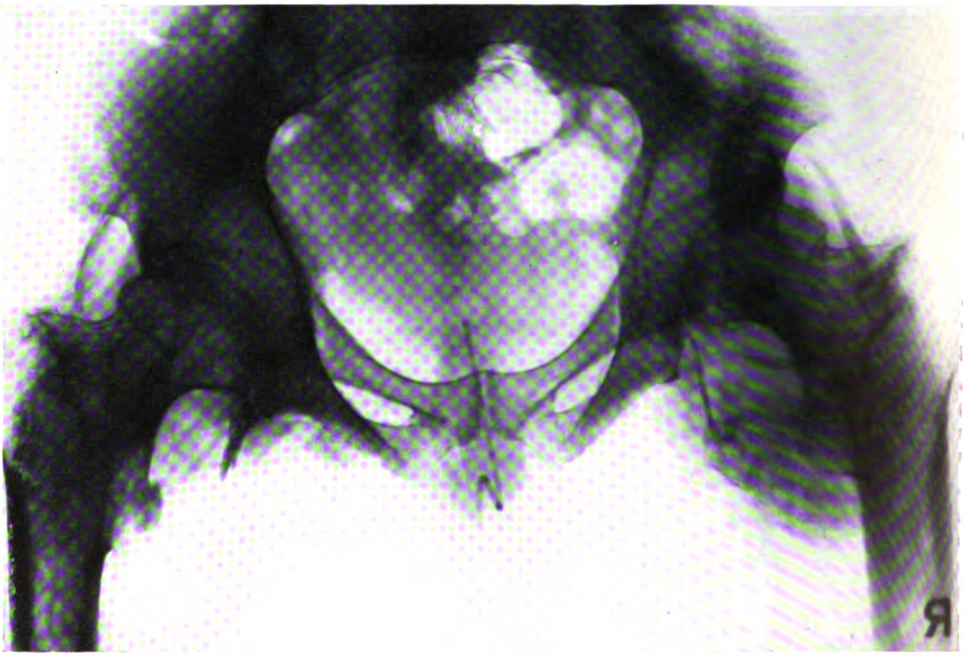


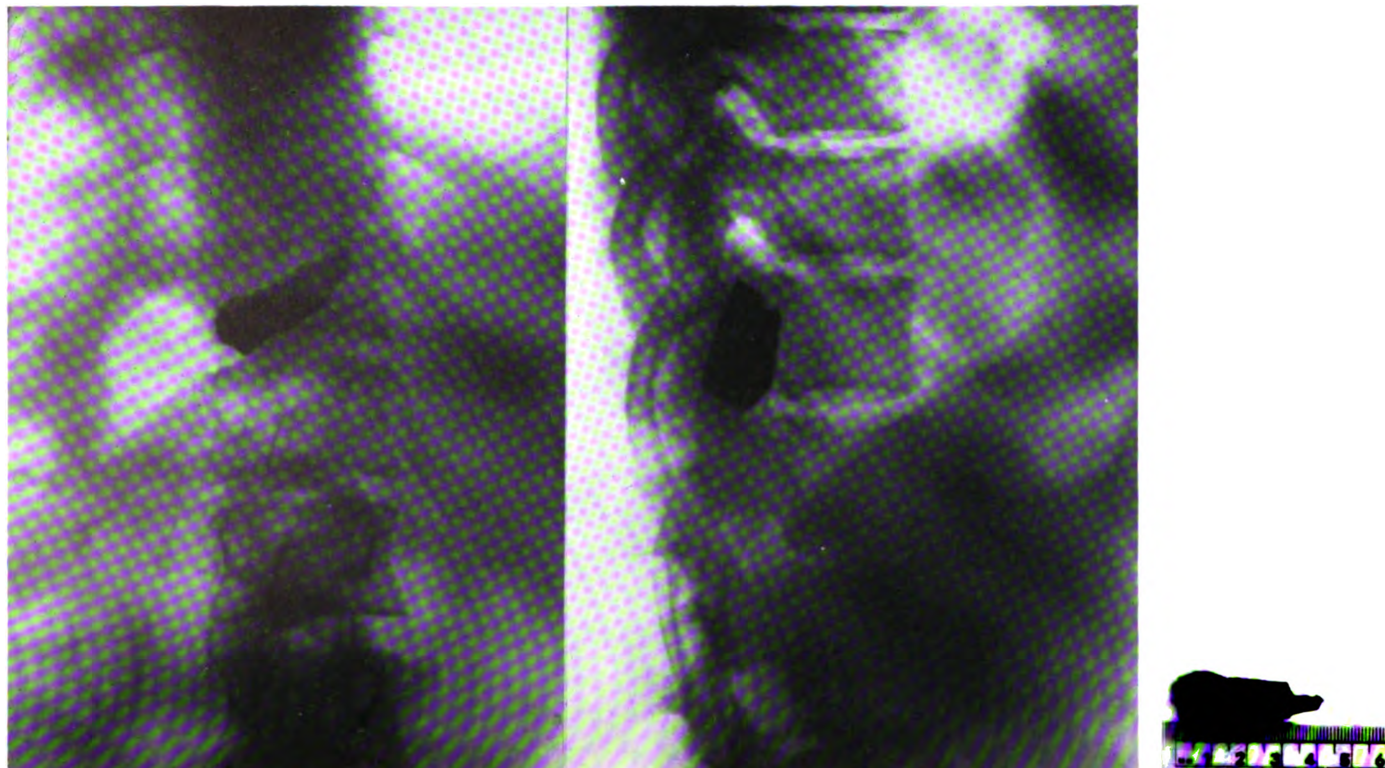
PLATE VII. Soft-tissue-ossification around both hip-joints, especially in region of the insertion of the adductor muscles on left side. Case of traumatic paraplegia below T.11 (Page 447).

(*a*)

(*b*)

(*c*)

PLATE VIII. Effects of prolonged immobilisation in plaster bed in a case of traumatic cauda equina lesion. Note the atrophy of shoulder muscles, hyperextension of lumbar spine, backward distortion of pelvis and pressure sores. (*c*) shows same patient 2 years later. Note hypertrophy of shoulder muscles (Page 448).



(*a*) (*b*) (*c*)

PLATE IX. Gunshot injury to eleventh thoracic vertebra resulting in transection of spinal cord with leakage of cerebro-spinal fluid from wound. (*c*) showing the f.b. after removal. Complete transverse spinal syndrome below T.11 (still unchanged after 8 years) patient working full-time as an artist (Page 451).

there is no indication for prolonged immobilisation at all, as the stability of the spine is intact or only insignificantly affected. Recently, Watson-Jones (1950) expressed his disagreement with the use of plaster beds in traumatic paraplegics after fractures of the spine.

LAMINECTOMY

In assessing the indications for laminectomy, it is essential first to make a clear distinction between traumatic paraplegia due to closed spinal injuries and paraplegia due to compound spinal injuries, such as stab wounds and, in particular, gunshot and shell wounds. Moreover, the term 'early' treatment must be defined more clearly than has been done in the past. It has been interpreted differently by various authors. Some, when they refer to 'early' laminectomy mean exploration within forty-eight hours of injury, whereas others believe that operation after one to three weeks is still early. A distinction should be made between surgical intervention at the most acute stage within the first three days, and operation during the next two or three weeks. Surgical intervention within the first three days may be termed 'immediate' operative treatment, as opposed to 'early' operative treatment when the most acute stage has passed.

IMMEDIATE OPERATIVE TREATMENT

Open spinal injuries. In compound spinal injuries, regardless of whether or not they have resulted in complete or incomplete transverse spinal syndromes, immediate operation is indicated as soon as general shock has been overcome, provided only that there is no associated injury to the lungs or other internal organs. However, as a rule, it should consist only of débridement. Foreign bodies, such as bullets, pieces of cloth and bone splinters, should be removed, whenever possible. The removal of such foreign bodies is indeed vital if there is leakage of cerebro-spinal fluid. Dural tears should be closed and penicillin and streptomycin applied locally. If the dura is found to be intact, it should not be opened, unless there is absolutely clear evidence of localised subdural haematoma; if there is such a haematoma and if, as in the case of lesions of the cauda equina, it involves the anterior and posterior roots, these should be disentangled. Such procedure was adopted during the war by most British and American neurosurgeons, and as a rule, it proved satisfactory. As in the First World War, no data are available from the Second World War of successful sutures of roots of the cauda equina.

Closed spinal injuries with complete paraplegia. In closed spinal injuries due to fracture and fracture-dislocation, the writer is in complete agreement with those who advocate conservative treatment and are strongly opposed to laminectomy as an immediate measure. This applies to injuries with complete transverse spinal syndromes at any level, including cauda equina lesions. It may be emphasised that at this stage the Queckenstedt's test is of no diagnostic value in differentiating between subarachnoid block caused by oedema of the spinal cord and that caused by pressure from dislocated bone. Moreover, with complete transverse lesions in which flaccid paraplegia remains unchanged for forty-eight hours, there is usually proved to be either complete crushing and destruction of the cord or at least most severe damage, which is irreparable. These are the cases in which all efforts should be concentrated on rehabilitation from the very beginning. The main points which have to be considered in the immediate and early stages are:—prevention of pressure-sores, control of urinary infection, and prevention of contractures of paralysed limbs due to faulty position, such as keeping the legs constantly adducted, the hips and knees fixed and the feet and toes in plantar flexion. Already, in this stage, the development of the muscles of the trunk and upper limbs, on which the patient's future independence turns, should begin. Details of the management of patients with traumatic paraplegia have been published elsewhere (Sandifer and Guttmann, 1944; Guttmann, 1945, 1946, 1947, 1948, 1949).

Closed spinal injuries with incomplete paraplegia. In these cases also, the writer favours conservative treatment in the period immediately after injury, and as a rule operative intervention can be postponed safely. There are, however, extremely rare instances of rapidly increasing epidural or subdural haematoma, in which operation is indicated at this early stage (McLean, 1935).

EARLY OPERATIVE TREATMENT

Open spinal injuries. In compound spinal injuries, particularly those due to gunshot and shell wounds, the main purpose of early operative intervention is the removal of foreign bodies—especially when there is leakage of cerebro-spinal fluid with X-ray evidence of a foreign body within or in the neighbourhood of the spinal canal, and bacteriological evidence of infection of the cerebro-spinal fluid. In such a case, removal of the foreign body is vital. The following personal observations may illustrate such a case:

A soldier was admitted to this spinal centre from the battle-front in Germany on December 11, 1944, 14 days after being hit in the back by fragments of an 88 mm. shell, which burst near him. He had a complete transverse lesion at T. 11, with flaccid paraplegia. There was a wound measuring 4 × 2 cm. to the left of the 10th thoracic vertebra, discharging cerebro-spinal fluid. Bacteriological examination showed infection with *clostridia welchii*, haemolytic streptococcus and coliform bacilli. X-ray showed a large metallic foreign body in the region of the spinal canal at the level of T. 11 vertebra, which was fractured (Plate IX(*a*) and (*b*)). On December 16, the writer removed a metallic foreign body measuring 4 cm. × 1·5 cm. (Plate IX(*c*)). No attempt was made to close the dura. Post-operative treatment consisted of daily dressing with local penicillin. The wound healed gradually and the patient, although still paralysed, is gainfully employed as a commercial artist.

Closed spinal injuries. Here the indications for laminectomy during the early stages are:—

(*a*) incomplete lesions showing progression of the neurological signs. In the writer's opinion, the presence of bone penetrating into the spinal canal alone is no indication for surgical intervention in the early stages;

(*b*) permanent manometric block without evidence of fracture or fracture-dislocation of the spine. In such cases, which are very rare, laminectomy is justified in the early stages, irrespective of whether the transverse spinal syndrome is complete or not;

(*c*) severe and constant irritation of spinal roots by displacement of bone fragments or prolapse of intervertebral disk. This also, however, is very rare in the early stages. Elsberg (1940), for instance, in twenty years saw only one case of incomplete spinal lesion with root pain severe enough to indicate early operation. In the writer's own series of traumatic paraplegics during and after the war, there was not a single case in which surgical intervention was justified.

LATE OPERATIVE TREATMENT

Laminectomy in the late stages of traumatic paraplegics has been carried out to serve three main purposes:—

Restoration of neural function;
Treatment of intractable spasticity;
Treatment of pain.

RESTORATION OF NEURAL FUNCTION

As a rule, late laminectomy does not serve any useful therapeutic purpose in complete transverse lesions at any level. On the contrary, by weakening the stability of the spine and particularly the strength of those muscle-groups of the back which are so essential for the patient's upright position, it only delays the rehabilitation of the paraplegic to a useful social and industrial wheel-chair life. Moreover, the post-operative shock has a most harmful effect during the first few days on the peripheral vasomotor control in the paralysed part, thus causing lowered tissue resistance to pressure and greatly increasing the danger of pressure-sores. This conception is at variance with the opinion generally held that exploratory laminectomy is harmless. Not a single patient admitted to this spinal centre with a complete transverse lesion due either to closed or to open spinal injury had gained any recovery of the damaged spinal cord by exploratory laminectomy performed before admission. Our observations are in accordance with those of McCravey (1945) and Cutler (1945), and it may be noted that in December 1944, the American army surgeons had been directed that late laminectomies in this type of spinal injury should no longer be carried out, because it was considered useless as an attempt to restore neural function.

Furthermore, late laminectomy should not be carried out indiscriminately for incomplete transverse lesions. The writer is opposed to the recent recommendation that exploration is indicated even in the presence of neurological improvement, if there is radiographic evidence of laminal damage (Haynes, 1946). There is no hurry whatsoever, and it is nearly always safe to wait at least until the progress of recovery has ceased.

On the other hand, there is general agreement that laminectomy is indicated in incomplete transverse spinal syndromes when there is evidence of increasing neurological symptoms. The underlying cause of such clinical progress may be callus-formation or localised chronic pachymeningitis or leptomeningitis (arachnoiditis chronica, etc). Riddoch (1927) and other authors have described cases of post-traumatic chronic meningitis in which the post-operative results were satisfactory. Foerster (1929), though mentioning the satisfactory result of operation in several of his own patients, emphasised that, in most patients with chronic post-traumatic arachnoiditis, improvement in the spinal symptoms after operation was not very impressive, and he concluded that post-traumatic thrombosis of the spinal cord vessels was responsible for the irreversible lesion of the cord. There are also selected cases of osteomyelitis with local pachymeningitis, in which exploration is indicated.

RELIEF OF SPASTICITY

The heightened reflex activity of the isolated spinal cord, following transection or severe lesion, resulting in violent spasms of the lower limbs with complex reflex figures and movement patterns, represents one of the most incapacitating complications and formidable obstacles in the rehabilitation of paraplegics.

CONSERVATIVE TREATMENT

(a) *Elimination of Factors Lowering the Threshold of Spinal Reflex Activity*

Progress has been made in the treatment of spasticity, as the result of research on the various factors involved in its mechanism. A number of intrinsic and extrinsic factors may act as irritative stimuli to the unrestrained activity of the spinal cord below the level of the lesion. Distension of any internal organ in the paralysed area, particularly the bladder, is one of the most important intrinsic factors and violent initiators of reflex spasms. It is obvious that the smaller the capacity of the bladder (as found in contracted bladders following suprapubic cystostomy) the smaller the amount of urine necessary to elicit the reflex response of the skeletal muscles—i.e. the more frequently do the spasms occur. Of equal importance is the distension of the rectum and colon by the stagnation of faeces. Indeed, the beneficial effect of the evacuation of an overloaded rectum, by means of enemas, on the intensity of reflex spasms is often remarkable, as is also the prevention of stagnation of faeces in the higher parts of the colon, by the administration of liquid paraffin or cascara. Any intervening infection—in particular, urinary flare-up, or toxaemia from pressure sores, and last, but by no means least, anaemia, also lower this threshold of reflex activity of the damaged spinal cord. Frequently, the increased spasticity of the paralysed limbs was found to be the first signs of a urinary flare-up, long before the temperature rose and other symptoms appeared. Moreover, the successful treatment of these infectious conditions has always resulted in a decrease in the intensity of flexor spasms.

Another factor conducing to reflex spasms is the irritation of sensory organs in contracted joints and tendons. In non-paralysed persons, the irritation of the sensory organs in contracted joints, etc., is appreciated as pain. With complete transverse lesion of the spinal cord, sensation is lost in the paralysed area, but, nevertheless, the afferent impulses from the irritated sensory organs in the contracted joints or tendons remain just the same, and act as irritative stimuli to the isolated spinal cord, and thus its unrestrained activity is increased.

The prevention of contractures by placing the paralysed limbs in correct position, and by regular passive movements, has proved to be most effective in the treatment of spasticity. The effect of passive movements on the relaxation of the spastic muscles is increased if the patient is placed in a continuous bath at a uniform temperature while these movements are carried out under water.

It was found that alternating passive movements of paralysed, spastic legs, produced by cycling action in a pedal-exerciser, worked with the arms, has a remarkably relaxing effect on spasticity. The writer's design of such a pedal exerciser for paraplegic patients has been described in detail elsewhere (Guttmann, 1949). This pedal exercise has proved very useful in overcoming profound degrees of spasticity in both complete and incomplete lesions of the spinal cord. Moreover, at the same time it exercises the arm and trunk muscles in the normal parts of the body and promotes better circulation. The relaxation which represents mainly a fatigue effect lasts several hours —in some cases, even throughout the day, and this naturally gives great relief to the spastic paraplegic patient. Thus, in accordance with Riddoch's observations (1917) that fatigue has a depressant effect on spasticity, we are utilising the fatigue effect on the spastic patient to facilitate his activities in the wheelchair or walking in parallel bars or on crutches.

(*b*) *Utilisation of Postural Reflexes*

It has already been pointed out that the tone of muscle groups can be influenced by posture. While in the supine position the tone of the flexors of hips and knees is increased, in the prone and upright positions the tone of the extensors of the hips and knees increases. Therefore, the writer has systematically used the standing position of the paraplegic in parallel bars as a means of overcoming the exaggerated action of the flexors of hips and legs. It was found that, by training, the tone of the extensors of hips and knees can be increased to such an extent that standing and walking in parallel bars without the aid of any artificial support to the legs are achieved.

(*c*) *Effect of Drugs on Spasticity*

Apart from drugs of the atropine group, the effect of which was found, in this centre, to be either negative or uncertain, curare (tubocurarine), myanesin (tolserol, mephenesin) and prostigmin have been used (Braden, 1945; Schlesinger, 1946; Elkins and Wegner, 1946; Guttmann, 1946; Kuhn and Bickers, 1948; Abramson and Kruger, 1948 *et al.*), but it can now be concluded that the value of these drugs is either doubtful or negligible. In our own cases, if curarine produced a depressant effect on the spastic muscles, it also affected the normal muscles, which naturally made the value of the drug rather problematic. Myanesin, first described by Berger and Bradley in 1946 as a muscle relaxant in animals, has since been applied in the treatment of rigidity and spasticity, but toxic reactions such as haemoglobinuria and thrombophlebitis at the site of the injection were observed (Pugh and Enderly, 1947).

While the writer concurs with Abramson, Kruger and Kuhn that prostigmin given by mouth or intramuscularly is of no, or only insignificant, value in diminishing spasticity, there cannot be any doubt that intrathecal injection of 0·3 to 0·5 mg. greatly diminishes or abolishes reflex spasms in paraplegics (Kremer, 1941), but the effect lasts only a few hours (6–12), and it is obvious that this method is not suitable for prolonged treatment of spasticity. In cases of extreme spasticity, combined with contractures, the intrathecal injection of prostigmin can be used as an aid to ascertain the degree of contracture, once the spastic component is abolished at the height of the prostigmin action (Guttmann, 1946). The effect of intrathecal injection of prostigmin on the reproductive organs will be discussed later.

OPERATIVE PROCEDURES

(*a*) *Tenotomy, peripheral nerve section, osteotomy*

Tenotomies and peripheral nerve sections have their indications mainly in incomplete lesions of the spinal cord, in order to restore locomotion, if conservative methods have proved ineffective in overcoming persistent spasticity. In our own cases, the greatest hindrance was found in the adductor spasms, and the bilateral, intrapelvic, extraperitoneal resection (crushing is of no or only temporary value) of the obturator nerve (Selig, 1914) has proved a most effective operation. Moreover, the obturator neurectomy has also proved most beneficial for restoring the paraplegic's sexual function, as adductor spasms may render intercourse impossible (Guttmann, 1949). Most surgeons still use Selig-Chandler's approach for the resection of the obturator nerves; Harmon (1950) prefers the trans-abdominal, extraperitoneal approach.

The other important procedure for restoring walking capabilities in spastic lesions of the spinal cord is the elongation of the Achilles tendon, which, if the plantar flexion contracture of the foot is associated with marked inversion, should be combined with tenotomy of the tibialis posterior muscle. In some cases, if profound spasticity of the flexors of the toes is prevalent, subcutaneous tenotomy of these muscles has to follow the elongation of the Achilles' tendon, to achieve satisfactory results. It may be noted that the obturator neurectomy and elongation of Achilles' tendons were found to have a remarkably relaxing effect on the spastic withdrawal synergy as a whole. Subcutaneous tenotomy of the inner hamstrings, including sartorius, has proved beneficial in eliminating profound flexor spasms and contractures of the knees. Least effective was found to be tenotomy of the hip flexors, especially iliopsoas, for eliminating flexion spasms and contractures of the hip, as the latter have even been found to be articular. In two of the writer's own cases, osteotomy of the femur in its upper third (Mr. Armstrong) was necessary to overcome profound flexion contractures of the hip.

(*b*) *Laminectomy and myelolysis*

Various authors (Munro, 1945; Scarff and Pool, 1946) have carried out these operations in traumatic paraplegics of the Second World War, but there is little doubt that these operations can achieve only temporary if any relief, as already discovered by previous authors.

(*c*) *Posterior rhizotomy*

Foerster, in 1911, reported on the beneficial effect of posterior rhizotomy in 81 cases of spastic paralysis of various aetiologies, among them 4 cases of traumatic paraplegia, but in only two of these traumatic cases did this operation prove effective. Freeman and Heimburger (1948) tried this method in two cases without success, which is in accordance with the experience of other authors (Kreuz, 1932; Lehmann, 1936). The writer's personal experience on posterior rhizotomy gained at Foerster's clinic and later in his own at the Jewish Hospital, Breslau, is in accordance with these authors. In spite of excellent initial success in spastic cases, recurrence of spasticity occurred, despite extensive posterior rhizotomy from L.1–S.3 (Guttmann, 1931).

(*d*) *Anterior rhizotomy*

Munro has advocated anterior rhizotomy for relieving intractable spasticity (1945, 1948). He suggested the division of the roots from T.12 to S.2, and has reported satisfactory results in numerous cases. Recently, in 1948, he recommended electrical stimulation of the sacral roots, prior to their resection, while cystometry is carried out, in order to preserve satisfactory bladder function. Martin and Davis resected as high as T.10. Elkins and Wegner (1946), Maltby (1945) and others confirmed Munro's views, and Dick (1949) mentioned seven cases at Winwick, where anterior rhizotomy was carried out by Kerr from T.10 to S.1, and spasticity was abolished in several cases and the bladder capacity increased; however, in five of the seven cases the sexual reflex was also abolished. Mayfield (1945) and Kennedy (1946) stressed the point that anterior rhizotomy is indicated in selected cases only—a view with which the present writer agreed (Guttmann, 1946). There are certain disadvantages with this procedure, which deserve serious consideration:

(i) the identification of the spinal roots is not always a simple matter, as rightly pointed out by Botterell, McDonald and Mackenzie (1948). The difficulty of root identification is obviously increased in more distal cord lesions, when injury to the spine has more or less resulted in deformities and alterations in the topographical relations;

(ii) if, in the violent spasms, not only the leg muscles but also the abdominal muscles are involved, as in the case of mid- and upper thoracic cord lesions, a very extensive laminectomy or two laminectomies are necessary, in order to divide all the anterior roots necessary to denervate these muscles;

(iii) it must be emphasised that, in chronic traumatic paraplegics, a laminectomy represents a destructive operation, in that it further weakens the stability of the spine and results in local damage to those muscles of the back, which are so vitally important for the restoration of the paraplegic's upright position and independence. Moreover, the post-operative shock, which inevitably follows laminectomy—as in any other major operation carried out under general anaesthesia—has a long-lasting effect on the vasomotor control, resulting in lowering of tissue resistance to pressure, with its deleterious effect on the healing of sores and the danger of new ones developing.

Therefore, it would appear that a more simple method than anterior rhizotomy is desirable, to transform the upper motor neurone paralysis into a lower motor neurone paralysis, in order to relieve spasticity. Intrathecal injection of sterile, absolute alcohol would appear to offer a solution to the problem. This method, originally introduced by Dogliotti in 1931 for relieving intractable pain, especially that caused by cancer, using very small doses of 0·2 to 0·5 c.cm. because of the danger of producing paralysis of motor or bladder function, was recommended in 1936 by Stern for the treatment of other complications, such as itching, tremor, choreiform involuntary movements, chronic spasticity of various aetiologies, as well as hypersensitive ureter, due to small calculi, and even impotence. However, this author has failed to prove the usefulness of intrathecal alcohol injection for all these conditions.

In 1946 (Meeting of the Neurological Section of the R.S.M. of December 9, 1946), the writer published his first results on the effect of intrathecal alcohol injection for relieving spasticity in complete lesions of the spinal cord. For the first cases, only small doses (1 to 2 c.cm. of 80 per cent. alcohol) were injected intramedullary into the thoraco-lumbar junction. Although the immediate abolition of the most violent flexor spasms was very striking, it was found that this effect was only temporary, and further injections were necessary to produce more lasting effects. Since then, Canadian and American authors (Gingras, 1948; Sheldon and Bors, 1948) have published their experiences, using larger doses up to 15 c.cm., which were injected in the subarachnoid space between the 1st and 2nd lumbar, or, in certain cases, between the 11th and 12th thoracic vertebral interspaces, and they found that this gave satisfactory and long-lasting results. No doubt this procedure is simpler than the intramedullary injection, but in our experience even large doses up to 12 c.cm. do not always completely eliminate spasticity or prevent its recurrence. However, these spasms can easily be eliminated by another injection, if they are again disturbing. In patients with spasticity of both the lower limbs and abdominal muscles, it is necessary to do the intrathecal injection at higher levels (T.8–10).

Altogether, 31 paraplegics with profound spasticity have been treated by this method, 24 of whom were traumatic paraplegics with lesions ranging from C.5 to T.11/T.12. In all cases, the long-standing spasticity was of extreme degree and resistant to conservative treatment. In most instances, the spasms were of flexor type, although in six cases the lesions were not absolutely complete. On the other hand, in three cases with complete transverse lesions, the spasms were predominantly of extensor type.

In all cases, whether paralysis of flexion or extension, intrathecal alcohol injection has proved very effective in relieving the incapacitating spasticity. In the thoracic cord lesion, the beneficial effect of this procedure was the restoration of the patient's upright position, thus initiating or accelerating his rehabilitation. In cervical cord lesions with tetraplegia, the relief of spasticity in legs and trunk made the life of these unfortunate sufferers more comfortable and worth living, and of course immensely facilitated the nursing of the patients. Although in most cases even after injection of doses as high as 10 or 12 c.cm., some spasticity returned within a period of 10 to 15 months, this spasticity was by no means comparable with the initial one, and the procedure of alcohol injection was repeated with equally satisfactory results.

In those cases in which the muscle spasms were associated with pain, the effect of alcohol injection was dramatic in relieving the pain. This was especially apparent in cases with abdominal spasms (see later). Moreover, the outburst of profuse sweating, which is one of the components of the heightened reflex activity of the isolated spinal cord and one of the most troublesome symptoms in these cases, was immediately eliminated. This was mainly due to the fact that the alcohol injection transformed a hypertonic bladder into an atonic one for varying periods following injection. This had the great beneficial effect with contracted bladders following suprapubic cystostomy of increasing the capacity of the bladder. Patients with closed bladders needed urethral catheterisation or indwelling catheters for a period after the injection, until satisfactory micturition was re-established.

Another effect of the intrathecal alcohol injection was the loss of the sexual reflex, but it was found that this may not be permanent.

Last, but not least, the beneficial effect of alcohol injection was also obvious in the healing of sores.

RELIEF OF PAIN

Pain did not play a prominent part in the symptomatology of paraplegics admitted to this centre. It is true that many patients admitted complained of pain at one or another stage after injury, but in less than 5 per cent. of the cases did pain become a prominent factor, necessitating special procedures. Most of the cases were lesions of the cauda equina or lower cord, and the pain was of radicular type. The radicular type of pain in these cases has commonly been attributed to retained foreign bodies, callus formation, and post-traumatic chronic arachnoiditis, and removal of these factors has proved beneficial in some cases. The writer, from personal observations, has come to the conclusion that, among the factors responsible for pain in these cases, two play an essential part. The first of these is the post-traumatic scarring process, resulting in formation of fibrous adhesions, which develop not only inside but also outside the spinal canal around the nerve roots. Any type of prolonged immobilisation promotes increased density of these adhesions, resulting in firm fixation of the roots and their ramifications to the underlying tissues. It is, therefore, understandable that even slight movements cause irritation of the nerve fibres by stretching and twisting. The other main factor is the lowering of the threshold of pain by any cause which reduces the patient's general condition—in particular, toxic absorption from sores, urinary infection, and even distension of the colon by retained faeces. Indeed, recurrence or exacerbation of radicular pain was found to be one of the earliest and most reliable signs of a flare-up of the urinary infection. This conception of the mechanism of pain in these cases has led the writer to adopt a different approach to the treatment of this condition, as compared with his former, more operative approach. The essential principle of treatment was to improve, on the one hand, the patient's general condition to the highest possible level by healing and preventing septic conditions and treating the anaemia caused by sepsis. On the other hand, restoration and maintenance of elasticity and flexibility of all tissues, especially the spine, in order to make the nerve roots more adaptable to stretching, were considered equally important, and were achieved by early mobilisation of the traumatised spine by frequent passive movements and all forms of active physiotherapy. Such manipulative neurolysis, as opposed to surgical neurolysis following laminectomy, has proved very effective in our cases. Moreover, by proper psychological measures, in which early pre-vocational training as the best form of occupational therapy played an important part, psychoneurotic reaction (in particular, anxiety and frustration) of these patients was counteracted. In this way were mobilised those readjustment forces in mind and body of the patients, which, in the light of modern physiological conception, may be considered as suppressor mechanisms to sensory irritation, wherever they may be localised in cortical or subcortical centres of the brain. From the start the prescription of morphine and other heavy sedatives was reduced to a minimum, and in due course completely abandoned, as they obviously impede the development and mobilisation of these adjustment mechanisms. In paraplegics admitted from other hospitals or spinal units, treated there with morphine and other heavy sedatives, such as heroin or barbiturates, our first consideration was to reduce rapidly the amount of these drugs and discontinue them altogether in the shortest possible time, and at the same time introduce the régime of treatment just mentioned. The results of this treatment have proved very gratifying not only in the early stages after spinal injury but also in the inveterate cases, including even those in whom radical operations, such as rhizotomy, sympathectomy and bilateral cordotomy had proved unsatisfactory in relieving pain. The following case may illustrate this latter group:

A 33-year-old soldier sustained a fracture dislocation of T.12/L.1 on November 10, 1944 in Italy, resulting in complete transverse lesion below T. 10 ; 17 days later, laminectomy and bone reduction were performed. Paraplegia remained unchanged. Previous medical notes state that since May 1945 he complained first of burning pain in the genital region and later of tightness and pain in buttocks and legs, which became gradually worse, more on the left than on the right, and were untouched by pethidine and morphine. Two intrathecal alcohol injections into the lower thoracic region in March and May 1947, were unsuccessful. On May 22, 1947, a bilateral cordotomy was carried out by an experienced neurosurgeon, which, apart from temporary slight relief, proved as much a failure as the right lumbar sympathectomy carried out in June 1947 (the idea of left sympathectomy was then not proceeded with). The notes of September 1947, state that pain was worse and that the patient was having 'considerable doses of heroin'. On admission to Stoke Mandeville on December 11, 1947, this man was virtually a heroin addict and complained bitterly of pain and tightness in buttocks and legs and asked for heroin to relieve pain immediately he arrived. The neurological symptoms were those of a complete transverse spinal syndrome below T.10, with spastic paraplegia and complete sensory loss. Suprapubic drainage had just been discontinued before admission, and he had an automatic bladder. Having regard to the patient's good general condition, all drugs were discontinued at once and replaced by sterile water injections. This treatment was combined with appropriate psychotherapy and active physiotherapy, especially exercises in slings, to mobilise the spine and develop the abdominal and trunk muscles, and later with sport and pre-vocational training in cobbling. The man responded very well to this treatment and made a remarkable improvement. Not only did the pain disappear but the marked spasms of the abdominal muscles, which at first prevented the patient's upright position, almost ceased, and he was able to walk in calipers on arm crutches and in the walking chair. He took part in sports and distinguished himself especially in archery, in which he became the first holder of the monthly challenge cup, and is now working at home as a cobbler. He has been readmitted for check-ups in July 1949, and July 1950, and his condition remained excellent. On these occasions, he took part in our two annual sports competitions. There are no complaints now of pains or any other discomforts.

BORDER ZONE-IRRITATION AND OVER-ACTIVITY

In connexion with pain a special group of paraplegics are those with complete lesions of the lower and mid-thoracic cord, who have developed a zone of hyperpathy at the border of their lesion, which can involve one or more dermatomes. The slightest touch or simplest pressure of bed-sheets or clothes can elicit great discomfort, and the patient usually complains of a feeling of band-like tightness and pain. This irritation of the border zone of the spinal cord lesion is by no means restricted to the sensory function, but also leads to over-activity of autonomic mechanisms, such as sweating, as shown by the band-like hyperhidrosis, and in particular by painful spasms of the abdominal muscles. This border zone of reflex overactivity, resulting from post-traumatic changes of the spinal segments or spinal roots at the level of the lesion, can become very troublesome and painful and can make the patient's life miserable. There is no doubt that this border zone irritation can be successfully treated by conservative procedures with mobilisation of the spine, especially by sling exercises or by repeated paravertebral novocaine injections. In very obstinate cases, intrathecal alcohol injection can be most helpful, and in two of the writer's own cases with traumatic lesions at T.10, who were suffering for years from very painful abdominal spasms, the beneficial effect of 8 c.cm. of sterile absolute alcohol was quite dramatic—also with regard to the change of personality. In not a single case of the writer's series have radical, surgical procedures, such as sympathectomy, posterior rhizotomy, cordotomy, or posterior column tractotomy, been found necessary. It is true that, in some cases, pain has not been entirely eliminated, but this has in no way prevented successful rehabilitation. In this connexion, it may be remembered from the literature that, not to mention the others, even such a radical operation as bilateral cordotomy has proved either not a complete success or even a failure in certain cases, although carried out by neurosurgical experts.

From all our experience, it can now be concluded that these radical operations should have a very limited application in the treatment of pain in traumatic paraplegia, and should be reserved for very selected cases. Surprising as it may seem, the apparently intractable pain is best relieved by early rehabilitation and retraining of the patient.

VISCERAL DISTENSION AND PAIN IN PARAPLEGICS

In analysing the subjective phenomena in the spinal man—in particular pain due to visceral distension, especially of bladder and colon—two types of response can be distinguished. The first is discomfort or a throbbing sensation, which is localised by most patients with complete lesions more or less definitely in the lower abdominal region, occasionally spreading to the lower aspect of the thighs. This local effect of bladder distension was found in patients with lesions at any level. In lesions of the cauda equina, where the sensation in the bladder is preserved, the spreading effect of pain into the lateral aspect of the thighs on bladder distension is sometimes even more conspicuous. The other subjective response is not closely related to the distended organ and occurs after a certain latent period during bladder distension. The patient experiences a throbbing and sometimes quivering sensation, which extends upwards in the mid-line of the body to the throat and back of the neck, causing a feeling of fullness in the head and progressing to occipital and frontal headaches, the latter especially marked behind the eyes. It has been found that this remote nociceptive response is due to the profound effects which distension of the bladder or colon sets up on the cardiovascular mechanisms in parts of the body above the level of the lesion (already described in detail in this account). The importance of correct recognition by the medical and nursing staff of this remote nociceptive response of visceral activity in paraplegics, from a practical point of view, has also been stressed. Hoen and Cooper (1948) described a man with a complete transection at C.6, who experienced visceral pain from a gastric ulcer, and concluded that this pain was mediated via the phrenic nerves. Among the paraplegics of this centre, there is a patient with a complete transverse lesion at T.5, who had a duodenal ulcer before his injury, and a recurrence of this ulcer was accompanied by the same, though somewhat clouded, pain in the upper abdominal region, mainly on the right side, which he had before his injury. There is another with a traumatic lesion at T.2/T.3, with complete analgesia below that level, with appreciation of touch sensibility below T.11, who also had a duodenal ulcer before his injury. He, too, complained about his old pain, although diminished, when he had a flare-up of his ulcer.

Bors (1948) mentioned a case of complete lesion at T.5, associated with a perforated, prepyloric ulcer, who experienced pain in the shoulder but not in the anaesthetic area.

UROLOGICAL ASPECTS

It is obvious that, among the team of workers on whose efficiency and devotion the success in re-establishing satisfactory functional results of the paralysed bladder—as a most vital part of the patient's rehabilitation—depends, the urologist plays an essential part. This centre has been fortunate in having Mr. E. W. Riches as its urological consultant, who has taken special interest in the urological problems of paraplegics. The writer wishes to record here his and his staff's great appreciation of the invaluable help Mr. Riches and, during the last three years, also his deputy Mr. I. Griffiths, have given to the patients of this centre, by their surgical skill.

CLASSIFICATION OF BLADDER PARALYSIS

The stages of bladder paralysis, which inevitably follow severe lesions of the spinal cord or cauda equina, can be classified as follows:

(1) complete retention.
(2) passive incontinence due to overflow from the distended bladder.
(3) periodic micturition, either
  (*a*) by reflex activity of the automatic bladder, or
  (*b*) by expressing the urine, using the muscles of the abdominal walls; this can be supplemented by pressing the lower abdomen with the hand. The latter type of periodic micturition is the rule in lesions involving the spinal bladder centres or the roots of the cauda equina, which connect the bladder to its spinal centres, producing what is known as an autonomous bladder.

AIMS OF TREATMENT

The main aims of the management of the paralysed bladder and the urinary system are as follows:

(1) prevention of local damage to urethra and bladder by instrumentation and artificial drainage.
(2) prevention and treatment of ascending infection.
(3) maintenance or restoration of satisfactory bladder capacity.
(4) restoration of efficient micturition per urethram, with the least possible degree of residual urine or incontinence.

It may be stated at once that opinions still differ as to the most suitable methods of achieving these aims, and this applies in particular to the treatment during the early stages following spinal injury.

INITIAL TREATMENT OF THE PARALYSED BLADDER

In discussing and evaluating the most suitable method in the early stages after spinal injury, we have to consider the following possible procedures:

(1) non-interference with retention and overflow incontinence.
(2) retention and manual expression.
(3) urethral drainage (*a*) intermittent catheterisation (*b*) continuous catheterisation with or without tidal drainage.
(4) suprapubic drainage (*a*) aspiration (*b*) suprapubic cystostomy, high or low—(i) open methods (ii) closed methods.
(5) urethrostomy.

As a rule, the paralysed bladder is never so distended after an acute spinal lesion as to warrant immediate drainage by any method. Therefore, the writer agrees with Riches and others that the bladder can be safely left alone for twenty-four hours or longer, unless distension causes intolerable pain or sets up distress, due to reflex responses of autonomic mechanisms, as already described in this account. During this period of non-interference by instrumentation, repeated attempts by gentle manual pressure and massage upon the lower abdomen, or combined with digital massage per rectum, may be carried out, to overcome the retention and elicit voiding. It may be remembered that Vellacott (1919) described 7 cases in which manual expression only was carried out and an automatic bladder developed after three weeks. Four of these patients had sterile urine and three mild cystitis only. This method may, however, be hazardous in atonic bladders following lesions of the cauda equina and may lead to rupture of the bladder, which, in fact, did occur in one of Vellacott's cases. In exceptional cases, aspiration of the bladder through a serum needle inserted well above the pubis may be allowed, if surgical facilities for performing bladder drainage by urethral catheterisation or suprapubic cystostomy are unsatisfactory. The most important vital arrangements with regard to the bladder during this early period are:

(1) combating traumatic shock by blood transfusion;
(2) immediate transfer of the paraplegic to a spinal centre, or at least to a hospital equipped with all facilities for efficient handling of a paraplegic. It has already been stressed that, in war-time, spinal injuries deserve highest priority for evacuation by air;
(3) if an early transport to a spinal unit is not possible, the patient should be seen at the earliest moment by a specialist well-versed in the treatment of paraplegia, who should give advice on the immediate treatment, pending transfer of the patient to a spinal unit; this is already being practised satisfactorily in Canada. The closest possible contact between spinal units and all hospitals in their regions—in particular, those with accident service—is most desirable, in the interest of the speedy rehabilitation of paraplegics.

DRAINAGE OF BLADDER

If voluntary or reflex micturition has not developed within 24 to 48 hours, continuous drainage of the bladder is indicated. Three procedures have been used for drainage:

(1) urethral catheterisation—intermittent or continuous;
(2) suprapubic cystostomy—high or low;
(3) urethrostomy.

From experience gained, it can now be concluded that: (*a*) neither urethrostomy nor low suprapubic cystostomy should ever be used; (*b*) neither of the other methods has proved to be a safeguard against ascending urinary infection or the method of choice for every case of paralysed bladder, for certain circumstances may make one preferable to the other during the various stages of bladder paralysis; (*c*) whatever method of bladder drainage is used, it should be combined at once with systemic courses of sulphadiazine or sulphalucocyl (1 g. three times daily) and penicillin 50,000 units three-hourly from the start.

URETHRAL CATHETERISATION

Unless, for special reasons, high suprapubic cystostomy is indicated, the writer stresses that urethral catheterisation should be the method employed for bladder drainage in the early stages. Any medical officer concerned with the treatment of paralysed patients must be absolutely familiar with a non-touch technique of urethral catheterisation, the more so as this is also the method used in later stages, especially following closure of suprapubic cystostomy. However, what is still required is for all concerned with the teaching of medicine and surgery to recognise that inexperienced medical officers, let alone orderlies, should never be allowed to carry out urethral catheterisation in the early stage after injury.

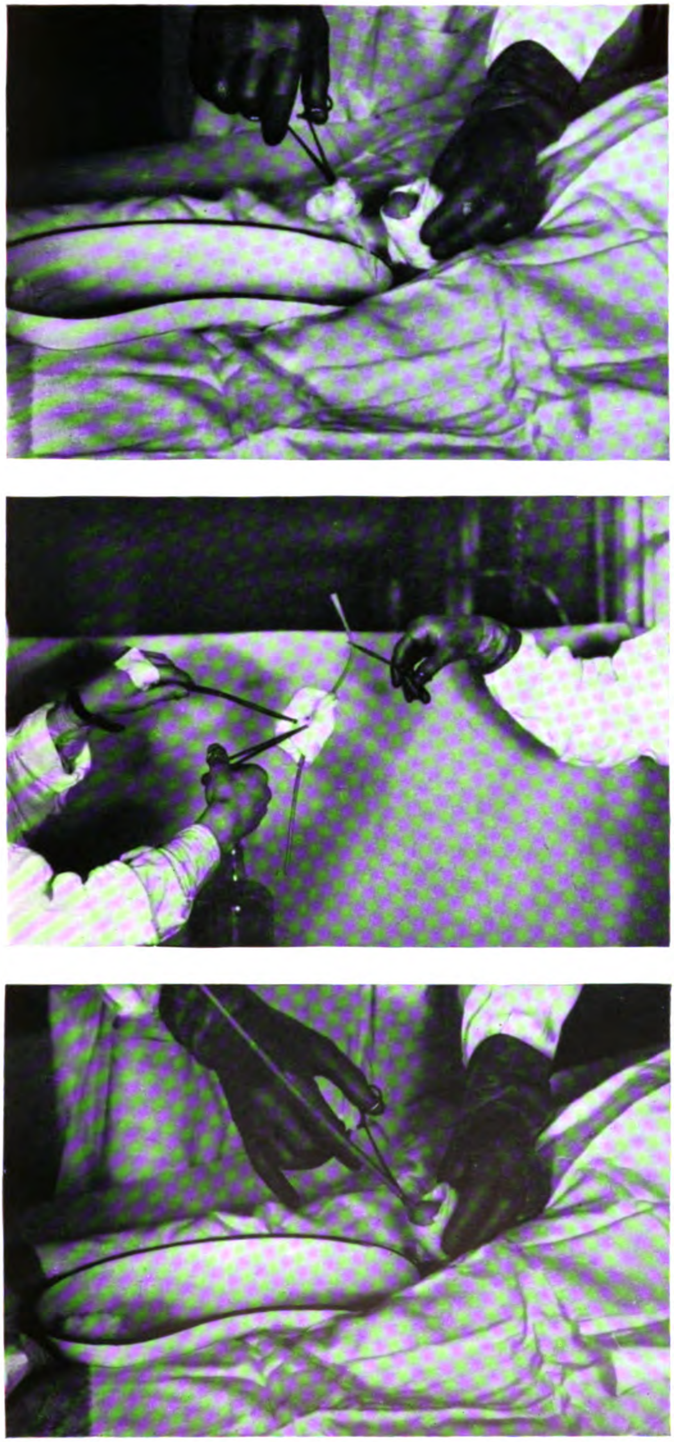


PLATE X. Non-touch technique of urethral catheterisation.

[*Facing page* 465

The writer's procedure is as follows:

1st stage. Intermittent catheterisation is performed every 8 to 12 hours for the first few days. The non-touch technique, described elsewhere (Guttmann, 1949) is shown in Plate X. The writer does not agree with the view that the urine cannot be kept sterile by intermittent catheterisation longer than for two days. The reason for first using intermittent catheterisation and not an indwelling catheter is to allow the urethral mucosa to become gradually accustomed to the foreign body. It must be remembered that, in the state of spinal shock and flaccidity, all tissues, including the urethral mucosa, have lost their tone and the threshold to pressure is lowered. Therefore, an indwelling catheter, especially one of larger size, can easily produce a pressure sore in the posterior urethra, with all its harmful consequences. Only a soft rubber catheter of size 16 to 18 F. should be used for intermittent catheterisation. With complete lesions, in which early return of bladder function can be expected, intermittent catheterisation allows distension of the bladder, which is a strong stimulus for promoting early return of bladder activity.

2nd stage. After four to eight days, or once the urine has become infected (this is inevitable, in time, whatever the form of artificial drainage used), an indwelling catheter, as already recommended by Kidd (1919), with daily bladder washouts, or combined, whenever possible, with tidal drainage, as recommended by Munro (1935), is the method of choice. The best type of indwelling catheter is the self-retaining Foley catheter of 16 F. (5 c.cm. balloon). It is essential that the indwelling catheter be changed every other day at first and later on at intervals of two to three days. In order to free the urethra from deposits, before inserting the new indwelling catheter into the urethra, this should be washed out with flavazole 1:2,000, using a small rubber tube fixed on to a 20 c.cm. syringe. Such washouts are especially necessary when urethritis has developed. Flavazole has also proved successful in the treatment of balanitis, which is liable to develop beneath a long foreskin. Early circumcision is indicated in such cases.

3rd stage. Once the automatic function of the bladder has returned, which, in uncomplicated transverse lesions of the spinal cord usually occurs after five to eight weeks, the indwelling catheter should be removed and replaced by intermittent catheterisation, which must be continued until destrusor action is powerful enough to empty the bladder or leave only a trace of residual urine. The same principle applies to lesions of the cauda equina, when voluntary micturition becomes possible by pressure on the abdominal wall.

SUPRAPUBIC CYSTOSTOMY

(*a*) *Indications in the early stage.* In the early stage of bladder paralysis, or when the injury is associated with local damage to the urethra or pelvis, or if the first urethral catheterisation reveals a stricture, suprapubic cystostomy is indicated in preference to urethral catheterisation. It has already been pointed out that, in war-time under battlefield conditions, suprapubic cystostomy represents a useful emergency method for the early treatment of the paralysed bladder, but only if the immediate transfer by air to more suitable surroundings is impossible and frequent transfer from one hospital to another, with its increased danger of unskilled care of the paralysed bladder, is inevitable.

(i) *Technique of open method.* The opening of the suprapubic wound should lie half-way between the pubis and umbilicus, and a suprapubic catheter of small size (preferably a Foley catheter 16 F.) should be inserted into the upper part of the distended bladder in an oblique, downwards direction. This procedure prevents adherence of the track to the pubis, an occurrence which was seen in this centre so often following low suprapubic cystostomy. As a rule, the first change of catheter should be made after eight to ten days, as this gives ample time for the formation of a good, oblique track. Self-retaining catheters of the Malecot or De Pezzer type, if used at all, should also be of small size only, and their introduction, as well as removal, should be carried out with great caution and gentleness, to prevent damage or perforation of the bladder wall. Donovan (1947) mentioned a case in which, on one occasion, the tube was pushed into the peritoneal cavity; fortunately the disaster was retrieved. Patients have arrived here with Malecot or De Pezzer catheters of size 32 or 34, which have proved detrimental to the bladder wall and have added local damage to the already paralysed bladder. The practice of pulling out such a suprapubic catheter briskly, without having straightened its proximal, self-retaining end with an introducer, is most harmful. The suprapubic catheter should be changed at least once a week.

(ii) *Technique of closed methods.* A trocar has sometimes been employed for suprapubic drainage of the distended bladder. The method adopted for this procedure is either Kidd's, using a trocar and cannula for the introduction of a self-retaining catheter of a larger size, or Riches' method of suprapubic catheterisation (Riches, 1943), employing a very small catheter (size 16 F.) fixed to a trocar. There are, at present, no comparative data available which would allow a definite decision whether, in paraplegics, closed suprapubic catheterisation is preferable to open cystostomy. Whatever closed method is used, care has to be taken that the trocar is inserted well above the pubis in the midline and, in particular, that the bladder is maximally distended and that the patient lies in a head downwards position. As a rule, this precaution diminishes the risk of injury to the peritoneum, because, during bladder distension, the peritoneum is raised and thus an uncovered area of the bladder is exposed, through which the trocar can be pushed into the bladder. It must, however, be noted that the peritoneum may be anchored down to the pubis, forming a pouch in front of the distended bladder, which may even contain small gut (MacAlpine, 1948). In such cases, the danger of causing peritonitis with any closed method is great, particularly if the distended, paralysed bladder is already infected, either spontaneously or by previous urethral catheterisation. It is essential that the catheter be firmly fixed to the trocar, otherwise it may break loose before entering the bladder and this may even result in peritonitis (personal observation). Once the catheter is inserted and suprapubic drainage established, care has also to be taken not to pull out the catheter on turning the patient during the first few days after this procedure, for, if a small catheter has been used, it may be difficult or even impossible to insert a new catheter through the very small opening.

(*b*) *Indications in later stages*

In later stages of bladder paralysis, suprapubic cystostomy may be indicated to allow the healing of urethral, scrotal and perineal fistulas, and also possibly in exceptional cases when infection of the bladder cannot be controlled by urethral catheterisation. This possibility is now very remote, since the discovery of streptomycin and other antibiotics.

EVALUATION OF SUPRAPUBIC CYSTOSTOMY IN THE TREATMENT OF THE PARALYSED BLADDER

Altogether, 306 out of the 351 traumatic paraplegics of the Second World War had suprapubic cystostomies carried out for bladder drainage before admission to this centre: in the majority of them (210), within three days after injury. Every case with suprapubic drainage, whether with or without urethral catheterisation prior to the cystostomy, showed signs of infection of the urinary tract; in a considerable number of cases the infection was of ascending type, including pyrexial attacks, and stone formation in bladder, ureters and kidneys, leading to pyo- or hydro-nephrosis. It must also be stressed that epididymo-orchitis is not prevented by suprapubic drainage. These findings do not prove the opinion held by urologists during the war that suprapubic cystostomy 'if done early will prevent serious infection' (Riches, 1943). Nor is urinary infection avoided if the suprapubic cystostomy is of the high type (Donovan, 1947). As can be expected, the infection is introduced and maintained by the suprapubic tube, especially if it is left in the bladder for several weeks and has become encrusted with phosphates. The danger of transferring virulent organisms *via* the suprapubic catheter and open ureters directly into the pelvis and calyces of the kidneys is considerable, in view of the fact that reflux into the ureters and kidneys has repeatedly been revealed by cystograms. In lesions of the medial and upper thoracic, as well as in the cervical cord and in certain lesions of the cauda equina, the bladder has repeatedly been found to be contracted. As, on the other hand, suprapubic cystostomy does not prevent the return of automatic bladder, it is obvious that the

Table IV

Urine Culture (Cauda Equina Lesion). Comparison of Urine Specimen and Catheter Swab

Organisms	March 1, 1944	March 13, 1944	March 21, 1944	*Catheter* March 21, 1944	March 28, 1944	*Catheter* March 28, 1944
Staph. pyogenes .				+++		
Str. haemolyticus						+++
Str. faecalis .				+++	++++	
Coliform bacilli .	++++	++++	+		++++	
Proteus vulgaris .				+++		+++

Organisms	April 3, 1944	*Catheter* April 3, 1944	April 11, 1944	*Catheter* April 11, 1944	April 19, 1944	*Catheter* April 19, 1944
Staph. pyogenes .				++		
Str. haemolyticus		++				+++
Str. faecalis .	+++				+	
Coliform bacilli .	+++		+++		+++	
Proteus vulgaris .		++		++		+++

Systematic and simultaneous bacteriological investigations of urine specimens and culture swabs taken from the bladder end of the catheter have repeatedly shown that the catheter contained bacteria other than those found in the urine specimen, for instance haemolytic streptococci, staphylococci and b. proteus (Table IV).

smaller the capacity of the bladder the more frequently detrusor action occurs, elicited by small quantities of urine. This, in turn, results in increased frequency of the accompanying reflex responses, such as spasms of the abdominal and leg muscles and those of autonomic mechanisms—in particular, outbursts of sweating—which make the patient's life miserable. In several cases with contracted bladders, extreme degrees of hydroureter and hydronephrosis were found, in spite of the fact that cystoscopy did not reveal blockage of the ureteric orifices. On the contrary, they were found to be patent and the cystogram showed reflux. (See also Donovan, 1947.) This observation is at variance with the opinion held generally that the only or main factor in the development of hydroureter and hydronephrosis is back pressure from the dilated bladder. As there is no evidence in our cases that a neurogenic factor, as the result of the spinal cord lesion, could be responsible for the vesico-ureteric reflux, these findings are in accordance with those seen at necropsy in paraplegics, already described in this report, which reveal profound, chronic, inflammatory changes of the ureters themselves (ureteritis and peri-ureteritis), as the result of the ascending bladder infection. These changes lead, on the one hand, to impairment of the elasticity or even destruction of the elasticity and valve-like action of the ureteric orifice, as already suggested by previous observers (Hagner, 1912; Kretschmer and Greer, 1914; Prather, 1944; Talbot, 1949), resulting in vesico-ureteric reflux. On the other hand, the ureteritis leads to impairment of elasticity and contractility of the ureter itself, while the adhesions between ureter and surrounding tissues caused by peri-ureteritis are responsible for the increased tortuosity of the ureter, which may give rise to mechanical obstruction.

It has already been pointed out that suprapubic cystostomy does not prevent the development of an automatic bladder, though, as a rule, the recovery of the detrusor action was found greatly delayed as compared with that in closed bladders. It is, therefore, understandable that suprapubic drainage does not prevent the development of epididymo-orchitis, once the infected urine is expressed through the posterior urethra by reflex detrusor action. All these facts have endorsed the writer's conclusion (Guttmann, 1947) that there is no reason whatever to consider suprapubic drainage as the method of choice in the treatment of the paralysed bladder, as advocated by urologists during the recent war (Ogier Ward and Riches, 1944). They definitely contra-indicate its indiscriminate use and routine performance in both peace-time and war-time injuries of the spinal cord and cauda equina. This view, which is in accordance with that of Kidd (1919) and Munro (1935, 1945), is also shared by other authors with extensive experience of traumatic paraplegics of the War of 1919–45 (Talbot, 1946; Martin and Davis, 1948; Freeman, 1949). Donovan (1947) points out that once the bladder has been satisfactorily closed pyrexial attacks may cease and the man's morale greatly improve.

The state of the bladder and urinary tract following suprapubic cystostomy, and the general condition of many patients on admission, were not sufficiently satisfactory to allow closure at an early date, as would otherwise have been desirable, if only from a psychological point of view. For, to most paraplegics, the suprapubic tube is repugnant. In our material, 249 out of the 306 cases have so far had their suprapubic drainage discontinued.

TABLE V

Date of Discontinuation of Suprapubic Drainage

1–5½ months	43	(Among these only 18 within the first 2½ months).
6–11½ months	56	
1–1½ years	58	
2–2½ ,,	33	
3–3½ ,,	27	
4–4½ ,,	20	
5–5½ ,,	9	
6–6½ ,,	2	
7–7½ ,,	1	
	249	

It is our experience that the sooner suprapubic drainage is discontinued the better the prospect of checking urinary infection, thus preventing ureteral and late renal changes, and of restoring a good capacity and satisfactory control of the bladder. However, in a case of incomplete transverse lesion at T.10, with suprapubic cystostomy of five years and four months standing, we found that a satisfactory result was achieved, although, in complete cord lesions with long-standing suprapubic cystostomy, once the bladder is contracted and fibrotic, such a good result is the exception. In cases in which suprapubic drainage has been continued for long periods, healing of the suprapubic wound is always delayed, and even if the track has been excised surgically it still has the tendency to break down (see also Talbot, 1946). Following the writer's observation, based on his experimental studies on catgut as an undesirable suture material for nerve sutures (Guttmann, 1943), and that a better healing of pressure sores after excision is obtained by avoiding catgut and substituting it by wire, this procedure has also been adopted for the surgical closure of suprapubic fistulas and has given more satisfactory healing results.

The 57 remaining patients with suprapubic drainage in our material include the 19 who died while still with suprapubic drainage. In most of them, ascending urinary infection was the only or main cause of death. There are also five cases who were transferred to other hospitals or institutions, about whom there is no information as to whether or not the suprapubic drainage was eventually discontinued. Of the remaining 33, only very few will for one reason or another eventually need permanent suprapubic drainage.

In conclusion, the view expressed by Ogier Ward and Riches (1944) that, in cases of total transverse lesion of the spinal cord, a properly conducted cystostomy opening is infinitely preferable to an automatic bladder, and their strong recommendation that suprapubic drainage should continue in such cases, has not been confirmed by the experience gained in this centre.

RETRAINING AND AFTER-CARE

Temporary pegging of the cystostomy tube is a most important step in the retraining of the bladder before discontinuation of the suprapubic catheter. When suprapubic drainage is discontinued, it is necessary, during the initial period, to carry out temporary drainage with an indwelling catheter of small size, which should be changed every other day. Afterwards, intermittent catheterisation at various intervals is necessary, in many cases, in order to measure the residual urine, to remove deposits and to combat infection by regular washouts. Repeated cystometrograms have proved invaluable in ascertaining the functional state of the bladder, for determining the various stages in the return of bladder activity, and in bladder retraining (Guttmann and Whitteridge, 1947).

Most paraplegics can be trained to an awareness of the degree of fullness of the bladder by appreciation of certain sensations associated with bladder distension. These sensations are pain, burning, quivering, or merely pressure, and may be referred to the bladder itself, the suprapubic region, the root of the penis, the penile urethra, or the lateral aspect of the thighs. In complete lesions of the upper thoracic and cervical cord, bladder distension sets up remote reflex responses of automatic mechanisms, as described in detail in this account. The patient gradually learns to urinate reflexly by employing certain trick mechanisms for starting micturition by rubbing the penis or medial aspect of the thigh, rubbing or squeezing the suprapubic region, or inserting a finger into the anus. In lesions of the conus and cauda equina, voiding is achieved by applying abdominal pressure, and it is obvious that, in these cases, the more the abdominal muscles are trained and overdeveloped the more satisfactory the voluntary micturition.

CONTROL OF RESIDUAL URINE

In many cases, after discontinuation of either suprapubic or urethral drainage, the voiding mechanism of the bladder is imperfect for some time, and residual urine results. If this is small in amount (under 1 to 2 oz. with a bladder capacity of at least 8 to 10 oz.), there is no harm, so long as stagnation of urine in the bladder is avoided by a high fluid intake. Carbachol has sometimes proved very useful in promoting return of voluntary or reflex micturition. Urecholine (beta-methylcholine urethane) has recently been recommended in doses of 5 mg. subcutaneously as very effective in hypotonic bladders without mechanical obstruction of the vesical neck but with chronic urinary retention (Lee, 1950). Repeated estimations of residual urine have proved most valuable, and, if larger amounts of residual urine were present, adequate measures were taken.

Transurethral resection of the bladder neck (Emmett, 1934 and 1947; Adamson, 1945) has proved, in selected cases in this centre, a very useful method, if the residual urine was due to obstruction of the bladder neck, caused by hypertrophy and fibrosis of the tissues of the internal meatus. This operation may have to be repeated to achieve appreciable diminution of residual urine and facilitate voluntary or reflex micturition. The danger of this operation is post-operative haemorrhage, which must be treated without delay, because of the disastrous consequences of loss of blood in paraplegic patients. The writer is in full agreement with Munro (1948) that this operation should not be performed indiscriminately, but only if all conservative means have been exhausted.

The elimination of sacral roots by surgical section or alcohol block is another way of overcoming retention of urine in the automatic cord bladder. Freeman and Heimburger in 1947 showed that selected cases of cord bladder with urinary retention can be successfully treated by bilateral block of the third sacral roots with novocaine or alcohol. Meirowsky, Scheibert and Hinchey (1950) divided the anterior roots from T.12 to S.5 in two patients, and the anterior and posterior roots from T.12 to S.5 in four patients. In a later publication, these authors recommend differential sacral neurectomy for the treatment of urinary retention, by which procedure selected anterior and posterior roots are divided through the sacral foramina, which the authors consider is technically easier and less extensive than the classical rhizotomy within the spinal canal. They were guided by pre-operative sacral novocaine block. More experience is still needed to come to definite conclusions about the value and indication for this procedure, especially compared with the result of intrathecal alcohol injection. For it has been shown that a similar effect—i.e. transformation of a spastic automatic bladder into an atonic bladder—can be achieved by intrathecal alcohol injection, as found by Sheldon and Bors (1948) in 19 out of 24 patients, and by the writer, as already mentioned in this account.

CONTROL OF INCONTINENCE

Incontinence of urine can be overcome by training the patient to adjust the frequency of micturition to the amount of fluid intake. However, most paraplegics, especially those with lesions of the distal cauda equina, need a urinal, as sudden movements and acute increase of abdominal pressure by coughing and sneezing may result in incontinence of a few drops or more of urine. As a rule, a person with a paralysed bladder should be provided with two urinals for hygienic purposes. There are various types of urinals recommended, but none has proved so far to be ideal for every case. It is of utmost importance in the after-care of paraplegics that the patient should be well trained in the proper use of his urinal, which includes its regular and thorough cleansing. In this centre, the following procedure has proved satisfactory: the urinal is rinsed with warm soapy water and then thoroughly with plain water. Thereafter, it is soaked for two hours in 10 per cent. solution of Milton, after which it is again rinsed with water and then hung up to dry before use. The patient is instructed after handling the urinal and manual attention to the urogenital area to wash his hands in soapy water, followed by soaking the fingers in the following solution: 1 teaspoonful liq. chloroxylenolis diluted in ½ pint of water. In order to prevent reflux of urine from the urinal into the trousers, which usually occurs when the patient is seated in his chair, the writer has designed a horse-shoe shaped sorbo cushion, which slopes towards the front, so that the urinal and penis lie in a downward direction.

COMPLICATIONS FOLLOWING BLADDER PARALYSIS AND THEIR CONTROL

URINARY INFECTION. MEASURES FOR CONTROL ARE:

(a) AVOIDANCE OF RECUMBENCY AND RESTORATION OF PHYSICAL FITNESS

Every endeavour is made to avoid prolonged recumbency by encouraging all forms of movements, even in the first stages after a spinal cord lesion. This is of vital importance, whatever method of bladder drainage is used, in preventing stagnation of urine, which encourages infection and leads to formation of stones in the urinary tract. In many cases, turning the patient day and night at regular intervals has proved most useful in preventing stagnation.

(*b*) IRRIGATION OF THE URINARY TRACT

(1) *Fluid intake*:

The intake of a sufficient amount of fluid, especially between meals, is the best method of irrigating the kidneys. It can be taken in the form of tea or barley water, which can be mixed with fruit juices to make it more palatable. As a rule, a paraplegic should drink at least five to six pints in twenty-four hours, and even this amount should be increased during attacks of pyelitis.

(2) *Local irrigation*:

(i) *Regular, intermittent bladder washouts.* In cases with suprapubic drainage or indwelling catheterisation, intermittent irrigation of the bladder should be carried out at least once a day, especially in the morning. In every case, the amount of fluid which the bladder can hold without overdistension should be ascertained. Where cleaning of the bottom of the bladder or of a diverticulum is necessary a bladder syringe rather than a funnel should be used and the solutions should be tepid (90°–98° F.). The fluid recommended for irrigation when the urine is alkaline is ½ per cent. acetic acid, oxycyanide of mercury 1:4,000, 4 per cent. boric acid, or flavozole 1:2,000. When the urine is acid, normal saline, silver nitrate 1:2,000, potassium permanganate 1:2,000 or flavozole 1:2,000 can be used. If the urine is infected with *bacillus pyocyaneus*, washouts with phenoxetol 2·4 per cent. followed by saline, can be used for two to three days. The efficiency of these irrigations is increased by frequent changes in the solutions employed and in the *p*H of the urine—an effect which can be intensified by administering 30 or more grains of acid sodium phosphate, given three or four times a day by mouth. Intolerance to this drug is indicated by diarrhoea, and it should be avoided in cases with high blood urea. Sodium phosphate may be replaced by 10–30 grains of ammonium benzoate in stearate or glutoid capsules, or by mandelic acid (mandamine). In cases with phosphatic deposits, solution G. (Suby, Suby and Albright, 1942) has been used for irrigation.

(ii) *Tidal drainage.* This has proved to be a valuable auxiliary method, with or without suprapubic drainage or indwelling urethral catheterisation, especially in the early stages. In the writer's experience, it has proved of special value in removing mucus and small stones from the bladder and from the posterior wall, when the patient has been lying prone. Although tidal drainage was introduced into this country by Laver (1917), it was not until Munro in the U.S.A. (1935) drew attention to this method and proved its usefulness that this type of drainage became more generally applied. Its value has also been stressed in this country by many surgeons. The writer has found Riches' design very satisfactory, which, being fitted with a manometer, can also be used for cystometrograms. However, tidal drainage is of use only if it is understood by all concerned, including the patient, and is constantly supervised. In certain cases of small bladders with uninhibited detrusor activity in cord lesions, and also in some cases of lesions of the cauda equina with rigid bladder wall, tidal drainage has not worked satisfactorily, in spite of all efforts. In this centre, owing to insufficient nursing staff, tidal drainage had to be used for selected cases only during the last three years, and was substituted by daily washouts. Donovan (1947) arrived at the same conclusions.

CHEMOTHERAPY

When an acidifying agent, such as acid sodium phosphate, ammonium chloride, ammonium benzoate or mandelic acid, is being given, hexamine (10 g. three times daily) has at least an inhibitory effect on bacterial growth, by liberating formaldehyde. However, larger doses may give rise to gastro-intestinal disturbances and haematuria. In pyelitis, the author has sometimes found intravenous injections of 5 c.cm. of cylotropin (combination of hexamine, sodium salicylate and caffeine) once or twice daily to be effective, and superior to other forms of chemotherapy.

The discovery of the sulphonamides, penicillin and streptomycin has undoubtedly increased our facilities for effective combat of infection of the urinary tract and has made possible a more specific treatment of various types of micro-organism. Of the sulphonamides, sulphadiazine and sulphamezathine have proved more suitable than sulphathiazole in pyelitis. Whereas the sulphonamides have been used in the treatment of both Gram-positive and Gram-negative organisms, penicillin has been found more effective against Gram-positive organisms especially the haemolytic streptococcus. The author's routine treatment of pyelitis, before streptomycin was introduced, consisted of combined courses of sulphadiazine or sulphamezathine, starting with 2 g. and continuing with 1 g. every four hours, up to 20–35 g., and intramuscular injections of penicillin 30,000–50,000 units 3 hourly, up to a total of 2,000,000–3,000,000 units.

With the discovery of streptomycin, chloromycetin and aureomycin, a new era in the treatment of urinary infection of the paralysed bladder has started. These antibiotics have proved to have a most powerful action against Gram-negative organisms, and their beneficial effect in the treatment of the infected urinary tract of paraplegics is beyond doubt. Future experience will show if and to what degree the new antibiotic, terramycin (Finlay *et al*, 1950) will prove more effective than the three others in controlling *pyocyanea* infection of the urinary tract of paraplegics, as found recently by Linsell and Fletcher (1950) in non-paraplegic bladders. In this centre, systematic studies were carried out by the writer in co-operation with Drs. Melzak, Sherries and Wilson, on the effect of streptomycin on the mono- and pluri-bacterial urinary infection in paraplegics with various types of bladder paralysis. The organisms found were *B. coli* (*B. aerobacter aerogenes* included), atypical *B. coli*, *B. proteus*, *Ps. pyocyanea*, *Staphylococcus pyogenes*, *streptococcus faecalis*, micrococci and diphtheroids, the three last of which we consider as non-pathogenic. In accordance with the results of previous investigators (Petroff and Lucas, 1946; Hewitt, 1947; Pulaski, 1946), we found streptomycin effective, especially in those cases which do not require regular instrumentation and catheterisation. Administration of these antibiotics in pyelitic attacks, both in cases with closed bladders and those still under suprapubic or urethral catheterisation, has resulted in dramatic clinical improvement, with prompt disappearance of the septic effects, improvement of renal function and decrease of leucocytosis. The antibacterial effect of the streptomycin was also seen in cases with very long-standing urinary infection, as found in survivors with injuries of the spinal cord and cauda equina from the War of 1914–18; the routine course of treatment, as used in this centre, is as follows: intramuscular injections are given at three-hourly intervals, the first three doses being 0·8 g. each, followed by three doses of 0·5, and this is followed by doses of 0·2 g., to a total amount of 8 g.—in special cases, up to 10 g. No toxic symptoms of any significance were observed during and after the treatment described. In the great majority of cases, paraesthesias in fingers and a sensation of tightness in the face, especially around the mouth, occurred, lasting one or two days. In a few cases, slight dizziness for a day or two was observed, especially when the patient changed his position. Some with increased blood urea felt very sleepy during the first day of treatment. Only two patients with mid-cervical lesions, who previously had had a course of streptomycin, showed marked symptoms of idiosyncrasy to local streptomycin treatment of their pressure-sores. With the régime described we succeeded in achieving immediate sterility of the urine in over 50 per cent. of the first 100 patients with closed bladders, of which, however, only 16 per cent. remained sterile, or contained only non-pathogenic organisms in their urine after four and up to seventeen months. In certain cases with pluri-bacterial urinary infection or those which became reinfected, a second or third course of streptomycin, carried out at various periods after the first course, succeeded in eliminating these organisms. In one case, the urine was infected with *proteus morgagni* and *staphylococcus pyogenes*. The first course of streptomycin (7·9 g.) eliminated the *proteus* but not the *staphylococcus*, although it was found to be sensitive to one unit of streptomycin but resistant to penicillin. Nevertheless, it was eliminated by a course of 10 million units of penicillin. The urine became reinfected with *B. coli*, which, after a second course of streptomycin (10 g.) was eliminated. The urine became sterile and was found to be still sterile after six months. It may be noted that repeatedly dissociations were found between the therapeutic effect and the sensitivity of organisms to streptomycin *in vitro*, and that while the sensitivity test might reveal streptomycin-resistant organisms, the therapeutic effect of the streptomycin course on the patient's clinical condition was unquestionable. A frequent voluntary statement of paraplegics, as the result of streptomycin treatment, was 'I feel much better in myself, less tired and not so hazy, and more energetic'. One patient just plainly said 'I feel less toxic'. As the antibacterial effect of streptomycin increases, the stronger becomes the alkaline reaction of the urine (Abraham and Duthie, 1946; Wolinsky and Steenken, 1946; Murray, Paine Finland, 1947), and we have used pot. cit. in doses 30 to 60 g. t.d.s. on the day before and four times during the treatment, to ensure a *p*H of 7 or more in the urine. However, in cases with raised blood urea, this alkalinisation is contra-indicated. In our experience, streptomycin has also proved of value in the preparation of patients for surgical procedures and as a preventative measure against widespread infections after such procedures. The following conditions have been found to be unfavourable to the use of streptomycin:

(1) obstruction in the urinary tract;
(2) presence of foreign bodies, such as calculi, and the existence of suprapubic or urethral catheterisation;
(3) undrained abscesses;
(4) marked trabeculation and formation of diverticula in the bladder;
(5) unsatisfactory healing of suprapubic tracts.

Crowley and O'Connor (1948) reported satisfactory results obtained in non-paraplegic patients with persistent colon bacillus infection of the urinary tract which was resistant to streptomycin, by pre-medication of these patients with sulphasuxidine and then combining this treatment with courses of streptomycin. This treatment was based on the idea that in these cases, transmigration of *B. coli* from the intestines is the cause of chronic urinary infection. We have used this method in 28 paraplegics in whom the streptomycin alone was unsuccessful, but in only three was sterility of urine achieved by this combined course.

STONE FORMATION

The main factors promoting calculi in the urinary tract are infection and stagnation, the latter as the result of recumbency and immobilisation, causing hypercalcinuria; an additional factor is the formation of kinks in the ureter. If there is a suprapubic catheter, stones usually form around it, but they are also common in closed bladders (Guttmann, 1949). Only in one of our traumatic paraplegics—an incomplete transverse lesion at T.11/12 with suprapubic cystostomy of 3¾ years' duration—was a stone found to be lodged in the posterior urethra. It was associated with two bladder stones, and it is most likely that this stone did not originate in the urethra but had migrated from the bladder. It obviously ulcerated through the urethral mucosa and came to lie in a diverticulum at the peno-scrotal junction, which, after the stone's removal (Mr. Griffiths) was easily demonstrated following urethrogram with lipiodol (Plate XI). The diverticulum was excised and urethra sutured. Suprapubic drainage was discontinued after healing and automatic emptying of the bladder *per urethram* achieved.

The few instances of stones in the ureter observed in our series of paraplegics were found to lie at the site of the normal narrowing of the ureter—namely, either at the pelvi-ureteral or vesico-ureteral junctions. In one case, a stone was situated at the junction of the middle and lower thirds of the right ureter. Of special interest is a patient with conus-cauda equina lesion, in whom two ureteric stones situated in the lower third of the right ureter produced complete obstruction, resulting in pyonephrosis with severe pyrexia. At operation on April 22, 1944 (Mr. Riches), after removal of the stones and relieving the kidney of its pus, it was decided, though with some hesitation, not to perform an immediate nephrectomy but to carry it out at a later date, should the kidney not recover function. However, this kidney subsequently regained its secretory function, as shown by intravenous pyelograms, and the patient made an excellent rehabilitation. Eventually, the suprapubic drainage was discontinued and the patient took up wood-work as vocational training, and wheel-chair polo and basket-ball as sport. Since his transfer to the Duchess of Gloucester house, he has been full-time employed in assembly work in a factory on the Great West Road, London. On the other hand, in a case of incomplete lesion of the spinal cord in the mid-thoracic region with only slight residual motor and sensory signs, nephrectomy eventually became necessary, due to persistent stricture of the ureter, as the result of a stone.

In our series, the renal stones, either solitary or multiple, formed in the calyces or in the renal pelvis, taking, in a few cases, the classical staghorn shape.

Of the 351 traumatic paraplegics of the Second World War admitted to this centre, 79 (22·5 per cent.) were suffering from urinary calculosis, 34 (9·6 per cent.) had stones in kidneys or ureters; 72 of these 79 were cases with suprapubic drainage, 7 with closed bladders. In the great majority, calculi were found in complete lesions of any level.

TABLE VI

Incidence of Calculosis

Author	*No. of Cases*	*Total Percentage*
Riches (Great Britain) . . .	35	20·0
Donovan (Great Britain) . . .	82	29·3
Guttmann (Great Britain) . .	351	22·5
Botterell and Tousse (Canada) . .	178	33·7
Munro (U.S.A.)	101 (soldiers)	29·0
	252 (civilians)	4·4
Bumpus, Nourse, Thompson, U.S.A.	101	68·7
V.A. Hospital, Van Nuys, California, U.S.A.	458	42·5

There is general agreement that the incidence of calculosis can be diminished by proper drainage, frequent change of posture in the early stages after injury, avoidance of recumbency, restoration of the upright position, physical activities including sport, and acidifying of urine. Calculi in paraplegics consist almost entirely of phosphates. Once formed, they show little tendency to disappear when the patient is able to get up, nor can they be dissolved easily or quickly by agents such as solution G (Suby, Suby and Albright, 1942). In most instances, they need surgical removal as early as possible, particularly if there is chronic infection with febrile attacks. The greatest care and gentleness should be exercised in the removal of vesical calculi in paraplegics, to avoid further damage to the already damaged bladder wall. They should be removed under direct vision whenever possible, and violent suction of the debris following litholapaxy must be avoided at all cost, as this may result in rupturing the bladder wall or, more commonly, in most profound vasomotor responses, including severe shock. Only small, quiescent stones confined to the cortical part of the kidney, or small mobile stones in the renal pelvis, may be treated conservatively. Nephrostomy and pyelolithotomy are the methods of choice, and these operations have even proved to be life-saving procedures in infected cases, where stones had resulted in blockage of the renal pelvis or the upper or lower third of the ureter. It is amazing in some cases how much a kidney, which at operation showed a rather unfavourable appearance from a pathological point of view, may recover satisfactory function following nephrostomy, as shown by post-operative intravenous pyelograms. Nephrectomy is, therefore, indicated only if it is proved beyond all doubt that the kidney has lost its secretory function, and is the cause of general infection. Recurrences of calculi have been observed, but these have so far proved the exception rather than the rule. If it happens, it can progress very rapidly—as found in one of our cases—and makes nephrectomy imperative. After removal of renal stones, frequent irrigation of the kidney with solution G. through the nephrostomy tube is recommended, to dissolve residual fragments, and an early return to the upright position and activity is necessary to prevent the recurrence of stones.

HYDRONEPHROSIS

It has already been pointed out that peri-ureteritis due to ascending urinary infection may lead to inflammatory adhesions between various segments of the ureter and the surrounding tissues, resulting in kinking of the ureter. This in turn may lead to mechanical obstructions and result in dilatation of the ureter and hydronephrosis. In our material, this kink-formation was found to be prevalent in the lower and upper segments of the ureter, in the region of the pelvi-ureteral and vesico-ureteral junctions, but it was also found in the middle segment. Intravenous pyelograms, or retrograde contrast filling of the ureter, showed that ureter-kinking may occur in coronal and sagittal directions (Plate XII(*a*)). Bloch, in 1923, recommended ureterolysis as treatment for this condition in non-paraplegics. Recently, at the writer's request, ureterolysis combined with nephropexy has been carried out in three paraplegics with hydronephrosis resulting from ureteral kink-formation (Mr. Griffiths). Exploration revealed firm adhesions, as was anticipated, at the site of the kink. Although it is too early to draw definite conclusions about the end-results achieved with this procedure, it may be said that the results so far achieved are encouraging, as contrast X-rays after the operation revealed removal of the kink (Plate XII(*b*)).

It is beyond the scope of this contribution to discuss the mechanism and treatment of all the other types of hydronephrosis which may result from complications in the urinary tract, following transverse lesions of the spinal cord. But it is worth while mentioning that, in certain cases of marked hydronephrosis without raised blood urea, pituitrin has been shown to have a remarkably beneficial effect on urinary function. This has been described by Bell (1949) in cases of hydronephrosis with or without paraplegia. We have confirmed these findings in a few selected cases of paraplegia with marked hydronephrosis and hydro-ureter (Guttmann, 1949). Cystograms taken before pituitrin treatment in a complete transverse lesion at T.4 showed gross unilateral hydronephrosis on the left side. After daily injection of 0·5 c.cm. of pituitrin for a fortnight, a decrease in the size of the kidney and ureter was apparent, and after further treatment for nine days the cystogram showed almost normal conditions. Examination after three months, in this case, still showed normal conditions, although the treatment had been discontinued for over two months. While it is rather premature to draw final conclusions, the results so far achieved are encouraging.

PERIRENAL ABSCESS

This complication was found to be very rare in our material; it occurred in two cases only.

EPIDIDYMO-ORCHITIS

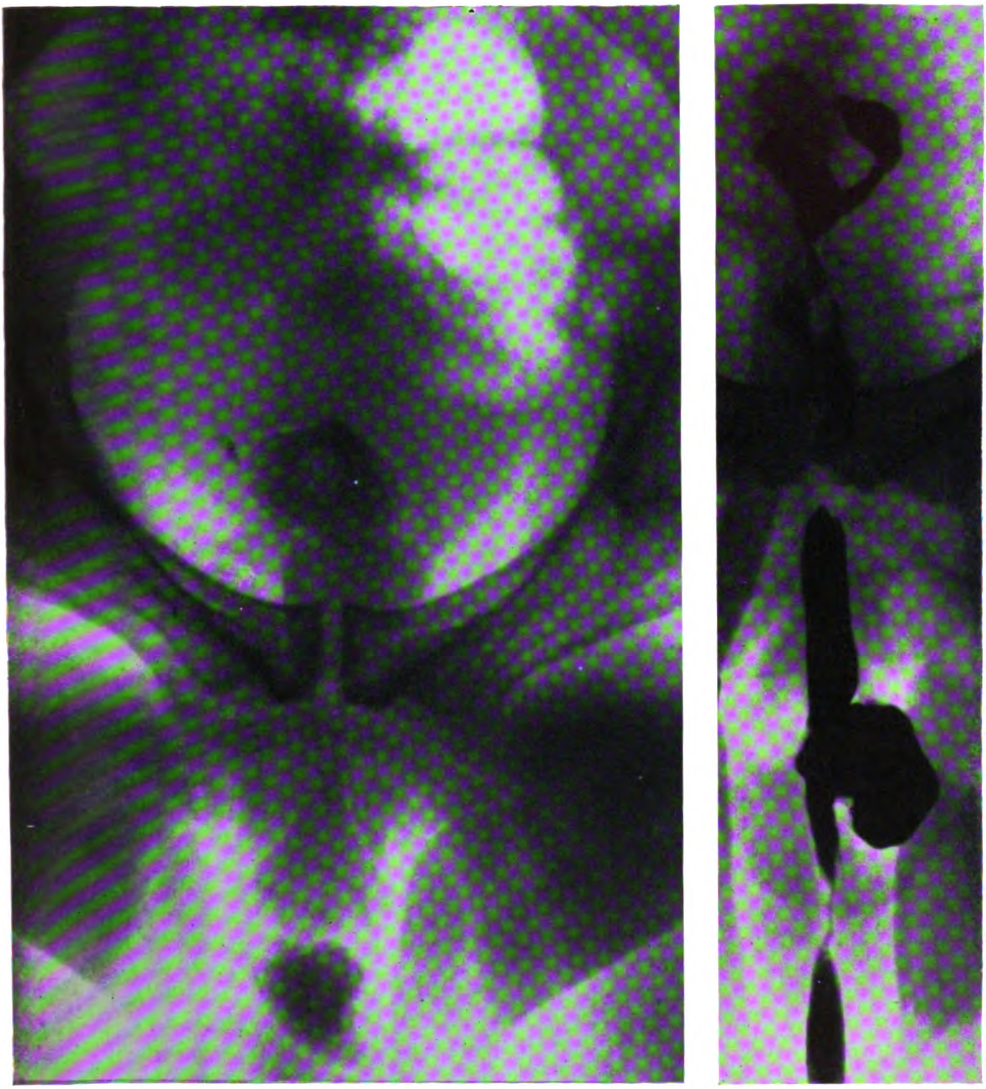
It has already been pointed out that suprapubic cystostomy does not prevent epididymitis, which may develop later when returning detrusor function discharges infected urine into the posterior urethra. However, in accordance with observations of other authors, it was also found in cases while under urethral drainage, as well as in those with closed bladders not subject to instrumental treatment at all.

The procedure adopted in patients with recurrent attacks of epididymitis, which proved obstinate to conservative treatment, was ligature of the vas. Scrotal abscesses involving the testicles were opened and drained, and only in one case was orchidectomy necessary.

URINARY FISTULAE

Breakdown of a suprapubic scar, with formation of a urinary fistula, was found to be not an infrequent occurrence in our material. This complication occurred particularly in patients with long-standing suprapubic drainage, in whom the suprapubic tract was allowed to close spontaneously, but it also sometimes followed surgical closure. A breakdown of the scar and formation of a suprapubic fistula can often be avoided if, as soon as a patient notices the slightest sign of swelling or inflammation of the scar, diversion of the urinary stream by urethral drainage is introduced immediately, combined with bladder washouts and treatment with the sulphonamides and antibiotics. In cases where this procedure proved unsuccessful, excision of the fibrotic tract in the bladder and resuture are necessary. However, the best prevention of this complication is discontinuation of suprapubic drainage at the earliest possible date, and there can be no doubt that our best results were achieved in those paraplegics in whom this was possible.

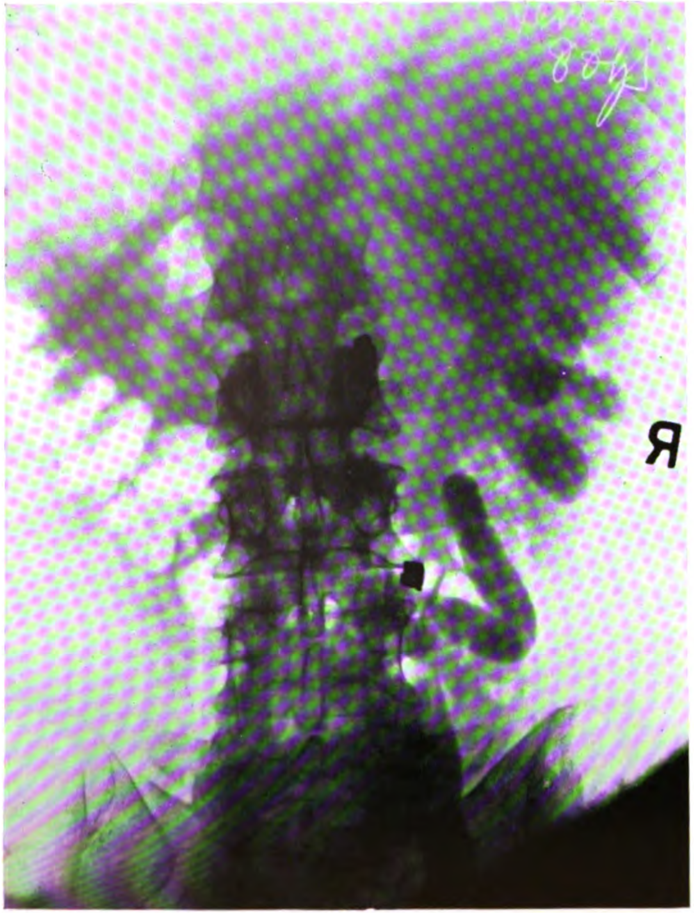
Urethral fistula following peri-urethritis or peri-urethral abscess at the peno-scrotal junction has been an extremely rare complication in our material. Only four paraplegics of the Second World War with closed bladders, whatever the initial form of management, developed fistulae at the peno-scrotal junction. One patient, while under suprapubic drainage, developed this complication following a pressure-sore at the peno-scrotal junction, due to lying in a faulty position. Taking into account the many thousands of urethral catheterisations carried out as a routine procedure in this centre all these years, this result can be considered as most gratifying, and proves decisively that this complication, previously considered as one of the most dreaded sequelae of urethral catheterisation, can be kept down to a minimum by a proper technique.



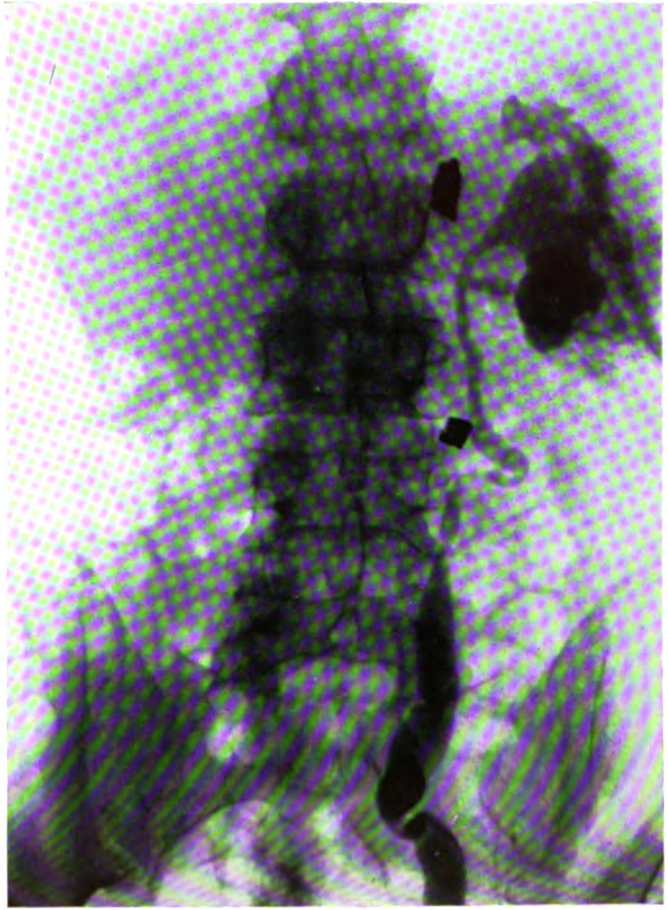
(*a*) (*b*)

PLATE XI. (*a*) Case of traumatic paraplegia below T.11/12 with suprapubic drainage showing 2 stones in bladder and one stone in posterior urethra.

(*b*) Urethrogram after removal of posterior urethral stone in same case showing the resulting diverticulum at the peno-scrotal junction (Page 477).



(a)



(b)

PLATE XII. (a) Profound kink formation in both coronal and sagittal directions of right ureter, with hydronephrosis, in a case of traumatic paraplegia.

(b) Same case showing marked improvement following nephrostomy and ureterolysis (Page 479).

A urethral fistula may heal spontaneously. The conservative method in this centre is diversion of the urinary stream from the fistula, by an indwelling urethral catheter of very small size, which is changed daily, combined with daily washouts of the urethra with flavazole solution 1–2000. However, there is general agreement that, in the majority of cases, plastic repair is necessary for closure.

A vesico-perineal fistula was seen in only one patient—with an incomplete cervical injury—who had had a perineal urethrostomy done for bladder drainage. This fistula proved quite resistant to any conservative measures and healed only after a second plastic repair operation.

Vesico-rectal fistulae were found in two patients admitted to this centre and occurred also in one case following transurethral endoscopic resection of the bladder neck. In the two cases mentioned above, healing was achieved conservatively by diversion of the urinary stream through urethral drainage by indwelling catheter.

BOWEL FUNCTION

In the early stage of an acute transverse spinal lesion, intramuscular injection of prostigmine 0·5–1·0 mg. or 1 c.cm. of prostigmine, every four to seven hours, proved beneficial in overcoming the intestinal paralysis. Furthermore, for relief of abdominal distension due to intestinal paralysis, the passing of a rectal tube proved invaluable. In dealing with paraplegics in later stages, it must always be remembered that bowel action may be due merely to overflow. Such patients will state that they have regular motion, while rectal and abdominal investigations reveal masses of old and hard faeces, which lead to overdistension of the colon and set up reflex responses of skeletal muscles and the cardiovascular system, as mentioned above. Regular enemas are required, drugs such as cascara and senna and liquid paraffin are useful, and attention must be paid to the diet.

Continuous overloading of rectum and sigmoid may also lead to obstruction of the venous return from the great pelvic veins, which may result in oedema of the legs. The author has, on occasion, observed that the oedema has disappeared once the overloaded rectum has been evacuated, and that it will not recur so long as the rectum is kept free. Profuse diarrhoea in paraplegics needs the greatest attention, for this, as well as profuse sweating, may indicate renal deficiency, and no time should be lost in administering saline solution intravenously, until the kidneys have recovered.

As soon as possible, the patients at this centre are taught to adopt a habit of having regular bowel motions. The method taught varies with each individual, according to the type of lesion and stage of intestinal paralysis. It can be concluded that the readjustment of the automatic intestines in paraplegics is easier than that of the bladder.

SEXUAL FUNCTION

Studies on the effects of spinal injuries on the reproductive function of paraplegics of the Second World War, have been published by various authors (Guttmann, 1946, 1949; Horne, Paul and Munro, 1948; Talbot, 1949; Bors, Engle, Rosenquist and Holliger, 1950; Kuhn, 1950). Experience has shown that, in a number of patients, sexual readjustment is possible to varying degrees, and the widespread belief that persons with severe lesions of the spinal cord are permanently impotent and sterile is unfounded. Talbot, who made current interview studies on 200 patients, found that 63·5 per cent. had erections, of whom 42·3 per cent. responded to local reflex stimulation, 21 per cent. to psychic stimulation, 23 per cent. were able to carry out intercourse, 10 per cent. had ejaculations, and an additional 6 per cent. had gratification without ejaculation. Erections returned in a higher percentage (75 per cent.), in injuries at T.11 and above, as compared with injuries at T.12 and below (53 per cent.).

In analysing the sexual function of paraplegics and the possibility of their sexual readjustment, it must first be remembered that, in a complete transverse lesion of the spinal cord, the erection reflex is one component of the reflex activity below the level of the lesion which returns once the spinal shock has subsided. This reflex can be elicited by appropriate local stimuli, which have been studied in some detail by Riddoch (1917) and Kuhn (1950), and the writer agrees that, in certain cases, the reflexogenic zone from which the erection reflex is elicited can be large. Martin and Davis (1948) could by strong pricking of the soles elicit incomplete erections and an engorgement of the penis, similar to the priapism described previously by Kocher in 1896. There is no doubt that, in some cases of paraplegia, the erection reflex can be utilised for intercourse. It is true that, in cases with marked spasticity, flexor and particularly adductor spasms may render intercourse impossible, and then denervation of the adductors by neurectomy of the obturator nerves must be considered. One patient, who had a severe though incomplete lesion at T4, was, after the operation, able to carry out his marital activities and is now the father of a child. With complete lesions of the distal part of the thoracic cord and of the cauda equina, the over-development of the abdominal and back muscles by training has proved to be of great value in restoring the sexual function of paraplegics.

Of the writer's patients with traumatic spinal lesions, ten so far have been able to beget children since their injuries. Of these, three had incomplete though severe lesions of the upper and middle thoracic cord (T.4, T.6 and T.9), three had complete lesions of the lower thoracic cord (one with a complete lesion below T.11 with spastic paraplegia, the other two with a flaccid type of paraplegia), and four patients had lesions of the cauda equina at various levels. One patient with a lesion of the cauda equina at L.4/5 has succeeded in becoming a father on two occasions, the result on the second occasion being—twins!

Paraplegics are naturally very anxious to obtain information about their chances of fertility, as sometimes on this information—especially in the case of patients of Catholic faith or who are engaged to Catholic girls—rests the decision of whether or not they should marry. The chances of fertility in paraplegics can be studied by examination of the ejaculate or by biopsy. Bors and his co-workers (1950) believe that examination of the ejaculate is far inferior to biopsy, because the ejaculate can rarely be obtained, which is in accordance with Kuhn's findings (1950); furthermore, they consider that specimens obtained by prostatic massage reflect more the degree of infection of the adnexa than the condition of the testes. Horne, Paul and Munro (1948) found that, in paraplegics, the amount of the prostatic specimen increased with prior electric rectal stimulation—a method which was previously used by Dexter, Lerner and Kaplan (1940) and by Joel (1941) in animal experiments and in man. However, Bors and co-workers were not impressed by the results in their own paraplegic patients. These authors studied biopsy specimens obtained from full testes in 34 patients with spinal cord injuries and found that, in all but three cases, the testicular biopsy specimens revealed tubular atrophy, while there was no disturbance of Leydig cells. Furthermore, with two exceptions, they found a correlation between the testicular biopsy findings and the level of the spinal cord lesion, in that cord lesions at or below T.11 showed a lesser degree of testicular abnormality. This study is of particular interest, as the authors have correlated biopsy findings with the results of sweat tests, using the quinizarin method, and were thus able to study the relation between testicular function and the autonomic system. This study revealed, with four exceptions, a close relation between testicular biopsy findings and the results of the sweat test. Lesser testicular changes were associated with normal sweating, while major testicular abnormalities were associated with impaired sweating.

The writer's own studies on fertility in paraplegics are concerned with the effects of intrathecal injection of prostigmine on the reproductive function. In the course of study on the depressant action of intrathecal injection of prostigmine on the skeletal spastic muscles (Kremer and Wright (1941)), he found in 1946 that a dosage of only 0·3 mg. was sufficient to elicit erections and emissions in traumatic paraplegics with complete transverse lesions of the spinal cord, who, hitherto, had been thought to be completely impotent and unfertile. Further investigations were carried out, together with Dr. Walsh, on 32 patients; 19 had complete transverse lesions or cauda equina lesions at levels ranging from C.7 to S.2; 12 had incomplete though severe lesions from C.6 to S.4; one patient had a triplegia following brain injury. The prostigmine was administered by lumbar puncture, the amount injected in all cases

TABLE VII

Details of the intrathecal prostigmine test in complete lesions

Case	Lesion	Hours after injection		Sperms		Vomiting hr. after injection	Degree of reflex function before injection						At time of ejaculation or at height of effect on motor function					
							K.J.		A.J.		P.R.		K.J.		A.J.		P.R.	
		Erection	Ejaculation	Motile	Entirely non-motile		R.	L.	R.	L.	R.	L.	R.	L.	R.	L.	R.	L.
1	C.7	1½	1½	+	—	1½	—	±	++	++	↓	↓	—	—	—	+	↓	↓
2	T.5	¼	4¼	—	+	2¼	+++	+++	+++	+++	↑	↑	—	—	?		(↓)	(↓)
3	T.6	1¾	2	*—	—	½	++	++	+++	±	↓	↑	—	—	(+)	±	↓	(↑)
4	T.6/7	1	1	+	—	—	+++	+	++	+++	↑	↑	—	(+)	—	(+)	(↓)	(↑)
5	T.6/7	2½	2¼	—	+	—	++	++	+++	+++	↑	↑	—	—	((+))	((+))	(↓)	(↓)
6	T.7	3	3½	—	+	—	+++	+++	+++	+++	↑	↑	—	—	—	—	(↑)	(↑)
7	T.7	2	2	+	—	—	+++	+++	±	++	↑	↑	—	—	—	—	—	(↓)
8	T.7	1½	2½	*—	—	¾	+++	+++	—	—	—	—	(+)	+++	—	—	—	—
9	T.9	2	2	+	—	—	++	++	++	++	↑	↑	(+)	(+)	(+)	(+)	↓	↓
10	T.10	2½	2¼	+	—	—	+++	+++	+++	+++	↑	↑	+	—	+	+	(↓)	(↓)
11	T.10	—	1½	*—	—	¾	+	—	++	++	↑	↓	+	—	++	(+)	↑	—
12	T.10	2¼	—	—	—	—	+++	+++	+++	+++	↑	↑	—	—	—	—	—	—
13	T.11/12	—	—	—	—	—	—	—	+++	+	(↓)	↑	+	—	(+)	—	((↓))	—
14	L.1/L.2	—	—	—	—	—	+	+	—	—	—	—	—	—	—	—	—	—
15	L.1/L.3	—	—	—	—	—	—	—	+++	+++	↑	↑	—	—	—	—	—	—
16	Spastic L.2	—	—	—	—	4	++	+	+++	+++	↑	↑	—	—	—	—	—	—
17	Spastic L.5	3¾	3¾	+	—	—	+	—	—	—	—	↑	—	—	—	—	—	—
18	S.1	1	1	+	—	1¾	—	—	—	—	—	—	—	—	—	—	—	—
19	S.2	2½	—	—	—	3½	+	+	+	—	↓	↓	—	—	—	—	—	—

* Fluid from prostate or urethral glands only.

without spinal block being 0·3 mg., in those with spinal block being 0·5 mg. In cases in which 0·5 mg. proved ineffective, intrathecal injection of 0·75 mg. had a stimulating effect on the reproductive function. The stimulating effect of prostigmine on the reproductive organs is in striking contrast to its depressant effect on the skeletal muscles and the bladder, as described by Kremer, 1941. As a rule, the first erection started one or two hours after injection, when the depressant effect on the skeletal muscles and the reflexes was already very apparent, and it was followed a few minutes later by an emission. Sometimes, there was a longer interval between erection and first emission. Once an erection had started, it continued in most cases for a considerable time, either intermittently or continuously, and sometimes it persisted for hours, even after emissions had occurred. In some cases, once an emission had occurred, it was followed by several others in remarkably quick succession, and as many as six to seven emissions were counted within two to three hours. In three patients, erections occurred without emissions; in three others, emissions without erections. Tables VII and VIII show the details of the intrathecal prostigmine test in both complete and incomplete lesions, in correlation to the effect on the reflexes of the skeletal muscles. In most cases, even with complete transverse lesions, the emissions were associated with symptoms of an orgastic nature, and in high cord lesions cardiovascular reflexes were elicited, similar to those described following distension of the bladder (Guttmann and Whitteridge, 1947). In several cases, especially those without sub-arachnoid block, vomiting and profuse sweating occurred. However, this was overcome by atropine, 1/200 grain, and intravenous saline drip.

TABLE VIII

Details of the intrathecal prostigmine test in two prostigmine tests on the same patient

Subject: Patient with cauda equina lesion plus cordotomy
Comparative microscopic results of seminal fluid in two prostigmine tests

Specimen	*Count*		*Motility*		*Volume*	
	February 13, 1948	*November* 5, 1948	*February* 13, 1948	*November* 5, 1948	*February* 13, 1948	*November* 5, 1948
	(millions per c.c.)		per cent.	per cent.	c.c.	c.c.
1	11	50	5	70	0·5	1
2	12	49	10	70	0·5	1
3	111	116	40	50	4·5	5
4	90	57	40	50	1·0	1
5	122	47	30	40	1·0	1
6	142	3·6	30	20	0·5	2

Differential count—February 13, 1948
Specimen 1 . . 50 per cent. abnormal forms
6 . . 40 per cent. abnormal forms

Differential count—November 5, 1948
Specimen 3 . . 55 per cent. abnormal forms
4 . . 65 per cent. abnormal forms

Microscopic examination of the seminal fluid obtained in these cases revealed motile spermatozoa in 50 per cent. of the cases, and it was possible to study details of spermatogenesis and reproductive deficiencies in these patients, which a short time ago would not have been possible, as shown in Table VIII on previous page.

The discovery of the selective effect of intrathecal prostigmine injection on the reproductive function of paraplegics has, no doubt, opened up new possibilities for clinical, physiological and biochemical research in a field where, hitherto, imaginative speculation and induction on scanty ground rather than well-founded evidence have prevailed. It can already be concluded that:

(1) the widespread belief that patients with severe injuries to the spinal cord are completely impotent and unfertile is unfounded;
(2) various types and degrees of reproductive deficiencies can be distinguished by the intrathecal prostigmine test;
(3) the intrathecal prostigmine test can be utilised for the sexual rehabilitation of paraplegic patients and for artificial insemination.

CARE OF THE SKIN

GENERAL

The vital importance of the maintenance of a good hygienic condition of the skin and its organs from the very beginning of the paraplegia is now well recognised, though not always practised. Cleanliness of the skin not only promotes better blood circulation but, by preventing clogging of the pores, it facilitates the function of the cutaneous glands, which take part in the elimination of metabolic waste products of the body. In fact, it was found in this centre that, in cases with acute renal deficiency—for instance, after nephrostomy or during acute pyelitic attacks—the increased activity of the sweat glands represents an important auxiliary mechanism for the elimination of waste products. Scrupulous cleanliness is especially essential in those cutaneous areas which are easily saturated with urine and faecal matter, and the soles and heels should never be allowed to become scaly, but must be kept soft and clean, as this is an important measure for preventing ill-effects of pressure. Indeed, it is no exaggeration to say that the degree of cleanliness of the soles and heels is an excellent indicator of the efficiency of the medical and nursing staff concerned with the management of paraplegics.

The toe-nails also need careful attention and must be trimmed at regular intervals. Ingrowing toe-nails are not infrequent incidents in paraplegics and should be dealt with immediately. Not only are they a constant irritation to the peripheral nerve-endings in the toes, thus increasing the spasms of the paralysed legs, but by inevitably becoming infected they are a potential danger to the general condition of the patient.

ILL-EFFECTS OF HEAT AND COLD

The loss of sensibility in the paralysed part of the body includes the loss of appreciation of heat and cold. Objects commonly used in daily life may produce the most frightful burns in these cases. The hot-water bottle was found to be the main cause of burns in those paraplegics admitted with burns to this centre, and its use should never be allowed in these cases, even if protected by a cover. Instead, woollen bed-socks should be worn in bed. The next on the list is the hot-water tap of the bath—especially in the case of ambulant patients. A paraplegic, before getting into the bath, should first make sure that the hot water tap of the bath is completely turned off, and in bath-tubs for paraplegics it is preferable to have water taps situated in the middle of the bath instead of at the end. Wash-basins for paraplegics, which must be high enough to allow the wheel-chair to be drawn up close to them, should have a bar on the floor to prevent the insensitive knees being burnt by the waste pipe when containing hot water.

A further cause of burns in paraplegics is the sitting too close to an open fireplace or electric fire, and when in such a position the limbs should always be protected. Precautions should also be taken in summer or hot weather, when exposing the body to the direct sun, especially in high thoracic and cervical lesions, where the spinal heat-regulating mechanisms are interrupted, as otherwise this may also have ill-effects.

In patients with spastic paraplegia, exposure of the paralysed limbs to cold invariably increases the spasms. Even more serious can be the effect on the blood circulation in distal parts of the lower limbs, especially in lesions of the cauda equina or lower cord. This can result in permanent damage to the small vessels, as shown by the pinkish-blue colour of the toes and feet. A useful precautionary measure was to prevent the legs being kept too long in one position. Long woollen pants, woollen socks and warm boots, such as flying boots, have proved very beneficial for these patients.

THE ILL-EFFECTS OF PRESSURE: PRESSURE SORES

Mechanism. The physiological mechanism underlying the causation of bedsores has repeatedly been the subject of discussion (Brown Sequard, 1853; Paget, 1887; Charcot, 1881; Riddoch, 1917; Trumble, 1930; Munro, 1940, 1943; Nissen, 1941; Dick, 1949; Guttmann, 1945, 1946; *et al*). Intrinsic and extrinsic factors determining the formation of bedsores can be distinguished. The most important intrinsic factor is the lowering of the tissue-resistance to pressure during the stage of spinal shock when, as the result of the acute interruption of the spinal vasomotor pathways, there results a flaccid paralysis of muscles associated with loss of vasomotor control. Sensory loss in the paralysed area also plays an essential part, because afferent impulses from a pressed area, which normally elicit discomfort and thus incite change of posture, are abolished.

Of the two extrinsic factors, pressure and maceration, the first is of cardinal importance. The degree and extent of the disastrous effect of local pressure in paraplegics, causing ischaemia of skin and deeper tissues, are determined by its intensity, duration and direction. The writer considers the effect of shearing stress to be much more disastrous than the mere vertical pressure, as the former cuts off larger areas from their vascular supply.

Localisation of sores. The incidence of pressure sores in traumatic paraplegics during the Second World War was very high (Poer, 1946; Kennedy, 1946; Kuhn, 1947). In this centre, at least 85 per cent. of traumatic paraplegics were admitted with sores, in most cases with multiple sores. They were found most frequently in areas over skeletal prominences: sacrum, trochanters, ischial tuberosities, anterior superior iliac spines, heels and malleoli. Sores over the malleoli, though, as a rule, only small, are characterised by a particularly slow rate of healing. Less frequent areas involved were the inner condyles of the knees, in cases with marked adductor spasms. This may be a very dangerous localisation, as such sores have the tendency to penetrate to the knee-joint. In cases admitted in plaster beds or plaster jackets, pressure sores were found over one or several spinous processes. Occasionally, the fifth metatarsal of the foot was found to be the site of a sore. In patients with lesions of cauda equina or lower cord, who developed contractures of the toes, especially the big toe, sores were found over the plantar and dorsal surfaces of the toes or of the first metatarsal. In one non-traumatic case, sores over the left 7th and 8th ribs were found, exposing these ribs. Occasionally, sores were found in the sensitive area above the level of the lesion, at the upper edges of plaster beds, and, in one case of incomplete cervical lesion admitted in a plaster cast, a sore was found over the occiput.

Types of sore. Various stages can be distinguished in the development of a sore, demonstrating the various clinical pictures on admission to this centre.

1. *Stage of transient circulatory disturbance.* Pressure has been sufficient merely to cause reddening of the skin without destruction of the tissues. It promptly disappears if the pressure is relieved and gentle massage applied.

2. *Stage of definite, superficial circulatory and tissue damage.* Various types of sores result from this damage. One is characterised by reddening and congestion of the pressed area, which does not disappear after decompression and leads to induration of the tissue. In another type, the superficial layers of the skin have been killed and may be excoriated, exposing the exuding cutis vera. In those cases in which the dead epithelium remains intact, it is raised by

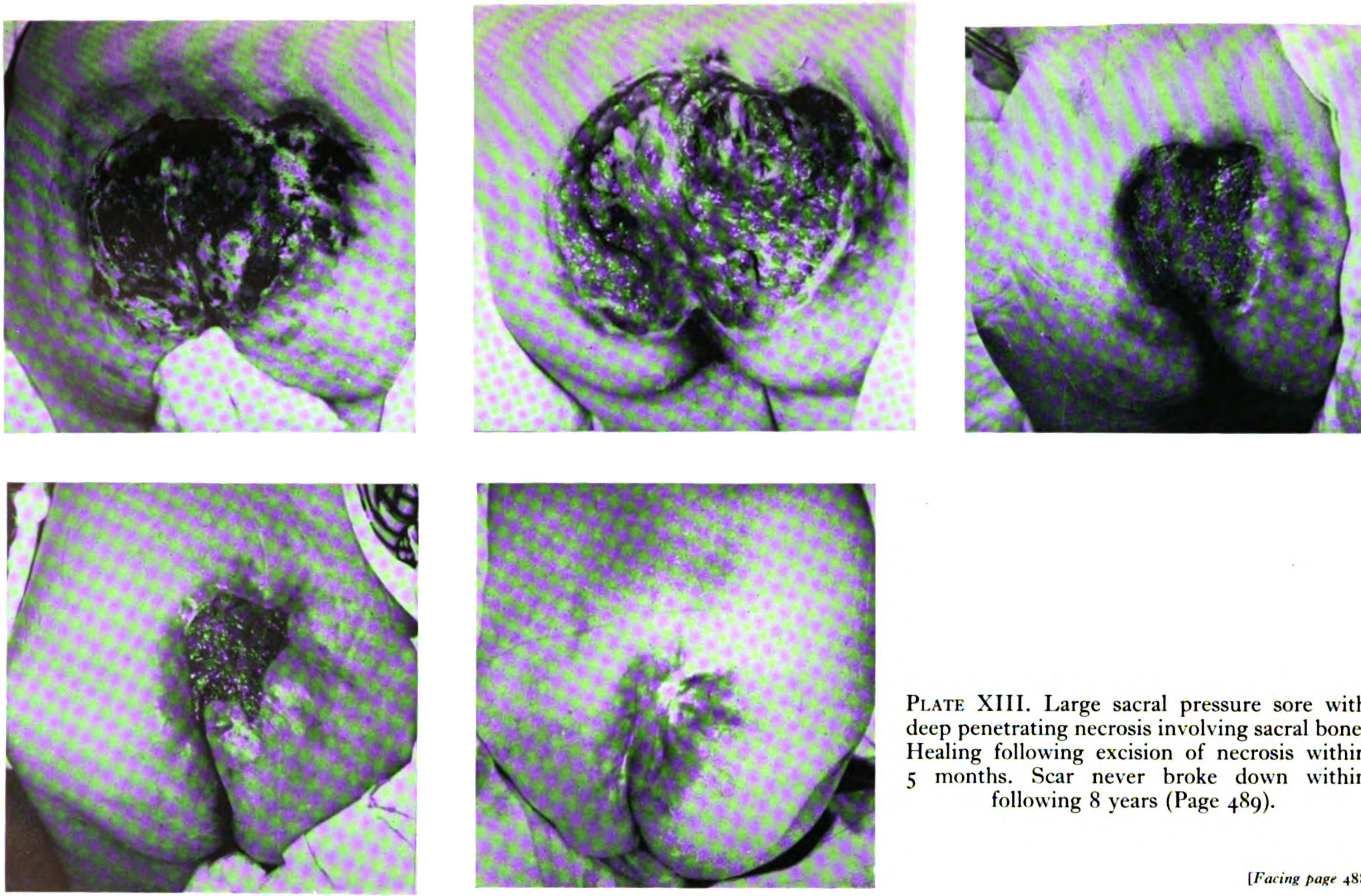


PLATE XIII. Large sacral pressure sore with deep penetrating necrosis involving sacral bone. Healing following excision of necrosis within 5 months. Scar never broke down within following 8 years (Page 489).

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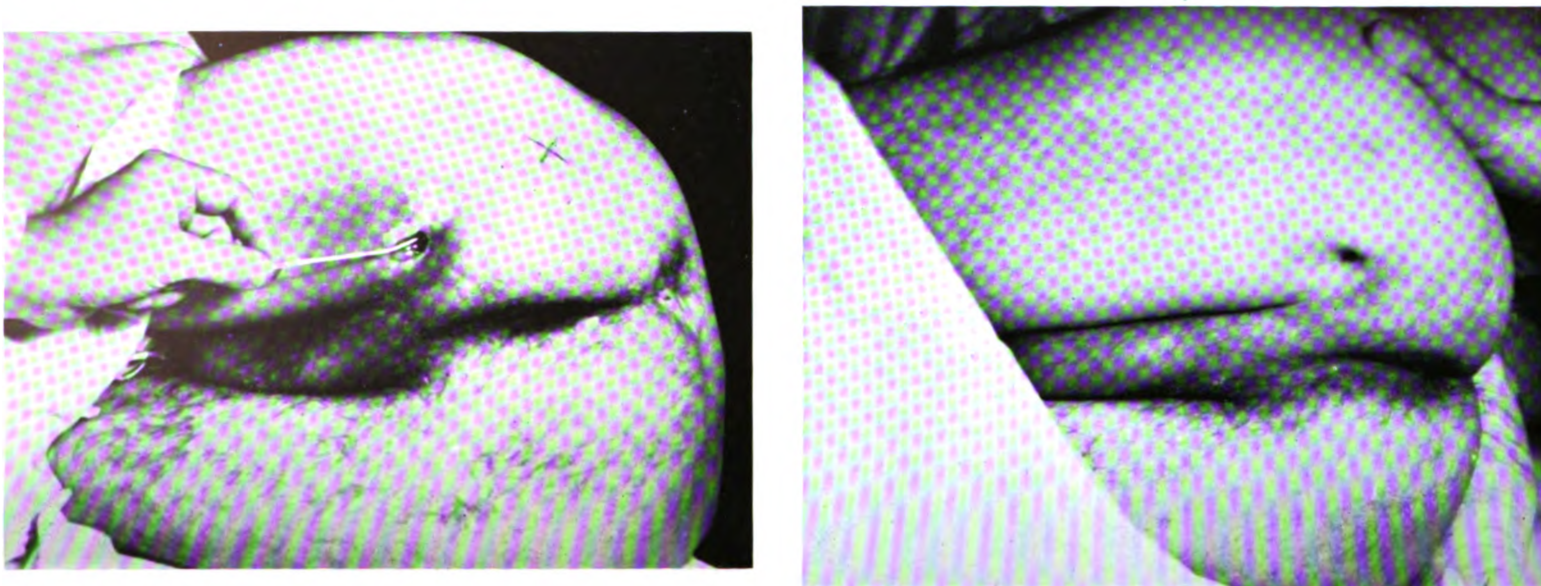


PLATE XIV. Ischial sore forming deep sinus and communicating with large bursa (x) adherent to ischial tuberosity (Page 499).

PLATE XV. Osteomyelitis resulting from pressure sores over ilium and ischial tuberosity. Infection penetrated into hip joint. Complete disintegration of head of femur (Page 490).

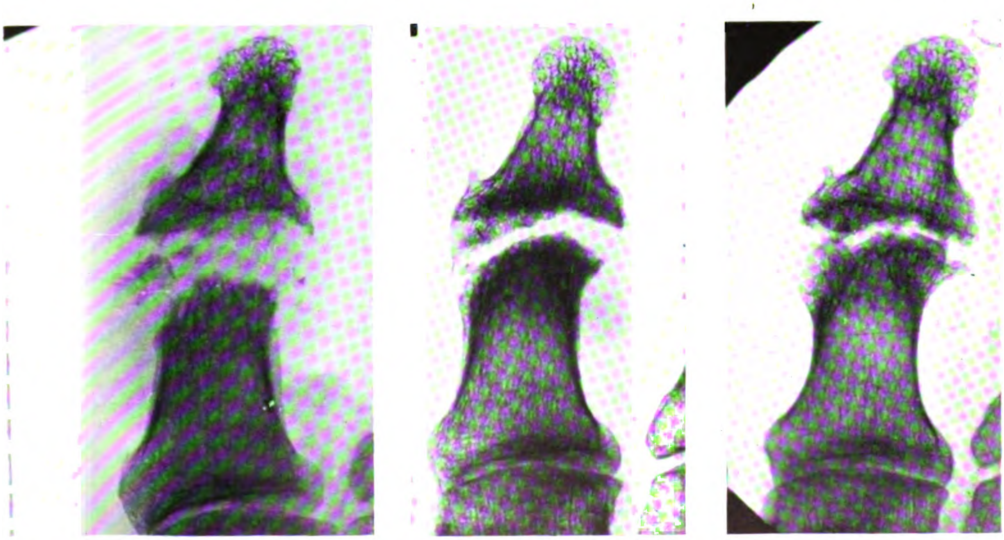
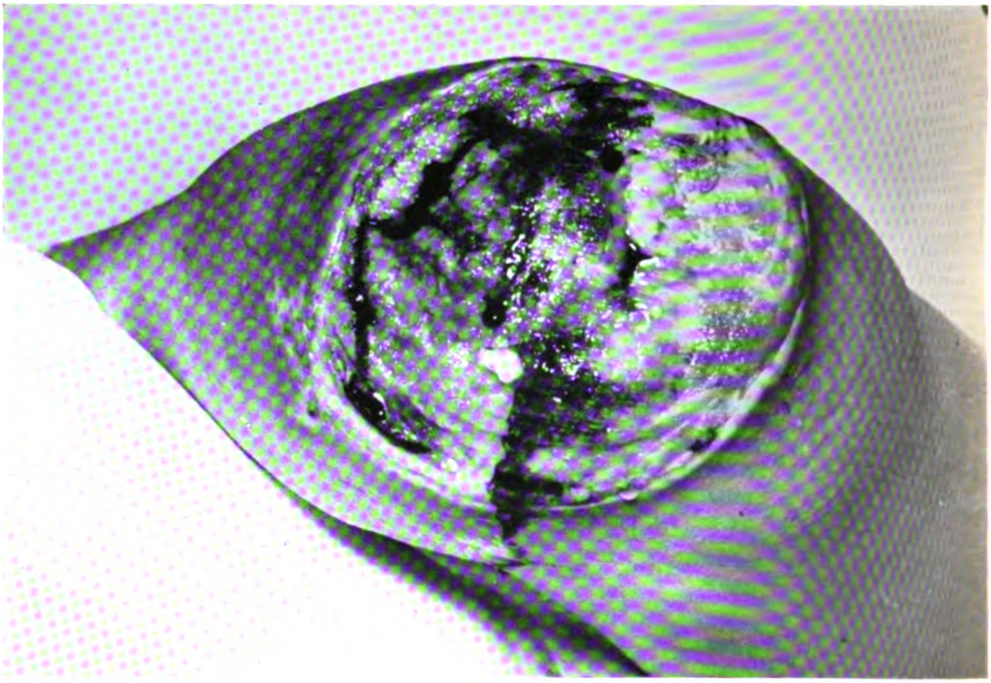


PLATE XVI. Complete disintegration of terminal phalangeal joint of left big toe due to osteomyelitis resulting from a penetrating pressure sore in a case of traumatic cauda equina lesion below L.4. Complete healing with formation of a new joint. Patient has been employed full-time in a factory for 6 years (Page 492).



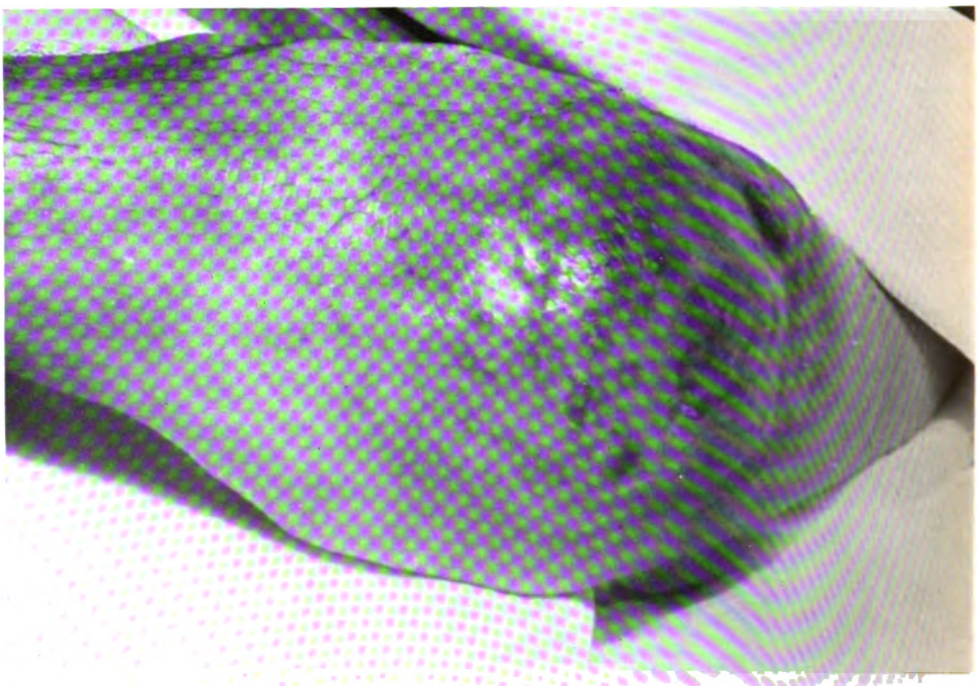


PLATE XVII. Large pressure sore over knee penetrating into knee-joint. Note the discharging synovial fluid. Complete healing within two and a half months. Last stage of epithelialization by seed grafts. No resulting contracture of knee-joint (Page 492).

exudation from the living cells of the cutis beneath, and a blister develops, which may be of dark colour if haemorrhage has occurred. In other cases, deeper layers of the skin may also be involved, and this results in superficial necrosis and formation of an ulcer, after the slough has been demarcated and removed. The border of such an ulcer may become pigmented.

3. *Stage of deep penetrating necrosis* (*malignant sore*). The destruction also involves subcutaneous tissues and includes fascia, muscles and bone. It leads to gangrene, and once the slough is removed a deep ulcer results. This type of sore usually develops over the sacrum and trochanters, and it may reach enormous dimensions and take grotesque shapes. Plate XIII shows various stages in the development and healing of a large sacral sore in a soldier with a complete lesion at T.6, following gunshot wound. Sometimes, such a large sacral sore may communicate with sores over the ischial tuberosity, which may have developed simultaneously or at a later date. Often the necrosis of the deeper tissues is more extensive than that of the skin, which accounts for the undermining nature of the sore in some cases. Trochanteric and, in particular, ischial sores (Plate XIV) also have the tendency to form deep sinuses, which may communicate with bursae. X-ray examination, following lipiodol filling of the sinus sore, has proved invaluable for the accurate diagnosis of the extent and direction of the sore.

4. *The closed ischial bursa.* This represents a special variety of the ill-effects of pressure found almost invariably in later stages of paraplegia. As a rule, it develops as a swelling after acute trauma to the ischial regions, such as bumping the buttocks when the patient moves from his bed to the chair or from the chair to a car, etc., but sometimes it develops without obvious acute trauma. Aspiration of the swelling reveals blood-stained or serous fluid (20 to 40 c.cs.), which usually recurs. Radioscopy after lipiodol filling will reveal a cavity of more or less elliptical shape. If adequate treatment is not applied immediately and the patient is allowed to get up, the circulation of the skin covering the bursa will invariably suffer, ultimately resulting in ischaemia, necrosis and formation of a sinus sore.

COMPLICATIONS FOLLOWING PRESSURE SORES

Nutritional effects. There is now general agreement that open pressure sores represent one of the main sources of nutritional deficiency in paraplegia, as the drainage from the sores results in continuous loss of protein. Poer (1946) found a daily loss of as much as 50 g. of protein, as a result of drainage from pressure sores.

Infection: osteomyelitis—septicaemia. Sores always become infected and, in the case of paraplegics, they are, with the exception of urinary infection, the commonest cause of sepsis. The micro-organisms most commonly found are *B. streptococcus haemolyticus*, *staphylococcus*, *proteus*, *coli*, *streptococcus faecalis*, *pyocyanea*, *and diphtheroids*. The infection of the sore, if not counteracted from the very beginning, will involve the deeper tissues and extend to the bone, causing periostitis, osteitis and osteomyelitis, with necrosis and sequestrum formation. The great danger of developing osteomyelitis after pressure sore of the trochanteric and especially ischial regions cannot be stressed too much, having regard to the neighbourhood of the hip joints. In fact, in some patients admitted to this centre, septic arthritis of the hip joints was found, with profound destruction of the acetabulum and head of the femur (Plate XV). In other cases with large sacral sores, the coccyx and part of the sacrum was found to be completely disintegrated, and the sacro-iliac joint obliterated. As one would expect, septic involvement of the bone has its repercussions on the haemapoietic mechanisms, resulting in more or less severe degrees of anaemia. The tragedy and great danger in these cases is that, as a rule, the septic complications following pressure-sores progress silently—a lingering type of sepsis without rise of temperature—and, moreover, if occasional flare-ups of temperature occur, these are often misinterpreted as due to ascending urinary infection. Among the factors determining the direction in which the infection from the sore spreads, posture may play an important part. It was found that, in long-standing ischial sores, when the patient lies in the prone position for a long time, the infection may travel towards the front, and break-through may occur in the groin. In one patient with a lesion of the distal cauda equina (a walking case), the infection travelled down along the back of the thigh and a breakdown occurred in the popliteal fossa.

TREATMENT

From all experience gained in the treatment of pressure sores, it can now be stated that, although it is not always possible to prevent a pressure sore in places such as the sacrum, trochanter and ischial tuberosities, with our present means *every sore can be healed*.

PROPHYLAXIS

This is of vital importance in the early stages after spinal injury, when sores may occur within a few hours after injury. The first-aid precautions—removing hard objects from patient's pockets, padding bony prominences, counteracting traumatic shock, immediate transportation to a spinal centre or hospital dealing with spinal injuries—have already been mentioned. Prophylactic measures are also most important in later stages, when, following operations—especially those under general anaesthesia—and intrathecal alcohol injections, and also during acute infections of any kind, tissue resistance due to loss of peripheral vasomotor control is lowered. The cardinal methods in local prophylaxis are frequent change of posture (every two hours day and night) and redistribution of pressure. For redistribution of pressure, nursing on a rigid bed, equipped with air or sorbo mattress, is essential. In addition, plenty of small pillows are needed to support the limbs and trunk in the various positions adopted as the result of turnings. Sores over the heels can *always* be prevented by placing pillows underneath the calves. Those notorious rings made of cotton-wool or other material to support the heels are apt to produce pressure by shearing stress, rather than prevent it. Research carried out by the writer, in conjunction with Dr. Bourdillon of the Medical Research Council Unit at this hospital, on more suitable arrangements for the prevention and treatment of sores, has led to the employment in certain cases of special packs of Dunlopillo material fixed on a board, in place of the full length sorbo mattress and the piles of feather pillows. This arrangement has proved to be more hygienic and also more economical than the many feather pillows, and these packs were found equally satisfactory in preventing sores. In the U.S.A., special turning beds (Stryker) are used for the prevention and treatment of sores (Kessler and Abramson, 1950). As already pointed out, plaster beds have been advocated for prevention and treatment of sores. They are mentioned here only to be condemned.

To promote good circulation, frequent gentle massage to pressed areas is essential. The skin should be kept scrupulously clean and rubbed repeatedly with alcohol (50 per cent. to 60 per cent.), and then dusted with powder. If the skin is harsh and dry, it is well to use a mixture of oil and alcohol. Creases and crumbs in the bed clothes must be avoided. Apart from the local prophylaxis, attention must be drawn to the paraplegic's general condition, which should be kept at the highest possible level.

CURATIVE TREATMENT

General measures. Once pressure sores have developed, the principles of prophylaxis should be enforced and every effort made to remove pressure from the sore. It is a custom in this centre to instruct the patient about the ill-effects of pressure to the bony parts of his body, as early as possible, to make him 'pressure' or 'sore conscious', and thus gain his full co-operation in avoiding pressure to the sore and in the routine of changing posture. The prone position for many hours has proved most effective. Furthermore, it must be emphasised that, whatever local treatment is applied, constant attention has to be given to maintaining and improving the paraplegic's general condition. The importance of combating nutritional deficiency, the maintenance of nitrogen balance and the treatment of anaemia, as some of the most important factors determining the rate of healing, cannot be stressed too much. In this connexion, the value of regular blood transfusions may again be emphasised. The beneficial effect of general radiant light treatment may also be mentioned.

LOCAL TREATMENT

Conservative procedures (these include surgical measures such as excision of sloughs and scraping of sinus sores)

Having regard to the fact that sores always become infected, the writer strongly advocated early excision of sloughs—i.e. as soon as the cutaneous necrosis is well demarcated. If, after removal of the cutaneous necrosis, the underlying fascia is also found to be necrotic and appears infected, this should be incised and sufficiently excised to allow free drainage of the infected material. In numerous cases, underneath such a necrotic fascia, pockets of necrotic fat or abscesses were found. The immediate improvement of the patient following the transformation of such a closed septic wound into an open one was very striking. Therefore, it would appear that Munro's view (1940) that sloughs should never be removed and that drainage of sores is contra-indicated, a view contrary to the old general surgical principle of transforming a closed septic wound into an open one, can hardly be accepted as a general rule.

There can be no doubt that the great majority of pressure-sores, however large and deep, can be healed by the conservative procedure practised in this centre. Moreover, Plate XVI demonstrates the healing of severe osteomyelitis of the middle phalanx of the big toe with complete disintegration of the terminal joints, after conservative healing of a penetrating pressure sore at the medial aspect of the toe, in a patient with a lesion of the cauda equina below L.3/4, following fracture of the spine. Of special interest is the reorganisation of the terminal joint. There has never been a recurrence of the sore or of the osteomyelitis in this case since healing occurred, which, moreover, was achieved before antibiotics such as penicillin and streptomycin were available in this centre. Since then, even large sores over the knee, penetrating into the knee-joint and with profuse discharge of synovial fluid from the open joint, were healed in two cases, thus obviating surgical procedures, such as amputation (Plate XVII).

A great variety of local applications have been tried in the treatment of sores, but the literature is too vast to be surveyed here. This has been done recently elsewhere (Guttmann, 1948). In the choice of local applications, the writer is always guided by the type of micro-organisms predominant in the sore, and regular culture-swabs taken from the sores have proved a most important routine examination. Chemicals to combat infection are used very cautiously, in order not to interfere with the formation of granulations, which are so essential for filling in defects and decreasing the size of the sore. If Gram-negative micro-organisms, especially *proteus*, are predominant, flavazole 1–2,000 or flavazole 0·1 per cent. in carbowax have proved very useful, and in the case of *pyocyanea*, boric acid solution or phenoxetol 2·4 per cent. Later, local streptomycin was found to be very effective in certain cases. In sores infected with the haemolytic streptococcus or staphylococcus, penicillin-saline in various concentrations has been effectively employed since 1944. Often, the local penicillin or streptomycin treatment is combined with a general course of these antibiotics. As soon as the infection is overcome, the writer has relied, in most cases, on saline dressings alternating with flavazole 1–2,000, Milton 5 per cent. or boracic solution or powder. Once the defect is filled with granulations, saline dressings were continued, alternating with pellidol ointment, *tulle gras* or allantoin powder, which have proved satisfactory stimulants for the growth of epithelium. In this connexion, it may be emphasised that the local treatment of sores by ultra-violet light has so far in no way proved superior to these measures, and in our experience there is no proof that the local application of ultra-violet light *alone* is of such value in accelerating the rate of healing of sores in these cases as is often stated by physiotherapists.

The effects of treatment and the rate of healing are judged by the appearance and size of the sore. These can be recorded by photographs and by tracing the outline of the sore at regular intervals. The latter is done by means of a sterile, decoated X-ray film, which is placed over the sore, a second film being placed on top. The outline of the sore is then traced on the top film, and thus a permanent record is obtained of its size and shape. This procedure is carried out periodically. After healing, the traced areas of the sore are measured by means of a planimeter (a method recommended in the First World War by Carrel and his co-workers (1916) for war wounds), making it possible to estimate the rate of healing of pressure sores under various conditions and by various forms of treatment, including plastic operations. Experience on many scars resulting from various types of sores has shown that the size of the final scar varies between one quarter to one third of the original size of the sore.

In connexion with the treatment of pressure sores, hydrotherapy may also be mentioned. In previous years, it was a popular method, especially on the Continent. In recent years special tanks (Hubbard) were introduced in the U.S.A. for the treatment of sores (Newman 1947). In this centre, a special bath has been constructed, provided with a hydraulic lift, on which the patient lying on a frame can be lowered into the water.

The resulting final scar of a pressure sore may remain firm and intact, if proper after-care is taken by all concerned, especially the patient himself. The sore, unhealed and healed, shown in Plate XVI is one of many which proved that this can be achieved even over a long period, as no breakdown has occurred in this case after over six years. It is essential to prevent or diminish stress on the vascular supply to the scar, by early gentle massage of the surrounding tissue and by passive and active movements. Once the patient is up in his chair, he must learn to become 'pressure conscious' and to acquire a habit of relieving pressure from the scar by change of posture at regular intervals.

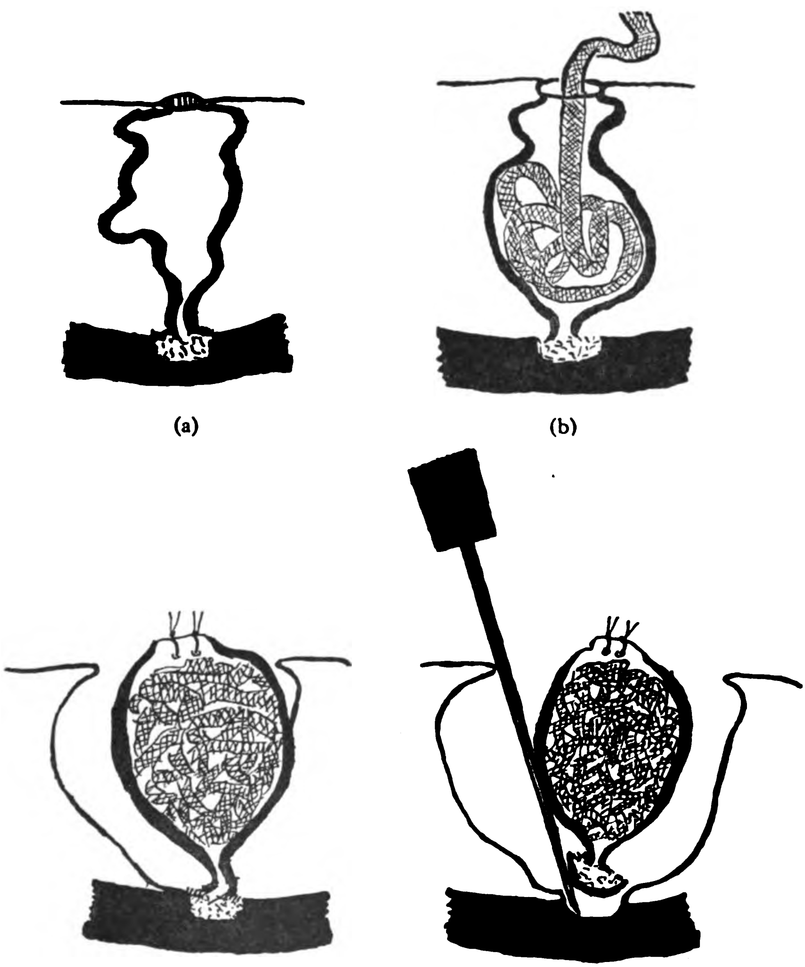
PLASTIC REPAIR OF PRESSURE SORES AND SCARS

In many instances, scars are liable to break down in the centre, where the vascular supply is most readily cut off by pressure or stress, and this makes surgical repair necessary. It is beyond the scope of this account to describe in detail all the various methods of rotation flaps, delayed flaps, sliding flaps, with excision of prominent bone underlying the scar, which have been recommended. They all give more or less satisfactory results. In the repair of sacral and trochanteric scars of small or moderate size, the writer found excision of the scar, combined with resection of prominent and usually callous or macerated underlying bone and primary suture, satisfactory.

In recent years, reports of closure of active pressure sores by plastic procedures have repeatedly been published, especially in the U.S.A. (Barker, 1945, 1946, and 1947; Harper, 1945; Conway *et al.*, 1947; Freeman, 1947; Kostrubala and Greeley, 1947, Bors and Comarr, 1948; *et al.*). From all the experience gained so far, the writer has come to the following conclusions:

(1) the chances of success of any plastic operation on pressure sores in paraplegics are doomed so long as the patient's general condition is unsatisfactory—in particular, so long as protein balance and anaemia are not fully corrected. In such cases, plastic operations are, as a rule, contra-indicated;
(2) heavy local infection of the sore has to be combated first, especially that due to *streptococcus haemolyticus*, *staphylococcus pyogenes*, and *proteus*;
(3) in deciding the date and method of plastic operation, great consideration has always to be given to the condition of the bone underlying the sore. X-ray examination of the bone, including a lipiodol test, has proved most helpful;
(4) the method of choice for plastic repair varies according to the size, location, and elasticity of the neighbouring cutaneous areas. Multiple scars in the neighbourhood of a sore are a decisive factor in determining the type of operation;
(5) multiple small flaps and skin grafts applied directly to granulating areas, and tension sutures over defects have, as a rule, proved unsatisfactory methods. Buried epidermis grafts are described as superior to any other type of free skin graft (Wangensteen, 1930; Bors and Comarr, 1948), and experience gained in this centre with this type of skin graft is in full accordance with that of these authors.

(6) in using rotation flaps in the repair of sores, especially ischial sores in cauda equina lesions, attention should be paid to diminishing the area of sensory loss. This is illustrated in the following case: in the patient with a lesion of the cauda equina, who was admitted with a profound distortion of the pelvis and two deep ischial sores, we succeeded in healing these sores completely by conservative means within two months. However, both sores recurred as soon as the patient was sat up, and indolent, undermined ulcers resulted. At the writer's suggestion, rotation flaps were performed (Mr. Elliott Blake), with the idea of diminishing the area of sensory loss, in order to restore the feeling of



(a) (b) (c) (d)

Fig. 1.—Surgical repair of sinus sore over ischial tuberosity by 'pseudo tumour' technique.

pressure as much as possible and thus to induce the patient to change his position. There has been no recurrence since the operation was carried out (1944);

(7) a routine procedure for the surgical repair of sinus-sores has been introduced by the writer, which may be called the 'pseudo tumour' technique. It has already been pointed out that an ischial sinus as a rule forms a bursal sac, adherent to the bone, which inevitably becomes infected. Sinus-sores may also develop over the trochanter. It is well-known that the healing of such sores is only possible if the whole bursal sac, including the infected bone, is removed (Report of Medical Research Council, 1924). However, it is often very difficult to define the wall of the sometimes multi-loculated sac. The operation is greatly facilitated if, immediately before the operation, the bursal sac is transformed into a pseudo-tumour by plugging it with sterile or antiseptic gauze. After this procedure, the opening of the sore is stitched up and the packed sac is dissected like a tumour and removed with adherent bone. Fig. 1 a–d shows the various stages of this pseudo-tumour technique, which, in the hands of Dr. Walsh in this centre, has so far proved most successful in promoting the healing of these sores, which have hitherto been the most difficult problem in the treatment of pressure-sores in paraplegics. Catgut has been abandoned for the suture of the deeper tissues, after removal of the sinus sore, and has been replaced by finest wire.

PSYCHOLOGICAL ASPECTS

A disaster in human life of such magnitude as an injury of the spinal cord which throws the body completely out of gear, inevitably must also have pronounced effects on the patient's mind. Although the literature on mental behaviour of traumatic paraplegics is still very scanty, some observations on the subject, related directly or indirectly to the injury, have been published in recent years (Michaelis, 1945; Guttmann, 1945, 1946; Poer, 1946; Kennedy, 1946; Weiss and Bors, 1948; Nagler, 1950). The writer has made his studies on the mental behaviour of paraplegics mainly during their routine activities in the ward, physiotherapy department, workshops, and later on in convalescent homes and resettlements. In agreement with Thom and others, it was found that, in these cases, formal psychiatric interviews may have the disadvantage of creating an artificial atmosphere, and, in fact, the indications for specialised psychiatric guidance in these cases were extremely rare in this centre. In the study of the mental state of paraplegics, in certain cases self-written reports by the patients about their reactions to the injury at various stages were of invaluable help. In the mental behaviour and mental disorders observed in our cases, the pre-traumatic personality, general mental ability, educational background, as well as duration of the paraplegia, and last but not least the type of initial treatment, were found to be essential factors in establishing the pattern of mental reaction. In particular, the importance of the disastrous effect of prolonged inactivity on the minds of paraplegics cannot be emphasised too much.

The mental disorders observed can be divided into various groups:

MENTAL DISORDERS RELATED TO THE SPINAL INJURY

(*a*) *Organic disorders*

These are caused by the septic condition associated mainly with the infection of the urinary tract and pressure sores, and the most characteristic symptom is increased tiredness progressing to complete apathy, all too often misinterpreted as being 'un-co-operative' or of 'bad type'. Sometimes, sudden and unmotivated outbursts of irritability and rudeness may be the first sign of a pyrexial attack. Real psychosis was found to be very rare. A man of 59 with a complete transverse lesion at T.10, developed on three occasions, during acute deterioration of his sacral and trochanteric sores, a toxic psychosis of paranoidacustic hallucinatory type, which promptly disappeared after excision of deep fascial sloughs with fat necrosis. The family history of this patient did not reveal any mental abnormalities. Most striking improvement of the mental conditions, especially apathy, also followed blood transfusion in cases with anaemia due to septic absorption.

(*b*) *Reactive mental disorders*

The sudden conversion of a vigorous man into a helpless cripple naturally leads to severe psychological shock. The immediate reaction may be a state of semi-consciousness or dazedness, in which the patient does not care what happens. This stage will be followed by a number of anxieties, some of which are identical with those of other severely disabled persons, such as fear of early death or chronic crippledom, with all its restrictions in social activities and economic consequences resulting in complete loss of earning capacity, thus becoming a burden to the family and everybody else. However, there are also anxieties of a specific nature associated with the disablement of spinal paraplegia, in connexion with partial or complete loss of control of bladder and bowels and sexual function. The writer agrees with Nagler (1950) that the sexual disturbances constitute a severe psychological shock in most paraplegics, regardless of whether married or single (the more as the libido remains), and the adequate supplementation of the sexual drive constitutes an important factor in the successful rehabilitation of the paraplegic. Experience has shown, for instance, that the positive result of intrathecal prostigmine test in eliciting erections and ejaculations, and the microscopic evidence of motile spermatozoa in the seminal fluid, were also a great relief to the patient.

The various anxieties and fears may set up a variety of reactions, such as depression, and a feeling of hopelessness and frustration, which may be associated with a sense of resentment against their fate and society. The feeling of resentment may increase if progress is slow and may result in lack of emotional control, leading to hysterical reactions and an aggression towards patients and nursing and medical staff, and to breaches of discipline. As one would expect, the emotional dysbalance is associated with autistic thinking and self-centredness. It was found particularly pronounced in psychopathic individuals. Trifling reasons, such as having to wait their turn to be attended to for changing their urine bottles, or being refused permission to get up, etc., may be exaggerated and result in outbursts of excessive irritability and displays of temper, in which they may be quite capable of doing damage to others and themselves. One of the writer's patients with a complete traumatic lesion at T.4, following a motor-cycle crash—a constitutional psychopath of paranoid-querulous type—became quite negativistic in such a state of emotional dysbalance and threatened to commit suicide by refusing to eat and drink, being well aware of the disastrous effect of the restriction of fluid on his kidney function, the more so as he had a congenital aplasia of one kidney and had to rely on the other kidney.

Another, though less common, reaction in paraplegics is self-deception. A defiant attitude ('we can take it' mentality) towards their disability was found in young paraplegics, especially in the early stages. Although self-deception concerning the incapacitating effects of the injury is very useful in the treatment at the beginning, in later stages of rehabilitation it leads to a very unrealistic and uncritical attitude towards their limited abilities, for it leads the paraplegics to choose occupations for which they are unsuited, with consequent disillusionment and disappointment later.

Another example is their unrealistic attitude towards their ability to drive motor vehicles. It has been observed that some of these men, when given a motor-propelled tricycle, although being instructed about the speed at which they should travel, tend to ignore these instructions, thus becoming a danger to themselves and the public. Therefore, the writer feels that it cannot be stressed too much that proper precautions should be taken by all concerned with the granting to disabled persons of licences for motor vehicles, be it tricycle or motor-car, to ensure that these men are road-safe.

Probably the most unfavourable mental reaction in paraplegics, from a rehabilitation point of view, is indifference. In agreement with other authors (Thom, Nagler), this attitude was found more frequent in patients with lower grade intelligence, but in particular in those who went through a long period of enforced inactivity, either in hospital or institution. There is a complete absence of any initiative and drive to solve the problems of social and occupational readjustment. They do not worry unduly about their disability and, although they do not show any direct aggression, they resent interference with the protection given to them in hospitals or institutions. If such a patient is left to himself without expert guidance, he will easily deteriorate into a professional charity case and become a bad example to others.

MENTAL DISORDERS UNRELATED TO THE SPINAL INJURY

There are only two patients in the writer's material with psychosis of schizophrenic type. Evaluation of their pre-traumatic personality and their family history has led to the conclusion that the psychosis in these patients is unrelated to the cord injury. Nagler (1950) has reported three cases of paranoid-schizophrenic type, and three cases were previously reported by Bors, Munro and Poer.

PSYCHOLOGICAL TREATMENT AND CARE

From the very beginning, careful attention to the paraplegic's mental condition and to his systematic psychological handling has been one of the most important therapeutic procedures in this centre. The staff had to be taught to understand the various psychological reactions and to help in their treatment. No doubt, the development of a strong doctor-patient relationship has proved to be a vital factor in preventing and counteracting the mental abnormalities, by gaining the patient's confidence and thus securing his co-operation. This was seen, as already pointed out, in the treatment of pain, but it also proved successful in overcoming inactivity and apathy. The creation of a cheerful atmosphere and good morale in the ward cannot be stressed too much. The whole unit must be deliberately impregnated with enthusiasm, for this inspires the patient to co-operate to the full, and has proved to be the best way to avoid the development of a 'spoiled child mentality' on the one hand and promote self-discipline on the other hand, and to keep breaches of hospital or institutional regulations by these long-term patients at a very low level. Indifference, anxiety, resentment, frustration, as well as self-deception, all have to be watched for in later stages also, when the paraplegic has left the spinal centre and lives in a convalescent home, resettlement or at home, because these reactions may impede successful rehabilitation and impair the patient's working efficiency. The most beneficial effect of regular work on the mental condition of paraplegics will be discussed later.

PHYSIOTHERAPY

One of the dominant activities of the specialist in charge of a spinal centre is the planning and personal supervision of the physical treatment of paraplegics, for upon his intimate knowledge of each case and his expert functional and psychological analysis of the patient's disability depend the indication for, and the duration and modification of the various forms of physiotherapy.

The two fundamentals in the physical treatment of paraplegics are an early start and a continuity of treatment. The chief objects to be pursued are:

1. TO APPLY PHYSIOTHERAPY TO THE PARALYSED PARTS OF THE BODY

This comprises—(*a*) maintenance of correct position, and passive movements, (*b*) electrotherapy in lower motor neurone lesions as a substitute for active exercises and (*c*) the treatment of spasticity. As the latter problem has already been dealt with in detail in this report, only the first two will be considered here:

(*a*) *Correct position and passive movements*:

The object is prevention and treatment of contractures and atrophy of joints, muscles and skin. In the early stage, the physiotherapist has to assist the nursing staff in preventing recumbency and in keeping the paralysed limbs in a proper position, in order to prevent adduction and internal rotation of the legs, drop-foot, claw toes, and pressure on the neck of the fibula. While, in general, care is taken to prevent drop-foot and contractures of the Achilles tendon, in many cases of lesion of the cauda equina the paralysed toes are found in profound flexion contractures. It is obvious that such a complication greatly delays rehabilitation in paraplegics, as not only is it impossible to commence walking exercises whilst the toes are in this contracted position, but there is an increased danger of pressure-sores.

Permanent fixation of paralysed limbs in any position must be avoided. In lesions of the spinal cord, the habit of placing the lower limbs in adduction and semiflexion by placing pillows under the knees is deprecated, as this must inevitably lead to adduction and flexion contractures which later on, when the flaccid stage of paralysis has passed, are a serious complication to spasticity.

Contractures may also develop in normal muscle groups, due to their unrestrained action following paralysis of their antagonists. This was found with lesions of the cauda equina, particularly below L.2/L.3, when contractures easily developed due to the unrestrained action of the intact muscles—namely, iliopsoas, quadriceps, adductors, and internal rotators—if the proper position of the patient in the early stages had been neglected. In cervical injuries below C.6, the over-action of the normal biceps, following paralysis of its antagonist, the triceps, was the usual cause of the frightful flexion contractures of the elbow, due to faulty position of the paralysed upper limbs in the early stages following injury. This condition should never be regarded as the inevitable sequel of this type of injury, as usually accepted by physicians and surgeons and demonstrated in textbooks, as it can easily be avoided if, from the beginning, care is taken that the patient lies with his arms extended and not flexed.

The most deleterious type of contractures was found in cases admitted in plaster beds, in which the patient had lain for months. The contractures of the joints and the atrophy of all tissues of the back caused by this type of fixation were profound, in spite of the fact that, in the medical notes, statements were made that these patients had received physiotherapy. Patients who had recovered from symptoms associated with lesions of the cord or cauda equina were frustrated for months because of the superimposed stiffness of the joints and of the distorted pelvis, developed as a result of this enforced fixation.

Regular passive movements of all joints of the paralysed limbs are carried out several times a day, starting immediately after injury, to prevent contractures and promote better circulation in the paralysed limbs, and this is continued throughout all stages of paralysis. These passive movements have also proved to be the most beneficial form of treatment in overcoming contractures which have already developed. In this respect the pedal exerciser is highly recommended. Effects of the treatment on the contractures are judged every week or fortnight by regular measurements which can be charted.

(*b*) *Electrotherapy*

In lesions of the lower motor neurone, such as those of cauda equina and cervical roots, daily electrical stimulation of the denervated muscles has proved beneficial in promoting better circulation and preventing extreme degrees of atrophy. Electrotherapy is used in these cases as a substitute for active exercises of the paralysed muscles in place of their normal contractions, and the treatment is based on the writer's experimental research in peripheral nerve lesions (Guttmann, 1941, Gutmann and Guttmann, 1944). The electrical exercise is begun as early as possible (seven to ten days after injury) and is applied in gradually increasing numbers of contractions. As many as 600 to 800 contractions were applied to paralysed muscle groups during one session of 30 minutes. The writer is not in favour of applying dogmatically a definite number of contractions—say 90, as recommended by Jackson and Seddon in the treatment of peripheral nerve lesions—to every case, as this number may be either too few or too many to achieve the desired effect. The denervated muscle needs a similar individual training by proper electrotherapy as the normal muscle by active exercises. The fear of over-fatiguing denervated muscles by frequent electrical stimulations has been grossly exaggerated in the past, and has led all too often to quite useless application of electrotherapy, such as 10 contractions only. In conus-cauda-equina lesions, electrotherapy is given in selected cases only and mainly to restore and improve the function of partially denervated muscles. Moreover, emphasis is laid on concentrating electrical exercise to those muscles which are important for standing and walking—i.e. quadriceps and glutei—as the complete—and, in these cases, as a rule, permanent—paralysis of the extensors and plantar flexors of the foot can easily be compensated for by simple toe-raising spring appliances.

2. READJUSTMENT OF NORMAL PARTS BY COMPENSATORY TRAINING

From all that has been discussed in the previous chapters on neurophysiological aspects, especially postural readaptive mechanisms in normal parts of the body of the paraplegic patient, it is obvious that compensatory training is directed to the pursuance of three main objects, in order to restore the patient's independence: (*a*) overdevelopment of trunk, and in distal cord lesions, also of abdominal, muscles, (*b*) reorientation and restoration of postural sensibility and co-ordination mechanisms and (*c*) readjustment of vasomotor control:

(*a*) *Overdevelopment of trunk and abdominal muscles.*

From the start, emphasis is laid on exercises of those muscles which are essential for the patient's upright position, especially those with attachment to the pelvis. The most important muscles to be exercised in spinal cord lesions above T.7 are the latissimus dorsi, trapezius, teres major, serratus anterior, pectorals, and triceps—and, for distal cord lesions, also the abdominal muscles and long back muscles. The compensatory training of these muscles is carried out by auto-assisted movements—first with the help of simple metal chest-expanders and later on with suspension and slings and against resistance by means of pulleys and weights. The Guthrie-Smith apparatus has proved invaluable for sling exercises. In due course, the systematic training of these muscles results in their marked hypertrophy and increased power, which enables the paraplegic to become more and more independent of artificial aids in keeping his upright position and even regaining his standing and walking capabilities to a certain extent. Plate XVIII(*a*) shows the action of the latissimus dorsi on the pelvis, in a case of complete transverse lesion at T.3. Plate XVIII(*b*) shows the same patient from the front, but the hypertrophic latissimus dorsi can be seen bulging out on either side. The hypertrophy of some shoulder muscles in these paraplegics can sometimes be quite grotesque, as seen in the teres major and trapezius (Plate XIX), in a case of complete transverse lesion at T.6. As the lesion was also a longitudinal one in this case, having destroyed the anterior horn cells for the lower intercostals and abdominal muscles, the contrast between the denervated, atrophic lower trunk and the hypertrophic shoulder muscles is the more striking. The more distal the spinal cord lesion the greater the number of muscle groups, with attachment to the pelvis, available to the paraplegic, and Plate XX shows the co-operation of the abdominal muscles in the team of muscles which effect pelvic tilting, in a complete lesion at T.12.

(*b*) *Re-orientation and restoration of postural sensibility and co-ordination mechanisms.*

It must be remembered that, in complete transverse lesions of the cord, the loss of postural sensibility in the hip-joints, added to the other sensory disturbances in the paralysed parts of the body, represents a serious complication, for it makes the paraplegic unable to keep his balance. Therefore, new afferent impulses subserving postural control have to be developed. This is done by balancing exercises with arm raising in various directions, in a sitting position in front of a mirror, where the patient at first can compensate for the loss of postural sense with visual guidance, as shown in a case of complete transverse lesion at T.7. Later on, owing to the fact that proprioceptive impulses arising from any movement of the pelvis are transmitted centrally along the afferent pathways in the latissimus dorsi and other back muscles, these pathways connect the insensitive part of the body with the central apparatus subserving postural control, and the patient gradually develops a new pattern of postural sensibility. This enables him to keep his upright position without the aid of visual guidance, and eventually he can even sit keeping his arms raised, with his eyes closed and without any artificial aid.

(*c*) *Readjustment of vasomotor control.*

The maladaptation of the blood circulation to change of posture, resulting from the interruption of the splanchnic control in all complete cord lesions above T.5, is another obstacle to the physical rehabilitation of paraplegics. However, it was found that this disturbance of vasomotor control could be overcome by exercises, which included frequent change of posture, swinging in slings and breathing exercises, to such an extent that these patients could keep the upright position as able-bodied people, without fainting. The mechanisms involved in this readjustment of vasomotor control have already been discussed. In the beginning, the adaptation to the upright position can be facilitated by the use of an abdominal binder or belt, which prevents blood from accumulating in the lower part of the trunk and legs. Care must be taken not to apply the binder too tightly, as this would prevent venous return.

(3) SPECIAL METHODS OF RESTORING INDEPENDENCE

Of the procedures which serve the purpose of restoring the independence of the patient, only the following need be mentioned here:

(a) *Dressing exercises*

To prepare him for future independence, dressing exercises are included from an early stage. The paralysed patient is taught and encouraged to dress himself in the minimum of time, and this procedure includes hoisting himself from his bed into his wheel-chair, either with or without the aid of the chain and handle fixed over his bed. It has been found that a well-trained paraplegic patient, paralysed from the waist downwards, should be able to dress himself in about five minutes, and, with high lesions, in between eight and eighteen minutes; this includes his transfer from bed to wheel-chair.

(b) *Walking exercises*

When the muscle-power in the normal parts and the balance of the body have improved sufficiently, standing and walking exercises are begun between parallel bars or in walking chairs, or walking frames, followed by walking on arm and elbow crutches. Time and distance are gradually increased. The gait in these cases is that of a tripod action of each of the two crutches, maintained by alternating tilting of each side of the pelvis upwards, by the use of the abdominal and back muscles. The other type of walking is the propulsion of the body by swinging movements, with the aid of arm crutches (swinging-to or swinging-through type). This is the type which is mainly used in higher lesions, where the propulsion of the body is achieved by associated action of the muscles of the shoulder girdle and pectorals. Naturally, the walking capabilities of a paraplegic, especially with a cord lesion above T.10, will always be very limited, but however small the walking capability may be it will increase his range of activity and independence, when he is discharged from hospital. Moreover, daily walking exercises are in themselves one of the best means of maintaining good circulation of the renal system and also counteracting the kink formation of ureters in these cases. Deaver and Brown (1946) have given many details about crutch walking, among other activities of paraplegics and other disabled persons, which, however, cannot be accepted rigidly as standard time values.

(c) *Appliances*

The utilisation and development of the natural readjustment forces in the muscular system of the normal parts, to restore the upright position of the paraplegic, have resulted in a fundamentally different approach towards appliances. It is quite obvious that complicated and cumbersome leather and steel corsets for the trunk, of the usual orthopaedic type, are not only unnecessary but even contra-indicated

(a)

(b)

PLATE XVIII. Hypertrophy and tilting action of latissimus dorsi on pelvis in a case of complete spinal cord lesion below T.3 (Page 502).

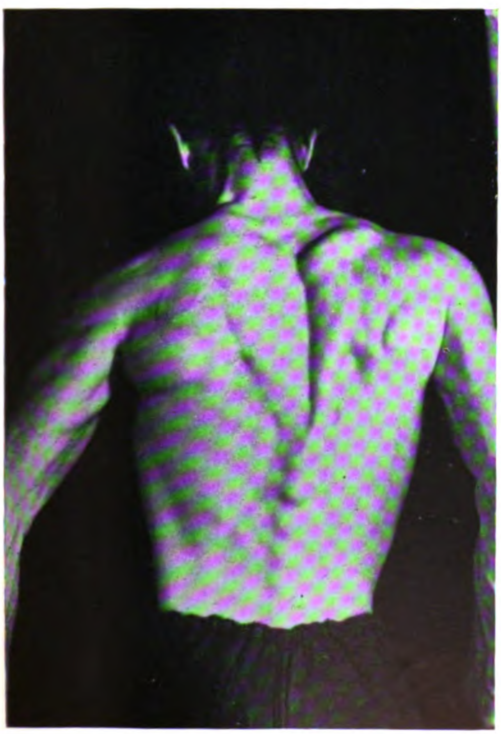


PLATE XIX. Marked hypertrophy of shoulder muscles, especially trapezius and teres major, in a complete transverse lesion below T.6 (Page 502).

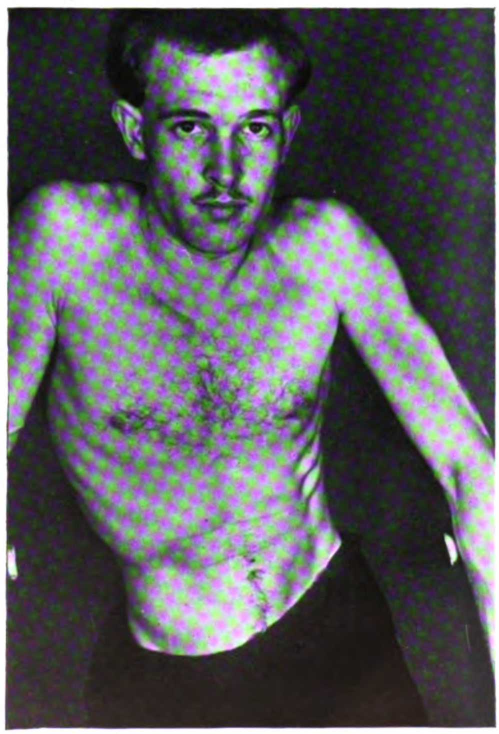


PLATE XX. Pelvic tilting by combined action of abdominal and trunk muscles in a case of complete spinal cord lesion below T.12 (Page 503).

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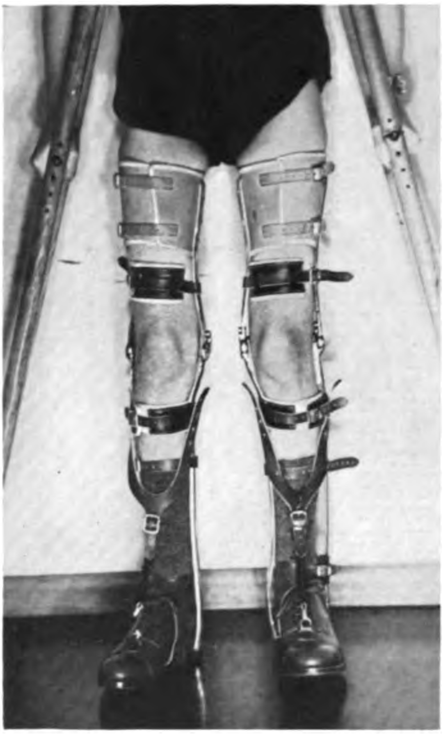
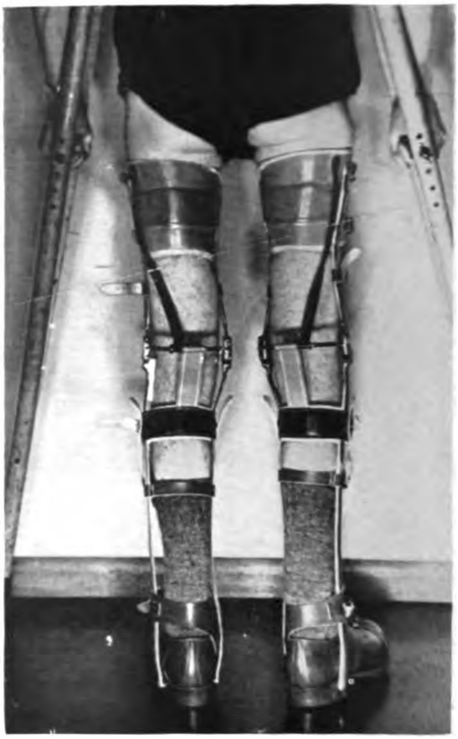


(*a*)



(*b*)

PLATE XXI. Walking calipers for paraplegics. Note the absence of weight-bearing to avoid pressure sores over ischial region (Page 505).

Plate XXII. Netball match during annual tournament for paraplegic sportsmen held at Stoke Mandeville Spinal Centre in July, 1949 (Page 506).

PLATE XXIII. Archery competition during annual tournament 1949 (Page 506).

for most paraplegic patients, as they interfere with the action of just those muscles of the trunk which guarantee the upright position of the body and tilt the pelvis. What the paraplegic needs in the way of braces is nothing but long walking calipers, which fix the knees by locking knee-joints and keep the feet at right-angles. It must be remembered that the paraplegic has to lift the weight of the paralysed part of the body with a few intact muscles. Therefore, any additional weight by calipers is a greater burden, and it is, therefore, obvious that these calipers must be constructed of light material such as duralumin or, for heavy patients, light steel. Moreover, they should not be of weight-bearing type, as the leather support in the ischial region tends to produce pressure sores. Furthermore, in order that the paraplegic can put on his own calipers in the shortest time possible, the writer has substituted leather bands and buckles for the usual lace fastenings. Plate XXI shows the type of walking calipers used for paraplegics in this centre. Pelvic bands are necessary only in very selected cases, mainly to prevent internal rotation of the legs in certain types of lesions of the cauda equina, as shown in a case of a lesion at L.2/L.4. In cases with degenerative paralysis of the abdominal muscles light abdominal belts are quite sufficient to keep the internal organs in good position.

(*d*) *Sport*

From the beginning, sport has played a most important part in our methods of physical and psychological rehabilitation of paraplegics, and it has been proved beyond all doubt that many games, such as darts, billiards, snooker, skittles, punch-ball, badminton, table tennis, netball, climbing ropes, chair polo, javelin-throwing, putting the shot, and archery can be adjusted to the disability of paralysed patients. It was found that archery in particular is a suitable sport for the following reasons:

(i) it is of enormous therapeutic value for the overdevelopment of those muscles of the trunk and shoulder which guarantee the upright position of the patient.

(ii) it offers great variety in application, as the amount of exercise taken can be varied by increasing the pull-weight of the bow and by shooting at greater distances.

(iii) it has a great fascination, as the archer accomplishes everything by his own judgment and strength and nothing is mechanised for him. The archers in this centre shoot every month for the best gold trophy which is held by the winner for the month in his or her ward. Archery tournaments have already been held here between paraplegic archers and clubs of able-bodied people.

The skill paraplegics can attain in these various games can only be believed if it is seen. There is no better evidence of the development of a new pattern of co-ordination in the paraplegics than this achievement in the field of sport. Plate XXII is an action picture of the final match in wheel-chair netball between the teams of Stoke Mandeville Spinal Centre and Lyme Green Settlement, at the second annual sports tournament (July 1949), in which the latter team won by 6 goals to 3. Plate XXIII shows competition in archery at the same tournament.

We have gone even a step further. It has already been proved on two occasions that paraplegic teams can take part as a special section in their own sports, in competitions of able-bodied sportsmen —and in certain sports take part in the general competition itself— and the writer considers this achievement as the first step in a fundamental change in the conception of the organisation of sport. It is hoped that the time is approaching when national or international sports meetings, such as Olympic Games, will include a section for paralysed and other disabled persons.

(4) CULTURAL ENTERTAINMENT AND RECREATION

Various forms of cultural entertainments, such as concerts, lectures, cinema shows and visits to exhibitions, are included in the programme of rehabilitation of these patients who are also encouraged to take the initiative in various recreational activities. A chess club was formed among the patients and a choir was started by the writer, under the leadership of a voluntary conductor. In the summer of 1946, the 'choir on wheels' performed most successfully at a public concert in the hospital concert hall.

A few patients have shown interest in the piano. As, however, they were unable to use the pedals, one of the patients has designed an ingenious device which enables any paraplegic patient to operate the pedals with his elbow.

Also, at one stage, a dramatic society formed among the patients, produced, entirely alone, the dramatic play 'Libel', with great success. One of the main characters in this play was played by a man with a complete transverse lesion at C.7. The producer was a girl suffering from poliomyelitis, with complete paraplegia of both legs and all abdominal muscles.

REHABILITATION BY WORK

From the beginning, it was realised in this centre that a satisfactory rehabilitation of long-term hospital patients such as paraplegics—i.e. their restoration as useful and socially accepted citizens—could only be achieved if their physical readjustment went hand in hand with their re-adaptation to work adjusted to their permanent disability. This principle was observed in this centre from the start, and emphasis has been laid on early vocational training.

Rehabilitation by work in paraplegics can conveniently be classified in two stages:

REHABILITATION BY WORK IN EARLY STAGES OF PARAPLEGIA

Naturally, in the early stage of treatment, when the patient is still immobile because of his active pressure-sores and urinary infection, work first takes the form of toy-making and other simple handicrafts, as taught by the occupational therapist. However, everybody concerned with occupational therapy for paraplegics must clearly understand that the purpose of this therapy is by no means merely occupation as a diversional measure. It is used immediately to restore the lost power of concentration and to revive initiative, in order to shift the psychomotor capabilities of the paraplegic from the paralysed to the normal parts of the body. This type of work has the great value of developing the mobility and dexterity of the fingers and arms, upon which the future vocation of a paraplegic depends, and thus represents already the first step in the paraplegic's industrial rehabilitation. It should be noted that several patients who showed particular interest and ability in toy or rug-making, needle-work or leather-work, have actually continued this work later on and have started businesses on their own, at home. For others, the skill achieved in making leather handbags proved most useful in their training later for shoe and boot repair.

However, in certain cases, specific pre-vocational training was introduced in the early stages following injury, at first by correspondence courses, in commercial arts, accountancy, banking and law.

The first man to pass his examination in law at this centre, ten months after his injury, was a young officer, who was admitted in June 1944, from the battlefront, with a gunshot injury through the right lung, causing a large haemothorax, and through the spine, resulting in a complete transverse lesion at T.11/12. He was encouraged to start his studies while laid up with fever. Fourteen months after injury, he entered Oxford University, as an undergraduate at Lincoln College, and, at the writer's suggestion, was provided with a special grant from the Ministry of Pensions to employ an attendant. Four terms later, he was elected secretary of the law society at his college, and in summer 1947 passed his final examination. Two months later, he was employed in the legal department of the I.C.I. Other examples of the value of pre-vocational training in paraplegics have been published elsewhere (Guttmann, 1946).

REHABILITATION BY WORK IN LATER STAGES

In due course, the Ministry agreed to put pre-vocational training in hospital, as part of medical rehabilitation, on a wider basis, by providing more facilities for training, such as cobbling, typing, precision engineering with hand-operated lathes, and woodwork. Later on, with the assistance of Lord Roberts' Workshops, clock-assembly was included, and, with the assistance of the Engineering Department of the Ministry of Works, draughtsmanship. When the patient is able to get up, he attends daily at one of the workshops, and this work is graded and correlated to the physical improvement of the patient and, of course, his intellectual ability and personality. Regular reports are given by the instructors, and it has sometimes been necessary to switch patients from one occupation to another.

Naturally, it was not to be expected that everyone would make full use of the various facilities offered. In numerous cases, especially those who had long spells of sepsis and those admitted in later stages from other units or hospitals, where they had been kept in prolonged, enforced inactivity, it took a considerable time to arouse the patient out of the state of frustration, apathy and inertia to which he had resigned himself. Such patients need unremitting guidance and encouragement by the medical officer, who must supervise the nursing staff, as well as the instructors, to ensure steady progress. Moreover, other factors, such as education, temperament, and individual inclination towards work had to be taken into consideration, and obviously a spinal cord injury does not necessarily change a previously work-shy man into a first-rate worker. Furthermore, it does not necessarily follow that every patient who has taken up pre-vocational training in a particular subject will carry on with the same occupation when he returns to his home or is transferred to a permanent resettlement. Circumstances were sometimes found to be unfavourable for carrying on with the same occupation for which the patient was trained at this centre. However, from all experience gained in the last six and a half years, it can now be concluded that early vocational training has proved invaluable in restoring activity of mind and is a most important step towards the social rehabilitation of paraplegics. Most of the patients have shown keen interest in pre-vocational training and many have made tremendous efforts either to adjust their former trades to their permanent disability or to take up training for a new occupation. In some instances, even the whole educational level of such a patient has been raised, and the following is an example: A young soldier, whose previous occupation was that of an agricultural labourer, was admitted in June 1944, with a high lesion of the cauda equina, associated with a gunshot injury to his left elbow. As an experiment, he received training in precision engineering and was so successful that, since discharge from hospital, he has worked for about the last two years in an engineering firm near his home, making small parts for agricultural machines. He is full-time employed.

Even in 1944, before full facilities for pre-vocational training had been made available in this centre, an experiment was carried out by arrangement with a local factory, when several patients took up regular part-time work while still inpatients at this hospital. While this experiment proved beyond all doubt that paraplegics could be successfully placed in factories side by side with able-bodied people, pre-vocationally it was not completely successful, as the work was too monotonous.

Another experiment has been carried out with the assistance of the Engineering Department of the Ministry of Works. Several patients, who had taken pre-vocational training in draughtsmanship in this centre, have been accepted by the training college of the Ministry of Works at Worcester, to continue their training there. Three of these patients have passed their final examinations, and two of them are already employed in offices of the Ministry of Works in London, and a third will be employed shortly.

DOMESTIC AND INDUSTRIAL RESETTLEMENT

1. AT THE PARAPLEGIC'S OWN HOME

The majority of traumatic war paraplegics treated in this centre—i.e. 186 out of 318 survivors—have so far returned to their own homes, to live there with their families in the old environments. This achievement no doubt represents the most satisfactory form of domestic resettlement for paraplegics, and it should be aimed at also for civilian paraplegics as much as possible in the future. Before their final discharge, most patients were sent home first on leave, in order to give them, as well as their relatives, the opportunity to readjust themselves to the new scheme of living. At one stage in the development of this centre, the British Legion placed an old rectory in Aylesbury at our disposal, which was converted into a 'home', in order to give married and unmarried paraplegics, whose homes were not suitable for their reception, the opportunity of spending several weeks with their families, in an atmosphere similar to that in their own homes. During their stay at Walton House, the men remained under the medical supervision of this spinal centre, and wives and parents were instructed in the efficient handling of their paralysed husbands and sons. This temporary domestic readjustment was discontinued as soon as the Ministry, the British Legion and other voluntary organisations were in a position to readjust the patients' own homes to their wheel-chair lives, by widening doorways, building ramps and putting bathrooms and toilets on the ground floor, etc. Moreover, in numerous cases, the local housing authorities allocated specially constructed bungalows to paraplegics and their families. It is beyond the scope of this account to describe in detail the various types of bungalows which have been designed for paraplegics in this and other countries.

139 (74·7 per cent.) out of the 186 traumatic paraplegics of the War of 1939–45, discharged to their own homes, are at present gainfully employed, the majority of them (68·4 per cent.) being on full-time work. In evaluating the type of industrial resettlement, several groups can be distinguished, some of which may be mentioned here:

(*a*) The first group consists of men who, before their war injury, had already been employed as skilled or unskilled workers, and have succeeded in getting back to their former trades, in spite of their severe disability.

The very first patient of this centre is an example of this group. He was wounded in Italy, 1943, and was admitted on February 3, 1944, with a high lesion of the cauda equina (L. 2/L. 3), suprapubic drainage, and deep pressure sore over the left buttock, and he developed, in due course, a paravertebral abscess. Before joining the Army, he had been employed in a factory as a glove maker. As a preliminary to his industrial rehabilitation, he started needle- and leatherwork for as long as he was confined to bed. Later on, he became a member of that working party mentioned earlier, on which an experiment in vocational training in a radio factory was made. As soon as our workshops were opened, he was one of the first to take up cobbling. After discharge from this centre on May 2, 1946, he returned to his former job, and the factory provided him with appropriate facilities to enable him to carry out his work from his wheel-chair. He has worked full time since, and his absences from work during the past three and a half years have been negligible.

Other patients of this group, who were engaged in clerical work previous to their injuries, had, of course, little difficulty in carrying on with the same or similar work after their discharge from hospital. Some of them have even succeeded in returning to their former jobs with higher qualifications, having worked for and passed examinations while in this centre.

As one example, a man with a complete transverse lesion at T.11 associated with amputation of the left leg following gunshot injury may be quoted, who, previous to his war injury, was employed in a bank. He was advised to prepare, by means of a correspondence course, for a higher qualification, and in due course successfully passed his examination. When his condition was satisfactory enough for him to be transferred to our convalescent home at Chaseley, Eastbourne, arrangements were made there for him to start part-time work as vocational training at a local branch of his bank. He now lives in a specially built bungalow in another town, and drives several miles every day to his bank, where he is doing as good a day's work as anyone, at a specially adjusted desk.

(*b*) This is a group of paraplegics who, owing to their permanent disability, were not able to return to their former jobs but succeeded in getting a different job in their former trade.

A good example is a man who, previous to his war injury, had worked in a chemist's shop, and sustained a complete transverse lesion at T.6. He is now employed by one of the largest pharmaceutical firms in the country, making abstracts from various medical and pharmaceutical journals. At times, he works up to twelve hours a day.

Another example of this group is a parson, who sustained a complete transverse lesion at T.7, due to gunshot injury. He is now employed as chaplain at a foundlings school, where he carries out all his duties from his wheel-chair.

(*c*) This group consists of paraplegics who were not able to return to their former occupations, such as regular soldiers, bricklayers, coal-miners, etc.

They are now employed in a great variety of skilled and unskilled jobs. There is, for instance, a young naval lieutenant, with a complete transverse lesion at T.12, who took a correspondence course in agricultural science. He is now employed full-time by the Bucks. Agricultural Executive Committee.

A former coal-miner from Wales, with a complete transverse lesion at T.10, took up first cobbling and later clock-assembly, as pre-vocational training, and after his transfer to our convalescent unit at the Star and Garter Home continued with training in watch-repair. He won his diploma and is now working as a watch-repairer very successfully.

A flying officer, with a complete transverse lesion at T.3, following crush fracture, took up pre-vocational training here in the precision instrument workshop. After his transfer to our convalescent unit at Chaseley, Eastbourne, arrangements were made for temporary employment as a cashier in a butcher's shop. This experiment proved very successful, and the man is now full-time employed near London, with a printing firm. He drives to work in his own car. It is worth while quoting an extract from an article he published in *The Cord*, (1949), in which he described his life at home: "An average working day in my life goes something like this. Wake up at seven drink two glasses of water and get cracking on bowels, while wife fixes breakfast. Bowels I have to do in bed, because sitting on the W.C. is for me a dead loss so far, although I am trying. This I manage lying on my side on a rubber sheet and a chunk of cellulose tissue. I never make more mess than I can clean up and dispose of on my own. Then, I dress, wash and shave myself. Breakfast. Go out and get into car and drive off to work on my own. Morning work from 9 a.m. to 1 p.m. The man with whom I work is a gem. Sometimes, I try to do something a bit too clever and fall out of my travaux (chair). He picks me up, dusts me off and replaces me in position without making any more fuss than to inquire whether I have hurt myself. And he believes me when I reply 'I haven't, thank you.' Home to lunch and a spot of sitting or lying quiet, and back to work at 2.30 p.m. When I arrive home or at work, I drive up to my chair and get out into it unassisted. Home from work again at 5 p.m. In the evenings we have dinner, which I help to prepare and cook sometimes—and I help with the washing up. About once a week, we go out to dinner. We either go out somewhere for the evening, or have a domestic evening at home, exactly as normal people do. Then, I have a bath, which I run, get into, get out of, empty and wipe round myself, in that order. Last job before bed each night is to clean and disinfect my rubber urinal and put it ready for the morning. My wife and I sleep together, because we would have done so had I been normal."

(*d*) This group consists of paraplegics who, at the time of their injuries, were either totally untrained or whose training had been interrupted by the war.

As an example, a young man may be mentioned here, although he is not a traumatic paraplegic. Before joining the Navy, he was an apprentice in a Diesel works. While serving in a submarine off Singapore in 1945, he developed a transverse myelitis, which left him with severe spastic paraplegia of both lower limbs. When admitted to this centre five months later, not only was he in bad physical condition, produced by sores and urinary infection, but he was quite demoralised, due to enforced inactivity. He had to undergo several peripheral operations to overcome the spasticity, but in the intervals between he started training in our precision instrument workshop, and it was most gratifying to see how this boy changed from being one of those headaches to the medical and nursing staff into a splendid co-operative patient. He was the first patient to take up draughtsmanship, once facilities had been made available in this centre, and soon satisfied his supervisor so much that the Ministry of Works agreed to train him in their training college at Worcester. He passed all examinations with flying colours and is now employed full-time as draughtsman in one of the London offices of the Ministry of Works, driving several miles in his own car from his home to his office.

2. AT SPECIAL TEMPORARY OR PERMANENT RESIDENTIAL SETTLEMENTS

There are paraplegics who are not able to return to their own homes or prefer, for one reason or another, to live in institutions or permanent residential settlements of colony type. At present, there are three institutions affiliated to and medically supervised by this centre. In these paraplegics can continue their rehabilitation on the same lines as at this centre, pending their final domestic resettlement, while some of them can make them their permanent homes. These units are:

(*a*) *Star and Garter Home, Richmond, Surrey.*

At the end of 1946, one large and one small ward of altogether 22 beds were segregated in that well-known home for ex-servicemen from the First World War, for the admission of paraplegic ex-service men from the Second World War. Two types of paraplegics are admitted:

(i) those permanently unfit to live in their own homes ;

(ii) convalescent cases, mainly from the London area, pending their discharge to their own homes or residential settlements.

A special workshop has been set up, where the men can be trained in clock-assembly and watch-repair. Several patients have passed their examinations for a diploma of the British Horological Society and have set up business since. Other patients there are working in sock-making, plastic work and printing. Of the 12 pensioners from the War of 1939–45 transferred there from this centre, 8 are working.

(*b*) *Chaseley Convalescent Home, Eastbourne.*

In 1946, a large house near the sea-front, which was converted into a home for 36 paraplegic ex-servicemen, was placed at the disposal of the Ministry of Pensions by Lady Michaelis. Three types of patients are admitted:

(i) those who still need active hospital treatment but, having spent long periods in hospital, need a change of surroundings ;

(ii) convalescent patients, pending discharge to their own homes or permanent settlements. For some of them, Chaseley has become their permanent home, where training and employment outside the home has been found for them ;

(iii) paraplegics who are already living at home but require a holiday.

Out of 28 inmates at present at Chaseley, 10 are working, 7 of them being full-time employed in clerical work at the regional dental board. The others are engaged in photography, bird-breeding and leather-work.

(*c*) *Duchess of Gloucester House, Isleworth.*

This institution, specially constructed for the use of paraplegics, was opened at the end of 1949. Although it was originally planned for the admission of paraplegic war pensioners only, it is now open also for civilian paraplegics. This is a residence for:

(i) fully medically rehabilitated paraplegics, who are able to take up work in industry or business immediately after admission.

(ii) those convalescent patients who can finish the last stage of their convalescence at this institution, pending readiness for work either in the neighbourhood or at home.

The Duchess of Gloucester House is purposely situated in an area of light industry, and out of the 19 war pensioners from the War of 1939–45, transferred there from this centre, 11 of them are out at work in nearby factories or firms. Seven more war pensioners are continuing their pre-vocational training there, pending their readiness for work outside.

During the last few years, the British Red Cross Organisation has opened two residential settlements of colony type for paraplegics:

(*d*) *Lyme Green Hall, Macclesfield, Cheshire.*

In this settlement, married paraplegics can live in specially built bungalows, and unmarried paraplegics in small rooms for three or four people. Only those paraplegics are admitted who are capable and willing to do regular work as cobblers, watch-repairers and wood-workers, in workshops set up on the premises of this settlement. At present there are 24 paraplegics living there, and all of them are at work. There are, however, no facilities for work outside.

(*e*) *Kytes Settlement at Watford, Herts.*

This settlement was originally planned as a colony of bungalows for those married paraplegics only who are capable of doing regular work outside the colony in industry or business. Experience has already shown that some of the residents have set up their own businesses in their homes, and it remains to be seen whether, in future, facilities will also be provided for work within the settlement, by setting up workshops. In the writer's opinion, the ideal settlement of colony type should include facilities for both work at home and work outside.

FOLLOW-UP

Every patient, who has passed through this centre and has been discharged either to his own home or to a settlement, is called up for regular check-ups—in particular of the urinary tract. This is done in conjunction with the Ministry of Pensions Regional Offices. This procedure has proved extremely beneficial in preventing or counteracting any deterioration at an early date.

CONCLUSIONS

The facts given in this account suffice to demonstrate the fundamental change which has taken place in the whole conception of the treatment and rehabilitation of paraplegic patients. Perhaps the most gratifying result achieved in this connexion is the complete change in the mental attitude in most of these disabled people towards work, and their realisation that regular work is an important factor for human happiness. One of the patients from this centre, who had great difficulty in readjusting himself to the new life after leaving hospital, put that fundamental change of mind into the following words, which are well worth mentioning here:—'It is a treat in the morning to be out first thing. I used to be miserable and fed up before, but I am not now. My appetite is better and I eat like a horse. I can sleep much better at night. Life is worth living now!'

Most of these men and women had to build up an entirely new scheme of life in becoming useful members of society again. However, the contribution of these most disabled war victims to society has already been great. It cannot be denied that, by their fine example of courage and perseverance, they have helped to overcome prejudice and correct that false conception of capacity for work, held through the centuries by society, which as a rule condemned the disabled as unemployable, unproductive and socially useless.

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CHAPTER 11

PERIPHERAL NERVE INJURIES

(i)

Surgery of Peripheral Nerve Injuries

By H. J. SEDDON and GEORGE RIDDOCH
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ORGANISATION

SERVICE patients with peripheral nerve injury were segregated in special centres, which were specially staffed and supervised by men experienced in the neurological features and surgery of nerve injuries. The centres in England were within orthopaedic centres in the Emergency Medical Services.

The term 'Service' covered all military patients; many patients from the Air Force were also admitted but few from the Navy, the latter preferring to deal largely with their casualties themselves.

The three centres in England were at: Botley's Park Emergency Hospital, Chertsey, Surrey, under the direction of the late Brigadier W. R. Bristow; Wingfield-Morris Orthopaedic Hospital, Oxford, under the direction of Professor H. J. Seddon; Winwick Emergency Hospital, Warrington, Lancashire, under the direction of Professor (now Sir) Harry Platt.

Two centres were later formed in Scotland at: E.M.S. Hospital, Gogarburn, near Edinburgh, under the direction of Professor J. R. (now Sir James) Learmonth; and E.M.S. Hospital, Killearn, near Glasgow, under the direction of Professor C. R. W. Illingworth. Unlike the English units, they did not form part of orthopaedic centres, though orthopaedic surgeons took part in the work at both centres.

ADMINISTRATION AND PERSONNEL

When the Peripheral Nerve Injuries (later called the Nerve Injuries) Committee of the Medical Research Council was formed, the Director-General of the Emergency Medical Services asked that this committee, through its chairman, should advise him on the practical management of these centres and upon administrative and clinical problems. The chairman, Dr. (later Brigadier) George Riddoch, thus became Consultant Adviser to the E.M.S. on Peripheral Nerve Injuries, and he was also Consulting Neurologist to the Army.

Unique opportunities for co-ordination of the work on peripheral nerve injuries in military patients were thus made possible.

(*a*) The M.R.C. Committee instigated and supervised research at the different centres. Research grants were given by the M.R.C. to certain men for special purposes, on the recommendation of the committee.

(*b*) The committee through its chairman—as Consultant Adviser E.M.S.—recommended policy in regard to organisation, equipment, personnel, rehabilitation and follow-up of patients in the centres. Their plan, which was embodied in a report to the Medical Research Council, was accepted by the Council and by the D.G.E.M.S., and was the first of its kind to be devised and put into force. The committee also drew up a scheme of note-taking—with charts for motor, electrical and sensory examination—and a method of assessment of motor and sensory recovery, all of which were adopted at the centres, with the result that the method of recording was made remarkably uniform. A system of filing of notes and of card-indexing was also instituted by the 'Follow-up' Committee of the Ministry of Health, of which the Consultant Adviser on peripheral nerve injuries was a member. He was also a member of the Rehabilitation Committee of the Ministry of Health.

(*c*) As Consulting Neurologist to the Army he was able, in co-operation with the Consulting Orthopaedic Surgeon (also a member of the Nerve Injuries Committee), to influence military policy with regard to peripheral nerve injuries.

A principle early laid down was that each patient should be dealt with in the centre nearest to his home and that he should be transferred there before the primary treatment of the damaged nerve had begun. If for some reason primary treatment had to be carried out at another centre, he would then be transferred as soon as possible with a copy of his notes to the centre nearest to his home. The 'follow-up' would then be arranged by this centre, a summary of the progress notes being sent to the first centre.

Another principle was that patients should not be kept in hospital for longer than was absolutely necessary. As soon as possible, it was decided whether the patient would be likely to be fit to return to military duties within six months—in exceptional cases nine months; if not he was at once invalided out and as soon as his primary treatment (which of course might include operation) was finished he was ready to be discharged to his home. Whatever the immediate status of the patient, his treatment and supervision continued without interruption. Before discharge, a Ministry of Labour representative interviewed him and his medical officer at the centre, to decide the nature of work he could and would desire to carry out in civil life. If possible, appropriate arrangements were made through the local Labour Exchange. Also, his family or panel doctor, or the medical officer at the local hospital received a personal letter with a summary of the patient's notes, the physiotherapy advised, advice on the complications to be watched for and how to guard against them, and instructions to communicate by letter with the centre if progress was not satisfactory. Also, a copy of the notes was sent to the D.G. of Medical Services (M.S.2), Norcross, Blackpool, for filing by the Ministry of Pensions. At the same time, men entitled to pension came within the official 'follow-up' scheme of the Ministries of Health and Pensions. The latter, through M.S.2, on notification from the appropriate centre, informed the patient that he was required to return for re-examination, sent him a railway warrant and paid for time lost from work. These arrangements were made through the regional offices of the Ministry of Pensions and worked very well throughout Great Britain and Northern Ireland; the proportion of defaulters was very small, rarely exceeding 5 per cent.

A five-year 'follow-up' was planned by the M.R.C. Committee in order to fill the great gap in our knowledge about end-results. After the War of 1914–18 enthusiasm died down, largely because of the absence of a proper organisation, and in all countries which had been at war the work was dropped long before it was completed. It was realised that this major defect must be avoided.

RECORDS

The method of note-taking devised by the Nerve Injuries Committee was adopted at all the centres, and stress was laid on the accurate recording not only of physical signs but also of symptoms.

Areas of cutaneous sensory loss were photographed at the Oxford Centre (a method which has much to commend it), but at the other centres they were recorded on outline charts which again were uniform. All forms required were ordered direct by the centres and paid for by the Ministry of Health. A summary of each set of notes was set out on a form which constituted the front page of the dossier. Each centre had its own filing and card index system and retained its own records.

Typewritten copies of each set of notes were made and the distribution was as follows:

(1) Original copy retained and filed at the centre.

(2) Typescript forwarded to the Ministry of Pensions to be filed there with the patient's other records.

(3) Typescript sent to the Nerve Injuries Centre nearest to the patient's home should he have to be transferred there for follow-up purposes. This rule usually applied only to patients who, because of the urgency of their injuries, had to be admitted in the first instance to the nearest centre. From there, they were transferred as soon as their condition permitted. If the investigation of the nerve injury and its primary treatment had been carried out at the first centre, the second centre forwarded a copy of their records of subsequent examinations to the first centre. On discharge of the patient to his home a copy of

the summary of the notes was sent to the doctor who would supervise his treatment.

Publications. In 1942 the M.R.C., for the Nerve Injuries Committee, published a booklet with photographic illustrations on *Aids to the Investigation of Peripheral Nerve Injuries* (M.R.C. War Memorandum No. 7; H.M. Stationery Office). It was very popular and in a few months the edition was sold out; a second was produced with corrections in the spring of 1943. At the same time, the M.R.C.'s old report on *The Diagnosis and Treatment of Peripheral Nerve Injuries* (M.R.C. Special Report Series, No. 54. H.M. Stationery Office, 1920) was reprinted in Canada. Supplies of both publications were bought and distributed by the medical branches of the three Fighting Services as well as by the E.M.S.

FEATURES OF THE CLINICAL ORGANISATION

Outstanding points which should be stressed are:

(1) Segregation of cases in special centres at home and abroad.

(2) Personnel at these centres chosen for their special knowledge irrespective of major interests in medicine and surgery, and junior members trained by them.

(3) Research at the centres controlled by the Nerve Injuries Committee of the M.R.C. Grants, instruments, etc., provided by the M.R.C. on the recommendation of the committee; methods of recording, etc., more or less standardised.

(4) Full co-ordination of effort in research (M.R.C.) and care of patients (E.M.S.) achieved through liaison by chairman of the committee as Consultant Adviser E.M.S., and Consulting Neurologist to the Army.

(5) Utilisation in war effort of patients discharged from the Fighting Services through liaison with the Ministry of Labour.

(6) Continuation of physiotherapy near home and place of occupation through the E.M.S.

(7) Follow-up organised through liaison with the Ministry of Pensions.

REHABILITATION

The condition of Service patients arriving at E.M.S. peripheral nerve injuries centres from abroad varied considerably, chiefly owing to variability in the care of the affected limbs in hospitals abroad and during transit home.

In the Middle East, patients with peripheral nerve injuries were segregated in selected hospitals and in time adequate physiotherapy was provided. Those who were evacuated for home were retained *en route* at military hospitals in Natal for several months waiting for transport. In time, physiotherapy and occupational therapy improved greatly at these hospitals.

If the patient travelled by hospital ship some physiotherapy might be provided; but otherwise, and in other transport, there was none. Thus unless the patient himself kept his injured limb supple, either by his own efforts or by the help of others, he was apt to arrive home with stiff joints. The condition of the limb varied also with the intelligence and co-operation of the patient; this of course also applied to patients at home but, because of better supervision and skilled aid, to a lesser extent. In India, segregation was also practised but physiotherapy was difficult to provide because of the lack of trained personnel.

In Great Britain rehabilitation was carried out in two phases: (1) at the nerve injuries centre, and (2) after discharge from the centre when the primary treatment was finished.

(1) *Rehabilitation at the Peripheral Nerve Injuries Centres.* The aim was to provide special and general remedial therapy: (*a*) *Special Remedial Therapy*, massage, electrotherapy, active and passive movements, warmth and splinting. Special re-educative exercises were also used, often in the form of occupational therapy, with a view to improving muscle co-ordination and tactile discrimination. This work was arduous; one physiotherapist could not give more than fifteen courses of treatment a day, for half an hour had to be allowed for each patient. (*b*) *General Remedial Therapy*, both mental and physical, in order to keep the whole man active, interested and occupied. These measures included physical training, occupations both indoor and outdoor—carpentry and gardening, for example—games, lectures and entertainments, the activities being graduated to suit the capacity of each individual and of different groups. A fairly formal programme was followed and each day was pretty fully occupied.

(2) *Rehabilitation after Discharge from the Centre.* If a patient was invalided out of the Service he was discharged home, arrangements being made for him to attend the orthopaedic or fracture centre, or other clinic nearest to his home, in order to continue with the physiotherapy required. At the same time, through a Ministry of Labour assessor and the local Labour Exchange, the patient was provided with a new employment if he was incapable of returning to his former occupation. From the first it was recognised that the best form of general rehabilitation was suitable re-employment, and this aim was achieved whenever possible as soon as the primary treatment was finished. Thus the man was enabled to continue with physiotherapy as an out-patient at a near-by clinic and return at intervals of three, six or twelve months to the peripheral nerve injuries centre for re-examination and re-assessment while earning his living in suitable employment. The Ministry of Labour's vocational training scheme was used at an intermediate stage in cases in which the patient was either untrained or, because of his disability, had to be trained for some other occupation.

CLINICAL WORK

METHODS OF EXAMINATION

No elaborate appliances were used in sensory examination. As a test for tactile sensibility cotton-wool is, perhaps, too delicate, and a number of workers were happier using *von Frey* hairs that bent with a deforming force of one and two grammes. Compass points were used for two-point tactile discrimination, and a sharp needle for pain sensibility. In the early period of the war most centres used tests for thermal sensibility, but as the work increased in volume these tests were abandoned, especially as they did not provide any additional information of clinical significance. Nothing, apart from carefully executed passive movements of appropriate joints, was used for the determination of postural sensibility. Guttmann's (1940) sweat test proved a most valuable guide to the extent of cutaneous sensory loss. Richards (1943, 1946) made a detailed study of the vasomotor changes following nerve injury, his instrument of choice being thermocouples, connected to a galvanometer, for measuring skin temperatures.

A simple system was used for grading muscle power; no special apparatus was required, and the method was sufficiently objective to permit of comparisons being made between assessments made by different observers.

5. Contraction against powerful resistance.
4. Contraction against gravity and some resistance.
3. Contraction against gravity only.
2. Movement only with gravity eliminated.
1. Flicker of contraction.
0. Complete paralysis.

For the electrical examination of paralysed muscles the ordinary galvanic and faradic apparatus was rightly considered inadequate. Bauwens (1941, 1943) and Ritchie (1944) showed conclusively that the most useful information could be obtained from the estimation of strength-duration curves. Reliable apparatus, delivering square-wave impulses of various durations and frequency, became available, with the result that a method of examination previously confined to the laboratory became established as a valuable diagnostic aid. Similarly, electromyography was translated from the laboratory to the clinic by Weddell and his colleagues (1943). These methods of examination, though ancillary, enabled the state of a nerve to be determined with remarkable precision. And although it remained true throughout that Riddoch was right in insisting that exploration of a nerve was often a necessary step in diagnosis and prognosis, the findings at operation could be interpreted more intelligently in cases where the state of paralysed muscles had been assessed by electrical stimulation and by electromyography.

CLASSIFICATION OF NERVE INJURIES

In 1942 Seddon proposed a simple classification which, he believed, was reasonably accurate from the pathological standpoint and was useful clinically. It was not new, in that the three kinds of damage he described had been known for at least a generation; what was novel was the attempt to classify nerve injuries clinically into three main types and various combinations of them.

Neurotmesis (τμῆσις, which implies a separation of related parts), was the term used to describe the state of a nerve that had either been completely divided or was so seriously interrupted by scar tissue that regeneration was altogether impossible apart from surgical repair. The term is more inclusive than *division* since it embraces lesions in which the nerve preserves an appearance of continuity but is, in fact, completely blocked by scar formation.

Axonotmesis. Here the essential lesion is damage to the nerve fibres of such severity that complete peripheral degeneration results, though the stroma of the nerve remains intact. Since the endoneurial tubes are preserved regeneration occurs spontaneously and is of excellent quality, the endoneurial tubes guiding the out-growing fibres back to their proper peripheral connexions. Such lesions can be caused by war wounds but much more regularly by closed fractures. Clinically, the most important point is that there is no immediate means of distinguishing between neurotmesis and axonotmesis. In both there is complete degeneration of the nerve below the lesion and in both the clinical picture is that of complete interruption.

Neurapraxia (ἀπραξία, non-action), the third type of injury, is a benign lesion. The paralysis is predominantly motor, and there is little muscle wasting or significant change in electrical excitability. Cutaneous sensory loss is not always present and, if found, is of less extent than the motor disturbance. The actual damage is predominantly a localised degeneration of the myelin sheath, which explains why the motor fibres suffer most. The axons remain in continuity and recovery usually occurs in a few days or at most several weeks.

Causalgia was seen far less frequently than during the War of 1914–18. It was tempting to attribute the decreased incidence to the great improvement in the treatment of wounds. On the other hand, its frequency in the American armed forces was fairly high, though their standard of wound treatment was in no way inferior to the British; and among our own cases there were many examples of causalgia in patients whose wounds healed rapidly and without significant sepsis. In all the belligerent countries upper thoracic sympathetic ganglionectomy emerged as the most reliable means of relieving the pain, when it showed no tendency to abate spontaneously. Speculation about the nature of causalgia was, naturally, focused on the sympathetic nervous system; Doupe, Cullen and Chance (1944) put forward the ingenious notion that there was a sort of short-circuit between sympathetic and sensory fibres at the site of the lesion and that the well-known causes of aggravation of the pain, such as thermal changes and emotional stimuli, acted in virtue of the increase they produced in sympathetic discharges which, in turn, induced activity in pain fibres at the site of damage.

NON-OPERATIVE TREATMENT

It was quickly realised that the most important single factor in the maintenance of the injured limb in a healthy condition was preservation of mobility (Ritchie Russell and Harrington, 1944). The most tragic cases were in men who made a slow journey by hospital ship with the paralysed part carefully splinted, but without any instructions to keep the peripheral joints moving either actively or passively; a man who was taken prisoner and treated in a casual manner fared far better, so far as his nerve injury was concerned. Oedema was particularly liable to develop if there was extensive paralysis and if the part was allowed to be dependent, for the return flow of lymph from a limb depends almost entirely on muscular activity. Within the swollen part stagnating lymphocytes accumulate and become transformed into fibroblasts which, in turn, cause deposition of collagen throughout the soft tissues. Thus there is formed a sort of three-dimensional cobweb of 'adhesions' which causes grave restriction of mobility. The other important cause of limitation of movement is muscle shortening. A normal muscle may shorten at the expense of a paralysed antagonist, a factor so well-recognised that preventive splinting was all but universal. However, it was not so clearly realised that a paralysed muscle can shorten; denervated muscle always undergoes more or less interstitial fibrosis and if it is maintained in full relaxation, and regular passive movements of the joints it controls are neglected, a disabling contracture will develop. Serious shortening of paralysed muscle was most commonly seen in the extensors of the fingers.

The practice of splinting paralysed muscles in relaxation is mainly traditional; all that is known for certain is that persistent *over stretching* of a paralysed muscle is very damaging. Hence, there were widespread differences in practice as between the various nerve injuries centres, and even individual surgeons were not invariably consistent. However, there was general agreement about the desirability of some form of support in cases of radial paralysis; some surgeons were in favour of protecting the paralysed intrinsic muscles of the hand; and the toe-raising spring in cases of sciatic paralysis was universally used if only as a convenience to the patient. But ultimately no one questioned the necessity of putting the paralysed part through a full range of movement at least once daily.

Before the war, animal experiments had tended increasingly to show that the progressive shrinkage and fibrosis of denervated muscle could be largely controlled by regular stimulation with an electrical current of long duration (galvanism). Experiments carried out at Oxford by Gutmann and Guttmann (1942, 1944) were conclusive, but they, like many others, treated their animals with a frequency and an intensity that was hardly practicable clinically. A clinical experiment was, therefore, carried out by Shirley Jackson (1945) under the supervision of Seddon. Comparable cases of ulnar, or combined ulnar and median nerve injury were treated over long periods with or without galvanism, the treatment being identical in other respects. The volume of the hand was used as a rough index of muscle wasting, and it was found that daily treatment of tolerable duration, compatible with the patient's returning to work, was most beneficial; it arrested but did not reduce the wasting. However, it was not shown that galvanism was equally effective in preventing wasting in large masses of muscle, since a tolerable stimulus does not affect all parts of a large muscle mass equally, the deep fibres tending to escape altogether.

OPERATIVE REPAIR

Primary Suture. In the *Official History of the War of* 1914–18, Thorburn (1922) wrote: 'Primary suture of divided nerves is, as it always has been, the ideal method of treatment'. It was admitted that this ideal was rarely attainable where the injury was due to a war wound, but during the War of 1939–45 it seemed possible that, as a result of the spectacular improvement in the treatment of wounds, primary or delayed primary suture might prove satisfactory. This, however, was not the case, and Zachary and Holmes (1946) showed how it was that even after a clean, incised, accidental wound primary repair of a nerve was inferior to early secondary suture.

Sepsis is not a serious bogey. The most important factor is the interstitial damage to the stumps that occurs when a nerve is severed by any but the sharpest instrument. It cannot be recognised at the time of primary repair, and it may subsequently be found that a dense block of interstitial scar tissue is present at the site of what had been an apparently satisfactory suture. It is possible to avoid this hazard by excision of the nerve stumps, but it will then be necessary either to flex a neighbouring joint acutely, or mobilise the nerve extensively, in order to approximate the stumps. Both procedures are undesirable. It was found that after acute flexion of the wrist for repair of the median or ulnar nerve there was often either limitation of extension of the wrist or, worse still, partial separation at the suture line, the nerve stumps and even the anterior capsule of the joint having become involved in the primary scar; and mobilisation in the presence of a fresh accidental wound will be disastrous if sepsis occurs. Thus it emerged that the correct treatment was to tack the nerve ends together, to close the wound, and to carry out early secondary repair three or four weeks later. By this time the extent of intra-neural collagenisation is perfectly evident; extensive mobilisation can safely be performed; and the nerve sheath will have thickened over several centimetres in each stump, with the result that repair by suture can be carried out far more exactly than at a primary operation, when the sheath is at best thin, and at worst split and frayed. A comparison of the results of primary suture with those of early secondary suture showed that although the primary operation was often most successful, it was far less reliable than early secondary repair.

INDICATIONS FOR OPERATION

Although the surgery of war is traditionally the surgery of wounds, the incidence of closed injuries was high enough to warrant some mention of those in which peripheral nerves were involved. Motor-cycle accidents were responsible for hundreds of cases of traction injury of the brachial plexus; the radial nerve was not infrequently involved in closed fractures of the shaft of the humerus; and adduction injuries of the knee caused traction lesions of the lateral popliteal nerve. Traction injuries produce lesions of enormous extent; in some it was found that intra-neural collagenisation extended over about 20 centimetres. By comparison with such a formidable obstacle to regeneration, the presence or absence of rupture of the nerve is of little moment. In consequence, there were few cases in which operative repair was feasible. Fortunately, the damage was frequently less serious, and useful, spontaneous recovery, though often incomplete, was not uncommon; the return of voluntary power was usually long delayed, probably on account of the difficulty experienced by down-growing axons in traversing, and attaining functional maturity in, a long zone of intra-neural scarring.

More localised nerve injuries due to closed fractures, in which the damaging force was mainly compression, gave little trouble. In most cases excellent recovery occurred spontaneously, and exploration was carried out only when evidence of recovery was lacking at a time when, from calculation based on knowledge of the level of the lesion and the rate of regeneration (Seddon, Medawar and Smith, 1943), it should have been present had the lesion been an axonotmesis.

OPEN WOUNDS

Beyond noticing that paralysis was present, and arranging for conservative treatment to be started at the earliest convenient time, surgeons in the forward area dealt simply with the wound as such. If a divided nerve was seen during the course of excision of the wound the ends were brought together; if part of the nerve had been destroyed the stumps were sometimes anchored to adjoining muscle or fascia. If by chance a nerve was seen to be in continuity, a note to that effect informed those subsequently responsible for the case that there was a chance of spontaneous recovery. Cases of nerve injury enjoyed a fairly high priority in evacuation since it was recognised that the sooner a man reached a nerve injuries centre the sooner his nerve could be explored and, if necessary, repaired. Unfortunately the exigencies of war sometimes caused grave delay, and a large number of men with nerve injuries accumulated in South Africa owing to the impossibility of finding sufficient ships to bring them to the United Kingdom. The plan to establish a nerve injuries centre in the Union was unhappily delayed by the loss at sea of the surgeon designated for this work, an exceptionally able young New Zealander, W. B. Highet, who had gained his experience at the Oxford centre. As communications improved the delay between injury and the arrival of patients at nerve injuries centres steadily decreased, and after D-day men began to arrive at the centres within a week or two, sometimes within a few days, of the time of injury. During the second half of the war a number of nerve repairs were carried out by Army surgeons in India, Palestine and Italy, and the progress of these cases was subsequently followed at the centres in the United Kingdom. With improvements in primary wound treatment and chemotherapy the interval between injury and exploration was progressively reduced, and by 1943 it was found safe to explore a nerve within a few weeks of the healing of the wound.

Every case in which there were signs of complete loss of conductivity was explored, except where the early notes clearly indicated that the nerve was in continuity and not grossly damaged. The basis for this radicalism was the evidence from the War of 1914–18: it had been found that in half the cases of nerve injury due to war wounds the nerve was divided—and the proportion proved to be much the same in the War of 1939–45. There is no means of determining whether or not division is present, apart from exploration or waiting for the appearance of signs of spontaneous recovery. In the first war many surgeons, and in the second a few outside the United Kingdom, were content to pursue an expectant policy, limiting exploration to cases in which useful spontaneous recovery failed to occur. However, the experimental work of the Oxford team (Holmes and Young, 1942; Gutmann and Young, 1944; and Bowden and Gutmann, 1944) clearly demonstrated the harmful effects of delay in the peripheral stump of the divided nerve, and in the muscles it supplied. In order to give the patient presenting the syndrome of complete paralysis the best possible chance of recovery, it was therefore deemed justifiable to subject him to operation even though there was an even chance that repair of the nerve might not be required. The soundness of this policy has been borne out by analysis of the results of suture.

No significant advance was made on the technique of secondary suture developed during the War of 1914–18, but the limitations of this method of repair became clearly manifest. It is possible to close very large gaps by extensive mobilisation of the nerve stumps and flexion of appropriate joints. However, where the gap is considerable, the subsequent straightening of the acutely flexed limb, no matter how cautiously carried out, usually inflicts a traction injury on the nerve of such severity as to preclude recovery (Highet and Holmes, 1943; Highet and Sanders, 1943). Thus it became necessary to determine the biological limit of resection, which was considerably stricter than the anatomical. In working out the results of suture from all five centres (which appears in detail in the Report to the Medical Research Council), Zachary endeavoured to determine the greatest extent of the gap that could be closed with a fair prospect of recovery. The provisional figures, taken from the unpublished interim report, are as follows:

Median:	high and intermediate resections	7·0 cm.
	low resections . . .	7·5 cm.
Radial:	high and intermediate resections with anterior transposition .	7·5 cm.
	all resections without anterior transposition . . .	5·3 cm.
Ulnar:	. . . .	about 6·0 cm.
Sciatic:	not yet determined with certainty.	

As a rough guide it may also be said that any suture requiring more than 90 to 100 degrees flexion of a joint carries a considerable risk of failure.

If, as was formerly believed, there is no alternative to end-to-end suture, this information would only be of prognostic interest, but from his experience in a series of some 60 cases Seddon (1947) showed that autogenous nerve grafting is a reliable method of repair. Cable grafts, made up of strands of cutaneous nerve, were used with success; and there was also an encouraging group of cases in which the less important of a pair of extensively damaged main nerve trunks was used to provide a graft for repair of the other. In a series of 13 cases of great loss of substance in nerves in the upper limb, a segment of one nerve was used for repair of the other, or part of one main nerve was split off and used to bridge the gap in the remainder; in 9 of these cases recovery was as good as that seen after a favourable end-to-end suture. Unfortunately, attempts to repair the medial popliteal nerve with a pair of grafts taken from the lateral popliteal gave disappointing results, and it was subsequently shown that these large grafts, if taken from the central stump, were liable to undergo necrosis (Holmes, 1947). It became apparent that some method for preservation of the blood supply of the large grafts would have to be found. At the Winwick centre and later independently, by Strange (1947) at Dunston Hill, near Newcastle, nerve pedicle grafting was successfully developed as the answer to this problem. Thus, autogenous nerve grafting has not only taken its place as a reliable method of repair, but the scope of its application is wider than was at first suspected; not only is it likely to supersede such extraordinary methods of repair as bulb-suture and end-to-end suture after bone shortening, but it should be used without hesitation where, although end-to-end suture is technically possible, the gap is so great that the post-operative stretching is bound to be harmful.

Homogeneous nerve grafting was an unqualified failure (Seddon and Holmes, 1944; Barnes, Bacsich, Wyburn and Kerr, 1946).

Several new suture materials were tried. Stainless steel and tantalum wire enjoyed some popularity, though both are liable to tear the nerve sheath; Guttmann (1943) recommended human hair, which is very satisfactory for repair of the smaller nerves if there is no tension. The introduction of fibrin clot as a means of gluing nerve stumps together (Young and Medawar, 1942; Seddon and Medawar, 1942) was a significant advance. While there was little to commend it for the repair of large nerve trunks, stitches being indeed superior for accurate coaptation of the nerve sheath, the fixation of small nerves was greatly simplified. Plasma suture has abolished the chief technical difficulties in the operation of cable grafting.

If closure of large gaps presents the greatest technical problem in the surgery of peripheral nerve injuries, the one calling for the greatest exercise of judgment is the decision for or against resection, when a nerve damaged by an open wound is found to be in continuity. In the early days of the war there was a natural and proper tendency towards conservatism. By 1942 it became possible to make comparisons between the spontaneous recovery that had occurred in such cases where the nerve, injured in continuity, had simply been explored, with that seen after favourable suture of comparable nerves at comparable levels. It was also possible to distinguish those lesions in continuity that could be counted on to show good recovery, from those in which the prospects would have been better had resection of the damaged segments and end-to-end suture been performed. If the nerve was found to be of normal consistency and showed no gross abnormality apart from proliferation of the epineurium then it was likely that recovery would be excellent—that is to say, the lesion was in the main an axonotmesis. If the familiar fusiform neuroma was found, the prognosis was largely determined by the consistency of the lesion; a firm swelling indicated severe intraneural fibrosis and recovery would be correspondingly poor. Palpable intraneural scarring might be found in the absence of any striking change in the shape of the nerve; the prognosis would then depend on the extent of the scar, but was uncertain at best. A hump-like lateral bulge is a certain indication of partial division; there may even be separate bulges corresponding to the central neuroma and the peripheral glioma of a completely divided nerve. Where paralysis was complete, it was found best to regard the partial division as a lesion seriously involving the whole thickness of the nerve, for, as was shown by Zachary and Holmes, there was invariably a gross disturbance of the part of the nerve that appeared to be intact. Trial incision of the exposed nerve, though superficially a risky procedure, emerged as the most reliable diagnostic aid. In cases in which the damaged segment was firmer than normal, a small transverse incision was made in the segment of the nerve where the induration was greatest, and almost invariably it was found that the intraneural scarring was more widespread than had been suggested by palpation alone. Involvement of more than half the nerve by scar tissue is a clear indication for resection and suture; and it is worth remembering that the radical operation is being carried out under very favourable conditions, since the resection is minimal and rotation of the stumps completely avoidable.

RESULTS OF SUTURE

The value of careful planning has nowhere been more apparent than in the assessment of the results of nerve repair. In 1943 the Nerve

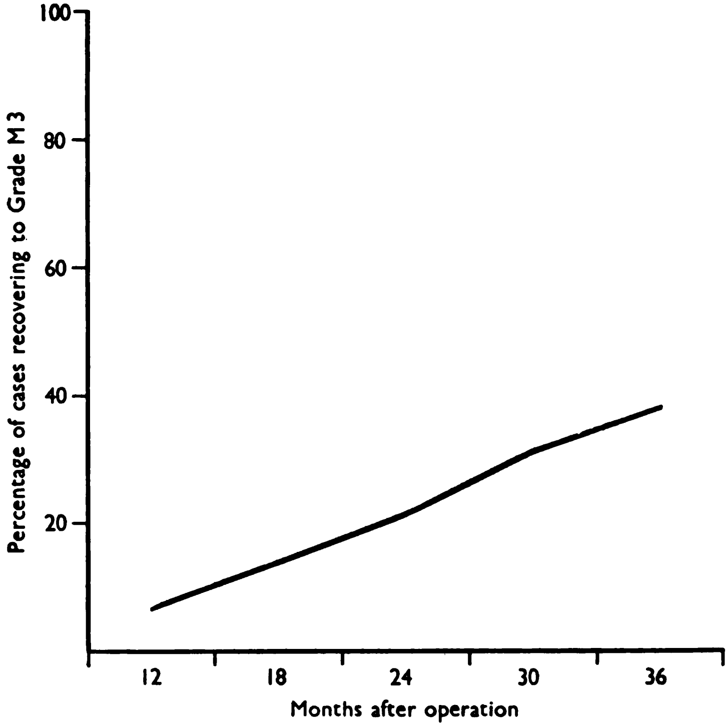

FIG. 1. Motor recovery in all median nerve sutures

Injuries Committee adopted a system of neurological grading of recovery proposed by Highet:

I. *Motor Recovery*:
Stage 0 No contraction.
Stage 1 Return of perceptible contraction in the proximal muscles.
Stage 2 Return of perceptible contraction in both proximal and distal muscles.
Stage 3 Return of function in both proximal and distal muscles of such an extent that all *important* muscles are of sufficient power to act against resistance.

Stage 4 Return of function as in Stage 3 with the addition that *all* synergic and isolated movements are possible.
Stage 5 Complete recovery.

II. *Sensory Recovery*:
Stage 0 Absence of sensibility in the autonomous zone.
Stage 1 Recovery of deep cutaneous pain sensibility within the *autonomous zone* of the nerve.
Stage 2 Return of some degree of superficial cutaneous pain and touch sensibility within the autonomous zone of the nerve.
Stage 3 Return of superficial cutaneous pain and touch sensibility throughout the autonomous zone with disappearance of any over-response.
Stage 4 Return of sensibility as in Stage 3 with the addition that there is recovery of two point discrimination within the autonomous zone.

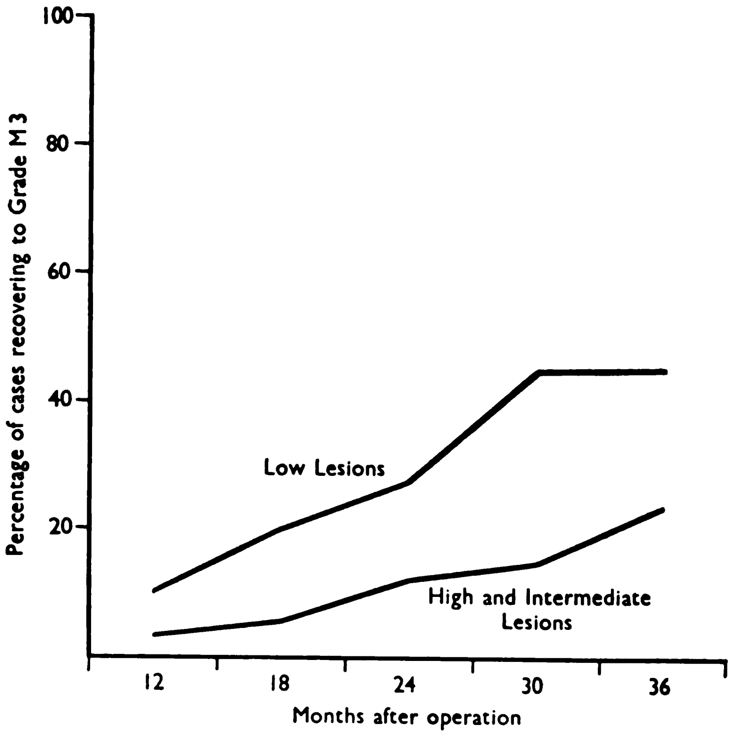

FIG. 2. Median nerve suture. Motor recovery

Workers at all the centres agreed to follow their cases for at least three years, and in several hundred cases observations have been continued for five years. There is now a unique corpus of data from which it is possible to draw a number of authoritative conclusions. An interim analysis has already been made by Zachary, and the final results appeared in the Medical Research Council Report.

In every case the neurological assessments used have been those recorded at the earliest date after 12, 18, 24, 30, 36, etc. months after operation, no account being taken of the actual date of operation. It was found that the most significant factors affecting the prognosis were (*a*) the level of the lesion, that is to say, the site of suture in relation to the distribution of the nerve; (*b*) the delay between injury and operation; and (*c*) the extent of the gap after resection. The method of assessment is illustrated in detail in relation to motor recovery after repair of the median nerve. Fig. 1 shows the progress of recovery in a series of 324 cases followed for periods ranging from twelve to thirty-six months. The figures on which the charts are based are the percentages of cases available in each post-operative period that have attained a useful grade of

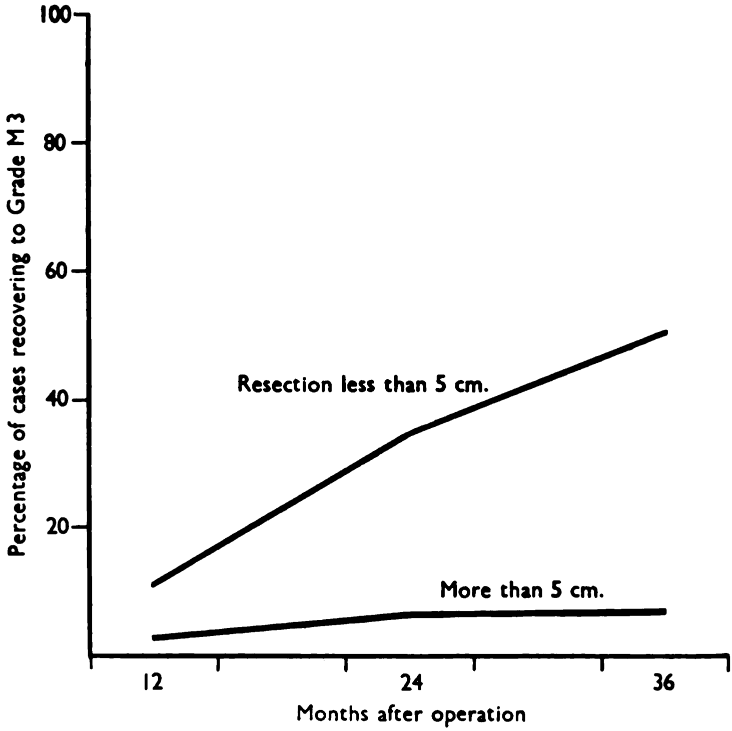

FIG. 3. Median nerve suture. Motor recovery

recovery. In the group as a whole there is progressive improvement until and perhaps beyond the third year after suture. Fig. 2 shows that the high and intermediate sutures give significantly worse results than the low; furthermore, as would be expected, the latter reach finality before the high and intermediate lesions somewhere round the thirtieth month. The latter, even at thirty-six months, are inferior to the low sutures at twenty-four.

Low median sutures alone were analysed in relation to the length of resection, according to whether the gap after resection of the stumps was more or less than 5 cm. Fig. 3 shows that the results are very considerably better when the gap is less than 5 cm.; the *critical resection length* was found to be about 7 cm., and any larger gap is better closed by autogenous grafting. Similar analyses have been made to determine the effect of delay and what might be termed the *critical delay* after injury. So far as motor recovery in the median nerve is concerned it was found to be nine months for intermediate and high lesions, that is, those in which motor recovery is important.

As a practical summary of the value of nerve repair, it may be said that, provided the interval between injury and operation does not exceed a year, and that end-to-end suture is not employed where the gap in a nerve is more than 7 cm., a worthwhile result is obtained in most cases of radial, median, and internal popliteal nerve injury. Repair of the lateral popliteal component of the sciatic nerve is rarely successful (that is, enabling the patient to dispense with a toe-raising spring) unless the lesion is situated distally and the gap after resection of the stumps is less than 5 cm. Repair of the ulnar nerve is hardly worth attempting if the lesion is proximal to the elbow; and successful repair of the brachial plexus is limited to lesions of the upper trunk, cervical 5 and 6.

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(ii)

Histology of Peripheral Nerve Injuries

By J. Z. YOUNG
M.A., F.R.S.

In attempting to find the solutions for many of the problems presented by war injury to the peripheral nerves experimental methods were employed, as well as ordinary observation of material removed at operation. In addition to the classical methods, considerable use was made of the new silver-on-the-slide techniques (Bodian, 1936; Holmes, 1942). Histological examination of the pieces of traumatised nerve removed at operation has been carried out as a routine by centres dealing with nerve injuries, but it is too early yet to correlate degree of recovery with amount removed or state of the stumps which have been sutured.

A major difficulty with these lesions has always been diagnosis, especially in cases where the nerve has been incompletely divided. Seddon (1942) has suggested a classification of nerve injuries into three main classes, neurotmesis, division of the whole thickness of a nerve, axonotmesis, interruption of the axons, but not of the supporting tubes in which they run (Young, 1942), and neurapraxia, paralysis unaccompanied by peripheral degeneration. After axonotmesis the rate of advance of fibres down the peripheral stump (Guttmann, *et al.*, 1942; Seddon, *et al.*, 1943), and the speed and quality of recovery are all greater than after neurotmesis. The condition of immersion foot (Blackwood, 1943) provides a particular type of axonotmesis, with rapid and thorough re-innervation. It has been shown that pressure may produce paralysis with delayed recovery, swelling of the axis cylinders, local demyelination and considerable mesodermal reaction, but not Wallerian degeneration (Denny-Brown and Brenner, 1944). This agrees with the conception that the trophic dependence of a nerve fibre on its nerve cell depends on an intra-axonic pressure, in whose absence the myelin rounds up under its surface tension ('degeneration') (Young, 1944).

Since a nerve is often deprived of its blood supply by operative procedures or trauma it is important to know the effects of ischaemia. Removal of the entire regional blood supply of the sciatic nerve in the thigh of a rabbit produces, in most cases, no obvious histological change (Holmes, *et al.*, 1944). On the other hand complete ischaemia, such as that associated with Volkmann's contracture, produces severe changes in nerve, varying from typical Wallerian degeneration to an obliterative endoneurial collagenisation or even complete necrosis (Adams, 1943). Evidently therefore the longitudinal blood supply is usually able to maintain an adequate circulation (Adams, 1942), and there is no objection to the classical surgical technique of mobilisation of long lengths of nerve.

In an attempt to improve the unsatisfactory results which usually follow nerve suture several workers have re-investigated the fundamental processes of nerve union. Weiss and Taylor (1943) have shown the importance of the longitudinal orientation of the fibres of the clot which forms between the nerve stumps. Such orientation enables good connexion to be made by the Schwann cells which grow out from the peripheral stump (Holmes and Young, 1942). The outgrowth of new nerve fibres can be considered as essentially a process of flowing (Young, 1942), the axoplasm passing over the surfaces of the Schwann cells and down the tubes left after degeneration in the peripheral stump. Further evidence has been presented that there is no special neurotropic attraction of fibres into a peripheral stump (Weiss and Taylor, 1944) and few continue to support this theory (Lavrentjev, 1942). The union was found to be less effectively made if there was a long delay between the severance of the nerve and the union of its stumps (Holmes and Young, 1942). One reason for this is that the wandering activity of the Schwann cells is greatest at about three weeks after interruption of a nerve and thereafter progressively declines (Abercrombie and Johnson, 1943). There have been other indications that recovery is less effective when suture is performed at long periods after injury. Delay prejudices the medullation of the new fibres in the peripheral stump, apparently because there is a progressive shrinkage of the tubes (Holmes and Young, 1942; Sanders and Young, 1944). After long periods of atrophy the innervation of muscles is very much less complete than after early suture (Gutmann and Young, 1944). These investigations suggest that if nerve injuries were operated within the first month after injury recovery would be more satisfactory than after the long delays which have been frequent in the past. Clinical practice is tending towards earlier operation, and results are reported to be favourable, but critical data are not yet available.

The use of sulphonamides has contributed to make early operation feasible. Reasonable doses do not injure nerve nor delay regeneration but large amounts may do so (Holmes and Medawar, 1942; Hammond, *et al.*, 1943) and very serious results have followed accidental injection of sulphonamides into the sciatic nerve (Seddon, 1943).

Histological study has been made of various methods for the surgical union of nerves. Gutmann (1942) investigated the reaction produced by various suture materials, confirmed the undesirable reaction produced by catgut, and found woman's hair and plain white silk to produce the least reaction. For experimental purposes concentrated plasma has been found very useful for holding nerve ends together (Young and Medawar, 1940; Tarlov and Benjamin, 1943). In man the technique has been found to be useful mainly in the placing of nerve grafts (Seddon and Medawar, 1942; Tarlov, *et al.*, 1943). Remarkably good unions of nerve stumps were found in animals by means of the use of arterial sleeves

(Weiss and Taylor, 1943; Weiss, 1943), but clinical trial of this method has not yet been reported.

As in the War of 1914–18, there has been much discussion of methods for overcoming the difficulty of bridging the gaps left in a nerve after the resection which is necessary following many gunshot wounds. The usual procedure is still to mobilise a long length of the nerve and make the suture with the joints flexed. The subsequent process of straightening is often accomplished successfully, but where very extensive resections of the lateral popliteal had been bridged by this method the stretching of the nerve during straightening of the knee produced changes as severe as the original traction lesion and hence a failure of recovery (Highet and Holmes, 1942). Evidently there is a limit to the amount which can safely be removed from a nerve.

Further experimental investigation of nerve grafts (Sanders and Young, 1942) has shown that autografts in rabbits are incorporated as live tissue and produce very satisfactory recovery. There is evidence that thin autografts in man behave similarly (Seddon, *et al.*, 1942) and that they can be used in suitable situations such as the nerves of the palms of the hands (Sanders, 1942). Homografts, on the other hand, though they may be successful in animals (Bentley and Hill, 1940; Gutmann and Sanders, 1942) have been found in man to be converted into scar tissue, not invaded by nerve fibres, and a complete failure functionally (Seddon and Holmes, 1944). Heterografts and grafts of material fixed in alcohol or formaldehyde produce even more violent reactions (Sanders and Young, 1942). They were extensively tested by the French in the War of 1914–18 with little success, and were not used by British surgeons in the War of 1939–45 (see, however, Klemme *et al.*, 1943; Lavrentjev, 1942.)

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CHAPTER 12

INJURIES OF BLOOD VESSELS

By Sir JAMES LEARMONTH
K.C.V.O., C.B.E., M.D., Ch.M., F.R.C.S. Ed.

In peace, British surgeons have few opportunities of studying the effects of missiles upon blood vessels, and they would have been relatively unprepared to deal with this highly important aspect of war surgery, had it not attracted the attention of Sir George Makins, both in the South African War and in the War of 1914–18.

In 1919 Makins published his book *On Gunshot Injuries to the Blood-vessels*, a classic in which he assembled and analysed his extensive clinical experience, and gave wise directions for the management of these injuries. Although certain types of injury were common to both wars, Makins noted the changes in the pathological anatomy of the wounds of 1914–18 which had resulted from changes in the outline and velocity of fragments of shells and bombs, and from the instability in flight of rifle and machine-gun bullets. Further changes have followed the developments in explosive compounds and in artillery methods which were elaborated between 1918 and 1945. The extensive use of the mortar, which scatters many small fragments at very high velocities, has modified injuries to blood vessels in two ways: the large area of disruption surrounding even a small fragment may affect a considerable length of a main vessel, and that severely; and the multiplicity of fragments tends to interrupt collateral channels, with consequent threat to the vitality of distal parts. At lower velocities fine fragments may wound or contuse a main vessel, or produce one of the forms of arteriovenous aneurysm, types of injury also produced by bullets. Such injuries resemble those seen by Makins in 1914–18, in 'the tendency to spontaneous cessation of primary haemorrhage', and in 'the large proportion of them which are followed by the development of one of the several forms of traumatic aneurysm'; but whereas Makins noted 'the frequency with which such forms of injury are the occasion of secondary haemorrhages', in E.M.S. hospitals secondary haemorrhage has been comparatively infrequent. The absence of this complication reflects the absence of infection, or of serious infection, in wounds generally, and is not a special characteristic of vascular injuries of the War of 1939–45.

The immediate problems in the treatment of vascular wounds are simply stated: they are the preservation of the life of the patient by early control of any bleeding sufficiently profuse to threaten life, and the preservation of nutrition in the territory of the wounded vessel distal to the wound. These two problems are not necessarily always present together: thus a casualty may bleed to death, as a result of the division of numerous small vessels in a large flesh wound which does not threaten the nutrition of parts other than those in the immediate vicinity of the wound; whereas a wound of a main artery, itself the source of no considerable loss of blood, may be followed by gangrene of distal parts. Nevertheless, both problems obtruded themselves in E.M.S. hospitals; in the victims of air raids, both control of haemorrhage and efforts to maintain nutrition were often required; in casualties from Europe, haemorrhage had been controlled, but, at least in the early stages of the invasion, casualties reached this country in whom the problem of maintaining nutrition was still pressing. Moreover, the latter problem, whether it was posed after air raid or battle-wound, could not be regarded as solved by the preservation of sufficient blood flow merely to ensure the continuing life of a part. Ill-nourished tissues are notoriously prone to infection, and particularly to infection by anaerobes; the ideal was to provide, if possible, an immediate and maximal blood supply to threatened parts.

The period 1918–45 saw substantial progress towards the solution of both problems, and the factors which contributed to this progress may now be considered.

CONTROL OF HAEMORRHAGE

For the temporary control of bleeding some form of pressure continued to be the only available method; this may be exerted by a tourniquet, by a dressing firmly applied over a wound, or by an artery forceps applied to the bleeding vessel. Progress in this aspect has been the literal progress of trained personnel towards the casualty, whether in air raid or on battlefield; an administrative rather than a technical achievement, of the value of which there can be no doubt. For the permanent control of haemorrhage, the ligature continues to be the most generally applicable method. New methods of controlling bleeding from numerous small sources and from certain special tissues have become available. Thus many E.M.S. hospitals have been equipped with surgical diathermy machines, which provide a precision of coagulation impossible with the cautery; in the brain and elsewhere, the natural arrest of bleeding may be initiated and completed by the application of fibrin in the form of a 'foam', and large raw cavities may be packed with oxidised cellulose soaked in thrombin, which provides both a scaffold for clotting and local pressure (Bering, 1944; Uihlem and Claggett, 1945). Definitive surgery has also been brought closer to the casualty, with consequent saving of both life and tissue. To the technical advantages of early surgery in controlling bleeding must be added the prevention or limitation of infection, aided by the early availability and widespread use of chemotherapy—by sulphonamide drugs in the early years, and in the last year of the war by these drugs and by penicillin; a combination which reduced the incidence of secondary haemorrhage.

In the control of this, when it does occur, Makins's advice to secure the bleeding point still holds good; moreover, such interventions may now be more hopefully undertaken, since usually the accompanying infection can be rapidly brought under control.

MAINTENANCE OF NUTRITION IN TERRITORY OF WOUNDED ARTERY

Restoration of blood flow through damaged artery. In the treatment of arterial wounds it would be ideal if the blood flow could be re-established through the wounded vessel, with the least possible diminution of its calibre. The lesions in which the possibility of such operative treatment arises include:

(1) Arterial wounds in which loss of tissue has been small enough to allow of their edges being coapted without tension;

(2) Complete or nearly complete division of an artery, without much loss of substance, when its continuity may be restored by anastomosis of its proximal and distal segments. In order to ensure that there shall not be tension at the suture line, some proximal and distal freeing of both segments may be necessary. This dissection may have to be discontinued at the origins of important collateral branches, and therefore anastomosis is most applicable when the division has involved a segment of artery devoid of any but insignificant branches;

(3) Arterial haematomas, or traumatic aneurysms, in which it may be possible to suture the opening in the arterial wall; and

(4) Arteriovenous fistulae, in which it may be possible, after controlling the circulation through the limb, to expose the arterial defect by opening the vein at a point opposite to it, and closing it by sutures.

The technique of vascular suture has scarcely altered since 1905, when it was perfected by the experimental work of Carrel and Guthrie; and it might be supposed that it would find a wide application in war. However, the circumstances under which recent war wounds must be dealt with, involving as they usually do pressure of work, conditions short of ideal, and lack of complete certainty that the wound will remain aseptic, militate against the use as a primary procedure of an operative method which demands for its success unhurried performance, and strict asepsis. By the time casualties reach such a setting, local haemorrhage and local oedema combine to make suture operations difficult and hazardous; and by general consent they are best postponed, if the nature of the wound permits, until a period of two or three months has elapsed during which the parts become less difficult to dissect; an interval which also allows of the development of a better collateral circulation, of vital necessity if the suture operation should fail and thrombosis occur, or if it prove impracticable and ligature be required.

In the past, thrombosis at suture lines was of common occurrence. This difficulty has been largely overcome, at least theoretically, by the discovery of anticoagulant substances which exerted their action *in vivo*: namely heparin (Howell, 1916; Charles and Scott, 1933), and dicoumarin (Campbell and Link, 1941; Butt, Allen and Bollman, 1941). Heparin is administered intravenously or subcutaneously, dicoumarin by mouth. In the surgery of war wounds, both have certain disadvantages, of which two may be emphasised. The first is that the administration of both drugs must be controlled by frequent laboratory tests, in order that dosage may be regulated; the second is that if they are to be used, haemostasis must be absolute, and this may not be practicable in a large wound or in multiple wounds. As a result, vascular suture has not been employed with any frequency in the early treatment of wounds. It has, however, had a place in the deferred treatment of such conditions as traumatic aneurysms and arteriovenous fistulae; in 1944 arrangements were made to segregate such cases in special 'Vascular Centres' both in the field and in the United Kingdom, where trained personnel and adequate surgical and laboratory facilities were available.

Since as a rule the ideal has been impossible in the early treatment of arterial wounds, it is natural that surgeons have sought some temporary method of restoring blood flow through a wounded artery, both to control primary haemorrhage and to gain time for the establishment of collateral circulation. In the War of 1914–18 silver cannulae were used but were rarely in position more than a few hours before they were blocked by formation of thrombus. In this war, glass and plastic tubes have been employed (Mustard, 1944) and also cannulae of vitallium lined by an autogenous vein graft, so that an unbroken intimal surface was presented to the blood (Blakemore, Lord and Stefko, 1942). Especially when it has been possible to 'heparinise' patients, these have been more successful, and reports of their efficacy have been made; but cases have been so few, and of so diverse natures, that accurate evaluation of the part played by the cannulae is difficult. The method has not been widely used; it has undoubted possibilities, and will no doubt be modified so as to command more general use in the future.

Restoration of blood volume. It is obvious that the total volume of circulating blood, and the pressure at which it is delivered, both have an influence on the vitality of parts nourished by vessels which include a main artery only partly available (arterial haematoma), completely blocked, or completely divided. The successful restoration of blood volume, and so of adequate blood pressure, has been accomplished in a high percentage of wounded, whether in battle or air raid, by the magnificently organised British Transfusion Services. (These are described fully in Chapter 2.) Here it is sufficient to say that their availability in the early stages of treatment, in conjunction with early surgical care, has reduced the immediate mortality from primary haemorrhage in arterial wounds; thus it has proved possible to secure for a larger number of patients at least the possibility of operations embodying the principle of vascular repair. Moreover there is no doubt that if adequate general circulation be restored, ischaemia from local vascular damage is reduced or even avoided as a result of the more adequate contribution from collateral vessels.

Operations on vasoconstrictor nerves. In the interval between the two world wars, the work of Hunter and Royle made it clear that circulation in the limbs could be increased by division of the vasoconstrictor nerves destined for them. This increase is of much greater magnitude in the subcutaneous vessels than in muscular branches; but after properly planned 'sympathectomies' the total input of blood into a limb is increased. Arteries in proximity to the tracks of missiles are often thrown into spasm, with consequent ischaemia in their distribution and reduction of the total available calibre of collateral vessels. It was logical to hope that interruption of the appropriate vasoconstrictor nerves would lessen or abolish this spasm. This interruption may be accomplished by operative exposure, often unjustifiable because an additional tax on the wounded man; or by procaine block, which temporarily interrupts vasoconstrictor impulses. Obviously both methods will be without useful effect until blood volume has been restored; in addition it has been found that vascular spasm may persist after the vessels have been disconnected from their extrinsic nerves by either method. When spasm is absent, the total cross-section of blood vessels in the limb (including many collaterals) may be increased by sympathectomy. Opinions on the value of these procedures vary. On the whole, in early cases they seem to be of little or no benefit. In late cases it is difficult to separate the possible advantages of sympathectomy from the improvement in circulation resulting from the spontaneous increase in collateral circulation which has occurred in the interval; but when cutaneous nutritional lesions are present, and it is desired to preserve the limb, operative sympathectomy is a useful procedure.

TREATMENT DESIGNED TO MINIMISE THE NEED OF TISSUES FOR BLOOD

Cooling the tissues (e.g. of a limb) lowers their metabolic rate and so the amount of blood needed to maintain their vitality. When blood supply has been reduced from arterial injury, it is of benefit to keep this vital need at a low level. A reasonable temperature would seem to be in the neighbourhood of 15° C., below which cold may be directly harmful to the tissues; in campaigns in warm and tropical zones, active measures (such as the application of ice or of evaporating lotions) may be indicated. A further and highly important advantage of maintaining a comparatively low temperature in a wounded part is the brake it puts upon the multiplication of bacteria contaminating the wound.

THE END-RESULTS OF ARTERIAL INJURIES

It will be apparent, from what has been said, that the functional end result of arterial injuries—which is what matters most—must depend upon a number of possibly unrelated factors. These include (1) the circumstances in which the wound has been inflicted—the importance of the vessel, the possibility of early arrest of haemorrhage, the availability of early surgical treatment; (2) the age of the patient, because in total war any age group may be involved, and the older the patient, the less resilient the arterial tree and the less likely the evolution of adequate collateral circulation; (3) the availability of early and adequate measures to restore blood volume; (4) the incidence and severity of bacterial infection; and (5) the availability, whether at primary operation or later, of special facilities both technical and of personnel.

(1) Naturally the circumstances in which wounds have been inflicted are as variable as the number of wounded, and each case follows its own course; but so well organised were the medical services in battle and in air raid precautions that it may be confidently asserted that lack of immediate attention was an insignificant factor in loss of life or loss of tissue. So far as individual vessels are concerned, it will probably be found that statistically their vulnerability has not changed with the years: indeed the multiplicity of wounds which was common in the War of 1939–45 may have led to a still more sharp accentuation of the unenviable position, in this regard, of such arteries as the popliteal, where the same or adjacent missiles may wound not only the main artery, but also its important collateral branches.

(2) The inclusion of older age groups in the toll of casualties from air raids will weight any ultimate statistics against favourable results after the surgical treatment of arterial injuries. This is inevitable in total war; but it should be utilised as an example of the futility of considering arteries merely as arteries, without allowance for the changes in their biological sufficiency which are incidental to the general increase in expectancy of life. Statisticians alone can properly assess this factor.

(3) It has been shown that restoration of blood volume has been achieved to a degree that makes this a factor almost to be neglected in any but the most unfavourable circumstances.

(4) There is no doubt that, as a result of administrative improvements in surgical services, and of chemotherapy, the adverse influence of bacterial infection upon the end-results of arterial wounds has been notably diminished.

(5) The end-results of vascular surgery must await the ultimate assessment of the vascular units established largely as a result of the activity of the Medical Research Council. This assessment must stand by itself, for no comparable organisation existed in the War of 1914–18. It is a matter for regret that these arrangements, so pregnant of possibilities in

the elucidation of the pathological physiology of arterial injuries, were not completed during the earlier phases of the war.

At the worst, arterial injuries may be fatal as a consequence of primary haemorrhage. An intermediate group will end in loss of tissue; in general this affects skin less than muscle, with the reservation that, whereas damage to muscle is permanent, loss of skin is rarely so extensive as first feared, and may be replaced either by natural repair or by grafting operations. At the best, interruption of a main blood vessel has as its sequels some diminution in the total function of e.g. a limb, as evidenced by diminished blood pressure, muscular wasting and consequent loss of power, anaesthesia of an acral distribution, possibly ultimate contractures, and cutaneous nutritional lesions which may make amputation the treatment of choice in the general policy of restoring the wounded person to some form of economic productivity.

CONCLUSION

That the outlook for a patient who has sustained an arterial injury has been better in this war than in the War of 1914–18 is indisputable. That this improvement is a matter more of organisation than of advance in surgical technique seems inescapable. Those who in the future have the responsibility of arranging for surgical services, whether in war or in peace, may well find matter for reflection and, it is to be hoped, action in so inevitable a conclusion.

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CHAPTER 13

THORACIC SURGERY

(i)

General Survey

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POSITION AT END OF FIRST WORLD WAR

THE beginning of the War of 1914–18 saw very little active thoracic surgery applied to the treatment of wounds of the chest. Thoracic surgery in general was practised hardly at all and only by a few pioneers; moreover the experiences during the South African War of relatively clean wounds which healed satisfactorily on a conservative régime caused a conservative policy to be adopted towards the casualties from the battles of France and Flanders. As the war developed the limitations of this policy were realised; at first in regard to the need for excision of wounds and later in relation to the recognition of the need for open thoracotomy in certain cases. In this connexion the development of facilities for blood transfusion made certain operations so much safer that surgeons were encouraged to greater boldness. This was notably so in the case of abdomino-thoracic wounds, the mortality of which, in the hands of certain surgeons, fell markedly during the latter part of the war. The disadvantages of the conservative treatment of many cases of haemothorax, especially those in which clotting or infection had occurred, became apparent and open thoracotomy and evacuation of the clot was advised and practised. The occurrence of blast injuries of the lungs was also recognised. By the middle of the war a large amount of intrathoracic operating had been done. Surgeons had come to lose much of their fear of open thoracotomy and their experiences engendered confidence enough to encourage them to perform many bold and well-conceived operations which had before been considered impossible or unsafe.

Sepsis still remained the principal feature to cause anxiety and bad results, and in spite of these advances the war left a big legacy of chronic empyemata, encysted haemothoraces, retained foreign bodies with chronic suppuration, and many examples of chest-cripples with rigid and severely deformed chests.

DEVELOPMENTS BETWEEN THE TWO WARS AND POSITION AT BEGINNING OF THE WAR OF 1939–45

The period between the two world wars saw a dramatic development of thoracic surgery encouraged chiefly by the impetus received from the first war and by the return to civil practice of the young surgeons who had seen the possibilities offered. The introduction by Brun and by Shenstone and Janes of the one-stage lobectomy by the tourniquet technique was epoch-making, for it enabled surgeons to practise and to develop the surgery of lung-resection, and hence of the wider problems of open thoracotomy in a way and to an extent that had not been possible before. At the same time technique of anaesthesia for intrathoracic operations developed so remarkably as to be a very material factor in this progress. The further development of blood transfusion, especially the establishment of blood banks, also contributed greatly to operative safety and enabled the more severe operations to be successfully introduced and developed. The importance of good physical treatment to prevent deformity and impairment of respiratory function was also appreciated and a new and improved régime was evolved and adopted.

In this way thoracic surgery soon developed into a robust speciality and by the time of the Second World War surgeons were much better equipped to deal with the problems of wounds of the chest. Important special experience was also gained from the later study and secondary treatment of pensioners from the earlier war, especially in regard to the late results of retained foreign bodies, chronic empyemata from gunshot wounds and from imperfectly treated haemothorax.

By 1939 thoracic surgeons were being trained in increasing numbers and, in addition to the older pioneers who had followed the first war, there were enough younger thoracic surgeons to provide personnel for the Armed Forces and for the special E.M.S. thoracic centres throughout Great Britain.

SCHEME OF ORGANISATION IN THE WAR OF 1939–45

The general scheme of organisation for dealing with chest-wounds and chest-illnesses was as follows:

ARMED SERVICES

Navy. A thoracic physician (Surgeon-Captain W. D. W. Brooks) was in general charge of the organisation; there was also a civilian consultant adviser (Mr. Morriston-Davies). No special thoracic surgical units were, however, organised, but in Great Britain the E.M.S. Thoracic Units were used for diagnosis and treatment of those special cases which were not dealt with by the naval surgeons.

Army. There was a civilian consultant adviser in thoracic surgery (Mr. A. Tudor Edwards) but no commissioned consultant or adviser was appointed. No special chest-units had been actually formed by the time the battles in France developed, although plans were being made. Two small thoracic surgical units were later organised for service in the Middle East; these consisted essentially of a thoracic surgeon, a thoracic physician, and a thoracic anaesthetist. These units also saw service in Italy. Two additional similar units were organised for the campaign following the Normandy landings. No special provisions were made in India or Burma, although one of the B.L.A. units was scheduled to go to India at the time the war finished in the East. The main mass of Army cases which were not dealt with by the Army organisations were dealt with by the E.M.S. centres. In addition, these centres continued the primary treatment initiated by the Army surgeons in a very large proportion of cases and in virtually all that were returned to Great Britain.

Royal Air Force. Here again a civilian consultant adviser (Mr. (afterwards Sir) C. Price Thomas) was appointed, but no commissioned thoracic surgical consultant. The civilian E.M.S. centres were used in the first part of the war but later a small special centre for the Royal Air Force was formed at Midhurst.

EMERGENCY MEDICAL SERVICES

The organisation of the thoracic centres of the E.M.S. was under the control of a consultant adviser (Mr. A. Tudor Edwards). These centres were to be based on the regional system, but it was not possible to staff a sufficient number of units to provide one for each region; consequently in certain areas a very large district had to be served. The main centres outside London were as follows:

Scotland

Glasgow (Hairmyres Hospital)

England

Newcastle
Manchester
Liverpool
Leeds (Pinder Fields Emergency Hospital)
Bristol (Kewstoke Emergency Hospital)
Leicester
Birmingham (Barnsley Hall Emergency Hospital)

Wales

Sully, Glamorgan

For the London Area three thoracic units were established; two north of the Thames (Harefield Sanatorium, Middlesex, and Hill End Hospital, St. Albans), and one south of the Thames (Horton Emergency Hospital, Epsom). The Horton unit was the largest of these and at first three and later four thoracic surgeons were attached to it.

The London centres, in addition to serving the related London area, were responsible for thoracic cases in many of the adjacent counties. Thus the Horton unit covered Kent, Surrey, Sussex, Berkshire and Hampshire; and the two northern units covered Essex, Middlesex, Buckinghamshire, Hertfordshire, Oxfordshire, and Cambridgeshire. The surgeons also acted as consultants in thoracic surgery for these areas; the surgeons who staffed the provincial regional centres also acted as thoracic surgical consultants in their regions. These duties involved much important work in addition to that carried out at the actual centres themselves.

The E.M.S. thoracic units were planned to receive and treat civilian thoracic cases; they were also to receive and treat cases from all the Armed Forces and the Merchant Navy.

PERIOD UP TO DUNKIRK; THE BATTLES IN FRANCE AND THE EVACUATION

The period between the declaration of war and the actual onset of serious fighting in May 1940, enabled the E.M.S. thoracic centres to become organised and to develop; this was made possible by the admission of ordinary civilian sick and a moderate sprinkling of Service cases. The centres were, therefore, well organised and available to receive wounded when the first battle casualties began to arrive from Belgium and France. At first a trickle, the numbers rapidly increased until they began to pour in, in large numbers, as the Dunkirk evacuation developed. So great was the stream that the thoracic centres were unable to confine themselves to accepting chest cases alone, but had to take their share in the reception of mixed convoys. Even at the height of the evacuation the policy of segregation was remembered and attempts were made to guide cases with a chest wound to the thoracic centres.

At Horton, mobile thoracic teams were organised and received many calls. A team which visited Dover Emergency Hospital at the time this hospital was almost overwhelmed with casualties, did a number of thoracic operations and selected a number of cases with chest wounds to be transferred at once. Other teams visited hospitals in London and the southern counties for consultations and operated on many patients. After the evacuation had been completed there remained the process of further sorting out and segregating cases with chest wounds. This phase was marked by calls from almost all the south-eastern coast towns and from many of the inland towns in the south-eastern area and south-western London regional area.

The chief lessons learned in this phase came from the many errors which had been made in ignoring the general principles of primary wound treatment that should have been well known. For instance, it was found that almost every patient with a chest wound who had received primary treatment had had the wound sutured without excision and without drainage. All these cases were heavily infected and many were seriously ill with intrapleural suppuration as well. In contrast were many of those who had received only first-aid treatment consisting of the application of a field dressing; their condition was usually much better owing to the absence of severe sepsis. Some extremely ill men were received with wounds so severe that they had been left almost untouched on a stretcher in their uniform for three to four days; it appeared that these men owed their lives to the fact that they did not receive the primary treatment of tight wound suture which many of their comrades had undergone.

The later stages of this phase were marked chiefly by the large number of cases of intrathoracic suppuration in addition to heavy chest-wall infection which needed many weeks or months of treatment. These cases emphasised the importance of stressing afresh the need for correct primary wound treatment. In particular, it was thought to be important to stress that, rather than suture an unexcised or imperfectly excised chest wound (apparently this was done in an attempt to close the open sucking wounds), it was best, unless a complete early excision could be carried out under proper conditions, to do no more than apply a large surface pad of ample thickness and to strap it tightly in place by radiating and overlapping strips. This effectively controlled the sucking and led to a minimum of sepsis. It was also necessary to teach that material should not be packed into the wound but the ample dressing should be merely applied to the surface.

THE AIR RAIDS OF 1940–41 AND THE E.M.S. CENTRES

The summer of 1940 was chiefly taken up with the continued treatment of the battle casualties from the Dunkirk evacuation. Ordinary Service sick and a steady trickle of training accidents also came into the chest centres. By the end of the summer, however, the London centres were dealing with casualties from the Battle of Britain and these were soon followed by civilian casualties when the steady succession of air raids began.

A memorable phase was during late August and early September when daylight raids were occurring. The mobile teams received many calls to attend chest wounds from hospitals in London itself and in all the Home Counties as far as the coast. This was a time of great activity in which much was learned. It was soon found, for instance, that it was impracticable to send a complete operating team to every call. The policy that evolved was for the surgeon or registrar to go and see the case and either to arrange for a transfer to the chest unit or to summon the full team if needed. Only in this way was it possible to conserve the available resources.

Throughout the late autumn and until Christmas, 1940, while the almost nightly raids continued, cases came in a steady stream from the whole London area and regions around. The provincial centres in the big industrial areas and ports that also received heavy raids were similarly occupied with large numbers of chest casualties. Much valuable thoracic surgical experience and knowledge was accumulated. Blast injuries of the lungs were seen in large numbers and it was possible to share in the general knowledge that was being accumulated at this time in this type of case. Owing to the fact that serious penetrating chest wounds occurred in the street or in houses, often only a short distance from hospital, exceptional opportunities arose for early treatment that would not have been possible under battlefield conditions. Severely wounded patients were successfully operated upon, who would never have lived if they had received similar wounds in the field. In this way the value of thorough early radical treatment was soon learned; in this the excellent facilities provided by the blood bank organisation were of inestimable help. Very severely wounded cases would be treated by primary thoracotomy with complete excision of the primary wound, evacuation of clot, removal of retained missiles, and resection of damaged lung; these patients would mostly heal by primary intention and be almost ready to leave hospital in three weeks. This was in very marked contrast to the prolonged convalescence met with in the earlier septic Dunkirk cases. Another feature was the secondary management of cases in which the primary treatment had been incomplete, but which were not so late or neglected as in the early battle casualties. These often required secondary operations and their healing rate was slower, but many were rescued from chronicity.

Abdomino-thoracic wounds were met with in fair numbers and here again the value of early radical treatment was proved. Most of those who required operation were dealt with by thoracotomy, the abdominal lesion being approached through the diaphragm whenever possible. A number of wounds of the heart, pericardium and great vessels were also dealt with by primary operation or by later secondary operation for the removal of retained missiles. The late removal of retained missiles provided a steady flow of work; the policy adopted was chiefly towards removal of any fragment larger than 1 cm. × 0·5 cm. In many cases, wedge-resection of the lung to include the foreign body was preferred, whenever possible, to simple removal, as it was felt that in this way a portion of damaged lung was removed which, if left, constituted a possible source of trouble either immediately or later. Crushed and stove-in chests were also numerous, chiefly as a result of falling masonry from bombing, or traffic accidents. The value was learned of effective strapping in order to control paradoxical respiration; if a part of the chest wall was stoved in, this was supported by a pad placed in position before the strapping. Many a patient was changed from a dying condition, when strapped and given adequate oxygen and perhaps blood transfusion. Two other features were noted in these cases. The first was early, severe and rapid acute dilatation of the stomach. Before its occurrence was appreciated there were some deaths; if looked for and promptly treated it usually responded at once. The second and very important feature was the need for ensuring evacuation of bronchial secretions. Unless this was done the patient might develop severe purulent bronchitis and atelectasis and die from pneumonia or heart-failure. Unless there was early and satisfactory response to postural treatment and encouragement in coughing, direct intrabronchial suction was carried out either by bronchoscopy or by passage of a suction catheter. In some cases of bilateral multiple rib-fractures lives were saved only by frequent repetition of suction over several days.

This period also saw the first stages of the evolution of the management of haemothorax. Much of the general teaching at this time was in favour of delaying aspiration for thirty-six to forty-eight hours lest early aspiration should encourage free bleeding; air-replacement was also being advocated. Many of the more severe cases were treated by early primary open operation with excellent results. In those that did not require operation on account of the parietal wound or of continued bleeding, early aspiration was always used and air-replacement was never employed. Later cases of clotted haemothorax that did not respond to aspiration were operated upon and the clot evacuated. Many of these cases did well, but it was observed that in a proportion the lung did not expand quickly to fill the chest, and frequent aspirations were needed; in some of these, in spite of intensive physical treatment, residual pleural thickening occurred and therefore impaired function. It was not until 1944 that it was recognised that these cases needed decortication as well as evacuation of the clot. It is of great interest to look back on this phase in the evolution of our views on haemothorax and its treatment.

Anaerobic infection of haemothorax was also encountered, and at this time treatment consisted of aspiration and chemotherapy until a mature empyema had formed, and then drainage by formal rib resection. Cases treated in this way did well, in contrast to some that had been treated by early drainage as soon as the anaerobic infection of the haemothorax had been detected; there inevitably developed a total empyema which usually became chronic. Again, it was not until 1944 that we learned that anaerobic infection of a clotted haemothorax was best treated by primary evacuation of the infected clot and decortication of the lung.

NORTH AFRICAN CAMPAIGNS; ITALY AND THE MEDITERRANEAN

This phase provided the one example of a full-scale oversea organisation and experience of the management of chest casualties occurring in battle. The organisation of the units, the treatment at various levels, methods of transport, differences in conditions and their effect on the surgery needed, is supplied in a separate account by Lieut. Colonel A. L. d'Abreu, which follows this article.

POSITION OF THORACIC SURGERY AT THE TIME OF THE NORMANDY INVASION

From 1941 to 1944 the E.M.S. chest units continued their work, expanding and enlarging their personnel and with all their beds occupied so that waiting lists became necessary. A large number of civilian sick were treated in addition to the steady influx of Service cases. The latter were largely those returned to this country for continuation or completion of treatment already begun in the Mediterranean area or from India and Burma. In addition there were patients with chest wounds received in the course of training, or from fighting in the Channel, or from commando raids. The mobile teams were constantly needed for these cases, often visiting Dover and other coast towns.

Although the treatment of civilian chest cases was not traumatic war surgery, it fulfilled a valuable function in that the regional evacuation schemes demanded provision and continuity of treatment for civilian sick. There can be no doubt at all that this work had a great ultimate benefit in hastening the development of the ordinary thoracic surgical services of the country that has had its continued effects in peace. The provision of facilities before the war, in the provincial regions at any rate, was rather sketchy, but the relatively enormous developments at this time have been maintained and increased further. Inevitably it led to the training of larger numbers of personnel of all grades, a result that was of immediate great value in increasing the efficiency of dealing with war chest-casualties and has been further reflected in the great development of the speciality since the war. Many keen and efficient young men have been added to those specialising in thoracic surgery. At the same time the work and experiences of the Army chest-teams led to their increased efficiency and familiarity with the special problems presented.

The heavy raids in the early months of 1944 resulted in batches of severe chest wounds and the policy of bold primary treatment was again tested and found to be justified, at any rate under the conditions applicable, namely, early reception of the severely wounded patient by a well-equipped and well-trained surgical chest team with an expert thoracic anaesthetist. In these circumstances it is certainly possible to justify radical operations that would not be justified under less favourable conditions of more mobile warfare, with surgeons less familiar with chest cases

THE LAST PHASE

The beginning of 1944 saw preparations for the reception of casualties from the coming landings on the European mainland. The northern London and provincial centres were to retain their organisation. The special geographical position of Horton Emergency Hospital led to considerable change. This hospital was to be specially concerned with the reception and clearance of the possibly large numbers of wounded to be expected. The personnel was greatly augmented by a number of complete surgical teams from Scotland and the whole service of the hospital was reorganised to receive mixed casualties; the chest unit was not to deal with chest cases only, since it was felt that this would not be possible in view of the anticipated large number of wounded. Actually the convoys were far smaller and far fewer than anticipated and although general surgical wounded were dealt with by the chest surgeons, rearrangement and internal transfer of cases soon became possible so that those with chest wounds tended to pass to the chest teams. Moreover, the relatively small number of total casualties meant that it was possible to retain those with severe chest wounds rather than evacuate them, as was done with most of the general cases. The whole scheme was, however, affected almost at once by the onset of the heavy aerial attack by flying bombs; Horton Hospital was on the direct flying-bomb route and evacuation of Service casualties was ordered. In a few hours, therefore, an accumulation of at least 100 chest cases left the hospital for the Northern and Scottish centres.

The Horton chest teams now reverted to dealing with chest cases only. These came from civilian casualties from the flying bombs; large numbers were admitted and once more the mobile teams were called into action as in the earlier phase of the war. The other London chest centres were, of course, also dealing with chest casualties.

The Horton chest unit was also called upon for a special service, namely, to supply teams to attend to patients with chest wounds arriving at Portsmouth and Southampton and some smaller towns. Eventually the solution to this problem was found by obtaining wards and operating theatres at Queen Alexandra's Hospital, Corsham, and also at Southampton. This enabled a very large number of moderately recent, very severe, chest wounds to be dealt with under favourable conditions by skilled teams with very satisfactory results.

THE TREATMENT OF CLOTTED HAEMOTHORAX

This phase saw the evolution of certain surgical principles in the treatment of clotted haemothorax, which not only represented a great advance in efficiency but have remained as permanent contributions to our peace-time thoracic surgical knowledge and practice. There can be no doubt that this was the great contribution of war-time thoracic surgery to civilian work, apart from the hastened general evolution of thoracic surgical organisation already commented upon. Surgeons in the American Forces in Italy were already evolving the same principles (e.g. Samson and Burford, 1947), but the development proceeded independently and simultaneously in England. An admirable and important account of this work was presented by Price Thomas and Cleland (1945).

RE-INTRODUCTION AND EXTENDED APPLICATION OF DECORTICATION

The treatment of clotted haemothorax earlier in the war, as already mentioned, was by thoracotomy and evacuation of the clot. In a number of these cases the lung did not expand completely and immediately to fill the hemithorax, and repeated aspiration of fluid, or air and fluid, was needed; varying degrees of residual pleural thickening resulted.

Decortication of the lung for chronic empyema had been advocated by Delorme many years ago but had not found favour owing to poor results. It was now appreciated that the imperfect expansion of the lung in these cases of clotted or massive haemothorax was due to the rapid deposition of a layer of fibrin, which within only a few days began to organise and held the lung in a contracted, deformed position. The longer the delay the thicker this cortex became, until eventually it formed a thick, rigid layer on both lung and parietes. Moreover, the lung was collapsed, compressed and often grossly distorted during the acute phase of haemorrhage and exudation; for instance the upper lobe would fall right over and be fixed low down in the chest; the lower lobe would be forced medially so that the greater part of the diaphragm was laid bare. The lung was in this way held entrapped in the most bizarre positions and conformations, and it was no wonder that expansion to fill the hemithorax was difficult, prolonged or impossible. Expansion, when it did reluctantly occur, might often be in an uneven fashion so that one lobe or portions of the lung were emphysematous and the other lobe or other portions of the lung remained collapsed or imperfectly aerated. When infection was superadded, especially if there were retained metal fragments, clothing and rib-fragments, everything was very much worse and the most difficult and resistant cases of chronic empyema were liable to follow. Treatment by rib-resection and drainage in such cases, hitherto orthodox, was commonly followed by months and months of treatment in hospital and eventually a large chronic empyema extending to the apex of the chest; this often needed some elaborate thoracoplastic procedure for its closure, with consequent ultimate permanent disability of varying degree. One of the most significant features in production of these cases was soon recognised to be the collapse and falling over and downwards of the upper lobe, which was unable to expand into its normal position.

Decortication was found to be the answer, even though in cases only a few days old the cortex was a thin tissue-paper-like layer; this, if left, was quite enough to retain the entrapped lung. As soon as it was freed, the lung could be easily inflated by the anaesthetist to fill the hemithorax completely.

Although the operation was straightforward in the hands of a surgeon familiar with the simple principles involved and with thoracic operating, it was, nevertheless, a severe one and not to be undertaken in the absence of adequate facilities, including simultaneous blood transfusion. Operation involved revision of the original entry wound, if this had not already been done, and then a formal thoracotomy was performed either through an intercostal space or by resection of a long length of rib. All fluid and clotted blood would be cleared out, and also any foreign material carried in at the time of wounding. The lung would next be inspected, and at this early phase it was easy to detect the entry wound and site of any retained foreign body, which could then be removed together with any damaged lung, if thought necessary. It would often be necessary to resect lacerated, bruised portions of a lobe. If the lung did not then expand freely when inflated by the anaesthetist, as was mostly the case if the wound was more than four to five days old, decortication was done. When less than a week old the cortex was so thin that it was usually removed in very thin sheets which would readily break up; when at least seven to ten days old the cortex was much thicker and could be peeled and teased off as large fragments; after two to three weeks it might be 0·5–1 cm. thick. It was found to be essential to decorticate the whole lung from top to bottom, mediastinal as well as costal surface; the interlobar fissures had also to be defined and freed. The display of the compressed distorted lung and its immediate conversion, after decortication, into a freely aerating normal sized organ is surely one of the most dramatic sights of surgery (Plate I).

It was quickly noticed that in this operation lay the secret of success in treating those cases of severe anaerobic infection of a haemothorax, which had hitherto proved so difficult. A great deal of courage was needed on the part of the surgeon to do such a large operation on some of these patients, many of whom were desperately ill with high fever, and had been so for many days. It has well been said that desperate diseases demand desperate remedies, and the surgeon's courage in attacking these cases was amply justified. By using a formal thoracotomy the whole mass of purulent clot, often with clothing and metallic and bony fragments, could be cleared out, and after decortication the lung would at once expand freely. Here, at one step, had been solved the problem of maintaining drainage of a pleura full of infected clot, which was often impossibly difficult if partial lung expansion had occurred with formation of a number of separate pus pockets. At the same time the inevitable chronicity had given way to the possibility of virtual healing by primary intention. It was remarkable that the thoracotomy wound in these cases, made in the presence of such heavy infection and high fever, would always heal by primary intention if proper after-care were carried out to maintain lung expansion. This was the next important principle that was recognised. Unless the lung inflation was maintained, pleural infection would persist and the end-result might be little different from what it would have been if nothing had been done.

Lung expansion was maintained by two methods: first by closed pleural drainage with suction; second by ensuring that bronchial retention and secondary atelectasis did not occur. This latter was of absolutely fundamental importance, especially as the damaged lung might well cause thick blood-stained mucus to accumulate in the bronchi, apart from muco-purulent secretion. Bronchoscopy or blind bronchial intubation was frequently needed to clear the bronchi.

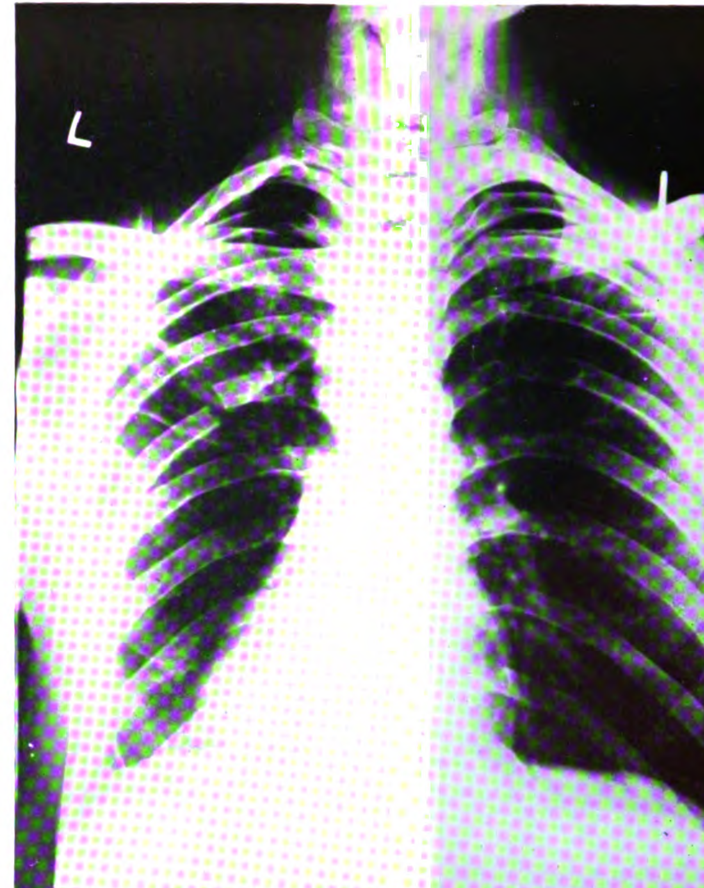
Two tubes were used for pleural drainage, one at the base and one high up at the back; these could both be intercostal. For the first twelve to twenty-four hours they would be attached to simple under-water seals because in a number of cases small fistulae would be present; after this time, if radiographs revealed that the lung had not fully expanded, suction would be applied. The tubes were often removed after only 48 hours, usually within three to five days. Occasionally a small residual pocket might need aspiration and less often a small residual empyema or pocket might need independent drainage. This, however, was always a relatively small matter that merely delayed convalescence a short time and left no permanent disability, in contrast to the months of treatment necessary, and probable ultimate residual disability, if the original total or multi-loculated pyothorax had been dealt with less radically. If all went well after the operation the patient could be out of bed in two to three days and completely healed in ten to twenty days. It was usually wise to retain him in hospital for longer so that physical treatment could be continued long enough to ensure perfect chest expansion and absence of deformity. These patients could, however, be evacuated to the more distant centres for this purpose some two to three weeks from their reception.

Quite apart from the vastly improved result for each individual patient was the enormous saving in bed accommodation, medical and nursing attention, dressings etc. Moreover, these patients often made such a good recovery that they could return to their units with only temporary or slight down-grading in contrast to being discharged as permanently unfit for service as was the case earlier. Although penicillin became available in larger quantities about this time and was used in many cases, and certainly helped greatly towards good results, it should be emphasised that these advances did not rest on chemotherapy but on improved methods of surgery. Just as good results were obtained without the use of penicillin. A word of tribute should be given to the skill of the anaesthetists who contributed greatly to the ability to carry out these operations successfully on patients who were often gravely ill and presented very difficult anaesthetic problems.

DECORTICATION IN NON-ACUTE CASES

Once the advantage of decortication had been recognised and the revelation made of the simple yet fundamental principles involved in completely freeing the entrapped lung, it was inevitable that its use

"Lancet"



"Lancet"

PLATE I. Massive clotted hæmothorax: 1. Before operation. 2. Five days after evacuation of clot and decortication with suction drainage, showing full re-expansion of lung and very slight pleural thickening.

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should be extended to cases of longer duration and even to chronic cases of the type on which it had been tried and abandoned many years ago. It had been supposed that decortication would not be possible in cases of haemothorax of several weeks' duration. This was soon shown not to be the case, although the operation was liable to be accompanied by freer oozing and by more small fistulae; the problem also arose of decortication of the parietes, because the ribs and diaphragm would both be held in a layer of rigid scar tissue. Ideally both lung and parietes needed decortication; in practice it was sometimes found necessary to stop the operation after decorticating the lung and freeing the diaphragm and doing a greater or less amount to the chest wall.

In chronic empyema excellent results were also obtained, even in cases in which decortication had already been tried and had been followed by secondary collapse of the lung and continued pleural suppuration. The most valuable results were obtained in those cases with a large cavity extending into the whole of the upper part of the chest; cases which, without decortication, would only be healed by extensive thoracoplasty.

As has already been stated, the advantages of decortication and the technique of its management have found a permanent place of value in civilian thoracic surgical practice, as is inevitable with a fundamental surgical principle of the type involved. It has been applied to the treatment of acute empyema, certain cases of which are suitable for primary decortication rather than the standard drainage operation, to many cases of chronic empyema, and it is now being used increasingly often in certain cases of tuberculous empyema; it is also applicable in cases of chronic pneumothorax in which the full expansion of the lung may be limited by a thin new-formed cortical layer of organised tissue. The application to the treatment of early infected haemothorax and to cases of acute empyema is in the nature of a revolution in methods, for until then it had been considered most dangerous and blameworthy to perform an open thoracotomy on such cases. The First World War in fact saw the conception and establishment of aspiration until a mature localised abscess had formed, and then drainage by rib resection. The difference lay, of course, in the fact, that this policy was evolved from experiences with cases of severe influenzal pneumonia with coincident pleural infection. In these cases early thoracotomy would still be a most dangerous or fatal procedure. When the pleural illness, however severe, follows external introduction of infection and the lung is substantially healthy, or when a primary lung infection has subsided, open thoracotomy and decortication is not unsafe but is definitely indicated.

OTHER THORACIC SURGICAL TRAUMATIC CONDITIONS

Heart and great vessels. Most thoracic surgeons operated on a few cases of injuries to the great vessels or for removal of retained missiles from the ventricular walls or pericardium. No case has been reported of removal of a missile from within a chamber of the heart, although one must refer to the brilliant work of Harken (1946) in the American Army who removed an intracardiac foreign body in 13 cases with success.

Abdomino-thoracic wounds. The greater familiarity with thoracotomy led to many more cases of this type of wound being operated on through the chest rather than through the abdomen, though there still remained a tendency for the general surgeon to prefer the abdominal approach. An abdominal incision doubtless, in general, suits an abdomino-thoracic wound and a thoracic one a thoraco-abdominal wound. Certainly if colon or small intestine is wounded an abdominal approach is preferable. Blackburn (1948) gives a valuable survey of experiences and results in the various theatres of war and shows that his mortality of 34 per cent. in 144 cases is similar to that in other series, and is not very different from the figure of 36 per cent in 75 cases reported by Gordon-Taylor in 1918.

THE B.L.A. THORACIC SURGICAL TEAMS

Two thoracic surgical teams were included in the B.L.A. organisation and their experience is set out by Mr. Collis and Mr. Qvist in their article.

INDIA AND BURMA

No special provisions were made for the treatment of surgical chest illnesses and wounds in India or Burma; those that occurred were treated by general surgeons; a number of the more severe cases were invalided home to the E.M.S. thoracic surgical centres. Arrangements were being made for a thoracic surgical team to go to India when the Japanese war ended.

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(ii)

Experience of Thoracic Surgery Gained in the Central Mediterranean Theatre of War

By A. L. d'ABREU
O.B.E., Ch.M., F.R.C.S.

In the preceding section Mr. Brock has indicated the frame of mind of thoracic surgeons at the outbreak of the War of 1939–45 and has shown how the treatment of the thoracic casualty ultimately became systematised so that a uniform therapy was adopted with conspicuously satisfactory results.

In the disastrous fighting in France and Belgium in 1940 the chest casualty fared ill. The author has vivid memories of severe sepsis often associated with grave pyo-pneumothorax and, although this in part reflected uncertainty in the methods used, it could also be largely attributed to the complete breakdown of the forward surgical work as the result of the devastatingly rapid advance of the German Army. Perhaps the greatest error committed was the suture of the unexcised wound and the failure to appreciate the need for early aspiration of the haemothorax. As a result of these deficiencies and because of the highly infectious terrain over which the battle waged, many seriously ill patients with gunshot wounds of the thorax were seen in the base hospitals.

In the Middle East, and to an even greater extent later in Italy, the remoteness from home and the difficulty of sea evacuation enabled us to see the thoracic casualty treated in many instances from start to finish, and as time went on the most excellent co-operation developed between the forward and base surgeons and important principles were established which enabled very high recovery rates to be recorded at the end of the Italian campaign. In the Italian theatre of war, both British and American thoracic surgeons soon grasped the transcendent fact that war wounds of the chest require treatment in two quite distinct phases: (1) the stage immediately after wounding when attention is devoted to correcting the physiological derangements that lead to death, namely, the prompt closure of the sucking pneumothorax, the correction of mediastinal displacement by the early aspiration of air and haemothorax fluid, the administration of oxygen and the correct use of blood transfusion. (2) The second phase which is directed largely to the prevention or treatment of infection and scrupulous attention to the return of lung function. In this phase it became established beyond doubt that the best method of preventing infection and at the same time of encouraging return of lung function was the assiduous aspiration of haemothorax fluid and of air, usually by the needle, but frequently by the employment of major thoracotomy followed by pleural toilet and the decortication of the lung, imprisoned by the organisation of fibrin on its visceral pleura. In this phase too, great stress was laid on the use of physiotherapeutic measures designed to re-encourage normal breathing and to prevent any thoracic deformity. In this period intra-pulmonary, intra-pleural and intra-pericardial missiles were removed, when the indications for such procedures existed.

EFFECT OF ADMINISTRATIVE MEASURES ON THE IMPROVEMENT OF RESULTS

In the Western Desert the establishment of the field surgical unit was the first important step in enabling the early chest casualty to have his physiological derangements corrected efficiently, but in that campaign insufficient attention was paid to the excision of the sucking chest-wall wound, and, although the use of vaseline gauze to occlude the opening was far superior to the method of suture without excision employed in 1940, it did not prevent an empyema incidence of 33 per cent. In the Libyan Desert an administrative advance was the siting of base hospitals far enough forward to receive chest casualties before crippling sepsis and faulty lung function had developed. In Italy the closest co-operation between the forward and rear surgeons was established by the consultants concerned.

In the last year and a half of the fighting in Italy the two phases already mentioned were recognised and dealt with administratively with the improvement in results which will be shown by the following figures. From the Battle of the Sangro (Italy 1943) 260 chest wounds were admitted to the 98th General Hospital (Lieut. Colonel A. L. d'Abreu and Major Litchfield, the thoracic physician), and of these 77 had proved empyemata (33 per cent.). This figure was identical with that seen in the fighting in the Western Desert and at the time of this battle the chest-wall wounds were not excised thoroughly as a routine. In 1945 the same unit received 184 cases from the final battle of the Po Valley; only 14 (7·6 per cent.) developed an empyema, and half of these were in German prisoners-of-war picked up late on the battlefield. In this last battle not only were the wounds excised as elsewhere in the body, but every effort was made in the forward units to evacuate the haemothorax early, and the casualties were transported at an early stage several hundreds of miles by air to the chest centre.

INCIDENCE OF THORACIC WOUNDS

In Italy these appeared to be in the ratio of 1 to 4 among those killed on the field and a proportion of 1 to 12 among those surviving to reach the field surgical unit. Major Wooller in 1,599 cases treated in the forward unit had 97 thoracic casualties, of which 53 were thoraco-abdominal, while Major G. C. Rob, had 46 thoracic wounds in 1,000 cases of which 30 were thoraco-abdominal. The figures for the base hospitals are misleading because in Italy these were aggregated as far as possible in two hospitals, one at Naples, and one at Bari. In 5,000 battle casualties treated at the base Lieut. Colonel d'Abreu had 1,000 chest wounds. Lieut. Colonel W. F. Nicholson dealt with 1,639 chest wounds in the Middle East and in Italy.

FIRST-AID TREATMENT ON THE BATTLE FIELD

The stretcher-bearer was instructed to plug large sucking wounds with the field- or shell-dressings, morphine in ¼-gr. doses was given, and the patient was propped up on the stretcher if respiratory distress was more serious than the effects of shock from haemorrhage. In the field ambulance, oxygen was administered by the B.L.B. mask and blood transfusions were given when indicated, and special attention was paid to postural drainage of the bronchial tree when this was flooded by blood and sputum. The early casualties stood long ambulance journeys badly, and the near-by locations of forward surgical units was an important measure in avoiding this. In these forward surgical units blood transfusion was liberally used, although the danger of waterlogging the lungs by over-transfusion was soon appreciated and avoided. Towards the end of the war the experiment of using triple-concentrated plasma for the treatment of the wet lung appeared to be showing satisfactory results (Major Cleland), but this method carried the inherent danger of transmitting serum jaundice and was never a substitute for extra-bronchial suction, or bronchoscopic aspiration when the bronchial tree itself was flooded. It was interesting to note that tension pneumothorax was rarely encountered and Lt. Colonel Nicholson only noted 24 cases in 1,639 penetrating wounds of the chest. When present it was recognised by extreme dyspnoea, displacement of the mediastinum and tympanitic note in the chest, engorgement of the veins of the neck and, where radiology was available, by the obvious appearance noted on the film. The introduction of a wide-bore needle connected to a water-sealed drainage system often led to an immediate and dramatic improvement.

LEVEL AT WHICH OPERATIONS SHOULD BE PERFORMED

Primary Phase. In practice this was carried out at the forward surgical unit or at an advanced casualty clearing station. Operation was frequently omitted in small penetrating wounds without much chest-wall damage or bruising; the chief duty in such cases being the early aspiration (twelve hours after wounding) of any associated haemothorax, and at the close of the war this early aspiration was universally accepted and employed without air-replacement, the bleeding almost invariably being from the chest-wall wound and not from the lung itself. A few soldiers arrived at the forward units with obvious massive and continuing haemorrhage; these were given the highest operative priority, the chest-wall wound being excised and the bleeding, frequently found to be arising from the intercostal vessels, arrested. Quite exceptionally the lung was bleeding, but the haemorrhage could be arrested by a few sutures. Patients with gross wounds of the large vessels usually died on the field. It may be of interest to state that the pre-war estimate that lung wounds would be excised widely or even treated by lobectomy was far from the practice seen in actual theatres of war, and the author knows of only one lobectomy done in Italy.

Patients with open sucking wounds and with lacerated wounds associated with rib damage were treated by formal excision, including the removal of shattered rib-fragments when these were driven into the lung. The haemothorax was sucked out by the use of a foot-worked pump and the thorax closed by suture of muscles, the skin being left widely open for a delayed primary suture some four or five days later at the base hospital. Easily accessible foreign bodies were removed, but no attempt was made to search for them through a formal thoracotomy wound. Although the ideal anaesthetic for these operations is probably the use of intra-tracheal cyclopropane and oxygen, much of this forward surgery was done under pentothal, a close-fitting mask being applied to the face through which oxygen and a little supplementary ether were administered. It was early realised that the lung parenchyma had a notable resistance to infection because of its excellent blood and oxygen supply and gas gangrene of the lung did not develop. When penicillin became available, this was left in the pleura after the haemothorax had been evacuated, and the patients were treated subsequently by parenteral penicillin. Bronchial secretions and blood clot were removed by intranasal suction and, although bronchoscopic aspiration was in constant use by the fully equipped chest centres at Naples and Bari, it was not readily available in the forward units. At this phase the greatest attention was paid to the post-operative care which consisted largely of the relief of pain by small doses of morphine, the use of a comfortable propped-up position and the administration of oxygen and blood. On alternate days any haemothorax fluid was aspirated and the patient encouraged to cough and to make an attempt to return to normal breathing. In the American Units the injection of novocaine into the posterior intercostal spaces was frequently used, and this was adopted by the British surgeons late in the campaign. In retrospect perhaps it is possible to say that bronchoscopic aspiration was not used enough in cases of collapsed lobes due to bronchial secretions, but it must be remembered that this surgery was carried out under difficult conditions often in tents, and that in addition to the chest casualty many other types of serious wounds were being dealt with under conditions of great strain, and this account in no way pays proper tribute to the magnificent work done by the forward surgeons to correct the physiological derangements of their

TABLE I

(d'Abreu, Litchfield and Hodson)

	No. of chest casualties admitted to 98th British General Hospital	Empyema rate per cent.	Deaths per cent.
Battle of the Sangro (October, November, December 1943)	260	77 (33)	15 (5·7)
Gothic Line Battle (October, November, December 1944)	373	31 (12)	5 (1·4)
Battle for the Po Valley (April, May 1945)	184	14 (7·6)	2 (1)

patients; so adequately was this done that many were able to be moved after a very few days by ambulance or air to the base hospitals. The ideal day for evacuation by air was between the third and the sixth day, and this, combined with the careful excision of the wounds and attention to the points briefly mentioned, allowed the two-stage operation to be elaborated with a high degree of success as can be seen in Table I. In this table is summarised the results of three large groups of casualties received at a base hospital from three different battles. In the first battle, which took place early after the invasion of Italy, the full technical and administrative details of the two-stage plan of treatment had not been fully elaborated, but in the second and third battles the system had come into full use with the pleasing results seen.

These figures do not provide a true account of the total battlefield deaths but represent the history of those who had survived and had passed through the forward centres. The decrease in the empyema rate is notable.

In contrast to the table above, at another phase of the campaign, 88 soldiers of all nationalities were evacuated from the guerilla warfare in Jugoslavia where early surgical treatment was not available, and, of these 88, 48 were admitted with empyemata.

Secondary Phase. On arrival at the chest centre of the base hospital, this second phase commenced and was devoted largely to encouraging the return of full thoracic function. A considerable part of the assessment depended on a careful noting of the contents of the field medical card. As soon as the immediate comfort of the transported casualty had been attended to, postero-anterior and lateral radiographs were taken as a routine, for progressive pathological states often developed in the course of the journey. Apart from those for which the indication for immediate interference was present, the casualties were given a good night's rest by the use of barbiturates, and the injection of morphine if pain existed. If patients arrived in a dyspnoeic and distressed condition this was usually due to a re-accumulation of haemothorax fluid, to the presence of atelectasis of a lobe or lung, or the result of anaemia. These difficulties were corrected by immediate aspiration, by postural drainage or bronchoscopic suction and by blood transfusion. A clinical estimation of the patient was made and compared with the radiological findings and in a well-organised battle the first wound inspection was made in the operating theatre on the day after admission. Before this first dressing the future treatment of the patient had been discussed at a conference between the physician, surgeon, and radiologist of the chest team, and the anaesthetist notified so that he could visit the wards before the list commenced. At this conference also a list of the patients requiring aspiration was made and the physiotherapist in the ward instructed as to her immediate duties on each case, special emphasis being laid on postural drainage and active breathing exercises.

A decision was also made as to the need or otherwise of continuing chemotherapy which had been maintained throughout the evacuation.

THE FIRST DRESSING

In Italy the forward surgeon made a note on the field medical card as to whether delayed primary suture would be indicated or not. In the last year of the war in Italy over 90 per cent. of the wounds which had been excised in the forward area were fit for immediate suture at the time of the first dressing, and this was done on innumerable occasions with primary healing as the result. If the radiograph and the clinical estimate indicated that a major operation for the removal of a foreign body or the treatment of a massive clotted haemothorax by surgical evacuation was indicated, this major intervention was frequently done at the time of the first dressing either through an extension of the primary wound or more frequently through a planned thoracotomy incision.

Technical Procedures employed at the Chest Centre

It is necessary at this stage to indicate briefly the common types of lesion seen, and of these by far the most important was the simple haemothorax. Lieut. Colonel Nicholson in his series of 1,639 casualties

TABLE II

Common Lesions in 1,000 Consecutive Thoracic Casualties at a Forward Base Hospital

Haemothorax				
	Simple	*Clotted*	*Infected* (empyema)	Total
	552	73	214	839
Lodged Intra-thoracic Missiles				
Pulmonary	*Pleural*	*Mediastinal*	*In Endo-thoracic Fascia*	Total
221	49	51	18	339
Lung Abscess				
Around Lodged Foreign Bodies		*Without Lodged Foreign Bodies*		Total
13		19		32
Wounds of Heart and Pericardium				Total
30				30
Thoraco-abdominal Wounds				Total
115				115
Extra-pleural Effusions (*in the plane of the Endo-thoracic Fascia*)				
Simple		*Infected*		Total
25		10		35

Deaths. 31 (3·1 per cent.)
(Five of these due to transection of spinal cord—if these are excluded mortality percentage is 2·8 per cent.) Many of these patients had other wounds.

saw 1,027 patients with haemothorax, and d'Abreu, Litchfield and Hodson in 1,000 consecutive gunshot wounds seen at the centre had 839 cases of haemothorax, an incidence of 84 per cent.

Some estimate of the type of lesion seen may be made from an analysis of 1,000 consecutive thoracic casualties mentioned above, and from an evaluation of the lesions seen in Nicholson's series of 1,639 wounds (Tables II and IIa).

TABLE IIa

1,639 Penetrating Wounds of the Chest

W. F. Nicholson

Haemothorax . . .	1,027
Infected haemothorax .	229 (13 'clotted')
Clotted or multilocular .	92
Thoraco-abdominal wounds	164
(Subphrenic abscess .	13 on the right 7 on the left.)
Pleuro-biliary fistula . . ('Bile empyema') . .	6
Broncho-biliary fistula .	2

Lieut. Colonel A. Logan had 622 patients with chest wounds in the Middle East at a base hospital and in this series there were 20 deaths, some due to associated injuries. There were 385 haemothoraces and 121 (31·5 per cent.) were empyemata. He removed 50 foreign bodies from the lung and 58 from the pleura, and two from the pericardium.

MANAGEMENT OF THE HAEMOTHORAX

It was the convinced opinion of all surgeons and physicians interested especially in the treatment of diseases of the chest that a haemothorax should be aspirated as early and as completely as possible because this measure relieved intra-pleural pressure, removed an excellent culture medium for organisms, encouraged early lung re-expansion, prevented massive clotting and in most patients enormously limited the period of incapacity. There was no doubt that the correct management of the early haemothorax was the one single measure most likely to diminish the later incidence of empyema. It was soon realised that the most careful clinical and radiological examination was at the best only capable of providing a rough impression of the amount of haemothorax fluid present, and, however small the effusion was thought to be, it was invariably aspirated, and the amount removed almost always exceeded the pre-operative estimate. It was also quite clear that a large effusion could be present without gross displacement of the mediastinum, and that through it breath sounds might be deceptively clear, and for this reason constant radiological investigation was always essential.

Technique. During a major battle it was not uncommon for 20 to 30 aspirations to be done each day in the chest centre, and this necessitated the setting up of a room devoted to this purpose where the aspirations were usually done by chest physicians. Patients were fully pre-medicated and the actual aspiration was done in a sitting-up position and it was essential to use a large-bore needle because of the frequent presence of small clots which blocked those of lesser calibre. The haemothorax was, as far as possible, aspirated to dryness and 50,000 units of penicillin injected intrapleurally at the close of the operation, until three haemothorax specimens were reported by the bacteriologist as being free from gram-positive organisms. The first large series of gunshot wounds of the chest in the world to be treated by penicillin were dealt with in this theatre of war (*British Journal of Surgery*).

THE CLOTTED HAEMOTHORAX

However thoroughly the aspirations were done in the early stages, clotting developed in 5 to 10 per cent. of the wounded, and the figure of 9 per cent. of clotted haemothoraces in a series of 526 published by Price Thomas and Cleland from patients treated in England was almost identical with the figures reported in Italy by Nicholson and by d'Abreu, Litchfield and Hodson. This incidence of clotting is not surprising when it is remembered that in a high proportion there were lacerations of the lung associated with small fistulae which delayed lung re-expansion and favoured mild infection of the haemothorax.

Three types of case were recognisable:

(1) Those in which the radiograph demonstrated multiple pockets containing air and fluid, combined usually with major lung-collapse.

(2) A massive pleural haematoma, usually seen quite early after a wound and with a remarkably small degree of liquid formation. In this group, pyrexia was usually far higher than in the simple haemothorax, and chest movements were almost completely absent on the affected sides. In the early stages of the campaign, because of the associated lung collapse, the frequent presence of bronchial breathing with the pyrexia led to a quite wrong diagnosis of pneumonia, but the radiological appearances were in fact quite different.

(3) In the third group infection was a serious complication and the difficulty was really one of multi-loculated empyema.

There were certain definite aetiological facts: the clotting process occurred twice as commonly on the right as on the left side and was much more common in patients with severe lung damage; and in Italy, where the *staphylococcus aureus* was a common contaminant in all battle casualties, it remained present in a clotted haemothorax. The fact that the organism produces no fibrinolysin was probably of considerable importance. The higher incidence in severer injuries, such as were caused by shell fragments, suggested that in these cases more thromboplastic substances were liberated than in the case of a clean through-and-through bullet wound, as the latter type of injury was accompanied by a much lower incidence of clotting.

If the clotted haemothorax was of considerable size its resolution was extremely slow and was invariably associated with the deposition of a fibrinous envelope over the parietal and visceral pleura, which hindered lung expansion and impaired chest movement. This fibrinous scaffolding became invaded by small blood vessels in the second to fourth week and if left in place ultimately became organised into dense fibrous tissue. The natural history of the condition, in cases not treated by major surgery, was the development of an imprisoned lung and a flattened immobile chest associated with great loss of respiratory function.

Treatment. In the early stages of the war it was thought that thoracotomy associated with complete clearing of the clots would suffice to encourage rapid lung expansion, but in practice this provided many disappointments because the imprisoned lung failed to occupy the pleural space as rapidly as was hoped; simultaneously in the American and the British Sectors the employment of the operation of lung decortication rapidly gained favour and major thoracotomy was employed more and more frequently with outstandingly good results. Through this wide exposure a thorough pleural toilet was combined with a complete removal of the fibrinous envelope from the lung and diaphragm, and often from the chest-wall pleura itself. After this the lung rapidly re-expanded and many of the casualties were ambulant and convalescing ten days after the procedure. Technical details of this operation have been given in Mr. Brock's section.

TRAUMATIC EMPYEMA

It will already have been noted from the previous account that the incidence of this, the most serious complication of gunshot wounds of the chest, depended greatly on the conditions of warfare and on the presence or absence of adequate surgery in the primary phase in the forward units, and the fall from an empyema rate of 33 per cent. at the beginning of the Italian Campaign to one of 7·6 per cent. at the close, represented in unmistakable terms the benefits of good administrative measures associated with timely surgery behind a successfully advancing army. The associated employment of penicillin used parenterally and locally played a great part in the reduction of empyema incidence as reported in the control series studied by d'Abreu, Litchfield and Thomson (*British Journal of Surgery*).

Recognition of Infection in a Haemothorax. This could not be made entirely on a study of the temperature charts because a moderate degree of pyrexia was always present even in the uninfected haemothorax patient. Major Litchfield cited the following criteria for making the diagnosis of empyema:

(*a*) Significant pyrexia. Temperatures higher than the nightly rise of 99° to 100° F. should be regarded with suspicion, especially if associated with rapid re-accumulation of pleural fluid after aspiration.

(*b*) The appearance of microscopic and macroscopic pus as seen on the smears made from aspirated fluid. This change in the nature of the haemothorax fluid was reflected in the transformation of the red colour to a turbid pink proceeding to the obvious colour of pus. It was frequently noticed that even at this stage organisms might not be detected in the fluid aspirated, but if thoracotomy was employed they were usually recovered from the centre of fibrinous clots removed during the operation.

(*c*) The presence of pathogenic organisms on bacteriological examination.

Treatment. A profound change was noticed as the campaign proceeded in the attitude of thoracic surgeons towards the gunshot wounds producing empyema, and the old view that major thoracotomy in the presence of pleural infection was a dangerous procedure was finally abandoned, and no hesitation was felt in doing a wide thoracotomy, decorticating the lung and removing all clotted masses from the pleural cavity, even in the presence of proved infection. There can be no doubt that the use of penicillin encouraged this boldness, but the new principle that evolved was that rapid lung re-expansion, if complete and early, was the best method of obliterating an infected pleural space. This new principle was outlined by Colonel E. D. Churchill, the Consultant Surgeon to the American Army in Italy, when he spoke at a conference of surgeons in Rome in 1945 in the following terms:

> I would like to point out that our surgeons have overthrown certain very basically fixed ideas. If one principle came out of the empyema epidemic in 1918 it was that the duty of the surgeon was to postpone interference until an empyema was localised. Now the thoracic surgeons do not hesitate to open an infected haemothorax which may be partially localized, and convert it into a generalized empyema in order to bring about quicker healing with a normally expanded lung. This is a complete reversal of one of our old precepts of the management of empyema.

Although no hesitation was felt in employing this major measure in the treatment of widespread empyema, many similar collections of pus were dealt with by the routine methods of rib-resection and closed drainage, these patients being managed along the generally accepted lines with retention of the drainage tube until the installation of lipiodol into the cavity followed by radiographic studies had proved that the empyema cavity was in fact completely obliterated. It remains to be said, but with a note of caution, that a considerable number of frankly infected haemothoraces were cured completely by repeated aspirations and the instillation of penicillin. In the hands of a team specially aware of the dangers of delaying operation, some brilliant results were achieved by this conservative method. Good results were only obtained when the technique of aspiration was of the highest quality and the whole treatment was controlled by radiographs taken on alternate days until the condition was proved radiologically to be cured, or the indications for major surgery established.

THE CHRONIC EMPYEMA

In gunshot wounds of the chest the cause of chronicity, as in civilian empyema, was delay in lung re-expansion. In traumatic cases this delay was often due to one of the following conditions; an original severe pulmonary damage which might have left permanent scarring or atelectasis of a lobe; the presence of multiple broncho-pleural fistulae; the retention of a foreign body in the lung, pleural cavity, mediastinum, or in the bed of a thoracic vertebra associated with osteomyelitis; a firm fibrinous envelope on the visceral pleura; a persistent pleuro-biliary fistula occasionally associated with a foreign body in the liver; and a trans-diaphragmatic communication leading to an inadequately drained subphrenic abscess.

From the list above it will be clear that the adequate treatment of some of these chronic empyemata demanded a surgical eradication of the cause, but in general the essential factor in treatment was the institution of adequate drainage, with or without lung decortication, combined with vigorous physiotherapeutic measures. In the Italian theatre it was universally considered to be unjustifiable to perform thoracoplasty for this type of patient, and if prolonged drainage associated with the other measures mentioned failed to produce a cure the casualty was evacuated, with the drainage tube still *in situ* to the United Kingdom for further treatment in a chest centre there.

THE SURGERY OF RETAINED FOREIGN BODIES

In the Italian theatre the tendency was to remove all retained metallic foreign bodies of the size of 1 cm. or more. It was believed that the early removal of such missiles would prevent both early and late symptoms such as haemoptysis, the effects of bronchiectasis, and the troubles of chronic lung abscess. In 208 cases of retained intra-thoracic missiles reported in 1945 (d'Abreu) death from haemoptysis occurred in two soldiers, and empyema resulted in ten patients who had peripherally-sited lung missiles which were subsequently removed at operation, and abscess cavities were noted round the ten lung fragments at operation. The high reported incidence of empyema associated with metallic fragments free in the pleural cavity is probably due to the fact that these missiles were originally quite superficially placed in the lung and then ulcerated into the pleural space, which became infected from the peripheral area of lung damage. At the same time recurrent pericardial effusions were noted when metallic fragments were present in that sac, and abscess formation developed with six retained mediastinal foreign bodies, three being associated with osteomyelitis of the vertebrae, and one with an ulceration into the oesophagus which caused the death of the patient.

The operative removal of intra-thoracic foreign bodies was technically easy in the early stages from the first to the third week after wounding because of the absence of dense fibrous adhesions; another point in favour of this early intervention was that its timing did not increase the period of convalescence of the soldier. In Bari and in Naples both d'Abreu and Nicholson removed a large number of foreign bodies to prevent the type of complication listed. In neither centre was there any reluctance to operate across a free pleura for the removal of foreign bodies, and the results appear to be justified from a study of the following list (Table III) of 339 retained intra-thoracic missiles which were seen in a series of 1,000 gunshot wounds of the chest.

TABLE III

Retained Intra-Thoracic Missiles—339

(d'Abreu, Litchfield and Hodson)

	Pulmonary	Pleural	Mediastinal and cardiac	In endo-thoracic fascia
Total number	221	49	51	18
Number operated on and removed	100	44	28	14
Number operated on and not removed	2	1	4	nil
Deaths, post-operative	2	nil	2	nil

Note. Not quite half the pulmonary missiles were removed, the others were considered to be too small and often consisted of multiple small fragments. The high incidence of removed foreign bodies from the pleura is noteworthy, and these were removed deliberately because of the realisation of the high empyema incidence associated with them. Over half the mediastinal missiles were removed; 9 came from the pericardium and among the other sites should be mentioned the bodies of the thoracic vertebrae from areas in close proximity to the great vessels (2 were in contact with the aorta) or the oesophagus; one was removed from the thymus gland and one from the lumen of the subclavian vein which was sutured without the subsequent development of oedema of the arm.

Deaths. (1) The lung. In both instances the fragments were huge, over 2·5 cm., and the lung damage was extensive and grossly infected; in one, death followed six weeks later from septicaemia due to a penicillin-resistant staphylococcus in a patient with an empyema and extensive buttock wounds. In the other case there was an associated brain abscess due to a penetrating wound of the skull and not embolic. At necropsy two days after the operation an infected pericarditis was present.

(2) The mediastinal group. These followed operation for cardiac missiles. In the first case a large shell fragment nearly 2 cm. in size was seen in the region of the interventricular

septum. The heart muscle at the site of entry was obviously very friable and removal was not attempted. Death followed the next day with the heart in fibrillation. In the second case death occurred at the close of an uneventful operation for the removal of a bullet that lay chiefly in the pericardium and partly in the wall of the left ventricle, well away from the coronary artery.

The radiological investigations necessary for the safe surgery of retained missiles were specially studied by Major C. J. Hodson, and he laid down the following duties of the radiologist.

1. Exact anatomical localisation
2. Investigation of the pathological state of the lung or pleura, inasmuch as they will influence the surgical approach that is to be decided upon.
3. An estimation of the damage to the lung provided by the state of the radiological appearance of the track of the missile.

The radiological assessment included a description of the relationship of the missile to structures such as the pericardium, mediastinal contents and to the lobes and fissures of the lung ; this type of description was of far greater value than reference to rib levels when the surgeon was about to operate on a free pleura, as the open thoracotomy naturally changed the position of any lung missile in relation to such bony points.

The pre-operative appearances of missile tracks, well described by Hodson, were of practical value because at operation these were often palpable and when followed down led to the fragment which, in some of these patients was not easily palpable on account of the surrounding lung contusion. In all radiological examinations an all-round screening of the heart was carried out in the case of cardiac and mediastinal foreign bodies, so that exact knowledge was available as to whether such missiles were intra-cardiac or para-cardiac. Finally the portable X-ray screen was frequently used in the theatre, the foreign body being located by the use of the parallax method, after which a sterile needle was often passed down to the missile.

During the actual removal of the metal fragment careful attention was always paid to the possibility of portions of battle dress or of ribs being associated. It may be said that with few exceptions the techniques employed for the removal of foreign bodies were not especially difficult, provided good radiology and good anaesthesia were available. The incidence of foreign bodies actually lying in the endo-thoracic fascia and associated with extra-pleural effusions was surprisingly common. Some of the effusions were associated with rib fractures and some with foreign bodies lodged just within the plane of the ribs. By careful screening the radiologist was able to localise the foreign bodies, and the typical features of an extra-pleural effusion were the density of the shadow, the indentation of the lung field by an oval or rounded mass and the close apposition of this shadow to the chest wall from which it rose gradually or steeply, and sometimes with an overhanging margin at its lower border. In 10 out of 35 cases noted infection developed and was treated by drainage and evacuation of the clot.

THORACO-ABDOMINAL AND ABDOMINO-THORACIC WOUNDS

Blackburn and d'Abreu were able to record an improvement in the treatment and prognosis of these serious wounds. Of those soldiers arriving at forward surgical units, the ultimate mortality rate was in the region of 30 per cent. It was soon realised that thoraco-abdominal wounds were commoner than abdomino-thoracic wounds and that the prognosis was better in the former. It was equally obvious that the left-sided wound always carried a more grave prognosis because of the frequent incidence of hollow-viscus injury on that side. Frequently a right-sided thoraco-abdominal wound was treated in the British Army conservatively, the usual attention being paid to the haemothorax, but thoraco-abdominal laparotomy was used widely in wounds affecting the left upper quadrant of the abdomen as well as the thorax. Both Blackburn and Rob had no deaths in those patients with right-sided abdomino-thoracic or thoraco-abdominal wounds which, after careful selection, they treated conservatively without major laparotomy or thoracotomy; and it was quite clear that small liver wounds were frequently the only abdominal lesion present on the right side, and that contrary to general expectation these frequently recovered without major haemorrhage from the liver.

In the forward areas considerable judgment was required when considering the advantages or disadvantages of an entirely abdominal approach or a thoraco-abdominal approach. In a series of 115 surviving patients with abdominal wounds operated upon in the forward area and received at the chest centre in 98th General Hospital, it was noted that one third of the patients had been operated upon by a thoraco-abdominal trans-diaphragmatic approach after the original wound in the chest had been excised, and that only four cases had been dealt with through a large thoracotomy wound and then by a formal laparotomy. The use of two separate incisions meant considerable disturbance of the patient and was avoided whenever possible. In the Italian theatre of war there appeared to be general agreement that a trans-diaphragmatic thoracic approach was preferable for the performance of splenectomy with an associated thoracic wound, and also for the exploration of the liver when that was the only abdominal viscus involved through a missile entering the thorax first. In these two groups the repair of the diaphragm was well nigh impossible through a laparotomy incision, but usually easily performed from above, and all surgeons were agreed upon the ease of trans-thoracic splenectomy.

In wounds confined to the upper abdominal quadrants thoracically minded surgeons employed the chest approach and many survivals were seen after wounds of the cardiac end of the stomach, the upper jejunum, the spleen and the splenic flexure of the colon. The post-operative course of these patients was a good deal easier because the diaphragmatic tear had been well repaired and any associated haemothorax had been thoroughly dealt with, and, curiously enough, the incidence of post-operative atelectasis of the lung was less frequent after a thoraco-abdominal approach than after a laparotomy. If any suspicion existed that the abdominal lesions were beyond the reach of the thoraco-abdominal incision, laparotomy was employed, but after the performance of such an operation it became clear that any associated haemothorax required the full treatment discussed previously. Wounds of the spleen were invariably treated by splenectomy, but often a conservative attitude was adopted in the case of renal wounds. It is of some interest to note that drainage for liver wounds was not much practised in the British Army, but it was the rule in the American Army, and perhaps this explains the curious fact that right-sided subphrenic abscess in British Hospitals after liver wounds was extremely rare, and much less frequent than in the American Service, but pleuro-biliary fistulae with bile-empyemata were on the other hand much commoner in patients treated by the British method. In this respect it is odd to note that Nicholson in the Naples Chest Unit had 21 subphrenic abscesses to deal with of which 13 were on the right side and 7 on the left, whereas d'Abreu on the Adriatic in 15 subphrenic abscesses found only two on the right side, the remaining 13 being on the left.

SOME TECHNICAL POINTS IN THORACO-ABDOMINAL LAPAROTOMY

The usual wound excision was followed by a full thoracotomy involving resection of a large portion of the appropriate rib. Any haemothorax fluid was aspirated by the sucker and lacerations in the lung closed by interrupted catgut sutures; the lung was then packed away by saline compresses and the hole in the diaphragm enlarged considerably to provide full access to the upper abdomen. This enlargement often necessitated cutting across the costal margin. As soon as the abdomen was open, blood was encountered and removed and, if arising from the spleen, splenectomy was performed. A thorough search was then made systematically for any visceral damage. It was always essential to inspect both the lesser and greater curvatures and the cardiac area of the stomach; wounds of these were closed in two layers in the usual way. Severe colon wounds were always treated by exteriorisation through a separate stab incision in the abdomen. In the latter part of the campaign several successful results followed the immediate suture of small perforating wounds of the colon, if these were situated on the antimesenteric border. When the abdominal conditions had been satisfactorily dealt with the diaphragmatic wound was closed in two layers by interrupted sutures, and, if drainage of the appropriate subphrenic space were required, the tube was usually brought out just below the tip of the 12th rib. The chest was closed in the usual way, frequently without drainage, 100,000 units of liquid penicillin being left in the cavity. The phrenic nerve was not crushed as a routine because an active functioning diaphragm was considered to diminish the later development of atelectasis of the lower lobe.

Post-operative Treatment. Both abdominal and thoracic complications were possible and each required treatment. Routinely the chief features of the post-operative treatment of the abdominal wound were the employment of continuous duodenal suction combined with venoclysis. Excessive intravenous salines were avoided as they were likely to cause waterlogging of the lungs in this particular type of wound. Assiduous attention was paid to the aspiration of any resultant haemothorax.

Thoraco-Abdominal Wounds at the Base Hospital. Although the death rate at this level was low, the morbidity rate was considerable. Nicholson received into his unit 164 thoraco-abdominal wounds of whom 23 died. On the other side of Italy, where air evacuation arrangements were a good deal easier, there were five deaths in 115 cases received.

The Commonest Thoracic Complications. In 115 thoraco-abdominal wounds admitted after forward surgery d'Abreu noted haemothorax as the commonest complication with 55 simple uninfected effusions; 29 of the patients had empyema, 7 with bile present in the infected fluid. It may be noted here that almost without exception a biliary fistula into the pleural cavity produces an empyema which requires subsequent drainage; in no known case did a biliary fistula from the liver persist after such drainage. Atelectasis of one or both lower lobes was noted in three of the patients and there were two examples of lung abscess. The treatment of this thoracic complication was on the usual lines. The abdominal complications, in the series of 115 cases stated above, included 15 subphrenic abscesses and two pelvic abscesses, all of which required drainage. The diagnosis of subphrenic abscess was not difficult if its possibility were always borne in mind in casualties with persistent pyrexia. The chief complication in diagnosis arose when a thoracic empyema or a collapsed lobe co-existed. Rigidity, guarding and tenderness over the involved subphrenic space was of value, but radiology perhaps provided the best information. On a few occasions lipiodol introduced into an empyema was shown on a radiograph to pass through a track in the diaphragm into a subphrenic abscess. Wherever possible preference was shown for drainage of these subphrenic abscesses by the employment of the extra-serous route described by Ochsner after resection of the twelfth rib. In this series of subphrenic abscesses six had co-incident empyema.

The Diaphragmatic Wound. It is impossible to assess the incidence of traumatic hernia, but, as many more diaphragmatic lacerations were carefully sutured from above in this war than in the War of 1914–18, it is likely that this later complication will not be seen very commonly. In Nicholson's large series of thoracic wounds five traumatic hernias on the left side were repaired by operation, and one on the right side which contained the liver only was not dealt with by surgery. d'Abreu dealt with three hernias on the left side, but on eight occasions a small hole was seen in the diaphragm many weeks after the primary operation, during such operations as clot clearance and decortication or during the course of an operation for removal of a foreign body in the lung. These lacerations were repaired by simple suture and several months afterwards none showed any radiological appearance of herniation.

In a considerable number of patients foreign bodies were removed from the liver or from a subphrenic space, but many missiles were known to be lodged in the liver without occasioning serious trouble, and Blackburn and d'Abreu noted only two liver abscesses in this type of wound.

CONCLUSION

The chief advance in thoracic surgery made in Italy was the firm establishment of the two-phase treatment of wounds of the chest, the first phase being devoted to the correction of disordered physiology and the adoption of a sound wound excision with early aspiration of the chest to prevent later infection; the second phase was devoted chiefly to the re-establishment of respiratory function and the correction of pathological disorders due to the simple and complicated haemothorax, the removal of foreign bodies and re-establishment of full function wherever possible.

The second great advance involved the application, for the first time in the history of war wounds of the chest, of penicillin-therapy of which the full details have been published elsewhere.

Finally, the application of modern thoracic surgical techniques and the use of modern thoracic anaesthesia led to a great diminution in the crippling effects of chest wounds noted after previous wars.

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(iii)

Thoracic Surgical Experience in the Campaign in N.W. Europe 1944–45

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In support of the medical services of the British 2nd Army and the Canadian 1st Army group, an apparently small provision was made for the surgical treatment of chest casualties. This arrangement was made because it was conceived from the onset that a large amount of the primary treatment of these injuries would be done by general surgical units, and that later they would be transferred for further care to Chest Units of the Emergency Medical Services in England.

THE TEAMS

The special provision consisted of one fully constituted team (No. 3 Surgical Team for Chest Surgery) and a section of the surgical division of a general hospital with especially drafted personnel. (No. 4 Surgical Team for Chest Surgery.)

No. 3 Surgical Team for Chest Surgery was formed in England in the early months of 1944. It consisted of a surgeon, a physician, an anaesthetist and a general duty officer together with four nursing sisters and four nursing orderlies. During the whole period of active service this establishment was supplemented, usually to the extent of an extra three nursing sisters, three further nursing orderlies and a physiotherapist. Although the team was a separate unit it was designed to function only in conjunction with a general hospital or casualty clearing station, and it was always anticipated that extra staff would be available from the parent unit in times of strain.

The team crossed to the Normandy bridgehead on June 27, 1944 (D + 20) and was immediately attached to a functioning general hospital at Bayeux. At this time the fighting was only a few miles from the hospital and consequently casualties ordinarily arrived with nothing but first-aid treatment previously applied. Under these circumstances it was not surprising that for this period all the possible functions of a chest team had to be fulfilled at one and the same time. All the chest-wounded of this large receiving hospital were sent to the beds of the thoracic unit and immediate surgical care had to be given, not only for the thoracic wounds but also for any other injuries that had been sustained. Secondly, a number of cases were regularly being transferred from surrounding units. At first these were few, but as time went on a steady increase occurred in their number. Lastly a number of cases had to be given later and planned surgical care, as for instance evacuation of clot and decortication of lung. In the main, this last type of case should have been returned to England during this rush period, but the condition of the patient, or temporary transport difficulties, would not always allow of this.

In addition to the actual surgical and medical attention to patients the team served two other useful functions. First, it provided instruction to a considerable number of medical officers who were gathering in the restricted area, many of whom either had no previous experience of field casualties or at least no experience of chest work. Many of these officers were able to come to the theatre while work was in progress, and to go around the wards at other times. Secondly, it supported and helped to clarify the views of the consultants as to the proper way in which chest casualties should be handled.

It is emphasised that the particular position in which the chest team found itself at this time, and later at Bruges, was seldom met with at any other time in the war. At both these sites the team was with a general hospital close to the site of fighting and was receiving cases at first hand. This provided a unique opportunity for observation of thoracic wounds in their early state and the immediate application to them of specialised technique. This experience led to a fuller appreciation of the fundamental principles of cardio-respiratory mechanics and their application to thoracic surgery; as this was a special contribution of this unit, the clinical details are reported briefly later.

It is interesting to note that the differing circumstances under which the team worked are reflected by the figures. In the early bridgehead days the pressure of work was great and conditions for evacuation to England were good. In this period 589 patients were attended by the team with 315 operations performed. Later in Bruges, behind the attack on Walcheren, when evacuation to England was not so easy, 166 patients were admitted and 136 operations performed. Later, in Holland and in the Battle for the Rhine, 229 patients came to the team and 235 operations were performed. The steady rise in the number of operations per patient admitted was almost entirely accounted for by the lengthening of the communications with England and the better facilities for a more prolonged stay. It will be noted that in all, 948 patients were admitted under the care of the team and 686 surgical operations were performed for their treatment.

CLINICAL GROUPING OF CASES

Some of the clinical details which seem most important will now be briefly summarised. Experience showed that casualties could be grouped into four classes:

(1) Minor injuries requiring no special treatment. This group includes through-and-through wounds of the chest with pulmonary contusion appearing as rounded radiological shadows but with no gross lesion occupying the pleural space. These wounds caused little disturbance and required no special treatment.

(2) Minor injuries requiring wound excision or aspiration of pleural blood only.

(3) Serious injuries such as those with a large retained foreign body, but in whom the cardio-respiratory mechanics were not seriously upset.

(4) Cases with lesions grossly upsetting cardio-respiratory mechanics.

The important point about Group 2 was that complete pleural aspiration needed to be effected as soon as possible. In association with aspiration penicillin was introduced, and this was undoubtedly of great value, though it was no alternative to proper removal of the blood. The team was able to check this statement because circumstances provided a series of cases which were given the same careful treatment, but in which penicillin could not be used. The results in these cases showed no difference of statistical significance. A similar experience was encountered with a series of 220 patients with sucking wounds, in whom the chest had been opened at operation and all blood sucked out. The reason for this situation seemed to be that if the pleura was aspirated or sucked dry no infection could gain a foothold.

TABLE

	Empyema incidence while with team	
	Penicillin per cent.	*No penicillin* per cent.
Non-sucking haemothorax . .	7·4	5·3
Non-sucking haemopneumothorax	13·3	6
Sucking wound	10·7	15·6

This table demonstrates that providing treatment is thorough, empyemata should be avoided even without penicillin.

It cannot be too forcibly emphasised that aspiration of all blood or air must be complete. Although for patients in Group 2 this is not necessary for the immediate survival of the patient, it is essential for his later progress. The object is to obtain apposition of the visceral and parietal layers of the pleura at the onset of treatment. When this has been effected any small amount of blood or potentially infected material left will cause pleural adhesion and the localisation or complete control of any infection. The apposition of the pleural layers will be relatively more interfered with by a small quantity of air than by fluid. For this reason it was frequently found that an aspiration at the apex of the chest was the most important part of treatment. A large air leak required special attention, but small ones had to be carefully watched for and further aspirations performed where necessary. Apart from the danger of infection it was found that, if the lung was left in a collapsed state for even a few days only, a fibrin layer formed over it, greatly interfering with its re-expansion. It was definitely the opinion of the team that this was a far more potent cause of non-expansion of lung than any direct injury to the pulmonary tissue. With regard to the exact position at which the needle was inserted for apical aspiration, this was over the trapezius between the vertebra prominens and the superior angle of the scapula. The surface marking will be referred to later in connexion with apical tubes.

The patients in Group 3, who had perhaps a large retained foreign body in the lung without extensive haemothorax or collapse of the lung, deserve special mention. There was a tendency to be hypnotised by the presence of a large foreign body and to feel immediate operation was essential. Certainly, undue delay only allowed infection to become established, but there was no urgency when consideration was a matter of hours. These patients were certainly better with many hours rest and sleep, so that they could have the operation for removal of the foreign body with slight immediate danger. It was always considered that undue delay was wrong with any foreign body measuring 1 in. × ½ in. on the X-ray film, and no point could be seen in leaving such cases ten to twenty days as was sometimes suggested. Foreign bodies under this size were not considered urgent unless they were either adjacent to some important structure or close to the hilum of the lung or near to the periphery of the lung. The great tendency for foreign bodies to enter the chest, pass through the lung and be stopped by the ribs on the opposite side of the chest, results in a very large number of fragments being on the surface and with the pleura damaged. Experience of the ill-effects of this resulted in a general tendency to advise early operation with smaller fragments retained. It should be added that of the ones not removed immediately only the smallest were left in permanently. For the rest, planned removal was recommended at a later date.

Patients in Group 4, with gross upset of their cardio-respiratory mechanics, are the real emergencies of traumatic chest surgery. In many, first-aid measures were able to be made so effective that time for resuscitation was available, but in some, corrective surgical measures were necessary before the patient had a chance to start recovering. The corrective measures might be such procedures as stabilisation of the chest-wall or stopping of bleeding from intercostal vessels or the closure of sucking wounds and complete expansion of the lung. In connexion with the actual leak of air from the lung, it has already been pointed out that it was always the practice of the team to take such measures as would ensure full pulmonary expansion immediately. It is emphasised that many patients in Group 4 had a small injury and were only ill because of a tension pneumothorax or large amount of blood in the pleura. It is further relevant to note that in many of these pneumothoraces the leak was not large and the patient's general condition was quite good. In any such cases, if aspiration failed to maintain the lung in full expansion, it was the practice of the team to insert an apical catheter and to connect it to an under-water drainage bottle. These apical tubes were found most valuable, and to be far more certain in their action than any rigid needle. The method used was to insert a No. 8 catheter through a cannula introduced at the apex of the chest posteriorly. The exact position chosen was a point over the trapezius midway between the vertebra prominens and the superior angle of the scapula. This site was found very convenient, because it allowed all the air to escape down the tube without blockage being caused by blood or clot. At the same time

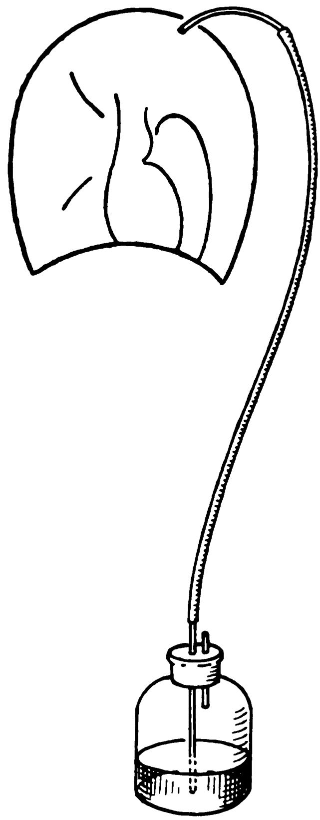

FIG. 1.—Apical tube in position and attached to an under-water drainage bottle.

the patient could not lie on his tube, which was also the least possible inconvenience to him. A similar tube was also used after any thoracotomy in which the anaesthetist could still demonstrate some air leak. Such a leak was often present after suture of the lung. Although it was always the practice of the team to use adequate incisions, cases were frequently encountered where a small sucking wound was present after a perforating injury of the chest in which the wound of entry might be extremely small and be very inaccessible from the small sucking exit wound on the opposite side of the chest. In these circumstances if the air leak was small, the situation was adequately controlled by an apical catheter. In later cases or where trauma had been severe, a basal drainage tube was used in addition to the apical tube. These tubes were routinely removed within 48 hours, and it was always found that their function had been served by then, unless surgery had been inadequate or gross infection was present.

In Fig. 1 an apical tube is shown in position and attached to an under-water drainage bottle. This is very effective in allowing pulmonary re-expansion to take place provided that a fibrin layer has not formed over the lung.

THE WORK OF NO. 4 SURGICAL TEAM FOR CHEST SURGERY

No. 4 Surgical Team for Chest Surgery was included as a section of the surgical division of a general hospital, to the establishment of which the medical and nursing officers were posted. This unorthodox arrangement proved very satisfactory, as the position of the hospital so far back (Brussels) meant that the great majority of thoracic cases admitted were about seven to fourteen days old and the stage of immediate surgery had passed. The cases, therefore, consisted chiefly of incompletely resolved or infected haemothorax requiring aspiration, or drainage, and only a very small proportion necessitating thoracotomy. The scope for thoracic surgery at this level was very limited, therefore, and it was most convenient to utilise the services of a general surgeon with considerable thoracic experience on the establishment of the surgical division of the general hospital.

The main object of the thoracic unit at this stage was intensive aspiration of haemothorax in order to expedite early pulmonary re-expansion, and thoracotomy was limited to evacuation of unresolved haemothorax, drainage of empyema, secondary closure of infected open pneumothorax and removal of foreign bodies in certain cases.

It would be pertinent to point out here the merits of a general hospital incorporating numerous special units, as was practised for one year at Brussels. This hospital had attached thoracic surgical, maxillo-facial and neuro-surgical units as well as eye and E.N.T. specialists, and it was, therefore, suitable for admission of any cases of supra-diaphragmatic injury, a convenient label on the line of evacuation of wounded. On several occasions it was possible to combine the teams for operation on multiple wounds. On one occasion, the services of the maxillo-facial unit were invoked for the closure of a severe compound transverse fracture of the sternum with infected open pneumothorax by the employment of the external pins used for fracture of the jaw, together with a pectoral muscle flap, with immediate relief of severe dyspnoea and an excellent result.

There were nearly 700 admissions during the year and the main clinical types for which treatment was indicated were as follows:

HAEMOTHORAX

From the point of view of treatment, there were two main types: simple, and compound or complicated.

(*a*) *Simple Haemothorax:* These included non-penetrating injuries and small penetrating wounds. The majority had been treated by aspiration in the forward zone. Most of the cases responded well to intensive aspiration and injections of penicillin. In only a small number was lung expansion delayed and in these thoracotomy and evacuation of clot was performed. A few practical conclusions emerged:

(i) *Method of Aspiration.* It is convenient to aspirate small effusions with syringe and two-way tap, but for large collections a blunt cannula or wide-bore needle attached to a water-seal bottle is preferable. A large A.P. needle is satisfactory, and the flow can

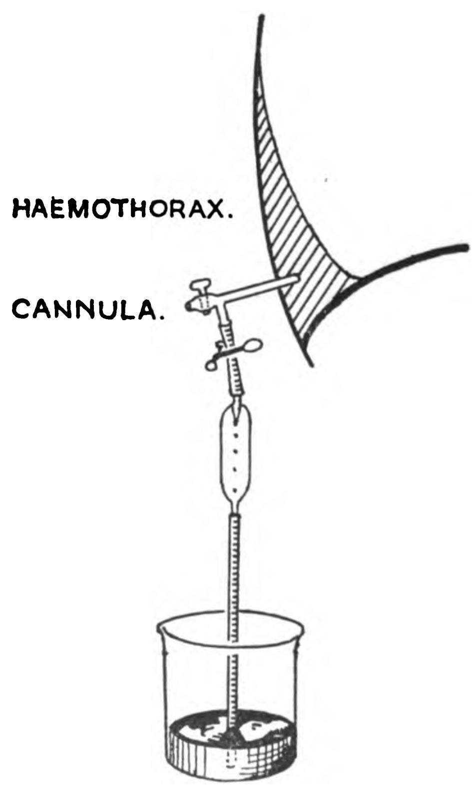

FIG. 2.—Aspiration of Haemothorax through wide-bore needle attached to water-seal bottle.

be regulated at a steady drip by means of a standard blood-transfusion drip connexion (Fig. 2). The use of general anaesthesia, suction bottles, or laborious aspiration with syringe is usually not necessary. In this way the minimum of attention is required—a point of some importance to the busy physician—and several cases may be dealt with at the same time, the only really essential apparatus being a sufficient number of suitable needles.

(ii) *Unresolved Haemothorax.* If aspiration fails to eliminate haemothorax within two weeks, surgical evacuation of the haematoma must be considered in order to avoid pleural fibrosis with an incompletely expanded lung. It is important, however, to select only the cases in which this is essential. The prognosis of persistent apical haemothorax is very much worse than that of basal haemothorax, because pulmonary efficiency is much poorer with collapse of the lung at the apex than at the base. In fact, the outlook for a sterile haemothorax is worse than for a basal empyema so far as final function is concerned. Hence, if the apex is well expanded there is no need for early surgical evacuation of the basal haematoma, and in fact such treatment is dangerous, because thoracotomy involves pneumothorax with the possibility of apical collapse. It is wiser to defer operation in order to ensure firm union of the pleural layers at the apex. On the other hand, if aspiration of haemothorax with collapse of the upper lobe is proving difficult, evacuation of the haematoma should be carried out as soon as possible.

(*b*) *Compound or Complicated Haemothorax.* These included penetrating wounds of large size and the majority had been subjected to thoracotomy at the C.C.S. or F.S.U., being admitted seven to fourteen days later. They travelled well, much better than did abdominal cases at this stage. The vast majority had had excellent primary surgery, due mainly to early treatment in the forward zone and particularly to the experience of most of these surgeons in previous campaigns (mostly from the M.E. theatre). Healing by primary intention was the rule in most of these cases, so that treatment at this stage was that of residual haemopneumothorax. It was in this group of cases, of course, that the majority of infections occurred and, as in most other regions of the body, the chances of infection were proportionate to the amount of unexcised damaged tissue and foreign material. The commonest infections were empyemata, and contamination of large wounds of the chest-wall with secondarily infected open pneumothorax.

EMPYEMA

Empyema occurred in 14 per cent. of 400 penetrating and perforating wounds admitted. It must be emphasised that this figure of infection rate was a maximum because the cases admitted included particularly those haemothoraces which were not progressing well or were already infected, while a large number of uninfected cases resolving rapidly with aspiration in other units did not find their way to the chest units. The association of haemopneumothorax with infected foreign material was the most common cause of empyema, so that the two essentials in prevention were early pulmonary re-expansion and adequate surgical toilet. Penicillin therapy was of value in prophylaxis, but was second in importance to radical surgery in the elimination of potential infection. Once infection had occurred it was best to carry out drainage immediately, since penicillin therapy for infected haemothorax was rarely successful, and its continued use led to pleural fibrosis and loculation. The most convenient way of dealing with severe pleural infection before localisation of pus was by intercostal drainage in the axilla without disturbing the patient in bed, followed a few days later by deliberate posterior rib resection drainage. In some cases of total haemopneumothorax with early severe infection, however, intercostal drainage was inadequate and it was necessary to evacuate clot and instal drainage by rib resection.

Chest Wall Infection

Infection of the chest wall was of small importance in the absence of pleural damage. If there was a communication with the pleura, however, the condition was serious, since there was always an associated empyema and the patient suffered from toxaemia and open pneumothorax. This condition was seen most commonly with wounds of the anterior chest wall, where anatomical conditions favoured infection, since the costal cartilages showed poor resistance and there was often difficulty in closing a wound after adequate excision owing to lack of available muscle. There was always an associated empyema, and often contusion or atelectasis of a section of injured lung, which was usually the upper lobe corresponding to the anterior wound. Treatment consisted in the first place in prevention of sepsis by adequate excision of wounds, particularly those in the region of costal cartilages. With established sepsis and a secondary sucking wound, the first step was drainage of the empyema with temporary packing of the wound. The general condition usually improved considerably, after which secondary closure with muscle flap was carried out.

Foreign Bodies

Indications for removal of a foreign body at this zone were very limited, being mostly incidental to evacuation of haemothorax or drainage of empyema.

Associated Wounds

A considerable number of thoracic wounds were associated with perforating wounds of the upper arm, often with fractured humerus. It was convenient to use a posterior plaster slab for the arm, with the elbow flexed, so that the limb could be moved enough to permit access to the chest for aspiration of haemothorax.

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CHAPTER 14

RADIOLOGY

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General Remarks on Radiology in the Field

RADIOLOGY played a vital part behind the fighting lines and constituted a material aid in accurate diagnosis. The radiologist was able to give the surgeon much help, not only in diagnosing fractures but in locating foreign bodies, wound-tracts, and internal damage, and in estimating the distribution, rate of formation and localisation of gas in the tissues before the clinical evidence defined a clostridial infection amounting to 'gas gangrene'. An X-ray examination, however, no matter how carefully conducted, was an ordeal, and the more seriously wounded the patient the greater the ordeal. For this reason there were conflicting views as to the advisability of furnishing advanced surgical centres with X-ray apparatus. All agreed that routine radiography was out of the question at those centres, but the relative urgency of dealing promptly with, or evacuating, certain types of case led to a difference of opinion which was not finally settled during the war.

When considering the advisability of an X-ray examination of an injured patient the main question to be answered was: 'Is it imperative that it should be done at this present moment?' X-ray examinations were only considered necessary when the findings were expected to affect immediate treatment or the disposal of the patient. Maxillo-facial, cranial and thoracic injuries were, whenever possible, not radiographed until they reached the unit responsible for their definitive treatment, for it was found that urgent examinations at advanced stations did not prevent the reduplication of the procedure at hospitals further back.

Fluoroscopy was sometimes undertaken with mobile apparatus but special caution was enjoined to avoid the risk of injury from radiation. The Ministry of Health issued circulars in which they advised that fluoroscopy should not ordinarily be performed under field conditions unless the radiologist or a senior radiographer were available. The smallest possible diaphragm and the absolute minimum time for screening were insisted upon, and the responsibility for any X-ray burn to the patients or staff was made to rest, not upon the radiographer, but upon the medical officer in charge.

The clinical administration of the X-ray department was the function of the radiologist, who was directly responsible to the officer commanding. In the only two hospitals in which the X-ray department was under the control of the officer in charge of the medical or surgical division, the arrangement did not prove satisfactory. To economise work and promote efficiency there was need for close co-operation between the divisional officer and the radiologist, who could often exchange valuable information.

RADIOLOGY OF WAR WOUNDS OF THE EXTREMITIES

Most radiological war-work concerned injuries of the extremities. In the British Army in 1943–4 about 70 per cent. of injuries in the field were in the extremities (Buxton; Law, 1944) and about the same proportion was noted in the German Army in 1942. In the modern mechanised army a considerable proportion of the injuries to the limbs were due to accidents in connexion with transport. Injuries to the wrists were very common. In radiology of the limbs much valuable information was sometimes overlooked by the too casual examination of the radiographs and the failure to insist on proper viewing conditions. It was noteworthy that with the development of a more conservative treatment of war wounds less radiography was needed at advanced centres but increasing importance was attached to accurate X-ray work at the base hospitals. The use of the Tobruk plaster and the other forms of splinting did not make for accurate radiography.

With regard to methods, stereoscopy was sometimes found useful but had definite limitations. Moreover it was found that under field conditions more skill and experience were needed to interpret the fluoroscopic image than a radiograph of the same region, and fluoroscopy also carried with it the possible danger of a burn of the radiologist's hands.

Certain types of fractures were more common than in civil life. 'March' fractures, due to prolonged foot strain, had such a narrow fracture-line that they might be overlooked by an early radiograph but always showed developing callus within two or three weeks of their occurrence. Persistent pain in the metatarsal region therefore called for repeated X-ray examination. Occasionally 'march' fractures occurred elsewhere than in the metatarsals, e.g. neck of femur (Samuel, 1942), shaft of femur, and the pubic bone, and tibia (Hartley, 1942). Even the first rib was sometimes the site of a stress fracture (Alderson, 1944) and a fatigue fracture of the same bone sometimes occurred from the carrying of two heavy barrack-room bags fastened over the shoulder by a strap.

Fractures of the pelvis and os calcis were common among the crews of sinking ships, due to the men sliding down the side of the ship and striking the bilge keel.

In the R.A.F. certain special fractures occurred which depended on conditions peculiar to flying. R.A.F. medical officers, including radiologists, were expected to take as full an interest as possible in the activities of flying personnel—a policy which benefited morale and gave the specialist an opportunity of studying the mechanics of flying accidents. For example, the pilot in bracing his foot against the rudder bar during a forced landing might sustain a fracture of the neck of the astragalus, and in addition the violence might be transmitted upwards and cause fractures of one or both femoral shafts, frequently near the junction of upper and middle thirds, and even of lumbar or dorsal vertebral bodies. Fractures of the spine (especially the dorsal region) might also be a sequel of parachute descents, though symptoms might not become manifest for some time, when a collapse of one or more vertebral bodies might be found.

Paratroopers were subject to two common fractures. The first was a fracture of the posterior articular margin of the tibial malleolus or posterior tibial lip, generally due to landing on one foot on irregular ground or in the wind. The second was a crack in the external malleolus associated with a silent fracture of the upper third of the fibula.

Among the mechanics air-pressure tools often caused fractures, particularly affecting the tip of the coronoid process of the ulna, but occasionally causing lesions of the wrist or shoulder.

Unlike the experience of former campaigns, radiology was not called for in the treatment of compound fractures in forward areas, but its importance at the base hospitals greatly increased.

During the war the need for examining serial radiographs to determine the degree of union became evident, and close collaboration between the surgeon and radiologist was required. Non-union due to distraction could be determined by the thin atrophic bone, the tendency to pointing of the bone, and later by the sclerosis of the ends.

When union had occurred but a discharging sinus persisted, it was sometimes difficult to determine whether a sequestrum was present. This might be shown by an 'overpenetrated' film, less commonly by tomography, but with greater accuracy by use of a contrast medium (barium sulphate or lipiodol) injected into the sinus, whereby the sequestrum was shown up as a clear area in the shadow cast by the contrast medium.

When infected bone was treated by penicillin, radiography showed rapid rarefaction followed by speedy new formation of bone. No sequestrum formation occurred in the cases treated by penicillin.

Joints. Radiology was used to show any injury to the joint surface, and the presence of any opaque foreign body. Routine antero-posterior, lateral, oblique and stereoscopic views were necessary. The joint-space could be clearly shown. It was preferable to use screened films for speed, as any movement seriously detracted from the value of the radiograph. Contrast radiography was of help in detecting less opaque foreign bodies. In the later stages of suppurative arthritis radiographs showed the degree of destruction of the articular cartilage by a diminution of the joint space. In non-penetrating injuries of joints the early stages of osteo-chondritis dissecans needed to be specially looked for. Local decalcification followed by a dense area in the centre of the rarefied area preluded the separation of the loose body which was shown smooth on one side and irregular on the other. Injuries to the inter-articular cartilages were very common and were dealt with as in civil life; sometimes arthrography was of help.

Soft tissues. Soft tissues were demonstrated either by using a low k.v. technique (20 to 40 k.v.) with a high milliamperage which enabled the radiograph to be taken under 2 seconds; or preferably by using a high kilovoltage with filtration of the beam with an aluminium filter. The latter method showed soft tissue detail and differentiation. By such methods haematomata or effusions into joints could be demonstrated clearly, and various tissues differentiated. In order to estimate accurately the track of the missile in penetrating injuries it was useful to mark the entrance and exit wounds with metal markers of different shape, and to approximate the affected part to the position it happened to be in at the time of wounding.

Radiography was of value in showing air and gas in the tissues before it could be detected clinically. It was necessary to distinguish radiographically between (1) air aspirated in with the foreign body or introduced in dressing the wound, (2) ordinary surgical emphysema, and (3) gas gangrene. Aspirated air generally appeared as large transparent bubbles round the foreign body and sometimes along intermuscular planes. Gas due to the introduction of hydrogen peroxide into the wound was to be seen as bubbles aggregated round the wound. Surgical emphysema occurred chiefly round the thorax and could be felt superficially by the hand.

Gas due to anaerobic bacilli was to be seen between the individual muscle-fibre groups and gave rise to a 'pectinate' appearance (Kemp, 1945). War experience proved that gas gangrene could not be diagnosed on a single radiograph, but, except in advanced cases, was only to be suggested when there was an inter-fascicular distribution of gas through more than one group of muscles. The effectiveness of X-rays in the treatment of gas gangrene was not established. It was recognised that local formation of gas due to anaerobic bacilli could occur without symptoms of general toxaemia.

The introduction of penicillin and the use of sulphonamides almost put an end to the importance of the early detection of gas gangrene.

The value of contrast media in showing up the course of sinuses and fistulae was frequently demonstrated. Arteriography was of use in demonstrating the condition of the artery near a traumatic haematoma, in estimating the collateral circulation with an aneurysm, and in showing the fistulous connexion between the arterial and venous systems in a case of arterio-venous aneurysm.

RADIOLOGY OF WAR WOUNDS OF THE ABDOMEN

Radiography was not always necessary in war wounds of the abdomen but it was often of great assistance. It determined the site of a foreign body, indicated the track of a missile, or gave evidence of free gas in the abdomen. At the same time it gave information as to associated lesions of the chest, could demonstrate retro-peritoneal haematomata, and helped in the diagnosis of post-operative obstructive lesions. The routine examination included the taking of a film (to include the diaphragm) with the patient supine, and another lateral radiograph of the upper part of the anterior abdominal wall. Sometimes an erect film of the diaphragmatic area could be taken or a horizontal antero-posterior picture with the patient rolled over on to the left side, but this was not always possible or advisable. The use of the 'lucidex' or Potter-Bucky grid improved the diagnostic quality of the film. Abdominal injuries could seldom be radiographed in forward areas, but exceptionally (as at Tobruk and in Normandy) this was possible when a base hospital actually functioned as an advanced surgical centre.

The fact had constantly to be remembered that anatomical structures could act as missiles; indriven ribs could cause as much damage to the underlying viscera as large metallic bodies. In estimating the degree of indriving of the ribs it was necessary to take tangential views of the chest. Wounds of the buttock necessitated survey-films of the whole abdomen.

The radiographic appearances which proved of significant help in diagnosis were as follows:

Pneumoperitoneum. Free gas was more likely to be seen in wounds of the colon, but generally speaking radiological evidence of pneumo-peritoneum was seldom seen.

Gas distension of the bowel. A rough guide to the site of single injury of the small or large bowel could be made by taking advantage of the significant fact that the bowel above the site of any injury was frequently distended and might show fluid levels—a fact which could be detected by X-rays.

Displacement of gas-filled bowel by large soft-tissue masses usually indicated a retro-peritoneal haematoma.

The general opinion was that abdomino-thoracic cases in which radiography was essential were better transported to a casualty clearing station for investigation. In any doubtful case it was necessary to undertake an X-ray examination of both coelomic cavities.

In cases of amoebiasis some indication as to the involvement of the liver could be obtained by noting the size of the liver and the extent of movement of the diaphragm.

Radiography was also of use in diagnosing non-penetrating injuries of the abdomen by demonstrating free gas in the peritoneal cavity, abnormal collections of gas in the bowel, or indications of retro-peritoneal haematoma.

In blast injuries, if a supine radiograph showed changes suggestive of paralytic ileus, one had to be suspicious of an injury to the bowel. Radiological examination of patients who had suffered from immersion-blast revealed gas distension of the bowel, abnormal soft tissue densities (haematomata), and occasionally free gas in the peritoneal cavity or abnormal gas or shadows in the soft tissues of the posterior abdominal wall due to gas in the retro-peritoneal tissue.

RADIOLOGY OF WAR WOUNDS OF THE URINARY TRACT

Radiology was helpful in many cases of injury to the urinary tract. Non-penetrating injuries of the kidney were more common in this than in former wars, possibly due to the greater number of accidents with motor-vehicles. In the case of a ruptured kidney a plain radiographic film gave one or more of the following signs: absence of renal shadow, obliteration of the psoas line, fracture of the twelfth rib, raised hemi-diaphragm, scoliosis of the lumbar spine (due to muscular spasm), and sometimes evidence of extraperitoneal haematoma. Intravenous pyelography was useful when the diagnosis or the indications for operation were doubtful; it could demonstrate any deformity of the renal pelvis or calyces, any extravasation of the dye outside the renal shadow, and the degree of function of both kidneys. It was noteworthy that in cases of schistosomiasis, which was fairly common among crews serving in the East, radiography showed there was a tortuosity of the lower ends of the ureters. Retrograde pyelography was only used in exceptional cases. A cystogram (using sodium iodide 12½ per cent.) was occasionally used to demonstrate an injury to the bladder.

WAR WOUNDS OF THE HEAD AND NECK

The radiological report of any injury of the cranium needed to include information as to the site of fracture, the size of the fracture-line, the type of fracture and whether or not it crossed a vascular marking. A routine X-ray examination was not insisted upon in a gravely ill patient when simpler methods could give the necessary information. In the majority of battle casualties it was only necessary to take an antero-posterior view with the central ray vertical, and a lateral view in the brow-up position; the skull needed to be absolutely immobilised. With a closed head injury a Towne's view was taken; by its routine use fifteen cases of sagittal fractures of the occipital bone were revealed in cases previously X-rayed and reported normal. A tangential view was taken if the extent of the damage were not obvious or if no damage were seen on the routine films.

Radiography of a fracture of the vault enabled one to see the degree of penetration and the nature of impact, whether direct or glancing. Elevation and depression of bony fragments and the presence of a missile could be detected, and an extra-dural haematoma might be indicated. The radiological demonstration of intracranial air was of importance since it usually implied a tear of the dura mater, though air cysts consequent on an injury of an air sinus were sometimes seen in the substance of the brain.

When foreign body and bony fragments were driven into the brain one could estimate whether the ventricles were involved by superimposing a tracing of a normal ventriculogram over the X-ray views of the affected skull in the various positions.

Maxillo-facial fractures, often caused in airmen by the impact of the face against the instrument panel, were a very important special problem. Matthews (1947) and Bromley (1948) both pointed out that the radiologist ought not to regard each facial bone as a separate structure for, as Bromley put it, 'each bone is part of a composite whole'. The same author emphasised the radiologist's heavy responsibility in recognising as early as possible the extent of the bony injury in these complex fractures, since their reduction became increasingly difficult with delay, and even three weeks after the date of injury such firm fixation might have occurred that correction of deformity could only be attempted by a tedious series of plastic procedures.

For injuries involving the facial bones it was advisable to take views from four aspects:

(1) Stereoscopic occipito-mental.
(2) Lateral view of facial bones.
(3) Occlusal and dental views of the nose.
(4) Lateral views of both mandibles.

For the upper jaw valuable information was obtained by the use of 30° occipito-mental view obtained by centring the tube 30° towards the feet, positioning the head as for occipito-mental and decentring the film so that the central ray passed through the centre of the film. Tomography was found of value in estimating the amount of displacement and in tracing the course of the individual fracture-line in fractures involving the upper jaw.

Fractures involving the facial bones almost invariably went through one or other of the nasal sinuses. When the fracture implicated the maxillary antrum one of three radiographic appearances was to be seen. There might be diminished translucency, a localised rounded opacity (probably due to submucosal haemorrhage), or sometimes a fluid level due to haemorrhage into the cavity.

In injuries of the soft parts of the neck radiography was chiefly used to determine the presence or position of a foreign body.

RADIOLOGY OF WAR WOUNDS OF THE CHEST

Pre-operative X-ray examination, however essential, was not allowed to interfere with resuscitation, but a portable X-ray apparatus enabled radiography to be undertaken in the resuscitation ward at the earliest possible moment.

At advanced surgical centres and casualty clearing stations all that could be done was to get a general estimation of the intrathoracic damage by means of a scout film taken at as short a distance as 30 in. (or even less) from the anode, so as to eliminate movement. The resulting distortion was no bar to correct interpretation since the lesion was usually maximal. It was important to try to take the antero-posterior film with the patient in the erect position so that fluid levels would not be missed. If this were impossible, an antero-posterior film in the supine position needed to be taken, and a horizontal beam used to obtain a lateral view in the same position. An over-penetrated film of the chest was always taken, because a normally-penetrated heart shadow or haemothorax might completely obscure foreign bodies lying behind them. The only use for fluoroscopy (at the advanced station) was for early diagnosis of cardiac tamponade.

At base hospitals more accurate radiographs were taken, though usually at a slightly less anode-film distance than the regulation six feet.

Periodic routine radiographs during convalescence were important to observe the recovery of a chest injury.

There were special points in technique and interpretation in connexion with the various types of thoracic injury. Many fractures of the ribs which might otherwise have been overlooked were discovered when the case was re-examined after an interval. Whenever the original radiograph was negative but the symptoms persisted it was necessary to repeat the radiography after ten days. In every case fractures of the dorsal spine were to be looked for in radiographic examination of the chest, and for this purpose stereoscopic films were found most useful.

Lesions such as extra-pleural haematomata and oedema of the chest-wall could be differentiated from lesions in the parenchyma of the lung, as the hilar shadow and the broncho-vascular markings on the affected side were unaltered.

With a 'stove-in' chest, radiography revealed the rib fractures and any accompanying haemo-pneumothorax, or massive collapse of lung.

Radiography of a lung injured by aerial blast revealed areas of mottling in the periphery of the lower lobes, and sometimes areas of lobular or lobar collapse and consolidation; the upper parts of the lung were often emphysematous. As a rule considerable clearing of the lung-fields occurred within three days and in about ten days the appearance was normal. X-rays sometimes revealed considerable changes even though there might be few symptoms. Immersion blast gave rise to similar radiological changes in the lungs.

Four other unusual lesions should be mentioned. *Haematoma* of the lung showed up on the radiograph as a central unilateral opacity with ill-defined borders which might obscure the hemithorax. With *mediastinal emphysema*, which generally resulted either from damage to a large bronchus or rupture of an emphysematous bulla, a lateral view revealed air in the mediastinum, whilst an antero-posterior view showed a diagnostic clear linear area along the lateral borders of the heart. *Traumatic asphyxia* showed lobular collapse affecting parts of both lungs; in this condition the increased slope of the ribs (tiling) enabled a distinction to be made from bilateral pulmonary oedema. With *fat embolism* the radiograph often gave bizarre pictures showing multiple areas of apparent broncho-pneumonia, which disappeared in a few days.

Foreign Bodies in the Chest. The relative radiotranslucency of many foreign bodies, especially light-alloy projectiles, sometimes caused them to be overlooked on the radiograph. For accurate localisation careful fluoroscopy was needed. Apart from localisation, radiography was able to estimate the pathological changes caused by the missile, of which haemothorax and pneumothorax were the most frequent.

The radiological signs of a haemothorax were those of a pleural effusion almost indistinguishable from a simple effusion. When the radiograph had to be taken in the supine position the loss of translucency extended over the whole of the affected hemithorax where the lung markings could only be faintly seen. Clotting of a haemothorax was suggested either by a mottling due to loss of uniform density, the appearance of multiple shallow fluid levels, displacement of the mediastinum towards the affected side, or a thickening of the visceral pleura.

Tension pneumothorax at an early stage was sometimes revealed by the displacement of the mediastinum, long before clinical signs were evident. Three conditions needed to be differentiated from it. Traumatic diaphragmatic hernia could be distinguished by the convex upper border to the air-containing cavity of the stomach, for a tension pneumothorax never showed a convex lower border. Emphysematous bullae and giant cysts of the lung could be differentiated by correlating the clinical with the radiological picture.

Though radiography was of little value in the early stages of an open pneumothorax, it was of extreme value in following the re-expansion of the lung, or the development of a haemothorax after operation.

Abdominothoracic Wounds. The radiological signs of rupture of the diaphragm were either invisibility of the injured dome, intermittent twitching movements of the muscle, pneumothorax or pneumoperitoneum, or haemorrhagic atelectasis. A traumatic diaphragmatic hernia might be hidden by an accompanying haemothorax but later the hollow stomach or intestines might be seen in the pleural cavity.

Missile Tracks. Hodson (1944) demonstrated that the track of a missile through the lung could sometimes be shown radiographically. He described three main types:—(*a*) Hollow tracks in which the tract was filled with air from a communicating bronchus; the track might appear as a circular or oval ring or as parallel linear streaks according to the direction of the beam of light; (*b*) Solid tracks which showed up as round or oval shadows or solid tubes respectively; (*c*) Metal tracks caused by small fragments of metallic casing scattered along the line of passage of the missile through the lung.

Acute and chronic empyemata differed little from those in civil life. An empyema frequently developed after an injury to the chest.

Injuries of the Heart. In this war foreign bodies were on many occasions removed from the heart itself (Dwight Harken and others).

Accurate pre-operative localisation was necessary and careful fluoroscopy was an essential part of the examination.

An over-penetrated film needed to be used before one could exclude an intra-cardiac foreign body. Cardiac tamponade could only be diagnosed with certainty by the use of the fluoroscope, which showed restricted or complete absence of pulsation on screen examination.

The enlarged heart, which was common in patients suffering from beri-beri, could be demonstrated by the X-rays.

WAR WOUNDS OF THE ORBIT AND EYEBALL

Foreign bodies were frequently embedded in the eyeball; of 600 ocular casualties, 300 were shown to have intra-ocular foreign bodies. Of these 50 per cent. were demonstrated on radiographic examination. An analysis of the manner in which these casualties occurred is shown in the following table:

	Per cent.
Blast	12
Bomb (air and mortar)	15
Bomb (grenade)	6
Booby trap	5
Mine	24
Shell	38

The occurrence of casualties involving the eye and orbit depended to some extent on the type of warfare and the terrain in which it was waged. The relatively static Italian front with its extensive minefields contributed a high percentage of ocular casualties. Likewise, branches of the Armed Forces principally concerned with clearing minefields were unfortunately more liable to this type of injury.

Injuries primarily involving the bony orbital walls were most frequent in personnel of the mechanised arms of the Services and especially among flying personnel. Although these injuries were neither as dramatic nor as dangerous as those involving the globe, their results were not unimportant.

Technique. In no branch of radiology was good technique so vital as in the investigation of injuries involving the orbit. The radiological approach depended upon the type of injury. In every case there were two problems: to show whether a radio-opaque foreign body were present, and, if present, to localise it accurately. Aluminium and magnesium and their alloys were extensively used during the war and their low radio-opacity gave rise to difficulties. Screened films gave less motional blurring but unscreened provided clearer definition. When possible both screened and unscreened films were used. It was better to use a small cone just sufficient to cover the affected orbit, and more than one film needed to be taken. Even with the best available technique a proportion of foreign bodies could not be demonstrated. In one of the campaigns the enemy used non-metallic mines and consequently 50 per cent. of intra-ocular foreign bodies were not radiographically demonstrable. No single method of localisation gave universal satisfaction. The presence of a foreign body was first established by taking a single antero-posterior radiograph. Foreign bodies lodged in the anterior corneal chamber were best detected by making use of a dental film which included no bone in the picture. Localisation of fragments near the periphery of the globe needed to be accurate to ½ mm. The methods of localisation practised in the war were (1) simple general methods and (2) more exact methods. The usual 'first-aid' or general rough method was to take antero-posterior and bitemporal radiographs, and if a foreign body were demonstrated, to take further bitemporal radiographs with the eye looking upwards and then downwards, so that by calculation from the double shadows thus produced the position of the foreign body might be estimated.

The more exact methods comprised the techniques of Sweet, McGrigor and Comberg, and later Bromley and Lyle's 'eye localiser', and the limbus ring and equatorial techniques. It was of advantage to use methods which could be brought to the bedside of the patient so as to avoid moving him unnecessarily.

The standard portable shock-proof X-ray sets were suitable for this purpose. Many radiologists employed variations of these techniques which they had themselves devised and in which they became specially adept.

Injuries of the Orbital Walls. In investigating such injuries it was essential to follow a routine technique if fractures and displacements of the orbital floor were to be accurately assessed. It was recommended that stereoscopic occipito-mental, 30° occipito-mental and lateral views should be taken. In some cases, especially for fractures involving the optic foramina, the 39° oblique view was found extremely useful. Tomographic studies were especially valuable when operative correction of displacements of the orbital floor were being considered. Any type of fracture might be found, involving the roof, medial wall, lateral wall, or floor of the orbit. Fractures of the medial wall were difficult to demonstrate on account of the many bony septa in the ethmoidal cells; the lateral view was of most value in that it showed the alteration in profile of the facial bones. Confusion sometimes arose in the differentiation of the fracture line from the normal maxillo-malar suture line. The constancy of position of the latter together with its characteristic direction usually sufficed to distinguish between the two.

RADIOLOGY AND AVIATION MEDICINE

The radiologist was of assistance in research into the problems of aviation medicine, particularly the effects of altitude on the body in different circumstances. Air contained within the body expanded proportionately to the altitude reached and this caused effects which were demonstrable by X-rays. For example, at a high altitude minute air pockets in recently filled teeth might cause excruciating pain, while a partial pneumothorax at ground level would increase till it displaced the mediastinum, if this were freely movable; if the mediastinum were fixed by adhesions the increasing pneumothorax herniated in front of the heart, compressing the great veins and causing serious cardiovascular embarrassment even at 8,000 feet.

INJURIES OF THE SPINE

Injuries of the spine in war-time may result from accidents similar to those which occur in peace-time, as for example crush injuries following the overturning of heavy lorries or accidents at the docks; or they may result from incidents peculiar to war, e.g. the explosion of a land mine may hurl the occupants of a vehicle into the air, or the collapse of a building may crush those within it.

In a series of 5,149 wounds occurring under active service conditions and seen at hospitals, there were 72 involving the spine; gunshot wounds of the spine were thus not common in hospitals, but it is likely that many other cases were fatal at an early stage, and therefore never reached a hospital. Of these 72 cases, 60 were associated with injury of the spinal cord (of these 5 proved fatal) and 12 were simple fractures of the spine.

Many of these cases of spinal cord injury were associated with other injuries, e.g. penetrating wounds of the chest or abdomen, which often contributed to a fatal outcome.

RADIOGRAPHIC TECHNIQUE IN SPINAL INJURIES

The technical approach to a spinal injury was dependent to a large extent on the general condition of the patient. With gunshot wounds of the spine the taking of an antero-posterior and a lateral film made with the least disturbance to the patient was all that was generally required. In many cases, e.g. with immobile patients, the lateral film was obtained by using a horizontal beam with the cassette placed at the patient's side.

A grid had to be used in such cases. Stereoscopic films were useful for the localisation of metallic foreign bodies and even more so in assessing the degree of bony damage. Localised views of the affected region, using a small cone, improved the detail and were always advised.

If the patient was able to move, right and left oblique views of the spine were taken. Taken with a 45° rotation of the patient's body, these views were essential in the lumbar and cervical regions when investigating injuries of the lateral joints and neural arches. Any investigation of the sacro-iliac joints needed to include the oblique views of that joint. They were of less value in the dorsal region of the spine.

Tomographs of the spine were also of great value in assessing the extent of bony damage, and especially in detecting fractures involving the lamina, articular facets and pedicles (Weinbren, 1941). Tomography was especially useful in fractures in the cervico-dorsal region, where it was the most accurate method of obtaining good lateral views of the vertebral bodies.

Lateral views of the spine with the patient in certain postures—e.g. full flexion—were also of much value. They were useful when subluxation of the lateral joints was suspected. (Views of the cervical spine in full flexion were also able to demonstrate subluxations when the usual film showed little abnormality).

Serial radiography of the fractured spine was just as necessary in the control of healing as in any other fracture to see that the deformity did not recur. Likewise in any doubtful case a repetition of the radiograph in 10 days might render the diagnosis obvious.

Injuries of the spine were classified either with regard to the way in which the injury was produced or according to the anatomical site of injury.

The mechanisms by which injuries might be produced were:

1. Forced flexion (causing crush-fracture)
2. Forced extension
3. Forced lateral flexion
4. Direct violence
5. Muscle strain on attachments
6. Dislocations.

Of these, flexion or crush fractures were the commonest injuries and the usual area affected was the dorso-lumbar junction. These crush fractures were commonly associated with a fracture of the spinous process of the vertebra above that which was crushed.

Crush fractures did not differ appreciably in any region. In the dorsal region there was one special difficulty in diagnosis; a paravertebral swelling might be present in cases seen late—weeks or months after injury—and this, together with narrowing of the intervertebral space, might make the distinction from Pott's disease no easy matter.

Extension fractures of the spine occurred when a man fell backwards from a height, or was thrown by an explosion and landed on his back across a beam or other projection, so that his spine was forcibly hyper-extended. This type of fracture was also most common in the lumbar area and usually consisted of a horizontal fracture of the neural arch together with fracture and gross displacement of the lumbar transverse process.

Fractures due to forced lateral flexion of the spine were uncommon, except the avulsion of tips of the transverse processes of the lumbar vertebrae. Direct violence, such as may result from the blow from a rifle-butt or hammer, might lead to fracture of a spinous process, especially in the lower cervical or upper dorsal region; while it was not uncommon for the transverse process of a lumbar vertebra, and more rarely for those of the cervical or upper thoracic, to be avulsed by muscular violence.

Dislocations of the spine in survivors were generally subluxations, and generally due to forced lateral flexion and a rotation of the head towards the flexion.

For practical purposes, however, spinal injuries were better classified according to the anatomical site of injury.

Penetrating Injuries	With retained foreign body.
	Without foreign body.
Non-penetrating Injuries	
(*a*) *Fractures of Vertebral body.*	1. Fracture dislocation.
	2. Simple crush fracture
(*b*) *Fractures of accessory processes*	
	1. Spinous process.
	2. Transverse process.
	3. Articular process.
	4. Pedicle.
(*c*) *Dislocations*	1. Articular joint.
	2. Spondylolisthesis.
(*d*) *Soft tissue injuries*	1. Ruptured ligaments.
	2. Prolapsed intervertebral disc.

PENETRATING INJURIES

Though radiology was of little use in localising the segment of the spinal cord which might be injured, it has been stated that myelography might be of some value in late cases of gunshot wounds in determining the nature and extent of meningeal adhesions. Radiology, however, could provide much useful information for it could demonstrate:

(*a*) The presence or absence of a foreign body.
(*b*) The site of the foreign body.
(*c*) The degree of bony damage to the spine.
(*d*) The presence of bone infection and sequestra.
(*e*) Injuries to other viscus.

Associated injuries to the thorax and abdomen could also be clearly demonstrated and the missile track estimated.

NON-PENETRATING INJURIES

This type of injury occurred more frequently than in civilian life. As with all injuries of bone, this was a consequence of the vast mechanisation of the War of 1939–45. The use of airborne and parachute troops contributed to the increased frequency of occurrence and certain other catastrophes of war—e.g. blast—produced 'crops' of such cases. Thus many members of a naval vessel which had been torpedoed suffered from fractured spines caused by sliding down the sloping decks and hitting the bilge keel before they entered the sea. Some of the crush fractures of the dorsal spine occurring in R.A.F. pilots were unusual in their site of occurrence in the upper thoracic region. This was due to the fact that, consequent on fixation of the lower limbs and spine by the pilot's flying harness, the site of angulation of the spine was higher (Watson-Jones, 1941). Wedge fractures of the lumbo-dorsal spine occurring in tank crews were caused by the compression force due to the heavy jolting of the tank being transferred to the spine of a man sitting crouched in a confined space.

Injuries of the Vertebral Body

1. *Fracture Dislocation of the Spine*, which occurred chiefly in the lumbo-dorsal region, was the subject of several papers during the war. Clarke in 1941 reported 89 cases caused by car accidents with a fatality rate of 25·8 per cent.; in his enthusiasm for early reduction he recommended that traction should be applied even before radiographic examination. This view was not held by Hall and Morley who (in 1940) discussed 57 cases which occurred in the R.A.F. and regarded it as essential that there should be a full primary radiological investigation of all cases with the least suspicion of spinal injury. In fracture dislocation of the lumbar spine it was necessary to make a careful X-ray examination of the articular facets before attempting reduction, for, if the facets were locked, an open-space reduction was recommended (Nissen, 1942). In any case a preliminary radiograph was necessary to differentiate the hyperextension from the flexion type. Stereoscopic X-ray films were especially valuable in assessing the relationship of the facets in such cases. Radiography played an important part in following the progress of such cases by serial photographs taken through the plaster. The radiological criteria of complete reduction were that:

(*a*) the depth of the vertebra anteriorly should equal the posterior depth;

(*b*) the intervertebral spaces should show no narrowing.

During the healing of the fracture, in the absence of visible callus, radiological estimation of consolidation was best made on the definition of the bony pattern in the vertebra.

2. *Simple Crush Fractures* were generally caused by falls from a height —e.g. following a plane or glider crash or a heavy weight falling on the shoulders with the spine in a flexed position. Approximately 60 per cent. of all fractures affecting the vertebral body were of this type. According to Samuel (1941) the recent use of electrical convulsion therapy for the treatment of mental disease has on occasion caused crush fracture of the dorsal spine; in these cases the degree of wedging was not marked and many vertebrae were involved.

Less marked forms of crush injury were those in which only a chip of the interior surface of the vertebra was detached. This condition had to be differentiated from a persistent epiphysis (a limbus vertebra). It could be differentiated by the fact that a limbus vertebra:

(*a*) tended to affect more than one vertebra;
(*b*) the demarcation line was smooth and had rounded margins;
(*c*) the separated fragment of bone was larger than the defect in the parent vertebra—indicating that it had grown since it was separated.

More severe crush fractures caused comminution of the vertebral body and in these cases the intervertebral disc was ruptured and driven into the comminuted body. In such cases the deformity tended to recur after reduction, and indriving of the compressed fragments into the vertebral canal might cause compression of the cord. Rogers (1945) described several cases in which simple crush fractures of the vertebral body were followed after a latent interval by transitory or permanent paraplegia. In view of this latent interval he stressed the necessity of keeping such cases at rest until reduction of the deformity and spinal plaster could be instituted.

Noteworthy were those cases of crush fractures discovered in a patient who had no recollection of a previous injury to his spine. Radiologically this condition needed to be differentiated from a healed tuberculous destruction by the presence of normal intervertebral spaces and the absence of soft-tissue swelling or calcified debris around the area of destruction.

Fractures of the accessory processes

No particular increase of our knowledge of these occurred during the war. Fractures of the transverse processes were generally due to muscular violence, and Hall (1940) maintained that spinous processes were sometimes fractured by violent action of the muscles and cited as an example the lesion of the spinous process in those who shovelled clay. Fuss (in 1941) maintained that the latter fracture was in reality a 'fatigue' effect analogous to the 'march' fracture.

Hyman in 1945 called attention to the fact that when several of the transverse processes were fractured a pseudo-arthrosis might develop between adjoining transverse processes, and he stressed the importance of inquiring into a history in injury of such cases.

Fractures of the articular processes and pedicles were easily overlooked and needed careful radiological examination (including oblique views of the affected vertebra) to detect. In cases where a previous fracture resulted in non-union, it might be impossible on radiological grounds alone to distinguish the condition from a separate epiphysis.

In connexion with spinal injuries the Medical Research Council issued general advice as to the precautions to be taken in moving, nursing and treating the patient, which were useful to radiologists. These were as follows:

(i) In moving or lifting, on no account must the spine be flexed, rotated, or over-extended at the site of injury.

(ii) Patient should be transported on his back.

(iii) To lift the patient on to the stretcher, four bearers are required. One bearer will apply traction on the head and another on the feet, so as to prevent flexion or further dislocation of the spine during the move. A bearer will stand on each side of the patient and lift him on to the stretcher, the straight position of the whole body being strictly maintained by the four bearers acting together.

(iv) For the prevention of pressure sores (in the case of paraplegia) care must be taken when the patient is laid on the stretcher that there are no wrinkles in the blanket.

(v) If the injury is in the cervical or thoraco-lumbar region, a folded blanket or pillow should be placed under the shoulders or small of the back, as the case may be, to increase the local extension of the spine.

(vi) With cervical injuries, the head should be steadied by a sandbag, pillow or pack placed on each side and fixed in position.

(vii) A folded blanket or a pillow should support the calves and thus relieve pressure on the heels.

(viii) In order to prevent a pressure sore over the sacrum (in the presence of paraplegia) the buttock area should be cleaned and a strip of elastoplast placed across the sacrum. The patient should then be placed on an air-ring if it can be spared.

(ix) Radiological work through plaster may have to be attempted.

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(ii)

Radiology in Tropical Climates

The Service radiologist, experienced in his specialty in temperate climates, meets a wealth of interesting and unusual material when commencing practice in tropical climates. Little of this originates in European Service personnel, whose illnesses are for the most part due to acute tropical diseases in which the radiological signs are few and usually not of much diagnostic value. Such personnel seldom remain in the tropics long enough for chronic disease and its associated radiological changes to develop, and their X-ray examinations are mostly for trauma and those conditions met with in any part of the world in such a selected community.

It is in the native population and, to a lesser extent, in native troops that the unusual material will be met; in the former group because the radiologist's department is frequently the only one in the area, or, if a civil department is at hand he will soon visit it and be invited to express opinion on many puzzling radiographs. In these patients will also be seen many of the pathological conditions occurring at home, but in tropical climates seen often in a more advanced degree owing to lack of early recognition and treatment. The native patient tends to be more tolerant of discomfort and disease, and geographical considerations hinder scientific diagnosis and foster 'witch-doctoring'. When confronted with such gross changes it is tempting to assume that tropical diseases are responsible and to overlook the common pathological lesions. This contribution is concerned with some of the conditions seen more frequently in the tropics than elsewhere.

THE SKELETON

Yaws. Pathological conditions of bone are numerically much greater than at home, especially in areas where yaws is endemic. Goldmann and Smith (1943) investigating the tertiary stage of this disease in Freetown found bony changes preponderate in the leg and particularly the tibia. They described the untreated disease as having active and inactive forms according to the presence of clinical and radiological evidence. In the long bones the active form is characterised by small oblong areas of translucency in the cortex without bony or periosteal reaction, giving an appearance of 'worm-eaten wood'. This may pass slowly into a condition in which the bone thickens and the medullary cavity is slowly obliterated by the thickened cortex. Decalcified streaks are still apparent and later a condition resembling 'marble bone' may develop in which the whole thickness of the bone consists of a loosely-knit bony tissue of great mass and little strength. Fracture occurs easily and callus formation is slow or absent. In other cases the cortex becomes thinned and the medullary cavity widens. Curvature of the long bones occurs with bulging of the cortex. Slight trauma or physical strain is liable to cause the reactivation of the inactive phase with reappearance of clinical and radiological signs of the active disease. A variable amount of bone may be involved or more than one bone may be affected. In children the epiphyses and joints are liable to be badly attacked causing destruction of the epiphyses and dislocations. Gummatous lesions of yaws may be found in any bone as a circular area of destruction with sclerotic margins. Periosteal reaction over such gummata occurs but is not marked. The astonishingly rapid response of the clinical and radiological signs to specific therapy helps to distinguish these lesions from those of syphilis but the bone condition seldom if ever returns entirely to normal.

Syphilis. In many tropical regions syphilis is common, and being frequently untreated gives rise to many bone lesions which are rarities in Britain. The X-ray changes are as described in standard radiological works, but as they can exactly imitate those of yaws the differential diagnosis is a matter of great difficulty in which serological reactions are not helpful. In the gummatous forms differentiation may be impossible but the presence of periosteal reaction is more common and more marked in syphilitic lesions.

Tropical Ulcer. This condition is very rare in Europeans but is common in many tropical areas and may assume epidemic proportions. Therapy is unsatisfactory, and it can cause much wastage among African native troops. Any part of the body can be affected but the lesions predominate in the lower leg, especially the antero-medial aspect of the tibiae. Brocklebank (1943) in Gambia found that about half of the cases showed bone changes but these were not necessarily proportionate to the size or severity of the overlying ulcer. The earliest change is a periosteal reaction below the cutaneous ulcer, and this reaction rapidly becomes profuse. Small cortical erosions then develop which quickly progress until the cortex is locally destroyed as far as the medulla. An appearance of frank osteomyelitis is then seen, with widespread lifting of the periosteum, formation of an involucrum, and sequestration of the shaft. Interesting features are the relative absence of constitutional symptoms, and the rapidity with which quite extensive bone lesions can develop. In one case the patient was still ambulant when half of his tibial shaft had sequestrated. The stage of healing follows the pattern seen in Britain but in all stages the intense periosteal reaction is most noticeable.

Infection. Because of the prevalence in the tropics of skin diseases, changes in closely underlying bone might be expected more commonly than is actually seen. Fungous infection by *Mycetoma* (Madura foot), blastomycosis, and infestation by chigger fleas can cause widespread skin infection and extensive bone involvement, the feet being most commonly involved. Irregular osteolytic destruction occurs, usually in multiple areas in the fungous diseases as in actinomycosis, but, as secondary pyococcal invasion is common, a variable degree of periosteal reaction often develops with or without sequestra. Osteolytic lesions in the hands and feet are rather more marked in nerve leprosy than in the lepromatous form (Murdock and Hutter, 1932).

Avitaminosis. Late deformities, often severe, caused by untreated rickets are quite common, particularly triradiate pelvis and osteomalacia in women. The acute epiphyseal changes in children are unlikely to be mistaken for those of syphilis and yaws, but the frequently concurrent infantile scurvy may produce changes greatly resembling those of hereditary bone syphilis. The medullary sclerosis and metaphyseal irregularity help to distinguish the latter condition.

Injury. The presence of unsuspected bone disease may be discovered by fracture occurring at the pathological site either spontaneously or after relatively minor trauma. Fractures of the vertebrae are quite common and of varied types in areas where much climbing of palm trees is done to collect nuts, sap and 'palm cabbage'. Among European troops the practice of playing football in soft canvas shoes against teams of native troops results in the common 'football fracture', usually right sided, in which the medial articular lip at the base of the terminal phalanx of the hallux is avulsed by ligamental pull.

THE ABDOMEN

Large Intestine. Although radiology has little place in the examination of the acute dysenteries, the opaque enema is of great value in the chronic forms. Bell (1939) reported irritabilities, spasms and irregularities of the colon in chronic amoebiasis, but the colonic appearance in chronic amoebic and bacillary dysentery is usually indistinguishable from that seen in ulcerative colitis and it is probable that there are no reliable differentiating signs. The extent of bowel involvement is clearly shown by the absence of normal haustration, and the tubular contracted appearance of the colon sometimes described as 'drain-pipe colon' or the 'ribbon sign'. Mucosal ulcers seen in profile may produce a ragged margin but the bowel wall usually appears smooth. This is the common appearance during a recrudescence of symptoms, but between attacks the colon often regains an astonishing degree of its normal appearance, and a demonstration of the mucosal defects by double contrast enema may be needed to determine the extent of the bowel involved. The normal mucosal plication is replaced by an irregular mottled network, and the appearance of polyposis may be seen in long-standing cases. A similar appearance of polyposis occurs in chronic intestinal bilharziasis (Ragheb, 1939). The deposition of ova in the submucosa originates numerous small papillomata, which reveal themselves with the plain opaque enema as small rounded indentations of the colonic margin and as circular half-shadows. The heaviest deposition is in the pelvic and sigmoid colon in which site the papillomata seldom calcify, but in the region of the appendix they are prone to calcification and may be seen as small rounded or club-shaped opacities not unlike calcified mesenteric glands. The uncommon hyperplastic form of chronic amoebic dysentery produces palpable tumours of the colon, frequently the sigmoid, and the opaque enema may show filling defects associated with the tumour. Infestation by roundworms is usually discovered accidentally in the later films of a barium meal. The worm ingests barium into its own alimentary tract where it remains longer than in the host. A solitary worm, often a bachelor male, will reveal itself as a thin line of barium several centimeters long, which may be actually in the worm's intestine or in the worm's stool after it has evacuated. Groups of worms may show as large whorled masses with the worms showing radio-translucent streaks between the barium surrounding them or the thin streak within them (Gage, 1937).

Small Intestine. In recent years more attention has been given to the radiological examination of the small intestine in cases of sprue and the deficiency diseases. Golden (1941) suggests the term 'disordered motor function' instead of 'deficiency pattern' for the characteristic changes that occur, as these are non-specific and are seen in such widely differing conditions as ankylostomiasis, amoebiasis, hypo-proteinaemia, carcinoma of the pancreas, and neurosis. This worker recommends a thin meal given by mouth consisting of 4 oz. barium sulphate shaken up in 5 oz. normal saline, followed by films exposed at 30-minute intervals up to 8 hours with periodical fluoroscopy. Drew, Dixon and Samuel (1947) used intestinal intubation with the Miller-Abbott tube in 26 cases of convalescent sprue, and by injecting nutrient opaque meals were able to show that the characteristic changes in the small gut were not secondary to any high fat content in the meal. The radiological changes in 'disordered motor function' are alteration of the intestinal motility, tonicity, and mucosal pattern. In the early stages a hyper-motility and hyper-tonicity is reported (Golden, 1941), but it is in the established disease that the characteristic loss of motility and disordered tonicity are seen. The passage of the meal through the bowel is exceedingly sluggish, and interval films may show little progress. Abnormal segmentation occurs most extensively in the middle third of the ileum, and the barium is scattered into almost featureless puddles in the dilated segments. The normal feathery 'herring-bone' of the mucosa vanishes and a coarse irregular pattern is seen which, in the latter stages of the disease, becomes more widely spaced until finally all semblance of pattern or folds may be obliterated. With recovery from the disease the normal intestinal appearances are restored (Drew *et al.*, 1947).

Liver. Hepatomegaly occurs in several tropical diseases and though gross enlargements will recognisably displace the colon and stomach, such findings are usually accidental rather than being intentionally sought. Localised enlargement displacing the diaphragm upward, usually in its anterior half, is valuable evidence of an amoebic liver abscess. The whole hemi-diaphragm is immobile or moves feebly, and below its bulge the abscess cavity on rare occasions may contain gas and, in chronic cases, deposits of calcium. Differential diagnosis lies between pyococcal subphrenic abscess and hydatid disease, but the issue is not often in doubt clinically. The diaphragmatic elevation may be obscured by a sympathetic pleural effusion, or, if the abscess ruptures into the pleura or lung the radiological appearances become only those of a large effusion or consolidation. The main diagnostic difficulty is to distinguish between the early case with a small degree of diaphragmatic displacement, and normal variations in diaphragmatic contour. Reduction of respiratory movement and visualisation of the elevation in two projections in different phases of respiration will assist differentiation.

Spleen. Garland (1945) states that the size of the spleen can be readily determined radiologically in 85 per cent. of cases and, using a standard focus-film distance of 36 in., regards enlargement as being reasonably certain if the length exceeds 17 cm. or the breadth more than 9 cm.

GENITO-URINARY SYSTEM

Bilharziasis is common and widespread in the tropics and subtropics, and in Egypt up to 90 per cent. of the population may have had this disease in their lifetime (Ragheb, 1939). In cases of chronic genito-urinary involvement the radiological appearances can be quite diagnostic owing to calcareous deposits in the submucosa, which so commonly follow the deposition of bilharzia ova therein, and the ulceration of the overlying mucous membrane. Initially an interrupted thin line of calcification is seen outlining the bladder; later it becomes thicker and continuous. This outline is circular when the bladder is full and slightly resembles a foetal skull. Partial filling gives a reniform outline, and when the bladder is empty the calcium gives a dense irregular ovoid shadow with transparent centre which can be distinguished from the usual form of vesical calculus by the lack of a laminated structure. Heavy calcareous deposits around the ureteric orifices cause them to be shown rather like small calculi. Ureteric obstruction at this site is almost constant and produces marked dilatation of the ureters and later of the renal pelvis. Progressive submucous calcification in the ureters later outlines their dilated and elongated form in a characteristic fashion. Occasionally the ureter is not dilated but its calcareous outline is thin and cord-like and here the renal pelvis and calyces often show a dilated and calcareous outline. True urinary calculi of bilharzial origin may accompany these changes but punctate calcification in papillomata may simulate multiple small calculi. Non-calcified papillomata in the renal pelvis may be revealed by pyelography.

Filariasis gives little radiological evidence of its presence but Garland (1945) states that pyelography may reveal deformity of the renal pelvis produced by blocked and dilated lymphatics.

HEART AND LUNGS

In many parts of the tropics the climate has a bad effect on asthma and pulmonary tuberculosis and the latter often shows rapid reactivation and spread. Syphilitic aortitis and aneurysms are more commonly seen in native populations than in the United Kingdom but the radiological appearances are no different. Patchy areas of pulmonary consolidation, not unlike those of primary atypical pneumonia and associated with irregular fever and a high eosinophilia, are seen in the uncommon condition known as tropical eosinophilia, and in the absence of specific therapy are of long duration.

Non-diagnostic pulmonary shadows are seen in cases of psittacosis and paragonimiasis, and widespread deposition of bilharzial ova in the lungs can cause a reaction showing itself as multiple small miliary nodular shadows throughout the lung fields. The results of ruptured hepatic amoebic abscess into the pleura and lung have been mentioned earlier.

SOFT TISSUES

The tendency of certain tropical parasites to become calcified enables their presence to be detected radiographically, but, because this calcification occurs after death of the parasite, their presence is more often accidental than an intentional and useful finding. Deliberate radiography of the soft tissues is of the greatest importance in cases having cerebral symptoms considered as possibly caused by cysticercosis. The radiological appearance of the calcified *cysticercus cellulosae* in skeletal muscles and the brain is fully described in standard textbooks and requires no repetition, but, as the onset of demonstrable calcification is unlikely within three years of original infestation by *taenia solium*, such demonstration of cysts in European Service personnel is uncommon until after their return from the tropics. As this infestation originates from eating 'measly pork' it is not found in any Mohammedan population. Infestation by *dracunculus medinensis* (guinea worm) is common in parts of Africa and India, and after its death the worm frequently calcifies and becomes radiographically demonstrable. The worm nearly always lies in the subcutaneous tissues of the legs and feet, and commonly shows as a sharply defined linear opacity 1 to 4 mm. wide and many inches in length. It is curved upon itself with many irregular convolutions but its course may be straight for several inches when it may resemble arterial calcification. If only small parts of the worm calcify they may be difficult to differentiate from calcified *cysticerus cellulosae*. The calcified worm is of little clinical significance but Hudellet (1919) has shown that the worm can be clearly demonstrated during its life by injection of collargol. Other workers have successfully used lipiodol as an aid to localisation for surgical dissection.

Brief mention may be made of 'Ju-Jus' frequently hung round an injured or diseased extremity of which fetish prevents the removal during radiography. These often contain a variety of semi-opaque objects which in a dense radiograph can sometimes momentarily puzzle the unwary.

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(iii)
Mass Radiography in the Army

The development of mass radiography has been well dealt with in the report of the Medical Research Council (No. 251) but it is of interest to trace the record of its use by the Army Medical Service during the course of the war. Though some consulting physicians pressed for the trial of mass radiography in the Army on a large scale commensurate with that in the Navy, this was deemed impossible on account of the lack of apparatus and of trained personnel, and the dispersal of the numerous recruiting centres. A start was made in 1941 with an apparatus devised by Army radiological experts and manufactured by the Solus Electrical Company. Good work was done by this machine whereby certain difficulties and deficiencies were shown to need correction.

Statistics of Cases Radiographed

MALES

Unit	*Total*	*Abnormal* per cent.	*Recent T.B.* per cent.	*Old T.B.* per cent.
1	—	—	—	— (Training Unit at A.X.S.)
2	19,610	222 (1·7)	62 (0·3)	140 (0·7)
3	22,784	503 (2·2)	60 (0·2)	37 (0·12)
4	5,610	142 (2·5)	13 (0·2)	3 (0·05)
Totals	48,004	978 (2·0)	135 (0·28)	180 (0·4)

FEMALES
A.T.S. Auxiliaries

Unit	*Total*	*Abnormal* per cent.	*Recent T.B.* per cent.	*Old T.B.* per cent.
1 and 5	5,583	58 (1·0)	19 (0·3)	27 (0·5)
2	390	8 (2·0)	1 (0·26)	2 (0·5)
3	1,216	12 (1·0)	2 (0·16)	3 (0·25)
4	733	3 (0·4)	3 (0·4)	0
Totals	7,922	81 (1·0)	25 (0·3)	32 (0·4)

In 1942, Watson and Sons, after much experimental work and research, devised a unit of admirable design and performance, which was accepted as a standard by both the Medical Research Council and the Army. Since at first it was necessary to take the machine to various centres it was installed complete with its own generator in an Army motor lorry. Major Duncan White was appointed to organise and train teams to work this mobile unit. Additional units were gradually equipped and in 1944 there were five complete sets in use. Even with the increasing number of such units it was found impossible to arrange visits to all or even the majority of the training centres, so reluctantly the units became static and were established at selected corps training centres. By this means, though the survey was not complete, it gave a fair sample of the whole of the intake of the Army.

The personnel were given a course of instruction on the whole apparatus which they were able to dismantle and reassemble, and were taught the technique of the photography.

The medical officers attached to the units were instructed in film interpretation and the criteria for classification into normal, abnormal or suspicious. They maintained close liaison with the hospitals to which the units were attached. None of the personnel were affected in health by their work on the units.

The cases seen at the static units were followed up. A complete bacteriological investigation of suspects was made, and suspects were admitted to hospital for further observation. It was very difficult and often impossible to follow up those suspects seen by the mobile units.

MASS MINIATURE RADIOGRAPHY OF REPATRIATED PRISONERS-OF-WAR

With the end of war in Europe the Army Medical Services were faced with the medical care of approximately 150,000 liberated British prisoners-of-war. Among the many medical problems, the need for a chest survey for the detection of possible cases of pulmonary tuberculosis in these soldiers was urgent, particularly since many prisoners-of-war had been mass-radiographed in Germany and it was important, for morale, to emphasise that the medical care in this country was as good as that given to them in Germany.

For the efficient examination of these repatriates it was considered essential that mass radiography should be an integral part of the arrangements made for their reception on arrival in this country. Fundamental requirements demanded of mass miniature radiography were:

(*a*) That all repatriates should be examined as soon as they arrived in this country.

(*b*) That the examination should not materially delay the repatriate's discharge from the military reception camp to his leave.

(*c*) That reports on his miniature radiograph should be immediately available to the officer in charge of medical inspection, so that prompt arrangements could be made to deal with those repatriates who needed admission to hospital.

With these requirements in mind it was decided that mass radiography could best be carried out by the use of a number of mobile units visiting the reception camps. The mobility of the mass radiographic units enabled a more comprehensive survey to be made with the 15 units available, and in spite of difficulties the method proved satisfactory.

Organisation and Administration. For this purpose the five Army static units were made mobile and a further 10 mobile units raised, so that 15 units complete with personnel and transport were ready for service. The parent unit for these mobile self-contained units was the Army X-ray school, which was responsible for raising and equipping these units. Personnel, both officers and other ranks, were trained in mass miniature work at the Army X-ray school and the same routine training was given as for the first five units. The war establishment of each unit was raised.

Results were recorded as 'normal' or 'abnormal' on the nominal roll. In the abnormals, no full-sized films were taken. These nominal rolls were forwarded to Records who, in the case of soldiers showing an abnormality, notified the medical board concerned that a full-sized chest film was required. Gross abnormalities, noted on the miniature examination, and likely to need immediate admission to hospital, were communicated at once to the senior medical officer of the camp. The repatriate was then called back for further medical attention. Weekly reports of the work done at each unit were forwarded to the appropriate authorities. At one point the daily numbers suddenly increased, as the R.A.F. brought home in bombers in one day thousands of repatriates to these camps. The organisation was able to cope with this influx.

Field Work of the Mass Survey. Most units were accommodated in Nissen huts or similar buildings. This accommodation was adequate and served as a permanent base for the mass miniature unit. Generally a Nissen hut was chosen in the immediate vicinity of the M.I. hut, as in the 'processing' of repatriates the mass miniature examination generally followed the medical inspection. Units which served other camps from their permanent bases often utilised a large Nissen-hut type of garage. Many officers and other ranks expressed their preference for working in this type of hut as conditions were more airy and space was greater. In some of the units a single-phase 30 amp. main was utilised as the source of electric power.

It was ordinarily found that 60–75 an hour was a comfortable rate of examining these prisoners-of-war, but the speed varied considerably, depending on the stress of circumstances. Sometimes a rate of 200 an hour was reached, where repatriates arrived in big numbers, but this rate was not maintained, except for short periods. Periodic check of the units for scattered radiation, using sensitised dental films, was carried out, and the safety arrangements were entirely satisfactory.

It is doubtful whether any other Service or civilian units examined such a large number of cases in so short a time. The Naval and R.A.F.

services examined large numbers, but in neither of these services was the effort so concentrated and sustained as the examination of repatriated prisoners-of-war.

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Mass Radiography in the R.A.F.

By J. F. BROMLEY
M.B., D.M.R.E.

In 1941 the R.A.F. installed a mass miniature radiographic set (the gift of the British Red Cross) for examining the chests of candidates selected for aircrew training, and this was soon extended to include as many R.A.F. personnel as possible, so that by August 1942, six radiographic sets (either mobile or semi-mobile) were operating, and over 1,000,000 persons (R.A.F., W.A.A.F., etc.) were examined in this way.

Organisation from the earliest stages was on a broadly clinical rather than a purely radiological basis, and units were therefore located as near as possible to R.A.F. hospitals with facilities for complete physical and bacteriological examination and in-patient admission if necessary. A headquarters staff in London controlled the complete system of numerically recording results, and was responsible for special training of medical officers and for maintaining uniform standards of work. Individual units did not retain films and records, but sent them to headquarters for checking and filing, thus facilitating reference and at the same time relieving the units (which moved fairly often) of responsibility for a bulk of records.

The staff or team of each mass radiography unit included the following personnel: one medical officer, one radiographer, one nursing orderly, two photographers, two clerks and two aircraft hands. Although each member of the staff was allocated and trained for special duties, all were expected to gain reasonable knowledge of the duties of the others and be able to help in any emergency caused by sickness, leave, etc.

Maintenance and repair were very important items, since a breakdown lasting 24 hours might easily result in several hundred recruits entering the Service without an X-ray examination. A team of electrical technicians located at and controlled by headquarters was prepared to travel immediately to any unit which reported a technical fault, and the success of mass radiography in the R.A.F. was due in no small part to the high standard of duty and skill of these technicians.

The scheme of operation of a mass radiography unit was to use the 35-mm. miniature film as a means of separating the normal from the abnormal, and when those with obvious open tuberculosis had been admitted immediately to hospital, others with abnormal miniatures were recalled for a large X-ray film; of these, a number were found to be in fact normal and were returned to full duty. Others again had abnormalities of only statistical significance, and they too were returned to full duty. Of the remainder, further clinical examinations, bacteriological tests, and X-rays might be required before final diagnosis and disposal. There then remained a small group whose position was either anomalous (e.g. ? pneumonia ? tuberculous), or justified a diagnosis of tuberculosis which, however, might be very small in extent and apparently inactive; such individuals were placed under supervision and allowed to do only very light duty for a period of three to six months, after which they came up for review (including further X-rays) to mass radiography headquarters.

The clinical results obtained in the R.A.F. from this survey of approximately one million persons focused chiefly on the incidence of pulmonary tuberculosis, though other interesting points (e.g. the so-called 'stress fracture' of the first rib, whose incidence appeared to work out at about one per thousand) also emerged. For discussion about pulmonary tuberculosis, the subjects were divided into age-groups as follows: 17 to 19, 20 to 24, 25 to 29, 30 to 34, 35 to 39, 40 to 45, over 45; and R. R. Trail (*et al.*) published in the *British Journal of Tuberculosis and Diseases of the Chest* for October 1944 a survey of the first quarter of a million persons X-rayed. Active tuberculosis of the lungs was found to occur more frequently in young women than in young men, and in males two especially dangerous periods were shown to occur, namely in the age-group 20 to 24 and after the age of 34. The total incidence of pulmonary tuberculosis was 0·77 per cent. (0·28 per cent. active) in men, and 0·94 per cent. (0·36 per cent. active) in women. The commonest non-tuberculous lesion was 'atypical' or 'partial' pneumonia.

For those interested, the whole subject is treated in considerable detail in the hand-book *Mass Miniature Radiography* by R. R. Trail, H. J. Trenchard, and J. A. Kennedy, published by J. & A. Churchill in 1943 with a foreword by the late Lord Dawson of Penn. See also chapter on Tuberculosis in the Royal Navy, 1939–45, by W. D. W. Brooks, in the volume on Medicine and Pathology in this series.

CHAPTER 15

OPHTHALMOLOGY

By C. B. GOULDEN
O.B.E., M.D., M.Chir., F.R.C.S.
with additions by
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MANY interesting ophthalmological problems arose in the course of the war. Quite apart from injuries there were several problems of vision.

Refractive Errors. Soon after the outbreak of the war a most satisfactory set of visual standards was devised so as to cover the whole of the conscript population. The eyesight requirements of the line-soldier and the tradesman were laid down so that each might be able to continue his vocation in the best conditions in an appropriate theatre of war. With only minor modifications the categories proved so sufficiently elastic that during the whole period of hostilities less than one per cent. of the potential male military entry needed to be excluded for gross visual defect. As early as 1916 the problem of whether the soldier should or should not wear spectacles had been finally settled for the British Army. It is interesting to record that in an actual combat area it was the instinctive reaction of most soldiers to remove their glasses before going out on patrol. In the World War of 1939–45 up to 10 per cent. of each batch of recruits required an ophthalmological examination. Up to 6 per cent. of each entry had to be furnished with Mark III spectacles to render them efficient soldiers. This incidence of refractive error was similar to that found in the American Armies in both World Wars. The incidence had been the same in the British Armies of the War of 1914–18 and the Boer War. The optical industry soon functioned extremely efficiently. It provided both men and materials for the optical sections that were to be found at every ophthalmic centre at home and abroad. Through this service the soldier was able to have his glasses replaced or repaired on the same day whether he reported to the mobile ophthalmic unit in the forward area or to the ophthalmic centre at the base. Contact lenses were only issued in some very special cases owing to the difficulty in training men to wear them. Some men are known to have worn these appliances for long periods in the heat of action.

Defects of Colour Vision. Men in such special arms as parachutists, glider-pilots, etc., had to undergo special tests for colour vision. The increased use by the Army of pyrotechnics in intercommunication, and of coloured paints to facilitate speedy recognition of objects, pointed to the need for a general testing of personnel on entry for defects of colour vision.

Night Vision. In civilian life the unusual condition of almost complete darkness in the streets brought into prominence certain problems caused by the difficulty the population had in getting about at night. The difficulty varied considerably with different people. Some had little difficulty while others could hardly move about in the dark, even with the use of electric torches. The problem was not investigated among the civilian population, but when conscription became general the choice of members of the fighting forces for duty at night became very important. Long and elaborate investigations were carried out, chiefly by the medical services of the Royal Air Force, to classify degrees of difficulty in undertaking night duties, with a view to choosing those who might with more success be employed in carrying out the duties of aircrew and related functions. It was found that individuals varied a great deal in this respect. There were of course cases with pathological changes in the eye which rendered the sufferer quite incapable of moving about even in the dusk, but there were some with apparently healthy eyes and excellent central vision (with or without correcting spectacles) who appeared to have difficulty in the dark. The reason for this variation was not obvious, and experiments with various vitamins, especially vitamin A, did not produce any increased aptitude at night in healthy people; in fact it was found that the store of vitamin A in the body provided a big reserve which only prolonged deprivation could affect. The tests applied were of two main types. First, those directed to the time needed for recovery from a known period of standardised glare for detecting the shape of various objects in low illumination. Secondly, those in which, after a standard period of passive dark adaptation, letters and objects were presented to the subject under very feeble illumination; the result of the test was measured by accuracy of description of the object. From these tests it was possible to separate those with good from those with night-defective sight. The Army's problem of vision by night was in many ways different from those of the other Services and the civilian population. Night-blindness has been known as a cause of malingering since the days of the Crusades. The difficulty has always been to institute tests, other than the purely subjective, for men who complain of this defect without presenting any observable pathological condition to account for it. In the Boer War the majority of the half-million combatants came from the countryside and night-blindness was not mentioned as a problem. In the War of 1914–18 and in this war the national armies were mainly composed of men from the towns. Such men had not been accustomed to the absolute darkness of open spaces and often needed to be trained to use their eyes by night. This fact, together with other inseparable psychological problems, caused men to report sick with night-blindness. They showed no pathological lesion to support their complaint. The Official History of the War of 1914–18 dismissed such cases as 'neurasthenia', but offered no solution to the problem. In the years immediately previous to the War of 1939–45 there had been considerable ill-informed references in the press to night-blindness and its connexion with the vitamins. Thus at the outbreak of hostilities the Army was in difficulties. As soon as there were unpleasant duties to be performed at night there tended to be epidemics of this complaint. As a consequence an official notice was issued that the Army did not recognise night-blindness. Thereafter the problem did not exist so far as the Army was concerned. It is of interest to recall that night-blindness without demonstrable pathological basis was never a problem to the British medical officers looking after the thousands of prisoners-of-war in either German or Japanese hands—this in spite of the malnutrition that was rife in the Asiatic camps.

INJURIES

General Remarks. The principle laid down in the War of 1914–18 that the ophthalmic surgeon should be brought as far forward as possible so as to be near his potential patients, proved basically sound. Mobile ophthalmic units were sited at the first bottleneck in the medical line of evacuation. The regimental-aid personnel applied the first dressing and then the ophthalmic casualties were transferred to the ophthalmic units as quickly as possible. At these units urgent operations only were performed, the regular administration of sulphonamides and penicillin was initiated and the cases were evacuated by air, road or rail to the ophthalmic wing of a base hospital. In general it was found that ophthalmic casualties formed 2·5 per cent. of all casualties in battle; although in the British Liberation Army there were occasions when they rose to 3·8 per cent. When ophthalmic injuries were grouped with neurosurgical and maxillo-facial cases the combined group might total 10 per cent. of the whole. These three special groups had begun to be grouped together at the end of the War of 1914–18 and this was the rule in the War of 1939–45, when the three specialities were brigaded at the first medical evacuation bottleneck. These combined units acquired the nickname of 'The Trinity' and did excellent work which can best be judged by the results. Whereas in 1916 Wurdemann estimated that in France 67 per cent. of all eyes injured in battle had subsequently to be removed, in the War of 1939–45 the percentage dropped to 37 per cent. Whereas after the earlier war St. Dunstan's had to provide for the care and rehabilitation of two thousand war-blinded men, after this war it only had to deal with some five hundred of the Empire's war-blinded men.

Anaesthesia. For operations in the forward areas it was found that a general anaesthetic was best for the patient. Pentothal given by the continuous intravenous drip method was most often used. At the base hospital local analgesia was of course possible.

Concussion Casualties. In the War of 1914–18 only 6 per cent. of ophthalmic casualties were attributed to blast. In the War of 1939–45 concussion injuries represented anything up to 40 per cent. of the whole number. Doubtless the more effective explosives employed and the greater fragmentation of projectiles were mainly responsible for this increase. In the majority of the blast injuries a traumatic keratitis developed subsequent to a solution of continuity of Descemet's membrane from the force of the explosion. Small vitreous haemorrhages were constantly present and veiled the presenting fundus picture, yet traumatic cataract was relatively rare. Retinal detachments were more frequently noted than in the previous wars, but the view was held that only 20 per cent. of the cases occurring in a field force were due to purely military trauma.

Penetrating Wounds. On analysis the wounds of entry of the sclera were nearly as common as those of the cornea or limbus. This naturally drew further attention to the need for improvement in *protective appliances* for the head and eyes. The design of the steel helmet was modified from a pattern that seemed to have been sealed at the time of Crécy, and much greater protection to the head and eyes obtained. Plastic anti-mine visors were introduced and were worn by the soldiers with some confidence. Considerable research went into the development of goggles to protect the eyes of men employed as anti-aircraft personnel (sentinels in particular). Also types of goggles were designed to afford protection against sun-glare and dust in the tropics and snow-glare in the Arctic. Apart from injuries with blunt objects such as blows from flying clods of earth, which might even cause rupture and disintegration of the globe and demand enucleation of the eye, interest mainly centred on perforating wounds with or without the retention of foreign bodies. What was new to ophthalmologists in civilian life was the large number of injuries caused by flying fragments of glass chiefly from broken windows. Sometimes these were the only important injury and many might have been avoided by simple protective precautions. When the period of attack by the long-distance bombs (V.1 and V.2) came there was the additional element of surprise by night and day, and injuries could not so easily be avoided as when the bombs came from piloted planes. So far as the eyeball itself was concerned these injuries in most cases caused loss of sight, and in many cases required removal of the eye. A fragment of glass which elsewhere in the body would cause but a trifling injury would injure the cornea so seriously that the eye would be rendered useless. Injuries to the lids, if caused by a shower of small particles of glass, might be very severe so that it might be difficult to provide sufficient protection to the eye to prevent its loss by exposure. It was seldom that a gash of the lid by a solitary fragment of glass left the globe uninjured. When wounds of the eyelid healed, a keloid often developed on the scar and tattooing of the skin by carbon particles carried in with the glass sometimes resulted.

Corneal Foreign Bodies. Minute fragments from projectiles, earth or sand sometimes became embedded in the cornea. Superficial and larger particles were removed but persistent attempts to remove the more deeply embedded particles did more harm than good. It soon became generally recognised that such foreign bodies were best left to work themselves out. By thus leaving them alone almost incredible recovery of the function of vision would sometimes occur. Thus one of the patients from El Alamein had 62 separate foreign bodies counted as embedded in the two corneae; he finally achieved 6/24 vision in each eye with minimal interference.

Retained Fragments of Magnetic Metal. Bomb and shell fragments varied much in shape and size. Moreover fragments possessed varying magnetic properties according to the composition of the originating missile. It thus frequently happened that the foreign body could not be withdrawn into the anterior chamber from its situation in the vitreous or inner coats of the eye. This led to a revival of the method of removal of the retained magnetic foreign body by an incision through the sclera, through which was introduced the pole of a small magnet, or, if the Mellinger giant magnet was used, one of the smaller rods supplied with the apparatus. It was of course necessary to locate the fragment accurately by X-ray examination. In the case of a minute and feebly magnetic foreign body it required great judgement to determine whether it would be better to leave the fragment *in situ* or make an incision in the sclera. Periodical examination of cases was required. Though as mentioned above there were a few Mellinger magnets in the base hospitals, the common giant magnet in use in the field was the Haab pattern (solus, portable). Many types of small hand-magnets were devised. Retinal detachment did not prove to be a complication of the removal by posterior incision, probably because of the diathermy technique which was an essential part of the operation. Previous methods of extraction had not permitted the close approximation of the pole of the giant magnet to the foreign body inside the globe. Admittedly the majority of the foreign bodies were reported as only feebly magnetic, yet the figures given by those ophthalmologists who had the patience to apply the magnets repeatedly were extremely instructive. The least satisfactory series of cases reported showed that intra-ocular foreign bodies were found in 30 per cent. of all penetrating injuries of the eye, and of these foreign bodies 30 per cent. were extracted. Some 40 to 60 per cent. of these removed foreign bodies were eventually extracted in the mobile units in the forward areas. As technique improved and the posterior extraction-route came into general use (as for example in the British Liberation Army) some 69·3 per cent. of fragments were successfully removed. Of the many methods (thirty or more) of locating the foreign body by X-ray, the limbus ring method was found by experience to be the speediest and most consistently efficient.

Injury by Non-magnetic Foreign Bodies. In those cases in which a non-magnetic foreign body was retained in the eye the same problem arose as to whether the operation for its removal would cause more damage than if the foreign body were retained. Particles of cordite or quartz did not seem to cause any inconvenience. The retention of particles of copper was always followed by pathological changes, including cataract, and it was recommended that an attempt should be made to remove such a fragment by means of forceps introduced through an incision in the sclera, guided by the ophthalmoscope. Help was obtained by preparing the site of the incision (which includes choroid and retina) by producing an area of coagulation necrosis by means of diathermy. If the injury were produced by a large fragment of glass there was often severe injury to the eyelids, damage to the eye needing enucleation, and frequently so much ploughing of the orbital contents that a useless socket remained into which it was impossible to insert an artificial eye. In some cases of less severe injury it was possible by a simple operation to make the socket serviceable, but when the injury involved deep penetration with bone injury and extensive lid injury, all that was possible was to remove the orbital contents, including the margin of the eyelids, leaving the injured person with a shallow skin-lined cavity. To hide this deformity a black shade could be worn and in certain cases an elaborate frost lens attached to a spectacle frame made the appearance better, although often such apparatus was more disfiguring than a simple shade.

Through-and-through wounds of the globe gave rise to some interesting examples of the repair of exit wounds (after they had been plugged) by a proliferative choroiditis. By leaving the perforating fragments *in situ* at the back of the orbit and giving full doses of the sulphonamides to prevent infection, it was found that the final effect on vision depended purely on the size of the entering fragment. So the efficient fragmentation of the modern projectile combined with its high impact velocity proved a blessing.

Sepsis. The maintenance of the policy of minimal surgical intervention and avoidance of frequent examination and dressings along the line of evacuation was excellent. The arrangement whereby dressings were only to be done either at the regimental aid post, the mobile unit or at the base ophthalmic wings worked well, and it was to this and to the routine local and general use of the sulphonamides and later of penicillin that the remarkable absence of sepsis was due. The general procedure was that at the mobile unit the giant magnet was applied, abscission of prolapse and conjunctival hooding performed, penicillin and the sulphonamides given and then the case was evacuated. The high priority by air obtained in the Far and Middle East for ophthalmic cases proved to be a potent factor in the saving of eyes. In the base wings the employment of specially trained ophthalmic nurses and orderlies was of inestimable value. But in the summer fighting in Sicily and in Southern

Italy those unfortunates who had to lie out for several days between the lines before they were rescued had fly maggots in their wounds. This infestation curiously did not occur in the fly-ridden Western Desert. In the later years of the war when long-prepared defensive positions were attacked, the German landmine with its concomitant stone and grit forced into the eye, caused a number of cases of vitreous infection. These are stated to have responded well to subconjunctival penicillin, whereas the intra-vitreous injection of penicillin was not a success. The introduction of penicillin modified the treatment of superficial injuries and infection of the eye. When it became generally available, the war was nearly at an end but it soon proved its great value. Abrasions of the cornea and wounds of the conjunctiva were thus kept free from sepsis. With perforating wounds, or in the case of a cataract extraction, sepsis could be prevented by the injection of a solution of penicillin (100 units to the c.cm.) into the anterior chamber.

Sympathetic Ophthalmia. During the War of 1870 it has been reported that 56 per cent. of all eyes injured in the German Army developed a sympathetic ophthalmia. During the War of 1914–18 only a very few cases were recorded in the French Army while the Official History notes that only one case was found in all the four years that the British Expeditionary Army were fighting in France. In the War of 1939–45 there was a similar absence of this lesion in any of the theatres of war. The legend of its omnipresence however died hard in spite of this remarkable testimony.

Retinal Detachment. The incidence of retinal detachment among the members of a field force, whose members had an average age of thirty, showed that more than 80 per cent. of the cases were due to the normal civilian hazards of life for men in the third decade of life. The chances of operative success on such cases as were due to purely military trauma were stated to be 65 per cent. A most satisfactory ophthalmic diathermy apparatus was designed and was generally available to the mobile units by the end of the war.

Casualties from War Gases. The Official History of the War of 1914–18 stated that among the gas casualties only in 5 to 10 per cent. were the cornea or the deeper structures of the globe involved. From 1936 onwards these old corneal and limbal lesions from mustard gas began to break down—a fact which aroused the interest of ophthalmologists all over the country. The initial causal lesions had been incurred nearly 20 years before in 1917 and 1918. Research was stimulated and resulted in the more general use of albucid and British anti-lewisite. During the War of 1939–45 fortunately the only series of cases that had to be dealt with (and then only on a minor scale) came from the successful German air attack on shipping in Bari harbour and from accidental explosions in the war-chemical factories. At the beginning of the war every soldier was issued with a container holding anti-gas ointment to carry on his person. This added one more to the classic list of drugs used by the malingerer.

Nutritional Eye Disease. Disease of the eye due to dietetic deficiency occurred on an epidemic scale among the British prisoners-of-war held by the Japanese in camps in Asia. A minor outbreak was noted among German prisoners-of-war held in camps in the desert in the Middle East. The disease took one of two forms. The first was a purely corneal manifestation of the nature of a granular or exfoliative keratitis responding well to the administration of marmite. The second and more serious type was often associated with other neurological signs of a grossly deficient diet. It presented itself as paracentral or central bilateral scotomata of either slow or rapid onset. There was much controversy as to the site and nature of this lesion. It was perhaps best described as due to a demyelination of the optic nerve owing to a lack of first-class protein and portions of the vitamin B complex from the diet. The main outbreaks in Asia occurred at the end of 1942 and the beginning of 1944. At these times the prison diet was at an inconceivable minimum, literally starvation level, and the Red Cross parcels were held up by the Japanese. The Middle East cases occurred at the end of 1945 and ceased directly the diets were raised after recognition of the condition. The Japanese did nothing to raise the standards of diet throughout the war, and since the majority of the prisoners in Asia were not released until the last part of 1945 it was feared that the rehabilitation of the sufferers would be very difficult and perhaps impossible. It was, however, amazing to see how the men returned to their several civilian vocations and carried on magnificently in spite of their deficient sight.

Trachoma. At no time did any epidemic of ophthalmia in the classic sense threaten the Labour Corps in the Desert or elsewhere, nor were the European troops brigaded with them affected. This was noteworthy inasmuch as from 1930 onwards Indian troops with signs of trachoma had been enlisted and many Labour Corps in the Middle East were recruited from races of the Levant and Africa with endemic trachoma; the Cyprus Regiment for instance on arrival in Egypt in 1940 showed an 80 per cent. incidence of trachoma. The value of the sulphonamides in the treatment of pure trachoma, as opposed to cases of mixed infection, was a subject of inconclusive debate during the war. An extremely interesting point arose concerning the influence of diet on the causation of trachoma. Those Indian troops who remained loyal to the Raj suffered dreadful privations in the Japanese camps and undeniably incurred considerable hastening of the progress of their disease. Under similar conditions the Europeans did not acquire trachoma. The Australians did not report any unusual incidence among the troops.

Reparative Surgery. The wounds of the eyelids and neighbouring parts of the face led to marked deformity, and plastic operations had frequently to be done so that the appearance might be improved and the socket, in cases in which the eye had been removed, made capable of retaining an artificial eye. In many cases this was not possible, for the result of the plastic operation with the artificial eye might be little less disfiguring than the original injury.

Artificial Eyes. A great improvement in the manufacture of artificial eyes resulted from the demand caused by war and air-raid casualties. In those cases in which an artificial eye was specially ordered to take the place of the lost eye the prosthesis was made of glass and the iris colour and pattern were produced by using melted coloured glass. This had always been the custom in cases in which the socket could not be filled from a stock of artificial eyes. During the war stocks of artificial eyes ran short and this stimulated research to produce an eye from other materials as well as an attempt to make a better match of iris colour and pattern. The material chosen was acrylin, one of the plastics which could be moulded at a comparatively low temperature, so that an iris drawn on paper could be incorporated. These artificial eyes could be modified in size and shape, a proceeding impossible with eyes made of glass when once they were finished. Nevertheless such eyes could not be produced in bulk. By the end of the war moulds of the socket could be taken and from these it was possible to make an extremely 'mobile' satisfactory acrylic prosthesis. Moreover, an attempt was made to produce eyes of different size and shape which would fit most sockets, though deformed sockets still needed to have a specially made eye. It became possible to produce a copy of the remaining eye by colour photography and to incorporate it in the artificial eye. The various hues of the sclero-conjunctiva could be more faithfully reproduced and the result was a great improvement in the appearance of the patient.

During the course of the war several unusual but interesting ophthalmic conditions were met with in one or other theatres of war. Thus in Singapore (after its recapture) and occasionally in Italy and Berlin there were several minor outbreaks of methyl alcohol amblyopia among the men who raided the grog-shops. Amblyopia due to quinine several times occurred during the first few years of the war, but when mepacrine came into general use these cases vanished. Of interest also were those established cases of macular damage which occurred in Italy and Africa and resulted from gazing at the sun during the partial eclipses which occurred in 1941 and 1945. The pensions' aspect of these cases provided an interesting problem since most of the men involved had spent three or more years in the Western Desert and naturally attributed their disability to that service. In the Mediterranean region several outbreaks of epidemic keratitis occurred, and the dendritic form of keratitis was often reported in all malarious areas and also in all types of cases showing high fever. Finally, cases due to infestation with the bot-fly (oestrus ovis) were reported from North Africa, and in the same area were noted cases of ophthalmia nodosa due to the cacti in that region.

CHAPTER 16

OTO-RHINO-LARYNGOLOGY

By

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At one time—not so long ago—there were no specialists in diseases of the ear, nose and throat in the R.A.M.C. During the South African War, 1899–1902, the small amount of this class of work was performed by general surgeons. Even in the War of 1914–18 the need for specialists in the subject was not sufficiently realised, for on mobilisation for that war all specialists in otology were required to fill administrative or executive appointments, and some served as R.M.Os., general surgical specialists, or in some cases even as combatant officers. During the course of that war the need for aurists and for special ear centres became apparent and was to a considerable extent satisfied by the appointment of specialists at suitable sites.

Even in the War of 1939–45 it took some time before the necessary complement of oto-laryngologists was provided, but that war demonstrated the great importance of providing an adequate service for treating diseases of the ear, nose and throat, not only in the Armed Forces, but also among the civilian population. In ordinary times these diseases are responsible for the greater proportion of all cases of minor illness and for a great number of major disabilities; during the war it was shown that there were many cases of untreated disease which only came for treatment when the time and opportunity provided by war-service made it possible.

PROVISION IN THE ARMY

Before the war no-one fully realised the relative inadequacy of the provision made for this important speciality, but it did not take many months to show the deficiencies of both staff and equipment. In the Navy, Army and Air Force the deficiency was at first not so obvious. Prior to the outbreak of war E.N.T. cases in the Army were treated by the few oto-rhino-laryngologists among the regular R.A.M.C. These were stationed at some of the larger military hospitals in the United Kingdom and there were two in India. A civilian consultant attached to the Q.A. Military Hospital, Millbank, assisted when called upon in difficult cases. He was also available in an advisory capacity to help the Consulting Surgeon to the Army, who was ultimately responsible for the supervision of the E.N.T. service as part of general surgery. With mobilisation several E.N.T. specialists entered the Army and were posted to hospitals at home and abroad, but no steps were at that time taken to co-ordinate the work and each specialist functioned as part of the hospital to which he was attached. His problems were for the most part handled within his unit by the C.O. and only occasionally were they referred to the consulting surgeon. This arrangement continued until November 1941, when Lieut. Colonel Myles L. Formby was appointed Advisor in Oto-rhino-laryngology, and in May 1943 the appointment was raised to consultant status with the rank of brigadier. In due course all advice on administrative matters relating to oto-laryngology was given direct to the branch of the Army Medical Department concerned—a much more satisfactory arrangement. The majority of military hospitals at home and all the 600-bedded and 1,200-bedded general hospitals which were mobilised at the outbreak of war had an establishment which included an otologist. The number of E.N.T. specialists embodied with the Territorial Army, called up from the Reserve, or enlisted among the early volunteers, provided sufficient cover for these hospitals during the early months of the war. It is interesting to recall that at the height of the war over 104 oto-laryngological full and graded specialists were in active employment in the Army, the majority of whom were drawn from the Special Reserve and Territorial Forces, and emergency commissioned officers. The only woman specialist in this subject in the Army was Major Dorothy Collier, who saw service in the North African and Italian campaigns.

PROVISION IN THE ROYAL NAVY

Even before the war the Admiralty had an E.N.T. civilian consultant and at the outbreak of war the main E.N.T. departments in the Royal Navy, to each of which a specialist was attached, were at the R.N. hospitals at Haslar, Plymouth, Chatham and Port Edgar, and there was also a similar department at the Boys' Training establishment at Shotley. In 1940 departments were opened at the R.N. Hospital, Portland, and at the R.N. Auxiliary Hospitals at Barrow Gurney, Newton Abbot and Kingseat; and in 1942 at the R.N. Auxiliary Hospitals at Kilmacolm and Seaforth.

Oversea a surgical specialist with E.N.T. experience was stationed at Malta, at Hong Kong and on the Hospital Ship Maine (Mediterranean Fleet). During the course of the war departments were opened at the R.N. Hospitals at Bermuda, Durban, Colombo, Alexandria, Brisbane, Sydney and Trincomalee. There were E.N.T. departments on six hospital ships.

In general, naval nursing sisters were not employed for special duties in E.N.T. departments and there were no special wards for E.N.T. cases. The staffing of an E.N.T. department rarely exceeded one or two male or female nurses under the care of a senior naval sick berth staff rating, or V.A.D. adequately trained in E.N.T. requirements.

During the war 38 whole-time specialists in ear, nose and throat work were employed in the Royal Navy; of these 14 were regular Royal Naval medical officers and the remainder were Royal Naval Volunteer Reserve, all of whom had filled E.N.T. appointments in civil practice.

When war broke out there was a shortage of the special instruments required for examination and operation within the confined cavities of the ear, nose and throat. Auxiliary hospitals and hospital ships commissioning in the United Kingdom were able to requisition and obtain the necessary instruments within reasonable time, but auxiliary hospitals abroad, and particularly hospital ships moving from place to place, worked under great difficulties. For the first two years of the war specialists serving outside the United Kingdom were almost dependent on their personal instruments. In the latter part of the war the Navy, in common with the other Services and for similar reasons, experienced a dearth of well-trained specialists. Some men with slight previous experience of the subject were trained within the Service, but with some difficulty owing to lack of suitable clinical material. The lack of a suitable training centre was felt and there was something to be said for the establishment of training centres which might be open to all the Services.

PROVISION IN THE R.A.F.

The organisation in the Royal Air Force was different from that of the other Services and conduced to the efficiency of treatment which was of great importance among those who depended so much upon accuracy of hearing.

The responsibility for all E.N.T. arrangements in the Royal Air Force lay with the D.G.M.S. through the consultant in oto-rhino-laryngology, a regular medical officer who combined specialist knowledge of the subject with long experience of the problems of aviation otology and laryngology. The Consultant was located at the Central Medical Establishment whence he undertook, in addition to the normal duties of a consultant, the organisation of all E.N.T. facilities for R.A.F. medical units, as well as the supervision and co-ordination of Service E.N.T. research. Either he or his deputy visited each E.N.T. centre in the United Kingdom at about six-weekly intervals.

Medical officers to undertake specialist ear, nose and throat duties were drawn, for the most part, from members of the medical branch of the R.A.F. Volunteer Reserve. They were classified, according to previous civilian experience, into two groups. Those who had held specialist appointments in the E.N.T. departments of recognised civilian hospitals were placed in charge of the new E.N.T. centres, while those who had experience as civilian E.N.T. house surgeons or assistants were given similar posts in the R.A.F. or else attached to one of the

Aviation Candidates' Medical Boards as advisers on the oto-rhino-laryngological fitness of prospective candidates for aircrew.

The R.A.F. started in 1939 with four main well-equipped self-contained centres at Halton, Cranwell, Uxbridge and the Central Medical Establishment in London, and by 1941 had 14 such centres serving 24 hospitals; each of these centres was under the charge of an E.N.T. specialist. So far as possible equipment at all the centres was standardised, an arrangement which made for convenience in working. In 1940 four endoscopic units were formed, based on the R.A.F. hospitals at Padgate, Wroughton, Ely and Halton. These were semi-mobile and could proceed if required to any R.A.F. general hospital or station hospital within a thirty-mile radius of their base. Two further endoscopic units were later established at Cosford and Northallerton. In all, 467 cases were investigated by these units from the time of their formation until September 1945.

Throughout the war, research work was being continuously carried out by the R.A.F. E.N.T. specialists, under the supervision of the Consultant, in all branches of oto-rhino-laryngology. Much of this work was concerned with aviation otology; for high altitude flight, rapid ascent into and descent from the upper atmosphere, and high-frequency noise in certain types of modern aircraft, had shown a tendency to produce pathological conditions in the human ear which required extensive investigation. A great deal of experimental work was undertaken at the acoustics laboratory which was set up in 1940 at the R.A.F. Central Medical Establishment as an integral part of the Department of Oto-Rhino-Laryngology. It was staffed by a physicist, an electrical engineer, a radio mechanic and a phonetics expert. The whole organisation was under the direct control of the Consultant. Among other undertakings, the acoustics laboratory was responsible for most of the research into the problems of noise deafness. Meanwhile the practical application of results was the subject of further experiment and this was mainly done at the R.A.F Institute of Aviation Medicine at Farnborough.

PROVISION ON THE CIVILIAN SIDE

On the civilian side matters were not so satisfactory. At the beginning of the war it was considered that clinics for ear, nose and throat cases were so well distributed throughout the country and so well equipped that no further provision need be made for this branch of surgery. This view overlooked the fact that many extra emergency hospitals had to be established with a very great increase in the number of beds available, and that the Emergency Medical Services were to be made responsible for the treatment of most of the Service E.N.T. cases in the United Kingdom. An estimate of the number of E.N.T. consultants for a civilian medical service would provide one for every sixty thousand of the population; in practice the number left in England was much smaller, and some consultants were dealing with populations of 200,000 or even 300,000. The number of patients, as stated above, was swelled by numerous Service patients, both men and women, who sought advice which they would not have troubled to seek in peace-time. It was soon found impossible to deal with every class of case at every hospital, for the facilities were so variable.

At a conference convened by the Director-General of the E.M.S. in October 1942, the work was co-ordinated by the appointment of regional consultants, and the hospitals were grouped into three grades so devised that the highest type of work could only be performed at hospitals of the highest grade, the less specialised at the second grade of hospital, and only minor out-patient work was to be done at the third grade of hospital. At the same time adequate equipment, which had been sadly lacking in many places, was provided. The advantages of concentrating serious cases into special centres were great. Wards could be set aside for male and female cases and for children, with sisters devoted to and skilled in the specialised work and with a medical staff competent to deal with every class of case. One of the best centres was that at Horton Emergency Hospital where Mr. Negus was in charge of the department. Here there were two consultants, an assistant surgeon, two registrars and two house surgeons. At this hospital 3,735 E.N.T. patients were treated between September 1939 and January 1944, of whom 1,788 were Service and 1,947 civilian cases. During the same period 3,779 operations were performed, 1,390 on Service and 2,389 on civilian patients. Though co-operation between Army and civilian specialists was nowhere officially recognised and at first there was much overlapping and inco-ordination between the Services and the E.M.S., later there was a good working arrangement at such places as Horton, Oxford, Maidstone, Canterbury, Colchester, Edinburgh and Cardiff, whereby Service and civilian patients were treated in the same E.N.T. centre and the respective E.N.T. specialists mutually assisted each other. A still closer integration between the E.M.S. and the Services might have produced a further economy in specialists. Such economy was indeed seriously needed. The increased demand for general duty officers on active service necessitated the calling-up of many men who might have been trained in the specialty, and the wastage in the Forces was made good with difficulty, and at one time could not be made good. When in 1942 the Central Medical War Committee made known its inability to supply the full number of otologists required, steps were taken to comb the R.A.M.C. for officers with some E.N.T. experience, and from them a number were taken and given special training in the larger military E.N.T. departments so that they could be classed as graded specialists. By this means, by the careful allocation of otologists in the various theatres of war, by concentration of cases at special centres and by making full use of the E.M.S. facilities in the United

Kingdom, satisfactory specialist treatment was provided for the numerous cases in the Army. When in any theatre of war it was found impossible to concentrate otological cases in special centres the specialist often had to travel long distances in order to treat cases at different hospitals—a most inconvenient and uneconomic arrangement. Late in the war a specified number of otologists were allocated to each force, in some commands as a pool, and they were then posted to hospitals specially selected for E.N.T. centres. It would probably have been better to provide an appropriate number of self-contained E.N.T. departments for any force and then to make each an integral part of a general hospital. As the campaigns progressed and plans became altered it would have been possible to transfer a complete department from one hospital to another without any dislocation of administration.

From the above account it will be clear that in the early days of the war, when they had to deal with such large numbers of cases, the otologists in the E.M.S. were very short of help and often had to work single-handed. The result was that many out-patient treatments could not be given, admissions to hospital were increased, the return of soldiers to duty delayed, and specialists' time too often wasted in carrying out petty details which should have been done by competent assistants. In the Army and the E.M.S. nursing orderlies and clerical assistants were lacking and, though in the United Kingdom valuable aid was obtained from V.A.Ds., and occasionally from convalescent patients, the specialists were greatly handicapped. Later the importance of having clerks and orderlies was realised and the position slowly improved. In the later stages of the war the main difficulty was in the adequate replacement of Service specialists.

GENERAL REMARKS ON THE CAMPAIGNS

AT HOME

The War of 1939–45 was noteworthy in that so large a proportion of cases were treated in the United Kingdom, chiefly in the hospitals of the Emergency Hospital Services, though excellent work was also done in the hospitals of the Fighting Services. After Dunkirk, during the Normandy attack and the European campaigns, serious cases were, whenever possible, evacuated to the United Kingdom, and many patients were even sent home for treatment from the Middle East. The work of the E.M.S. was therefore of great importance and may be briefly considered at the various stages of the war.

At the beginning of the war the provision of large numbers of beds for expected air-raid casualties, which did not occur, gave opportunity for the admission of civilian patients on the waiting lists of civilian hospitals. The benefit to the population by the reduction and in some cases by elimination of these lists was obvious. Unfortunately in some cases the shortage of staff prevented taking full advantage of this opportunity. A closer co-operation between the civilian and Service specialists might have avoided this.

Dunkirk. The commencement of hostilities and the evacuation of our Forces from Dunkirk in the summer of 1940 threw a large amount of work on the E.M.S. In hospitals where there was no segregation of cases some patients with injuries of the ear, nose and throat did not obtain specialist care, but such patients were well looked after in the special centres, where in some cases, wounds of cranio-cerebral type were also admitted; in the absence of a neurosurgeon the oto-laryngologist sometimes had to treat wounds of the latter type.

Air Raids of 1940–1. Before the military casualties from Dunkirk had been altogether cleared there began to be admitted a considerable number of air-raid casualties. Among these were a large proportion of head injuries, which were again in some cases grouped with the ear, nose and throat cases.

Invasion of Normandy, 1944. Between 1941 and 1944 the E.M.S. otologists dealt chiefly with routine cases of disease with occasional cases of accident and a few war casualties. Special arrangements were made for the reception of casualties from Normandy. Certain hospitals in the south were designated to act as transit hospitals and special teams with a full complement of surgeons, sisters, anaesthetists and R.M.Os., were allocated to them. Since the stay of patients was only for twenty-four to forty-eight hours it was impossible to segregate the ear, nose and throat cases, but it proved possible to ensure examination by an oto-laryngologist of all obvious or suspected cases of injury to the ear, nose or throat. A considerable number of blast injuries of the ear were discovered and suitably dealt with.

Flying Bombs and Rockets, 1944–5. While casualties were still arriving from the campaign in France there began the attack by flying bombs and rockets. The hospitals in the south-east of England were soon crowded with patients injured by the flying bombs, and the difficulties of the hospitals in the bombed area were so great that for a short time some of them were forced to stop taking patients. Airborne weapons continued to produce casualties throughout the winter of 1944–5, and military convoys continued to arrive, so that work was heavy. It was noted that there were a lot of cases of blast injury of the ear caused by the flying bombs.

ABROAD

France, 1939–40. Most of the Army general hospitals which accompanied the B.E.F. in 1939 had an otologist attached to them. As there were virtually no casualties until the retreat and evacuation from Dunkirk the E.N.T. cases largely consisted of casual sick. During the winter there was a fairly high incidence of acute upper respiratory infection with the customary complications, principally sinusitis.

Middle East. The first medical arrangements in this theatre of war, apart from the R.A.F. 5th General Hospital at Cairo, were mainly based on the pre-war R.A.M.C. personnel in Egypt. No special provision was made for the treatment of E.N.T. cases. As the Middle East Force grew and general hospitals with their specialists including otologists arrived, there was evolved a surgical service of considerable magnitude. The whole surgical service including the E.N.T. department was under the guidance of the consultant in general surgery. Later, in 1943, an adviser in oto-rhino-laryngology was appointed, and in retrospect it became clear that such an appointment made earlier in the campaign would have resulted in more efficient administration and service. A feature of the Middle East campaign was the long periods of inactivity interspersed with periods of brisk fighting with rapid movement over great distances. This made it necessary for specialists to be versatile and adaptable.

Central Mediterranean Force. This was the first properly equipped force to sail from the United Kingdom; it was well supplied with general hospitals and specialists allocated in accordance with the strength of the force—a better arrangement. In spite of the fact that all troops had been medically examined before embarkation many cases of chronic otitis media arrived in North Africa; they required constant care and were found unsuited for active service.

Invasion of Normandy. In the history of modern warfare no invading force has ever been more carefully and fully equipped in every detail than the 21st Army Group which landed in Normandy. Ten oto-laryngologists were included but they were each attached to a general hospital and not, as might have been more convenient, retained in a pool for the Army Group.

From the Army point of view several lessons emerged from the experience of otologists abroad. First, there was made evident the great value of co-operation between the oto-laryngologists and the specialists in maxillo-facial and neurosurgery. Secondly, it was soon seen to be inadvisable to send men oversea who were suffering from chronic middle ear disease. Thirdly, the total number of gunshot wounds of the sinuses and ear was remarkably small.

CLINICAL ASPECT

Otitis Media. Both in the United Kingdom and abroad the diseases which mostly called for treatment were the same, though they varied in proportion at different times and places. They were tonsillitis, otitis media, sinusitis, deflection of the nasal septum and otitis externa. Of these the condition which caused most trouble and led to the greatest loss of fighting power was chronic otitis media. This was not for want of suitable and skilled treatment. The Army had special treatment centres set up for the express purpose of dealing with these cases. In the

R.A.F. the greatest care was taken to see that otitis media was treated by the expert, and a detailed and standardised form of treatment was adopted and recommended to all medical officers in a memorandum issued in April 1940. The experience of those who treated these cases in the United Kingdom was somewhat at variance with that of those under whose care they came on active service abroad. The views of those who worked at home can best be gathered from the report of work done at Horton—one of the best equipped and best staffed hospitals in the country. It is of course realised that it was customary to reject those recruits who suffered from chronic aural suppuration showing granulations or cholesteatomata, and those who happened to slip through the recruiting medical boards were usually discharged later. But with the less advanced cases of chronic otitis media the results of treatment at Horton were encouraging. Of 331 cases treated at Horton (in a period of three years) only 33 needed to be discharged from the Army, while the remainder were enabled to carry on with their duties, though it is expressly stated that 15 were for home service only. On the other hand, those otologists who saw similar cases of otitis media on active service abroad had a more disappointing experience. In the Navy, Army and Air Force it was generally found that otitis media which might have been causing few or no symptoms at home almost invariably lighted up and rendered the sufferer unfit for active service. The considered views of the naval specialists were unequivocal and as follows: 'Chronic otitis media outweighed every other aural condition, both in numbers and reduction of fighting efficiency. It represented a tenth to a fifth of the total number of cases seen and came second only to upper respiratory infection (tonsillitis). Acute otitis media lapsing into a chronic state accounted for a few of these cases. Infection of the middle ear cleft following blast injuries accounted for others. The vast majority however were cases of long-standing middle ear disease, existing prior to service in the Armed Forces. It must not be presumed that all these cases had actively discharging ears when they were passed fit for service. In a great number dry perforations, attic scarring and other signs of quiescent middle ear disease were the only signs. It was exceptional for these men with quiescent disease to serve any length of time without reactivating the middle ear condition. The results both of conservative treatment and surgery in chronic middle ear disease were better than in civilian life as treatment could be continued irrespective of economic factors. However, relapse after discharge from hospital was inevitable sooner or later. It cannot be said that a man with chronic otitis media ever paid a dividend in fighting efficiency for the labour and hospital accommodation expended on him.

'From the beginning chronic otitis media, active or quiescent, was regarded as an absolute bar to service in submarines, diving, Fleet Air Arm and the operation of anti-submarine detector gear. Later, the service of these cases was limited to ships carrying a medical officer, and subsequently ships over a certain tonnage. This limitation to cruisers and above was introduced owing to the shortage of man-power. Ships of these categories carried adequate medical staff and equipment to deal with an urgent surgical crisis.

'The problem was brought to a head by the shift of the war to the Eastern theatre. Men used up transport to the East to serve only a few weeks before admission to hospital for treatment of their otitis media and invaliding back to the United Kingdom. At the end of 1944 a confidential Admiralty Fleet Order appeared barring all naval ratings, W.R.N.S. and marine other ranks with chronic middle ear disease from draft to the Middle East. Officers were considered less drastically as their smaller numbers enabled individual assessment to be carried out. Finally, in 1945, the invaliding of cases of chronic otitis media was considerably increased as the need for men "fit for shore service at home only" was decreasing rapidly.'

Confirmation of this view came from the Army Consultant in the Middle East, who commented as follows: 'With cleansing treatment and careful personal attention the majority of these ears dried up and the man returned to duty, but relapses were common and it was found necessary to retain these soldiers at the base. Their employment in most instances was uneconomic and there is no doubt that these men should never have been drafted to the Middle East. It was a matter of interest and future guidance that in the case of men who had previously had a radical mastoid operation performed, even though the wound had been healed for many years, it almost invariably broke down under active service in the Middle East.'

Looking back over the years, even in the South African War one-third of the admissions to hospital on account of disease of the ear, nose and throat were due to otitis media, and in the War of 1914–18, 'again and again it was found that quiescent middle ear disease broke down under the physical stresses to which the front-line soldier was exposed'.

As early as 1939 it was noticed by the R.A.F. Consultant that there was a tendency on the part of some medical officers to regard acute otitis media as a minor disease and to attempt to treat it by a diversity of methods all more or less haphazard and empirical. In consequence of this, the number of cases of acute otitis media which became chronic was, in his opinion, greater than it should have been with proper treatment. A memorandum was therefore issued, in April 1940, instructing all unit medical officers to refer personnel with acute otitis media to the nearest R.A.F. E.N.T. specialist as soon as possible and some standard form of treatment was adopted.

From a consideration of these accounts it would appear that, though a man suffering from chronic otitis media may be able to stand Service routine in the United Kingdom, it is unlikely that he will be submitted to the stresses and strains of active service abroad for very long before his ear trouble will disable him.

Otitis Externa. Another condition which was very troublesome was otitis externa. In the United Kingdom this was only fairly common and responded well to in-patient treatment with regular cleansing of the ear by mopping. In the Middle East it was very prevalent during the hot weather and showed a strong seasonal incidence. Swimming pools appeared to be an important aetiological factor, while the presence of sand in the external auditory meatus and some form of trauma, often very slight, to the lining epithelium enabled the causative organisms to set up an acute inflammation. At times the condition assumed epidemic proportions. In the C.M.F. there was an epidemic in Sicily in 1943. In the Air Force it was by far the most prevalent aural disorder during the war, while in the Navy it 'provided a nuisance value only secondary to that of chronic middle ear disease'. It was especially prevalent in men who had to wear headphones for long periods. Bathing *per se* was not considered a special factor, but the use of dirty towels in the drying of the ears, and the presence of sodden wax in a humid climate were the main predisposing factors. As might be expected its incidence was greater in the Middle East and the Far East than in the Home Command. In the Navy *B. pyocyaneus* and *B. proteus* were the usual infecting organisms, but fungous infections were stated to be responsible for the larger proportion of cases in the R.A.F. and the association of generalised skin disease with otitis externa was the rule rather than the exception. Primary otitis externa was the primary cause of invaliding of 81 cases in the R.A.F. during the years 1939–45. Prophylaxis in the form of improved sanitation and hygiene propaganda was undertaken on an extensive scale with considerable success. In this direction certain administrative difficulties occurred, especially in the case of members of transport command, who sometimes arrived in a territorial command suffering from an otitis externa contracted en route in another country. The importance of scrupulous toilet to the meatus was generally recognised. The response to treatment, in cases seen early, was good, but some cases were resistant to treatment and tended to become chronic. Aluminium acetate was preferred in the Navy but lead subacetate or ichthyol in glycerine were regarded as useful alternatives. The insufflation of sulphonamide was condemned as a routine, for widespread dermatitis sometimes ensued. To such an extent did this occur in the R.A.F. that a discouraging directive was issued from the D.G.M.S. in May 1944. The recurring and chronic cases responded well to lotio and linimentum calaminae when they returned to a temperate climate.

Tonsillitis was the commonest complaint but there were no unusual features about it. The remarkable number of tonsillectomies performed in the home hospitals may be judged by the fact that at Horton during the three years, 1,158 tonsillectomies were performed. Of these 481 were in Service patients. In this large series, though 10 had reactionary or secondary haemorrhage, there were no deaths. There was nothing unusual in the incidence or symptomatology of the many cases of sinusitis and deviated nasal septum.

Acute *sinusitis* was at times prevalent in the Middle East and had a seasonal incidence, often following bathing in a swimming pool. Chronic sinusitis in this area was of interest in that some individuals with long histories of infection improved and others got worse for no apparent reason. Treatment of sinusitis, which in civilian life is often disappointing, was even less successful in Service life. Men worked and slept in crowded messes, not only afloat but ashore, and chronic nasal infections tended to relapse, however adequate the surgical or conservative treatment had been. Cases of chronic nasal infection had, moreover, the disadvantage of spreading upper respiratory infection around the messes. Cases of gross nasal sinusitis, recurrent polypi and particularly pansinusitis were invalided. Chronic sinusitis was inevitably made worse by service in the tropics, and reactions following surgical intervention on the nasal sinuses were more frequent than in temperate climates. It was surprising that acute sinusitis was seen commonly in the tropics.

Injuries. Information as to the number and character of injuries of the ear, nose and throat was scanty up to the commencement of the war, but during the war additional types of injury resulted from the use of bombs with a high blast effect, and the air raids which knocked houses down over their occupants' heads or scattered innumerable bits of glass in every direction.

It was noted that in the United Kingdom there was a greater liability of civilians to head injuries; this was readily understandable since the civilian less often had the protection of a helmet. Multiple wounds were more common in civilians and simple wounds in soldiers. Head injuries were by no means synonymous with cranio-cerebral injuries. Statistics showed that there was a relatively small number of injuries of the ear, nose and throat, and those which did occur were usually associated with other wounds of the face, eyes, vault of the skull or even other parts of the body. These facts emphasised the necessity, whenever possible, of cooperation between the otologist and the other specialists dealing with neurosurgery, maxillo-facial or even orthopaedic surgery. It was noted by the consultant in otology for the Army that more gunshot wounds of the mastoid were seen in Italy than elsewhere. Free drainage of the infected cells in the early stages, together with adequate chemotherapy and later plastic repair, proved adequate treatment.

It was recorded that in the Air Force there were a considerable number of injuries to the nose, sinuses and ear, but very few affecting the larynx and pharynx. In the Navy, war injuries involving the sinuses, and in particular penetrating wounds, were not frequent. Wounds of the nose were usually associated with multiple or head injuries which overshadowed them. Fractures of the nose were fairly common; it was perhaps not sufficiently realised that it was important to reduce these fractures at an early date while reduction still remained easy.

Injuries of the larynx were very infrequent both at home and abroad on active service.

There were certain special conditions which chiefly concerned the ear which merit more detailed consideration. The first of these is motion-sickness or sea-sickness.

Motion-Sickness. It is well known that under the influence of unusual or unaccustomed movement anyone may develop unpleasant or even distressing symptoms—sweating, pallor, nausea and sometimes vomiting. According to the type of movement this is termed sea- or air-sickness or more generally motion-sickness. It is believed to be due to the effect of the unusual stimuli on the labyrinth. Five to 10 per cent. of those who fly for the first time vomit more than once during their first twelve hours in the air. The incidence of air-sickness is influenced by the weather, by the type of aircraft, the amount of noise and vibration, the degree of ventilation, the quantity and quality of the food taken, and various forms of disease such as otitis and sinusitis. It is interesting to note than when a pilot is flying his own aircraft he is rarely sick.

Naval personnel who suffered repeatedly from sea-sickness were of no use for service afloat. Laborious research into the prevention of sea-sickness was not possible and those who were subject to it were weeded out by transferring them to shore service or invaliding. The incidence of motion-sickness in the Fleet Air Arm and the R.A.F. was not high and did not constitute a serious problem. Among the commando personnel in landing-craft, motion-sickness was more serious. In the earlier raids on the Norwegian coast sea-sickness reduced the fighting efficiency of the men to be landed. Joint research was carried out with the Army but the results of drugs were disappointing, as indeed they were in the similar researches carried out in Canada and the United States. Selection and acclimatisation were more effective. The consensus of opinion among medical officers of landing-craft at the Normandy landings in 1944 was that sea-sickness was not an important factor, for the excitement and tension of the actual moment went far to overcome the symptoms.

Ruptured Tympanic Membrane. Both in the Navy and the Air Force this accident was not uncommon. On the home front also it was sometimes seen as the result of blast. Army reports from the Middle East stated that ruptured tympanic membrane was the injury encountered most frequently in that area. A high proportion were caused by the explosion of mines and hardly any appeared to result from the firing of guns in action. Very few of these casualties developed otitis media, unless ear drops had inadvertently been applied or the damaged ear syringed in error. When this occurred it was not unusual for a mastoiditis to develop. Once the importance of protecting these damaged ears and avoiding any interference became generally known, very few complications occurred.

In the Navy the increase in fire-power of guns in this war was responsible for the greater trauma to the ears than occurred in the War of 1914–18. Guncrews in turrets were reasonably protected but those manning guns in open mountings were exposed to considerable blast. The smaller calibre guns were found to be a more potent source of injury than those of larger calibre. Explosions and 'near misses' were also a frequent cause of aural injury. Injury of the drum-head was the essential lesion. It varied from a mild injection along the handle of the malleus and of Shrapnell's membrane to gross rupture of the tympanic membrane with haemorrhage into the external meatus, tinnitus and deafness. In H.M.S. *Exeter* following the battle of the River Plate several cases of rupture of the tympanic membrane were seen. It was noticed that they fell into two groups: vertical jagged tears which were invariably situated in the anterior quadrants, and circular perforations which were found in the posterior quadrants. There was considerably more haemorrhage from the former than the latter type. The former type tended to heal a little more rapidly than the latter. There was evidence to show that rupture of the drum reduced the trauma on the inner ear by absorbing some of the shock wave.

In the R.A.F., fighter operations during the first year of the war gave rise to a number of cases of aural injury. Newly trained aircrew personnel, flying modern high-speed fighter aircraft, were not always fully alive to the physiological dangers of rapid ascent to and descent from high altitudes. Cases of ruptured tympanic membrane occurred in pilots who, while executing a power dive, had failed to equalise the pressure within their middle ears with that of the surrounding atmosphere.

As mentioned above the great danger in cases of ruptured tympanic membrane was secondary infection from outside, thus converting a sterile injury into a more serious otitis media. This was almost inevitable when a man was immersed in the sea shortly after sustaining the injury, and it might also follow injudicious syringing or the instillation of drops. In the R.A.F. such a consequence precluded the sufferer from being an efficient member of an aircrew. So essential was it that men with this injury should have immediate and expert attention that the Consultant in January 1940, requested D.G.M.S. to instruct all R.A.F. medical officers to refer such cases immediately to an E.N.T. specialist, confining their first aid to the gentle packing of the external auditory meatus with sterile cotton-wool. Similar teaching became general in all the Services.

With ruptured tympanic membrane there was usually a moderate deafness of the whole frequency range with a negative Rinne. If no secondary infection occurred the hearing returned to normal. The milder forms of this type of deafness were very common and rarely reported to the medical officer, so that only a routine inspection brought them to light. Fig. 1 shows the air conduction of a rating aged 25 who got a bilateral middle ear deafness from the blast of a 12-pounder. It will be seen that his hearing was practically normal after fifty-six days.

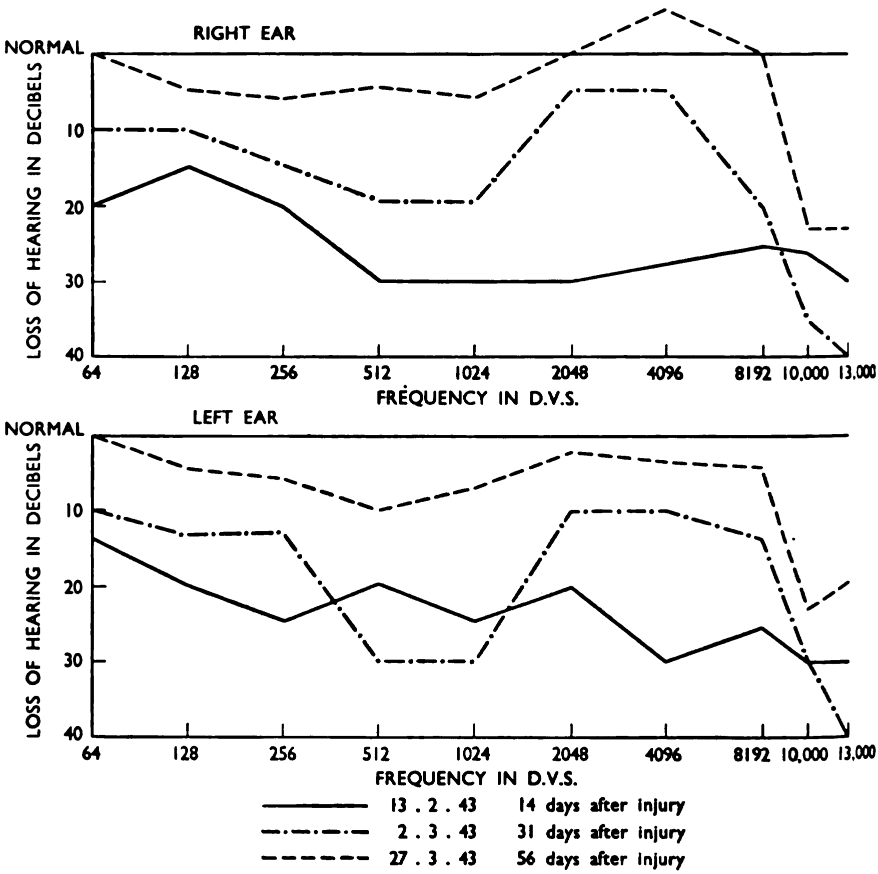


FIG. 1.—Charts showing method of recording of extent of loss of hearing after blast injury of the middle ear.

Cochlear Deafness due to Trauma. In addition to the deafness due to injury of the drum-head and middle ear there were many cases of cochlear deafness resulting from the effects of gunfire. Of course, there were other causes of cochlear deafness—cochlear degeneration, head injuries, or even the prolonged taking of quinine—but a large proportion were due to long service as gunners, exposure to the noise of aero-engines or to the engines of M.T.Bs., M.G.Bs., or landing craft.

There were two types of cochlear deafness. In the first, commonly known in the Navy as gunner's mate deafness, there was a *gradual* loss of hearing of the high tones. In the second an abrupt high-tone loss occurred.

Cochlear deafness of gradual high-tone loss type was caused by prolonged exposure to noise, and was very common in gunnery officers and ratings who had long service to their credit. Dalziel Dickson and his colleagues found that it occurred among airmen after regular flying,

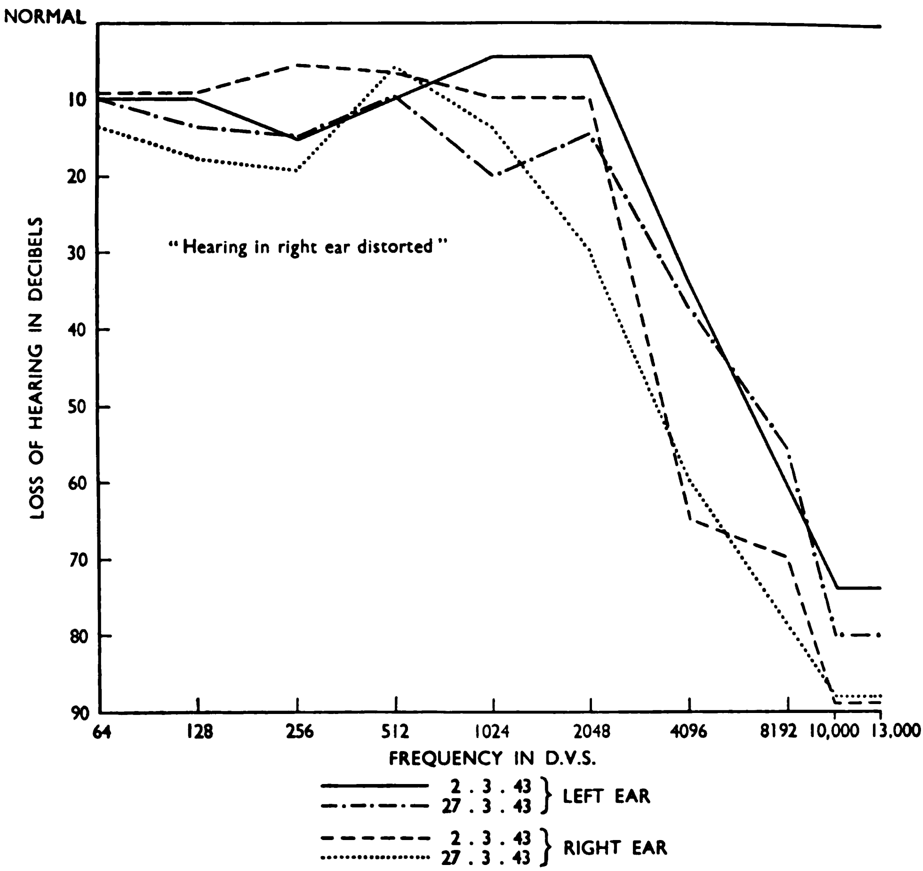


FIG. 2.—Cochlear deafness of abrupt high-tone loss type due to blast R.N.

even after a few hundred hours, without helmets in enclosed cockpits. It also occurred among personnel engaged in testing and tuning multi-engined aircraft. The earliest sign was a loss of hearing in the region of 4,000 cycles. As the lesion progressed the audiogram showed a steady fall in hearing from the low tones to the high tones.

Dickson found that the results of tests of hearing from speech confirmed the audiometric measurements. Mistakes in hearing the spoken word often occurred when accurate interpretation depended upon ability to recognise consonants whose essential characteristics are highness in frequency and weakness in intensity. The patients themselves were not always aware that their auditory acuity was impaired.

Cochlear deafness of abrupt high-tone loss was characterised by a severe high-tone deafness following a single instance of blast trauma. The audiogram was distinctive in that the lower tones were intact but there was a sharp fall in the curve of hearing perception usually between 1,000 and 2,000 cycles. In the severe cases the fall occurred between 500 and 1,000 cycles and in the less severe injuries between 2,000 and 4,000 cycles. The whole of the hearing for high-tone frequencies was lost and inability to hear speech was marked. This type of lesion was permanent unless it recovered within a few days, but no further deterioration occurred unless additional trauma was superimposed.

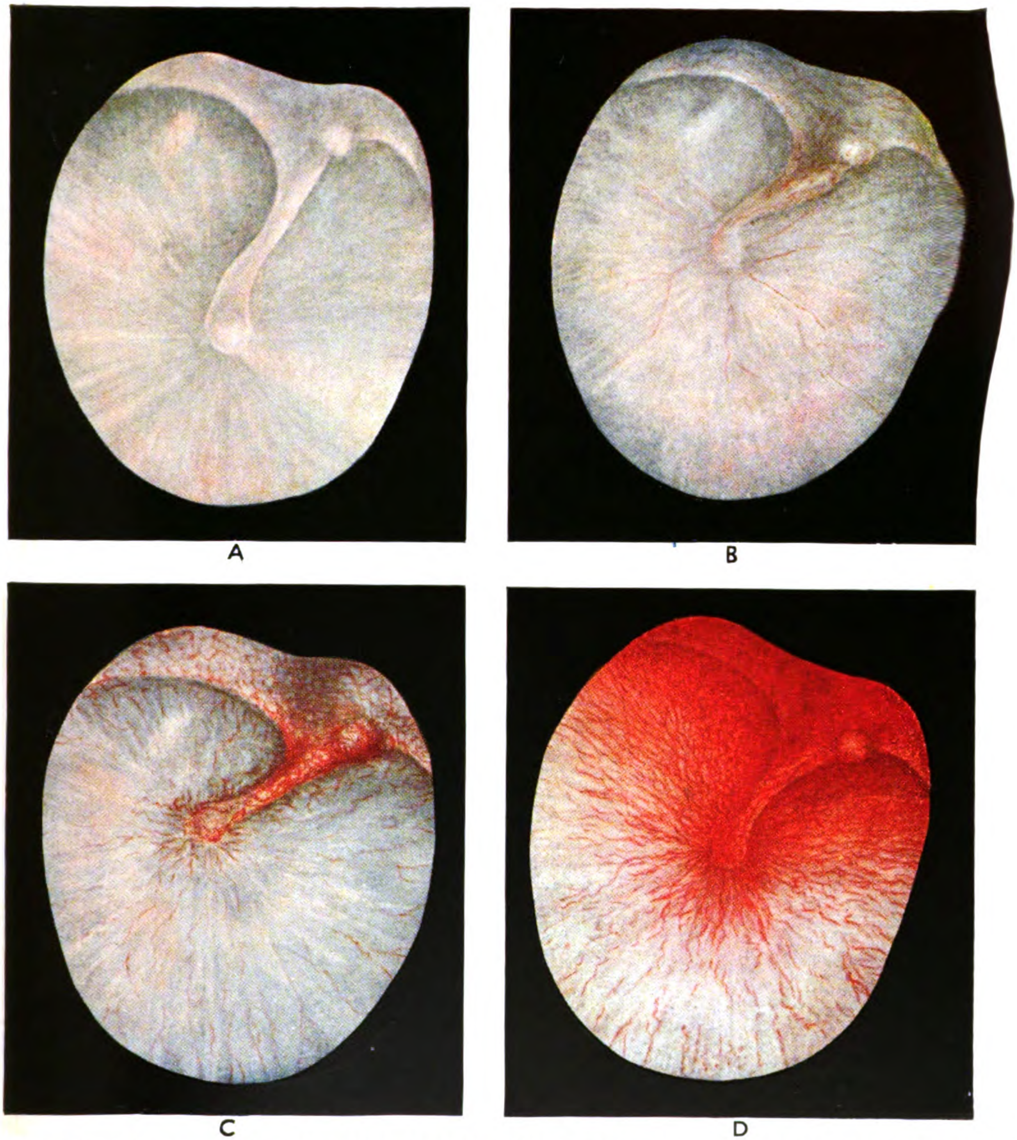
There is no doubt that cochlear deafness was diminished by the mounting of guns in turrets, and the modern practice of mounting secondary armament of H.M. ships in turrets has done much to reduce blast trauma in the Navy. The most frequent cause of blast injury was due to ratings being caught unawares in exposed positions (Fig. 2).

Recent work by N. E. Murray and G. Reid (1946) in Australia has shown that *temporary* deafness of the abrupt high-tone loss type was the rule after gunfire, but usually recovery took place within twenty-four hours. This suggests that much trauma suffered by guncrews passes without record.

With regard to prophylaxis it was shown that dry cotton-wool had little protective value, but towards the end of the war rubber ear-plugs were found to have protective value and were made a general issue to all upper deck personnel. In the R.A.F. much research was done to find the best method of protecting the ear. One of the simplest and most efficient was to pack the meatus with cotton-wool smeared with vaseline.

THE PROBLEM OF OTITIC BAROTRAUMA

The condition of the ears in which the pressure within the middle ear differed from that of the pressure exerted by the surrounding atmosphere was one which had long been known to be associated with flying personnel. Usually occurring in aircrew making rapid descents from the rarefied upper atmosphere, it was frequently aggravated by the presence of some degree of naso-pharyngitis in the patient which tended to cause an inflammatory blockage of the eustachian tubes. A similar condition could also occur in the nasal accessory sinuses. This clinical picture was formerly known by a variety of names, such as eustachian catarrh, aero-otitis, and aviation pressure deafness. In December 1942, it was decided to introduce within the R.A.F. the terms 'otitic barotrauma' and 'sinus barotrauma' to denote this group of conditions, which were in fact barometric in origin and traumatic in nature. So common was the incidence of these disorders among R.A.F. flying-personnel and so



Plates showing tympanic membrane changes. (Drawn from actual cases by J.E.G.Mc.G.)
A.—Normal tympanic membrane.
B.—Invaginated with minimal congestion.
C.—Invaginated with marked congestion.
D.—Attic congestion.

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PLATE I

[Facing page 640.

E.—Generalised congestion.
F.—Interstitial hæmorrhages. Residual hæmorrhage usually along handle and in attic.
G.—Rupture of tympanic membrane. Common site.
H.—Effusion with patent tube (bubbles). The more common type is with the posterior compartment full.

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PLATE II

(*Continuing Plate I*)

operationally disabling were their effects—aural pain and deafness—that aircrew suffering from otitic and sinus barotrauma were thereby rendered non-effective for periods of days while they were being treated. It was in fact usual to 'ground' personnel who were suffering from head colds if they showed a negative response to Valsalva's test.

The symptoms of otitic barotrauma were well described by Dickson. The disability may affect one or both ears. The main symptoms are pain, deafness, inability to clear the ears, tinnitus and occasionally vertigo; in 100 patients the predominant symptoms were: deafness alone 31; deafness and pain 55; deafness and tinnitus 5; deafness and vertigo 3, and pain alone 6. The onset of pain may be gradual or sudden and its intensity varies from a dull ear-ache to an unbearable pain which radiates over the side of the head and down the lower jaw. It persists until landing is effected and is relieved immediately the intra-tympanic pressure or equilibrium is restored by auto-inflation, catheterisation, politzerisation, or if the aircraft is put into a climb. Deafness, which is a very common accompaniment, is often overshadowed by the more severe sensation of pain. The deafness may become manifest during or after landing from a flight. It may persist for varying periods ranging from an hour or two to several weeks. This form is usually of the conductive type and audiometrically may show a loss in the low frequencies. More rarely it is acute and presents the feature of an inner-ear or nerve deafness which is often permanent. Vestibular reactions are not impaired. Its causation is not known.

In the Navy barotrauma affected the crews of the Fleet Air Arm and personnel concerned in submarine diving. The numbers involved in the Fleet Air Arm were of course fewer but the rate of incidence was about the same as in the R.A.F. In the Fleet Air Arm cases of barotrauma fell into two main groups. The first comprised cases which resulted from acute naso-pharyngeal infection, usually due to aircrew personnel flying while incubating an acute cold, or, having been grounded for an acute infection, returning to flying duties before the condition of the nose was quiescent. Neither of these contingencies could be completely guarded against, and grounding aircrew personnel for any length of time upset the time-table of those doing courses, or the work of a squadron. The second group, rather commoner towards the end of the war, occurred in aircrew personnel who, after long periods of active flying, were beginning to show signs of fatigue. Mild attacks of barotrauma of the ears or nasal sinuses were magnified against this psychological background. Even with careful clinical examination and the use of the decompression chamber it was not always easy to assess to what extent the symptoms were due to true barotrauma. In any case such personnel usually had to be permanently grounded.

In offensive diving, barotrauma presented problems peculiar to the Royal Navy. By the beginning of 1943 offensive diving was sufficiently advanced to be classed as a war weapon of some importance. The 'frogmen' who rarely went to any depth presented no problem, nor did the 'welman', a one-man submarine, as it was in fact a miniature submarine in which the subject remained at atmospheric pressure. In the other types of midget submarines, the X-craft and the 'chariot' the aural and sinus problems were similar since each used a free diving suit with oxygen bottles. The situation early in 1943 was that not less than 30 per cent. of crews in training were at any one time unable to dive for days and weeks, because they had sustained some degrees of pressure damage to the ears, and less frequently to the sinuses. Research was instituted and appropriate measures devised to counteract the great and sudden increase of pressure in the middle ear consequent on diving rapidly. It was found that the pressure increase of a crash dive was formidable, being comparable to an aircraft descending from 35,000 ft. to ground level in 4·2 seconds. Every candidate for diving had to undergo a searching oto-rhino-laryngological examination in which particular attention was paid to the post-nasal space and the sinuses, with X-ray assistance when considered necessary. A detailed history of any clearing trouble they might have had was elicited, and an attempt was made to establish visually a positive Valsalva. It was found that an experienced otologist could actually see a positive Valsalva in 90 per cent. of subjects examined. It was also shown that by far the most reliable method of forecasting the otological fitness of a subject for diving was to examine his ears while under pressure increase, either in a compression chamber or in the flood-up chamber of a D.S.E.A. tank. As a prophylactic, from the beginning of training tubal muscle drill was introduced into the curriculum. The trainees were taught to perform Valsalva at atmospheric pressure, then under positive pressure, then again at atmospheric pressure holding a dummy mouthpiece in their mouths and holding the nose, and lastly in the suit itself both on the surface and while descending. It was made clear to them that while descending the longer they delayed the clearing the more difficult it would be. By means of these various safety devices the incidence of aural damage was halved. Sinus barotrauma also occurred among divers but in a less proportion than the otitic.

Ascent rates were not a problem from the aural point of view since the eustachian tube acted as a one-way safety-valve.

Observation showed that there were varying appearances in the drum-head and middle ear as the result of the barotrauma. In the earliest stage (when there might be few or no symptoms) there was slight invagination of the drum-head with minimal congestion of the attic, handle of the malleus and the sheaf of vessels going back to the posterior malleolar fold. As the condition progressed the congestion extended and intensified until interstitial haemorrhage occurred in the substance of the drum-head. According to the otological report from the Navy, in divers the earliest stage of haemorrhage consisted of a bulla which occurred at the antero-inferior part of the tympanic membrane; this bulla was stated to rupture into the external meatus and the bleeding was sometimes noticed as the diver undressed. In the later stages of otitic barotrauma serous or haemorrhagic effusion occurred in the middle ear and in the most severe stage the tympanic membrane ruptured (Plates I and II).

In the pre-haemorrhage stage it was usually possible to demonstrate some loss of air conduction to low notes, 64 and 128 db, sometimes a negative Rinne and a Weber to the affected side. When the drum-head was ruptured the condition took at least two weeks to clear up, and usually longer. It was interesting to note that the milder degrees of otitic barotrauma could occur repeatedly without apparently producing permanent changes in the drum-head, or appreciable defect of hearing.

The treatment of barotrauma was, during most of the period of the war, conservative and consisted chiefly of repeated steam inhalations and occasional politzerisation in suitable cases. In 1945, however, irradiation therapy was introduced in the R.A.F. for the treatment of this condition. It was assumed, rightly or wrongly, in the absence of any predisposing factor in the nose, nasopharynx, or throat, that the cause giving rise to the symptoms was within the eustachian tube and was in all probability lymphoid tissue which has been shown histologically to extend as far as the isthmus of the tube.

This lymphoid tissue was treated by means of deep X-ray therapy with a dosage which never exceeded a total of 1,200 r and was spread over a period of fourteen days. An exact technique was worked out with accurate localisation of the X-ray tube. This technique was adopted in preference to the application of radium in the nasopharynx. The safe dosage of radium was considered inadequate to affect lymphoid tissue within the eustachian tube. Larger doses were considered dangerous as likely to result in burns and subsequent scarring. The results of irradiation were very encouraging and compared favourably with previous forms of treatment, 40 per cent. of aircrew so treated being enabled to return to full flying duty almost immediately.

HEARING TESTS

In view of the importance of good hearing in operational aircrew, who are completely dependent on wireless and telephonic intercommunication while flying, it was the wish of the Air Force Consultant, in 1939, to introduce some form of hearing test for aircrew to replace the 'forced whisper test' then in use. The latter was incapable of accurate standardisation and furthermore there existed some discrepancy between the test as administered in the R.A.F. and the test as used by the Combined Recruiting Medical Boards. The former required the candidate to be able to hear, with either ear independently, a forced whisper uttered at a distance of 20 ft. from him. The latter required the candidate to be able to hear, with either ear independently, a soft, but not forced, whisper uttered at a distance of only 6 ft. from him. Since, in any case a whisper is not a sound that can be exactly defined either in amplitude or frequency, the value of the test as an indication of an individual's auditory acuity was limited. The Consultant therefore proposed to subject candidates to a hearing test consisting of two parts, one of which was designed to give a rough form of pure tone audiogram and the other to indicate whether a particular individual was likely to be able to work in a loud noise and to receive speech signals in such a noise. The former consisted of sending the candidate a series of pure tone signals and testing his ability to hear these signals at a low intensity.

In this brief account of the work done and the researches achieved by the oto-laryngologists in the Services during the course of the war we have necessarily confined ourselves to the main issues and have been unable to give detailed accounts of many facts which, though interesting, did not bear directly on the historical record. We have included sufficient, however, to show that the achievements of the specialists in this branch were remarkable, and that the service improved in proportion as the oto-laryngologists were given a freer hand in the organisation of their department. It would take too much space to give full statistics, but in order that the reader may have some idea of the vast volume of work done in the Services the total figures of patients seen and operations done in the R.A.F. for the three last years of the war are appended.

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Annual Rates of Invalidings for Royal Navy and Royal Marines per 1,000 Strength for Diseases of the Ear

Year	Crude rate	Age adjusted rate
Average for 5 years; 1934–8	0·99	0·99
1939	0·59	0·54
1940	0·81	0·75
1941	0·99	0·96
1942	0·78	0·84
1943	0·54	0·60
1944	0·66	0·73

*Summary of E.N.T. Cases in R.A.F.**

In-patients and Out-patients
January 1942 to July 1945

Disease	Out	In	Unspecified in or out	Totals
Injury of the ear	418	126	42	586
External otitis	7,625	1,602	776	10,003
Acute otitis media and/or acute eustachian obstruction	3,128	2,084	822	6,034
Uncomplicated mastoiditis	215	410	73	698
Complicated mastoiditis	57	66	16	139
Active suppurative otitis media	9,305	2,317	1,101	12,723
Inactive suppurative otitis media	6,808	175	1,516	8,499
Old radical mastoidectomy cavities	547	68	83	698
Chronic middle-ear deafness	3,543	154	400	4,097
Traumatic inner-ear deafness	827	30	104	961
Other forms of inner-ear deafness of known origin	466	9	33	508
Otitic barotrauma	1,770	398	198	2,366
Miscellaneous forms of deafness not included in the classification	1,745	63	175	1,983
Vertigo	226	45	30	301
Facial paresis	55	36	9	100
Air-sickness	108	2	24	134
Miscellaneous ear conditions not included above	563	69	36	668
Injury to nose or sinuses	721	408	121	1250
Skin conditions of nose and nasal vestibule	257	30	43	330
Deviated nasal septum	2,707	1,652	477	4,836
Epistaxis	1,547	92	217	1,856
Nasal polyposis	920	511	139	1,570
Rhinitis	4,558	317	505	5,380
Infection of sinuses	7,388	3,829	1,251	12,468
Frontal sinus barotrauma	434	93	31	558
Miscellaneous nasal and sinus conditions not included above	626	120	123	869
Injuries of pharynx, larynx and neck	39	8	3	50
Tonsillar sepsis (pyogenic) and/or hypertrophy of tonsils including adenoids	10,330	7,320	1,799	19,449
Special non-pyogenic infection of tonsils and pharynx	316	194	103	613
Simple pharyngitis	504	83	91	678
Affections of cervical glands	121	53	22	196
Infections of larynx	685	203	124	1,012
Non-infective conditions of larynx	460	138	74	672
Endoscopic cases (excluding a number of cases of direct laryngoscopy)	184	224	59	467
Miscellaneous conditions of pharynx, tonsils, tongue etc. not given above	596	177	102	875
E.N.T. cases examined but no abnormality found	8,977	418	654	10,049
Totals	78,776	23,524	11,376	113,676

* Includes: *Aircrew* R.A.F.: *Ground Staff* R.A.F., W.A.A.F., Navy and Army, Sisters.

CHAPTER 17

PROGRESS IN GENITO-URINARY WORK DURING THE WAR

By A. W. BADENOCH
M.D., Ch.M., F.R.C.S.

PROGRESS made in the diagnosis and treatment of diseases of the genito-urinary tract was not, on the whole, greatly influenced by the war. There were, of course, certain injuries which only occur with any frequency in war-time.

The treatment of wounds involving the genito-urinary system was naturally influenced by the developments which occurred in the treatment of wounds in general. Many more cases of severe multiple injuries in which the urinary tract was involved were successfully treated in this war than in that of 1914–18. This was due to a combination of factors, the most important of which probably was the employment of forward surgical teams, the early and adequate application of methods of resuscitation, and appropriate and intensive chemotherapy.

WOUNDS OF THE KIDNEY

Treatment continued to be conservative unless severe haemorrhage or irremediable damage called for nephrectomy. In the War of 1914–18, secondary haemorrhage was a common complication, occurring in 22 per cent. of cases treated conservatively. It was very much rarer during this war.

Penetrating injuries, whether due to a gunshot or stab wound, rarely affected only the kidney. The renal lesion might be of several kinds. When the hilum was involved the artery or a large branch might be divided, and death usually followed before surgical aid was available. As the anastomosis of the renal circulation is poor, damage to a smaller artery was followed by cortical necrosis. In many cases, particularly in a penetrating injury, the renal condition presented a far less urgent problem than injury to other organs, and in a large number of cases conservative local treatment was all that was necessary for the kidney (Parker, 1947).

Closed injuries were also treated more conservatively than heretofore. It is probable that not more than 5 per cent. of these cases required operation. Urgent surgical intervention was rarely necessary. Resuscitation with careful observation, which included frequent recordings of pulse and blood pressure, was the routine in every case. In the early stages, operation was indicated when the pulse rate was rising and the blood pressure falling in spite of all resuscitative measures.

With excretion urography, it was possible to have a knowledge of the function of the other kidney before operation, and X-rays were usually possible in closed cases. The examination in the first few hours did not necessarily give an accurate picture of the degree of damage, as the kidney function might be completely upset soon after a relatively trivial injury, and there might be little or no excretion seen on the injured side in the original urogram. If this was so, a further investigation needed to be done before discharge from hospital. This might entail a retrograde pyelogram, particularly in a closed case, for the injury might have occurred to a kidney which was already the site of disease; nephrectomy would then be indicated for the pathological condition of the kidney, and not for the effects of the injury.

WOUNDS OF THE URETER AND BLADDER

Injuries of the ureter were very rare. It was most unusual for a complete division due to injury to be treated successfully, and nephrectomy was nearly always needed. On the other hand, partial injury could well be treated conservatively and the results were frequently quite good. (Everidge and Barnes, 1946.) In complete division of the ureter an early nephrostomy provided the best chance of saving the kidney, an attempt being made to restore the continuity of the ureter at a later date, when the effects of extravasation and sepsis had cleared up.

The results of treatment in wounds of the bladder were much improved (Sandrey and Mogg, 1944). In the War of 1914–18, pelvic cellulitis was responsible for more deaths than any other single cause in patients who survived the immediate operation for a bladder wound. During 1939–45, this was not often observed. The principles of treatment applied were: (*a*) Early operation; this prevented or obviated extravasation of blood and urine, haemorrhage was controlled and possible sources of infection, such as bone fragments and other foreign bodies, were removed. (*b*) Adequate exploration; a thorough examination was made of all aspects of the bladder and the adjacent structures. (*c*) Adequate drainage; the bladder needed to be drained to prevent further leakage of urine, and this nearly always entails a suprapubic cystostomy. Equally important was drainage of the prevesical and paravesical spaces when these were involved in the injury.

WOUNDS OF THE URETHRA

As the war progressed there was a tendency for gunshot wounds of the urethra to be treated at certain centres. This was all to the good (Poole-Wilson, 1947). The principles of treatment accepted were: (*a*) in the first instance to stop haemorrhage and to divert the flow of urine, and (*b*) to restore the continuity of the urethra as soon as practicable. In closed injuries and in open wounds, when there was not much tissue loss, the latter could often be undertaken early. Except for minor wounds of the penile urethra, in which an indwelling catheter might suffice, drainage was by means of a suprapubic cystostomy. All perineal wounds needed to be freely drained. If the loss of tissue was not too severe, approximation of the ends of the urethra might be possible. On the other hand, if there had been extensive loss, some form of plastic repair was necessary.

Apart from injuries of the genito-urinary system, the investigation and treatment of disorders of the bladder and upper urinary tract occurring in injuries of the cord, made considerable progress. Two conditions were also observed with much greater frequency in this war; namely traumatic uraemia or the crush syndrome, and non-specific epididymitis.

TREATMENT OF THE BLADDER IN INJURIES OF THE SPINAL CORD

Much work has been done on the treatment of the bladder in spinal cord injuries. It is, of course, well known that where this injury is due to a fracture-dislocation of the spine, complete recovery will not occur. On the other hand, when due to a gunshot or other missile wound, the exact outcome cannot be ascertained at first, and the final stage may not be reached for many months.

There have been two main schools in the treatment of the acute retention of urine which follows injury to the spinal cord. One advocates drainage by indwelling urethral catheter, and the other favours suprapubic cystostomy at the earliest possible opportunity. In the War of 1914–18, emptying of the bladder by manual expression was not infrequently practised. This method has been given up. In the case of British wounded, suprapubic cystostomy was favoured by most urologists. This is always done through a high incision (Riches *et al.*, 1943)—at least two inches above the symphysis pubis. Nothing has been since adduced to show that this is wrong, and while an indwelling urethral catheter was used extensively in American hospitals, this method was not considered to be so satisfactory even with tidal drainage.

There were two main clinical types of bladder following injury to the spinal cord, the autonomous and the automatic. There are, of course, various gradations between the two. In the worst type (autonomous), the residual urine is great, the bladder musculature is hypertonic, but the total capacity is very little above that of the residual urine. Urine is voided in uncontrolled spurts every few minutes and the patient is continuously wet. On the other hand, in the best type of cord bladder (automatic), while there is still some residual urine, there is a considerable difference between this and the total capacity, so that emptying occurs at relatively long intervals, up to three to four hours, and in between the voiding the patient keeps quite dry. Further, there may be a warning sensation that the bladder is full, or the patient may find a trigger area, stimulation of which leads to micturition. Up to this war, the main consideration had been to keep the patient comfortable and as dry as possible. With the autonomous type of bladder, practically all that could be done was to teach the patient manual expression, and to try to increase the function of the abdominal muscles. Failing this, intermittent catheterisation or the wearing of a urinal were the only measures which were found helpful. With an automatic bladder, on the other hand, the patient was rather better. He could be taught to find the trigger area and by stimulating this was often able to precipitate the act of micturition. Furthermore, by regular timing, he could often tell within a few minutes when the bladder was likely to empty.

Much work has been done on these problems. The cystoscopic picture is now well known. It is often quite unlike the neurogenic bladder found in tabes. The bladder is often grossly trabeculated and may even be sacculated. The bladder neck is not always open and sometimes the suggestion of a bar can be seen. Cystometric readings have been done on many series of cases. In some, these indicate that the detrusor function is good, but there is complete inco-ordination with the sphincter.

Recent work has shown that in certain cases, resection of a small amount of tissue from the bladder neck is followed by a diminution of the residual urine; and, while the total capacity of the bladder remains unaltered, the difference between this and the residual is much increased. The autonomous bladder has therefore been changed to the automatic type, and the patient may be kept dry for much longer periods. Occasionally the best form of spinal cord bladder may also be improved, as by a small resection the residual urine may sometimes be completely eliminated, and infection of the bladder can then be cleared up by chemotherapy. Riches has been able to produce closure in a number of suprapubic fistulae after a minimal resection (1·5–2 g.) at the bladder neck. (See also Chapter 10.)

TRAUMATIC URAEMIA AND THE CRUSH SYNDROME

After the War of 1914–18 there were incomplete clinical records in the German literature of cases of renal failure following various injuries. In 1941, Beall, Bywaters, Belsey and Miles first reported cases of renal failure occurring after injury in this war, under the title of the crush syndrome. It was pointed out that similar changes sometimes occurred in injuries not accompanied by crushing, such as in injuries of the head (Cummings, 1942). It was also found in blackwater fever (Bywaters and Dible, 1942), in pyloric stenosis with vomiting (McLetchie, 1943), and in septic abortion (Bratton, 1941). While the biochemical and renal changes associated with these conditions are not all identical, there is a similarity which suggests a common aetiological basis. It was at first suggested that the cause was obstruction of the tubules by a metabolic product which had reached the kidney by way of the blood stream, and the source of this product was said to be ischaemic muscle. This is certainly not so in all cases, and it is much more likely that the condition results from anoxia of the kidney (Badenoch and Darmady, 1947). Temporary ischaemia of the kidney may be caused by a prolonged lowering of the blood pressure or by spasm of the renal arteries following reflex stimulation (Barnes and Trueta, 1942).

Of over 83,000 casualties evacuated from Normandy by air, 10,000 of the worst were admitted to an R.A.F. hospital, and of these 44 died, (Darmady *et al.*, 1944; Darmady, 1947). Twelve of these deaths were directly due to renal failure. Five patients in whom renal failure was recognised clinically, recovered. The clinical features were characteristic. All the patients were severely wounded and had either suffered considerable loss of blood, or had required active resuscitation for profound shock. The onset of symptoms occurred between the second and sixth day after the injury. The first of these was usually anorexia with a tendency to hiccup, followed in the course of the next few days by vomiting. During this period, oliguria was present; the tongue was dry, the patient was drowsy and mentally dull, and hallucinations were common. Cyanosis was often present. Occasionally a petechial rash was seen over the upper part of the body, but this may have been a manifestation of fat embolism, which was a not uncommon complication in severely wounded casualties. Complete anuria did occur, although this was rare. As uraemia developed, the blood pressure rose, and in those who succumbed the patient became progressively worse and died within ten days. In those who recovered, there was a sudden improvement, quite often dramatic, from the sixth to the eighth day. The output of urine greatly increased and the mental condition became clearer.

The treatment of the condition is still very uncertain. It has been suggested that alkalisation of the urine is important. This is very difficult to achieve. Probably correction of the blood chlorides is more practicable. Recovery has followed splanchnic block, but there has also been spontaneous recovery without special treatment.

NON-SPECIFIC EPIDIDYMITIS

There was a marked increase in each of the Services in the incidence of epididymitis for which no cause could be found. Indeed, at times it amounted to epidemic proportions, as in Malta in 1943 (Tunbridge and Gavey). Ainsworth Davis (1943) reported 58 cases from a Royal Air Force hospital. In only 36 per cent. was there a discoverable urinary infection, and in the remaining 64 per cent. there was no evidence of infection elsewhere. Slesinger (1943) reported 65 per cent. without any infection and Tunbridge and Gavey almost 100 per cent.

In the Malta epidemic there was a prodromal fever with headache, backache and anorexia, which lasted for an average of five days. The temperature subsided and the patient was completely normal for some six days. There was then pain in the groin and lower abdomen on the affected side, followed by pain and swelling in the testicle. The scrotum became red and oedematous and the skin was often adherent to the epididymis. The latter was swollen and tender and the testicle was difficult to palpate on account of pain. There was usually a small hydrocele present and the cord was thickened, tender and hard. On account of the swelling it was not easy to identify the vas. As a general rule the condition reached its maximum in five or six days and then began gradually to subside.

Tunbridge and Gavey investigated their series of cases very completely. The only common finding appeared to be a raised erythrocyte-sedimentation rate. In the large majority of cases the urine was sterile, no tubercle bacilli were seen, blood culture was sterile, examination of blood smear for malaria was negative, and prostatic smear was also negative. On the other hand, Handley (1946) in 24 cases of non-specific epididymitis found evidence of infection in the large majority of cases. It was suggested that the condition might arise from back-flow of urine along the vas, due to exercise with a full bladder. This may have been the cause in a rare instance, but did not account for all cases.

Treatment of this condition consisted of rest. There was no apparent improvement on chemotherapy or after treatment by penicillin. In the majority of cases the condition quickly cleared up, and most were fit for duty in twenty-one days.

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CHAPTER 18

BLAST

(i)

The General Effects of Blast

By Sir ZACHARY COPE
B.A., M.D., M.S., F.R.C.S.

The War of 1939–45 brought with it a problem and a terror which had not been present to anything like the same extent in any previous war—the injurious effects of blast.

It is true that in the War of 1914–18 men at the battle-front were often blown to bits or hurled considerable distances by the blast from exploding shells or bombs, and men were sometimes found dead without signs of external injury. In the War of 1939–45, however, the problem increased in magnitude owing to the great increase of bombing from the air which frequently affected large centres of civilian population.

HISTORICAL

Very few references to such cases occur in the literature. In 1918–19 Hooker (1924) carried out some important experiments to determine the sequence of events which led to death in primary shock induced by air concussion.

In unanaesthetised cats and dogs the most striking effect of exposure to gun-blast was the sudden onset of extreme fatigue. Cursory post-mortem examination revealed normal viscera, except the lungs; these organs showed areas of red hepatisation, especially in the lower lobes, which were practically solidified. These haemorrhagic areas were the only gross lesions found post-mortem after exposure to air concussion, due to gun-blast or high explosive. In the high-explosive experiments (in which shock was not noted), the lung injury was extreme, extending in some cases to occupy the greater part of the pulmonary tissues. In 1939 experiments carried out under the supervision of Sir Joseph Barcroft showed that goats and rats exposed to the blast of the explosion of a 500-lb. medium case bomb suffered no damage at distances of 50 or 30 ft. but at 15 ft. received severe injuries to the lungs which were regarded as more consistent with sudden distension of the lungs with air rather than external pressure on the ribs.

It was only during the large-scale bombing of civilian centres which began in 1940 that the effects of blast first began to receive serious attention in this country.

F. G. Thomson (1940) recognised fatal lung-lesions which followed non-penetrating wounds of the chest, and A. L. Lockwood (writing in 1940) recalled his experience in the War of 1914–18 of men who were injured by a close-up shell or bomb explosion and died without any apparent wound, or from a wound so slight or in such a position that it could not of itself be the cause of death. Lockwood thought that there was a collapse of the lungs in these cases or a rupture of the visceral pleura, and foretold that such cases would be common as the result of aerial bombing.

Various ingenious theories were adduced to account for these deaths but no general agreement was reached. What little experimental work was done proved inconclusive. Mairet and Durante (1917) laid stress upon the pathological changes in the brain, in which they found minute scattered haemorrhages due to rupture of small vessels. More significant were the experiments done by George Crile at Rouen in 1917, who found that in rabbits and dogs killed as the result of an explosion in a confined space the main stress of the explosion did not fall exclusively upon the nervous structures but also fell in a marked degree upon the lungs, which were the seat of massive haemorrhages. (Official History of the Medical Services of the War of 1914–18, 1922, *Surgery*, Vol. I, p. 47). Unpublished work by Leonard Hill in 1918 (Williams, 1942) also stressed the lung-lesions due to blast. He carried out experiments on pigs and noted that death following exposure to explosion was accompanied by scattered haemorrhages in the lungs; he suggested that the lung might be affected by pressure acting through the abdomen. In the Spanish War of 1936–39 the effects of blast became more obvious and were remarked upon by Kretzschmer (1940), a surgeon who served in that war. He pointed out that the blast of high-explosive bombs commonly caused compression or concussion of the chest wall and might rupture the lungs without producing any penetrating wound; the rupture might involve only the internal alveoli and then the patient would have no symptoms except a mild haemoptysis and cough.

EXPERIMENTAL RESEARCHES

In 1940 Zuckerman (for an account of whose work see Medical Research Volume) carried out valuable experimental work on the subject for the Ministry of Home Security. His experiments dealt with the effect of aerial blast on the lungs and the organs of animals submitted to varying pressures engendered by the explosion of charges of H.E. The explosive was detonated in paper containers so as to get the effect of pure blast uncomplicated by wounds caused by flying missiles. The maximum pressure to which the animals were exposed was 70 lb. per sq. in.

The physics of bomb explosion have been studied by various observers. When the bomb is detonated the initial gaseous pressure within the metal casing is something between 100 and 650 tons per sq. in. After the casing has burst the gases escape in the form of a molecular spray which produces a blast-wave consisting of a single pulse of increased pressure, in general form similar to a large-amplitude sound-wave, followed by a phase of suction or negative pressure. The wave moves extremely rapidly but, in the case of a medium-sized bomb, the velocity falls to that of sound at a distance of about 200 ft. from the site of explosion. Within this distance the duration of the wave at any point is very short, e.g. at 30 ft. from a 70 lb. charge the pressure part of the wave lasts about 5 milliseconds and the suction part about 30 milliseconds. The duration of the pressure-component increases with the distance from the charge but the suction component remains more or less constant. The pressure caused by the wave diminishes in proportion to the distance from the source of the explosion. In the case of a 70-lb. charge the pressures in excess of atmospheric pressure at varying distances are as follows:

14 ft. .	. 110 lb.
18 ,, .	. 60 ,,
30 ,, .	. 15 ,,
50 ,, .	. 6 ,,

The suction component of the wave is much weaker and never more than atmospheric pressure (15 lb. per sq. in.). At any given distance the magnitude of the pressure is greater with larger amounts of explosive, but if the distance be doubled the amount of the explosive must be cubed to produce the same pressure. An interesting and important fact is that close to the point of an explosion the front of the advancing wave is uneven, so that objects at equally close distances can be exposed to different pressures; further away, the blast-wave becomes more even.

The primary effects of blast were experienced only close to an explosion—e.g. except with large bombs, within 20 ft. of the explosion. Moreover the effects of blast were influenced by circumstances. When a bomb exploded after it had penetrated into the ground a deep crater might be formed; and in this event the blast would mainly be directed straight upwards and might not injure those near to the edge of the crater.

The remarkable way in which some people close to an explosion might escape injury could be explained, either by the irregularity of the pressure wave or by the curious fact that a blast wave might be reflected from adjacent surfaces.

Zuckerman studied the effects of blast on mice, rats, guinea-pigs, rabbits, cats, monkeys and pigeons. He found that different species varied in susceptibility, though it was a general rule that animals exposed closer to an explosion suffered more than those further away. Small mammals (such as rabbits) were killed with certainty at pressures approaching 100 lb. per sq. in., might be killed instantaneously when the pressure was only 50 lb. per sq. in., but sustained no lesion when the pressure was as low as 5 lb. per sq. in. While animals close to an explosion were blown to pieces, there was a range of pressure further away in which all animals were killed immediately without sign of external injury, although there was often blood-stained froth, or blood in the nose, mouth and upper respiratory passages. At a greater distance was a zone of pressure in which animals were found alive immediately after an explosion, but died at varying intervals afterwards. These animals had the same lesions in the upper respiratory passages, but often suffered from air hunger, dyspnoea and increased respiratory rate; they were quiet, apathetic and would not eat, while the knee-jerks, corneal and pupillary reflexes were normal. A few animals showing most of these characteristics recovered. Still further away from the explosion where the pressure was lower there was no obvious external injury, but internal examination revealed changes in the thoracic and sometimes the abdominal viscera. At distances outside this zone the animals were not affected.

The pathological lesions corresponding to these symptoms naturally varied in degree according to the pressure to which the animals were exposed. In 1918 Marinesco and in 1924 Hooker showed that the chief lesion was haemorrhage into the lungs and this was confirmed by Zuckerman (1940), but it was found that 40 per cent. of the animals examined (the majority of which had actually been killed by the blast) also showed haemorrhagic lesions in various abdominal organs. When exposed to high blast-pressures some animals sustained spinal haemorrhages, either extra-dural or in the dorsal commissure, while in rabbits pial or interventricular haemorrhages occurred.

The lesions in the lungs varied according to the intensity of the blast. On inspection the surface of the lung might show small spots of haemorrhage, or large haemorrhagic areas having a tendency to follow the lines of the ribs. On section, the lungs might show local and scattered bleedings or large confluent zones of haemorrhage. The most vulnerable regions were the anterior borders. Whenever the blast was sufficient to kill the animal, blood was found in the bronchial tubes, the trachea and usually the mouth and nose. In no cases did the lesions take the form of small uniformly scattered foci of haemorrhage, and it was noted that the bleedings were of greater extent when the animals survived some hours—a fact which pointed to the progressive nature of the bleedings. Microscopically, the walls of the alveoli were often ruptured and the capillaries torn and bleeding. X-rays on cats showed that all but the lesser degrees of the lesions in the lungs could be detected as areas of mottling and shadow (Plates I and II).

Zuckerman made experiments to determine what was the chief factor responsible for the pulmonary haemorrhages, and came to the conclusion that the internal injuries due to blast were mainly caused by the impact of the pressure-wave on the body wall. Pulmonary lesions were mainly unilateral; and on the exposed side when the animal was placed so close to the explosion that one side shielded the other. This view was confirmed by experiments, which demonstrated that the damage to the lungs could be minimised or prevented by clothing part or the whole of the chest in sponge-rubber jackets. Moreover, when the animal's body was protected but the head exposed to the blast, pulmonary haemorrhages were slight or absent. These experiments were inconsistent with the view that the lesions were due to the effect of the pressure or suction-wave acting through the respiratory passages.

Further experiments by Krohn, Whitteridge and Zuckerman (1942) bore on the physiological effects of blast on the cardio-vascular system, the respiratory mechanism, and the cortical activity of the affected animal. It was shown that if an animal's body were adequately protected, the meati plugged and the ears padded and protected by cotton wool, then no damage to the thoracic or abdominal viscera nor to the external or middle ear would be found.

A constant feature in all the experimental animals was a fall in arterial blood pressure directly proportional to the force of the initial blast; this was not due to vagal inhibition. There was no lack of co-ordination of the heart-beat, but animals which died almost immediately showed a slowing of the heart-rate by 60–70 per cent. before death, even when the vagi had been divided.

There was usually a prolonged and great increase in the respiratory rate of rabbits which survived exposure to blast; the rise might be up to ten times the rate before exposure to the blast and was maintained for several hours. This rapid and shallow breathing was a direct consequence of the changes produced in the lung by blast. Animals exposed to high blast-pressures were not concussed, nor did the electro-encephalograph records point to any special effect on the cortex cerebri.

These experimental conclusions, derived from work done on lower animals, found their counterpart in the pathological lesions and the clinical signs and symptoms in human beings.

INCIDENCE OF AERIAL BLAST

As the result of a careful field-survey of various bombing incidents undertaken on behalf of the Ministry of Home Security in 1941, Professor Zuckerman came to the conclusion that very few air-raid deaths were due to the direct effects of blast alone. The threshold of lethal blast-pressure was unlikely to be experienced except in the immediate vicinity of an explosion, where the danger of fatal injuries from other causes (e.g. bomb splinters or violent displacements) was very high. Blast injuries were thus likely to be associated with other serious wounds. The casualty survey provided evidence to show that the zone within which internal blast injury was likely to occur was very restricted, and that blast as a cause of casualties was of far less importance than

PLATE I. Blast of the lung (1).
Appearance on opening pleura.

PLATE II. Blast of the lung (2).
Clot cleared from lung.

Colour photographs by Hennell of the Metal Box Company, Ltd.

either secondary missile or burial under débris. In the open, the blast from a 50-kg. bomb explosion seldom caused serious damage to anyone who was 50 ft. or more distant, while persons in a shelter did not as a rule suffer from the blast of a similar explosion which was more than 15 ft. distant.

Zuckerman concluded that with widespread bombing, cases of sublethal lung injury were likely to exceed in number the lethal cases; and pointed out the clinically important fact that an individual in a state of shock, who had been near a bomb explosion but had neither sustained splinter wounds nor been struck by flying masonry, might in fact be suffering from lung damage. Unless this fact were borne in mind air-raid victims brought into casualty stations in a dazed and shocked state, with no obvious injuries but with undiagnosed lung damage, might be asked to undertake feats of endurance wholly unsuited to their physical state.

The actual blast pressure needed to cause death in 50 per cent. of human beings exposed to bomb blast, based on animal experiments and confirmed by actual casualties, was estimated at about 400 to 500 lb. per sq. in. The blast pressure which would cause significant but non-fatal injury was estimated at 50–100 lb. per sq. in. Experiments carried out with the aid of volunteer human beings by Commander Knight, and recorded by Williams (1942) in connexion with the blast produced by the firing of big guns, would lead one to suppose that injury could be produced by lesser pressures. Williams stated that the maximum blast pressure that could be withstood without loss of efficiency was 2½ lb. per sq. in., and even when Commander Knight was clothed in a special protective suit of armour, the maximum blast pressure which he could endure was 7½ lb. per sq. in.; at this pressure he realised that he was within the danger area and felt sensations somewhat similar to those described by many who actually sustained serious internal injury.

GUN BLAST

A considerable blast-effect results from the firing of a big gun. Pressures up to 5 or 6 tons to the sq. in. have been registered at the muzzle, though these pressures became lowered rapidly within short distances of the gun. Unpleasant effects from blast can be felt even behind the gun. As stated above, the maximum blast pressure that can be withstood by an adult without loss of efficiency is 2½ lb. to the sq. in. —a pressure which has been observed 40 ft. away from the muzzle of a big gun at an angle of 45° to the line of the barrel.

In order to reduce the effects of gun-fire upon anyone on the bridge of a ship it was found that small baffle plates, fitted at an angle of 45° round the top of the bridge, were efficient, but these plates did not deflect the blast-wave upwards (as had been hoped) for any person unprotected by the plates received the full force of the blast (Williams, 1942).

Gun-blast seldom caused bodily injury, but in the Navy men manning guns in open mountings were liable to suffer injury to the drum-head which varied from signs of congestion to actual rupture of the tympanic membrane. (See p. 636.)

PATHOLOGY

Hadfield (1940) found that the lesions in human beings killed by aerial blast were similar to those which Zuckerman described in experimental animals and consisted chiefly of multiple haemorrhages deep in the lung. The amount of bleeding varied within very wide limits, sometimes amounting to haemorrhagic solid areas which were elastic in consistency. Sections taken through the haemorrhagic area showed that the blood lay almost exclusively in the alveoli and came from the alveolar capillary network. There was a considerable degree of general dilatation and congestion of the capillaries of the alveolar walls throughout the lung, and a disproportion between the amount of blood in the alveoli and the relatively slight damage to the alveolar walls.

In investigating any case of supposed blast injury, it had to be remembered that compression asphyxia, carbon-monoxide poisoning and lesions produced by other external traumata might co-exist.

SIGNS AND SYMPTOMS

One of the best descriptions of the signs and symptoms of injury of the lungs due to aerial blast was given by J. N. O'Reilly and Roodhouse Gloyne (1941), from whose account the following is abstracted:

> The main symptoms noted were shock, dyspnoea, cyanosis, pain in the chest, abdominal pain, haemoptysis, cough and restlessness. Shock, evidenced by pallor, and increased rapidity and poor volume of the pulse, varied in degree. Dyspnoea was a constant symptom which continued until death in fatal cases but often remitted within twenty-four hours. Cyanosis was always present and its intensity gave some idea of the severity of the case. Pain in the chest was of two kinds. A central deep constant pain was most evident in the severe cases and was possibly related to the mediastinal haemorrhages. This deep pain disappeared as the patient's condition improved. The second type of pain was felt more in the chest wall, was probably due to contusion of the intercostal muscles, and was responsible for some of the pain and difficulty in breathing. Abdominal pain and sometimes tenderness and rigidity of the abdominal wall might give rise to difficulty in diagnosis. Especially when there was vomiting it was difficult to exclude an abdominal catastrophe. Haemoptysis was an occasional symptom. Cough was not noticeable immediately after the event but was often a troublesome feature after the lapse of twenty-four hours. The sputum was moderately thick, muco-purulent, and sometimes stained with dark blood. As a rule the cough and sputum disappeared within ten days unless complications ensued. Restlessness was often extreme and needed morphine for its control; it bore a direct relation to the severity of the damage. Ruptured ear-drum was frequent. In a patient whose lungs had been affected by blast, the chest was usually held in a position of three-quarters expansion, and the respiratory movement was limited. At first the percussion note was resonant in all areas and the breath sounds were weak especially at the bases. Coarse râles could usually be heard over the whole of the lung areas. Sometimes a clinically typical lobar pneumonia supervened, and reacted well to treatment by sulphapyridine. Radiograms of the chest taken within twenty-seven hours showed mottling over large areas of the lung-fields. This heavy mottling was the characteristic radiological appearance after severe blast injury. In severe non-fatal cases it cleared up rapidly *pari passu* with the clinical signs, and the translucency of the lung became normal within seven days.

O'Reilly and Gloyne summed up the diagnosis as follows: gross shock out of proportion to the degree of injury, pain in the chest, restlessness, dyspnoea and cyanosis are the main symptoms. Blood-stained sputum or free haemoptysis may be present. Bulging of the chest wall, poor respiratory excursion, normal percussion note with perhaps impairment in one locality, distant breath sounds in all zones and numerous coarse râles or sometimes rhonchi, are the main physical signs. In milder cases the degree of the symptoms is less, and restlessness and cyanosis may be absent. The physical signs are similarly less prominent, and added sounds are few or absent. X-ray appearances are characteristic. They resemble in some measure a patchy pneumonic consolidation to which they are histologically very similar.

Though both experimentally and clinically it was uncommon to find severe cerebral symptoms or lesions, yet Ascroft (1943) recorded a case in which a patient had severe blast injuries to the lungs and, at necropsy, an unexpected finding was a peculiar discoloration of large areas of the cerebral hemispheres, due to great numbers of minute haemorrhages confined to the grey matter of the cortex. In a series of 21 cases recorded by G. R. Fearnley (1945), 12 patients were unconscious for periods varying from a few minutes to several hours after the injury, but in no case were abnormal physical signs found in the central nervous system. Psychiatric symptoms sometimes followed exposure to blast (Anderson, 1942) but in these cases no conclusive proof was furnished that blast alone could cause injury to the brain.

UNDERWATER BLAST

The problem of underwater blast became prominent early in the war. Even in the War of 1914–18 it had been noted. In the middle of 1916 several cases of injury due to blast in water, resulting from an exploding mine or depth charge, were reported by medical officers in the Royal Navy. These cases presented the symptoms of haemoptysis, bloody diarrhoea, and haematuria. Most of the men felt as if they had been struck a violent blow on the immersed parts of the body and some became temporarily unconscious. As soon as that war was over, interest in the subject died.

In this war, the frequent dive-bombing attacks, and the continual sinking of ships by mines and torpedoes, often brought it about that the majority of a ship's company were in the water after a ship had sunk. When thereafter a depth-charge, mine or torpedo exploded there was grave danger of serious damage from underwater blast.

Many men were subjected to underwater blast while they were swimming in the water; in such cases the head and upper part of the chest were often partly out of the water and the force of the blast wave then fell directly upon the abdomen. The question of underwater blast was studied by Surgeon Commander E. R. P. Williams (1942) who pointed out that the effect of an explosion in water was not quite the same as in air, as the pressure-wave set up was not followed by a wave of mass movement, nor was there any appreciable suction-wave. The pressure-wave in water travelled at the same speed as at first in air (1,500 metres per second), but the velocity was constant and did not diminish as the centre of explosion receded. The rate of fall of pressure was much slower than in air and varied directly as the distance. The human body having roughly the same density as water, the blast wave was transmitted through the body's solid tissues without displacement but when it impinged on a gas-filled cavity in the body, e.g. the lungs or intestine, there might be a disruptive effect owing to the liberation of kinetic energy in the layers adjoining the cavity. This might lead to rupture of the lung-alveoli or capillaries, or of the intestines or small blood vessels in the gut.

To provide information as to the pathological lesions which might be expected in such cases, Professor Cameron, Major Short and Rear-Admiral Wakeley (1942) carried out experimental work, chiefly with goats, dogs and monkeys. Their work showed that the lesions produced by underwater blast were comparable to those found by Zuckerman in his air blast experiments.

When a 320-lb. charge of T.N.T. was exploded at a depth of 48 ft. in water of a depth of 90 ft. most of the animals within 40 yds. of the explosion were killed outright without any external signs of injury, apart from occasional bleeding from the nose. The chief lesions were pulmonary, and next in frequency were lesions of the alimentary tract. The heart, spleen, kidneys and ductless glands showed little or nothing abnormal. Pulmonary haemorrhage was not the only indication of serious damage, for in a number of animals death was instantaneous, yet the pulmonary lesions were not severe, while in other cases pulmonary lesions were very severe, yet the animals survived. The right lung was more frequently affected, and the bases of the lungs were less damaged than the upper lobes and margins. Hilar haemorrhages were found in 40 per cent. of animals. There was also emphysema, both interstitial and vesicular, affecting particularly the upper lobes of both lungs in the majority of animals within 40 yards of the explosion. Microscopically, the capillary and alveolar walls were damaged, but not to the degree required for the production of the haemorrhages, which were lobular in distribution. The larger haemorrhages were the result of confluence of small areas and although superficially resembling infarction were quite dissimilar, for in no case was the bleeding traced to rupture of a large vessel. There was little plasma in the haemorrhage, and Cameron suggested that a massive enforced diapedesis of red cells might account for this. In the abdomen the chief lesions were subserous haemorrhages in the gut and stomach. It was noteworthy that hollow viscera such as the gall bladder, urinary bladder and renal pelves, escaped injury even when these were partly distended with bile or urine. This was in striking contrast with the behaviour of air-containing viscera, which often showed damage.

BLAST ABDOMEN

Though undoubtedly the chief lesions caused by aerial blast were in the lungs, it was by no means uncommon for serious abdominal lesions to occur—a fact which was in keeping with Zuckerman's experimental findings. As mentioned above, the abdominal lesions were more likely to be prominent when an underwater blast wave struck anyone immersed or swimming in the water; if the person were floating on the back so that neither the abdomen nor the chest was directly opposed to the blast wave no serious injury was sustained.

The following account of the effect of underwater blast following the sinking of a ship in 1943 is extracted from an unpublished official journal of her medical officer, Lieut. Bulstrode, R.N.V.R. and gives many graphic details of value:

> Some one or two minutes after the ship had been abandoned, a heavy explosion occurred in the vicinity of the ship; this was thought to be due to a depth-charge exploding deep as there was little disturbance of the water. At this time no man was further than 25 yd. from the ship and some were very much nearer. About 125 officers and men left the ship but only 90 were picked up an hour later. These losses were undoubtedly due to the underwater explosion. Several men were killed outright and others were so seriously injured that they did not survive for an hour.
>
> Men who had been swimming strongly, or holding on to rafts, sank immediately. Of those who were picked up, many had vomited or coughed up blood and several were passing blood per rectum. The extent of a man's injuries did not depend on the direction in which he was facing but rather upon whether he was swimming, i.e. comparatively horizontal in the water, or floating vertically; in the latter case the more severe injuries were seen. Despite this, some who were holding on to rafts were uninjured, while others who were swimming further away were badly blasted. The sensation produced by the explosion was likened to a kick in the stomach by a mule or being gripped in a vice. Before the explosion all were cheerful, as there was every chance of being picked up in a short while, but afterwards a feeling of extreme lassitude and exhaustion was observed, and most felt that it was an effort to keep one's head above water and that one did not care very much if one died.

In an investigation of a series of cases affected by underwater blast, Goligher (1943) concluded that the maximal injurious range for man of a charge exploding at depth was about 20 yards. The main lesions were in the abdomen, but blast lung was also sometimes seen. The main features in the abdomen were mainly confined to the alimentary tract, and consisted either of intramural haemorrhages or perforation of the intestine. The bleeding occurred in both subperitoneal and submucous layers, was usually widespread and, though the colon and stomach were sometimes affected, it chiefly involved the small intestine. The areas of haemorrhage were usually multiple, rounded or irregular in shape and varied in size—an average being a diameter of $\frac{3}{4}$ in. Perforations occurred chiefly in the small gut. It was common also to find a retro-peritoneal haemorrhage into the loose areolar tissue behind the right colic flexure without any accompanying injury to the colon.

Surgeon Rear Admiral Wakeley (1943) who saw as many as 80 cases of abdominal injury due to underwater blast, and actually operated on about 20, found that the clinical symptoms varied greatly according to the distance from the explosion, the nature of the explosion, and the position of the man in the water. At operation a constant finding was that of retroperitoneal and subserous haemorrhage. The gut lesions varied from intramural haemorrhages to actual laceration of the intestinal wall. In his experience the large bowel was affected more often than the stomach or small bowel. Moreover he found that the solid viscera were not immune from the effects of blast. In several cases he found lacerations of the liver, sometimes serious and accompanied by severe haemorrhage; these cases showed upper abdominal rigidity. Tears in the caecum were usually on the outer (lateral) aspect, and there was a tendency for infection to be localised as in some cases of rupture of the appendix.

Many of those subjected to severe underwater blast died at once, or soon after, from shock and severe haemorrhage. In those who survived, the clinical picture was dominated by the symptoms and signs due to the abdominal injury. The chief symptom was abdominal pain, which usually came on suddenly at the time of the explosion, and, as previously mentioned, was likened to that attending a kick in the abdomen. Usually, the acuteness of the pain subsided after a while, but recurred with increased intensity a little later. Nausea and vomiting occurred and an urgent desire to defaecate was often noted. In cases attended by perforation there was usually considerable shock and a raised pulse-rate. Examination revealed diffuse tenderness and board-like rigidity of the abdominal wall, which was not diminished by the administration of morphine. Occasionally, the tenderness and rigidity were limited to the lower abdomen. When there was no perforation, there was often abdominal tenderness, usually in the lower abdomen and often in one or other iliac fossa, but the abdominal wall, though showing a 'guarding' muscular reaction, never presented a board-like rigidity. In non-perforating injuries the giving of morphine caused a rapid improvement in the symptoms; in these cases the pulse-rate was not raised, unless there were associated injuries to the lungs. Occasionally, the rectum might be perforated and bright red blood escape from the anus (Martin, 1943a).

From a case reported by Martin (1943b) it would appear likely that subperitoneal haemorrhage, at the site of a perforation of most of the coats of the gut, may later burst through into the peritoneal cavity. The account of this remarkable case was as follows:

> A rating clad in shorts and shirt, and wearing a life jacket, was swimming away from the sinking ship, and, when about twenty yards from the wreck one of the depth charges exploded. He said he felt as if he had stopped a football in the stomach and he was winded for probably half a minute after which he had a feeling of numbness in the abdomen but no pain. He swam about in the water strongly and moved his legs normally for four and a half hours, when he was picked up by another minesweeper. He was rubbed down and given a cup of tea, which he enjoyed, but

this he vomited ten minutes later. He had swallowed a good deal of fuel oil and he continued vomiting for about an hour, but apart from the straining of the vomiting he had no abdominal pain. He was landed and walked to an ambulance in which about half an hour later, and just before arrival at the hospital (i.e. six and a half hours after the injury), he was seized with a sudden acute central abdominal pain, which persisted until relieved by morphine. He was quite definite that morphine relieved the pain. Laparotomy was performed and five perforations of the ileum were sutured. Recovery took place after a somewhat stormy convalescence with a pelvic abscess.

It is of course possible that the late onset of symptoms in this case was due to temporary inhibition of the movement of the ruptured segment of intestine.

The difficulty in diagnosis of serious abdominal lesions owing to latency of symptoms had its counterpart in the occasional presence of abdominal symptoms in lesions confined to the chest. O'Reilly and Gloyne (1941) recorded two cases in which abdominal pain, tenderness and muscular rigidity led to exploration of the abdomen in which the only lesions found were slight subserous haemorrhages; they attributed the abdominal symptoms to irritation of the intercostal nerves by haemorrhages which were found in the intercostal spaces of those cases which came to necropsy. Extreme care was however necessary in excluding an abdominal lesion, and in general, persisting and extreme rigidity of the abdomen, unless accompanied by obviously serious chest lesions, was an indication for early exploration of the abdomen.

TREATMENT OF BLAST INJURIES

Nearly every patient with severe blast injury suffered from severe shock. Morphine was needed to control restlessness, but great judgment was required with regard to the giving of transfusion, for in cases of severe injury to the lung harm might result from injudicious transfusion. To such an extent was this true that in some cases of congestion of the lungs venesection rather than transfusion of blood was required (O'Reilly and Gloyne). If fluid were needed, plasma was then preferable to blood.

Since there was always the possibility of the supervention of pneumonia the prophylactic giving of sulphapyridine was recommended.

For the dyspnoea the administration of oxygen was useful. B. L. B. masks were very useful, and failing that, nasal catheters or spectacles.

The decision as to when it was necessary to open the abdomen for suspected rupture of intestine was often very difficult. Injury to the chest often caused abdominal-wall rigidity, and muscle-guarding also resulted both from contusion of the abdominal wall or reflexly from retroperitoneal haemorrhage. Vomiting occurred, sometimes even when there was no perforation, but in general, if abdominal pain and vomiting persisted and the abdominal wall remained rigid, then, in the absence of pulmonary lesions, exploratory abdominal section was required. The mistake was sometimes made of thinking that there could be no perforation because the pulse-rate remained approximately normal. At operation any intestinal tear needed to be sutured, or in cases of severe laceration, it might be necessary to resect. When the liver was lacerated, the diathermic cautery might stop the bleeding, but sometimes plugging was necessary. In one case Wakeley stopped the bleeding from two rents in the liver by plugging them with muscle grafts taken from the rectus muscle.

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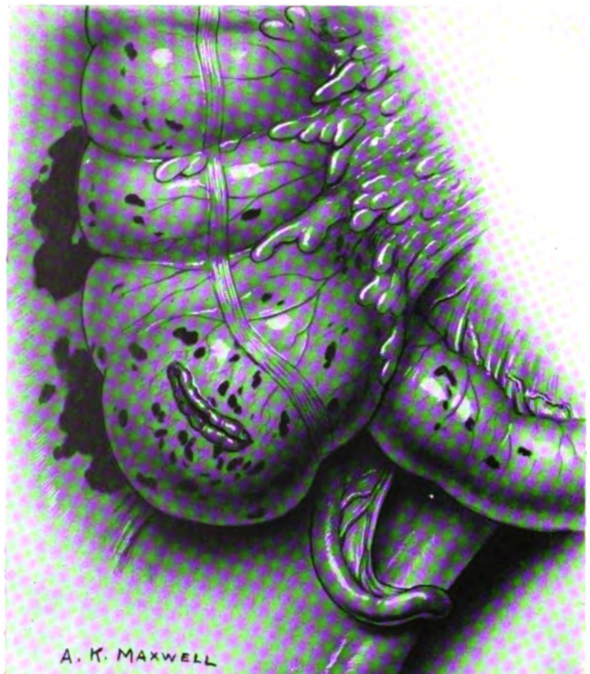
(See also Chapter 11, part (i) in the Medical Research Volume of this Series.)

(ii)

Abdominal Injuries due to Underwater Explosion (Immersion Blast)

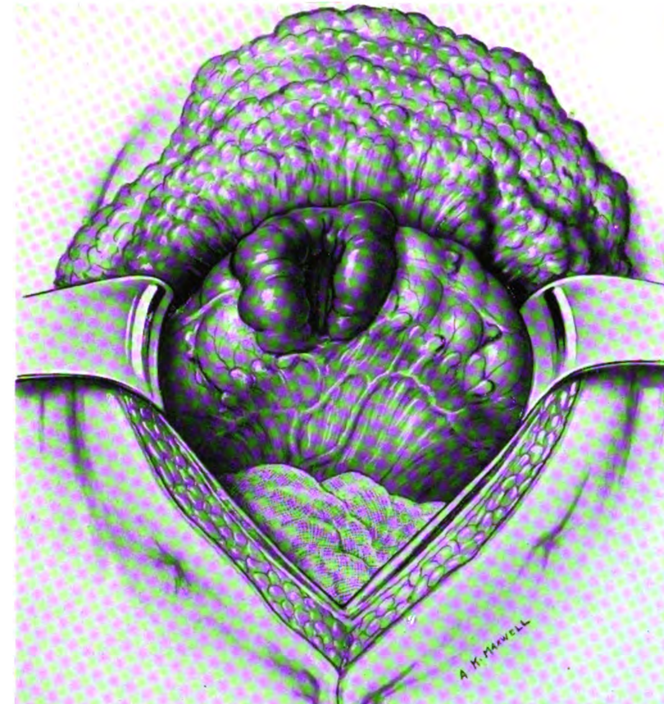
By Sir GORDON GORDON-TAYLOR
K.B.E., C.B., M.S., F.R.C.S.

Immersion blast was an almost unknown and certainly an unsolved surgical problem until the War of 1939–45, although it had claimed the attention of Fleet Surgeon W. E. Mathew, R.N. in 1917 during the First World War, and two operations had indeed been performed in 1918 for abdominal injuries due to this mechanism by Surgeon Lieutenant, (now Sir Cecil) Wakeley in H.M. Hospital Ship *Garth Castle*. The condition is peculiar to sea warfare and not inappropriately the most complete and exhaustive accounts have emanated from surgeons of the Royal Navy, particularly from Surgeon Rear Admiral Sir Cecil Wakeley, and from Surgeon Commander Rex Williams, the latter delivering a Hunterian Lecture on the subject.



Glasgow Medical Journal

PLATE I. Blast injury to caecum. Multiple retroperitoneal hæmorrhages.



Glasgow Medical Journal

PLATE II. Rupture of transverse colon due to blast.

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Despite the naval flavour of its name and environment, many victims were perforce landed at shore establishments of other Services and treated by surgeons of the Royal Army Medical Corps and the Royal Air Force.

In the first months of the Second World War, Surgeon-Captain D. H. Kernohan, R.N., drew the attention of the writer to four cases of immersion blast, landed at a naval hospital on the east coast of England, in one of whom a mass gradually developed in the right iliac fossa: an abscess formed behind the caecum and was opened, a faecal fistula resulting which closed spontaneously. A few months later, at the time of the Dunkirk evacuation, several more of these cases, far more severe in character, were seen by the writer in hospitals of various ports; some of these died after operation, but certain patients with severe injuries survived, notably those operated upon by Lieut. Colonel Hedley Atkins, Major Kark, R.S.A.M.C., Lieut. Colonel Ralph Coyte, and by Lieut. Colonel Wilfred C. Barber. Subsequently other cases were reported in communications by Breden, d'Abreu and King; Gill and Hay; Pinnock and Paul Wood; by Goligher, King and Simmons, and in the last years of the Armageddon by American naval surgeons. The exhaustive and well-illustrated contributions of Wakeley have already been mentioned and to these the reader is specially referred.

During the progress of the war thousands of shipwrecked men and women were exposed to blast from underwater explosion, and the mortality remained high throughout; many were killed instantaneously or shortly after the explosion and their bodies were not recovered nor rarely examined. The fatality and the severity of the injuries produced were related to the compressing force of the blast-wave, the distance of the victim from the explosion, his position in the water at the moment of exposure and the presence or absence of some protection, such as a Mae West, Kapok, etc. In one incident in which 24 men were involved 5 were killed outright; of the survivors, the moribund condition of two who were picked up precluded any surgery, and of the 7 who were submitted to operation for bowel perforation 4 succumbed, the total mortality being 11 out of the 24.

A description of personal experiences by two naval surgeons may not be without interest:

When swimming away from the sinking ship, the survivors suffered from the effects of the detonations of the ship's depth charges which exploded as she sank. The sensation was as of a violent blow in the back which knocked the wind out of me, and I lost the use of my legs for a few moments. I saw several men 'give up' and sink; other survivors described similar sensations to mine. We were picked up after two hours in the water and warmed up for about three hours in the engine-room of the rescuing ship. During this time I saw the other survivors professionally, some of whom were burnt or otherwise injured, but whose condition at that time gave rise to no concern; a few complained of vague abdominal pain immediately after being picked up.

At the end of about three hours I was seized with violent colicky pain in the abdomen; the spasms continued at intervals of a few minutes throughout that night and also the succeeding twenty-four hours. The pain was accompanied by copious vomiting, at first of oil fuel and food, later of large quantities of bile-stained fluid streaked with blood: the vomiting was effortless and not distressing.

A similar clinical picture was presented by all the survivors within two hours of the advent of my own symptoms. The severity varied from slight colicky pain and a single act of vomiting to a degree of severity such as has been indicated in my own case. An enema produced a good result in my own case and in three other cases who complained of severe pain.

When morphine was available on the third day after the incident, it acted beneficially with myself; the rating's symptoms continued for three more days, during which he was kept in the Fowler position and on frequent morphine till the ship reached port, when he was operated on, found to have severe peritonitis, but recovered. The paymaster died the third day after the incident, doubtless due to peritonitis from a rupture of the bowel.

A second personal narrative was the following:

After approximately twenty minutes in the water, the ship having disappeared, while I was swimming around collecting the men into groups, there was a sudden explosion estimated at 100 to 150 yds. away and definitely caused by an enemy torpedo which exploded at the end of its run . . . I found that everything had gone numb from the waist down, and I could not raise my legs. This condition lasted for an hour, then came a tingling sensation like that of 'pins and needles', until the movements of my legs became more or less normal again. I could not climb aboard H.M. destroyer that picked me up, so was hauled up on a rope's end and helped down to the washroom; but thinking of the lads still left in the sea I went back on deck and did what I could to assist.

The excitement probably took my thoughts off myself, for I cannot remember feeling any further effects until after landing and going to bed at the hotel, when severe griping pains started, and were particularly felt on passing my motions. The bowels were open at least seven or eight times a day, and it was then that I first saw that blood of a normal colour was being passed. The evacuation of blood persisted for a week, but the loose motions and pain continued for a month, and then gradually diminished.

PATHOLOGY

Intra-abdominal damage from underwater explosion as disclosed at operation, at autopsy or by means of experimental methods was characterised by numerous visceral, mesenteric and retroperitoneal haemorrhages with or without single or multiple perforations of the intestinal tract. Of these lesions perhaps the most frequently encountered were retroperitoneal and subserous haemorrhages.

Haemorrhages may occur as (*a*) scattered punctiform lesions beneath the serous coat of the bowel, more especially the caecum and terminal ileum, but the pelvic colon and other parts of the gut are not immune; (*b*) an annular distribution of petechiae or bands of haemorrhage of varying width arranged in transverse rings round segments of the gut. The annular haemorrhagic bands were often associated with clots within the lumen of the bowel; these clots might project in polyp-like fashion into the bowel and might even be sufficiently large to obstruct the lumen.

As a rule the haemorrhages were most frequent on the anti-mesenteric border of the intestine and were essentially mucosal in origin; in only the more severe cases were the submucosa and muscularis implicated, and in these victims perforation might be a primary or a late phenomenon. (Plate I and Plate I, Chapter 4.)

No anatomical explanation for the precise distribution of the haemorrhagic lesions was forthcoming; furthermore the suggestion of a possible relationship between the site of the lesions and the presence of hard faeces in the large intestine suggested by some observers (Friedell and Eckland) found no confirmation in the work of Wakeley and his colleagues. Moreover, bands of haemorrhage were often seen in the small gut, where the contents were fluid.

Haemorrhages of every size and shape were found in the mesentery; in experimental lesions the mesentery was more frequently involved when the abdomen alone was immersed than when both chest and abdomen were submerged. In one case thrombosis of the mesenteric vessels following an incident (Pinnock and Wood) determined gangrene of a considerable length of bowel, the case terminating fatally.

Anterior abdominal wall. In most of the victims there was no sign of injury to the anterior abdominal wall, but in a few the peritoneal surface was purplish-black from extravasated blood in the subserous and rarely in the muscular layers, and the extravasation might extend round to the perinephric areas.

Perforations involved a tear through all the tunics of the bowel; they were oval and situated at the bottom of linear tears through the mucous membrane and submucosa disposed at right angles to the longitudinal axis of the gut. Through the gap the ragged torn ends of the mucosa might prolapse; sometimes the perforation was partly closed by the formation of a small blood-clot in it, sometimes the clot might be moulded to the aperture, even project into the coelom beyond the intestinal serosa. On the other hand, bowel contents escaped into the abdominal cavity more tardily from the small gut than from the large. The aperture might also permit the effusion of blood into the coelom and as much as 2,500 cc. of fluid blood might be extravasated from within the bowel lumen into the pelvic cavity.

As in the case of the haemorrhages already mentioned, those portions of the small and large gut which occupy the lower and less protected region of the belly were those where perforation was most frequently found; the caecum and terminal ileum were the reaches of the intestinal tract which most frequently displayed perforations, but the transverse colon, pelvic colon, hepatic flexure and duodenum displayed on rare occasion this catastrophic lesion.

The special proclivity of the large gut to suffer perforation may have been due to the fact that the effects of blast are more severe in air-filled cavities, and doubtless it is not without some import that the large intestine does not possess the uniformly disposed musculature that characterises the jejuno-ileum (Plate II).

Perforations of the gut as disclosed at operation or autopsy might be single or multiple: in Moore's series of 8 cases where laparotomy revealed a perforation, in 4 this was a single ileal perforation; in Wakeley's series of 16 cases of perforated gut revealed at operation, in 11 there was a solitary perforation, but others had 4 or 5 lacerations. The ileum was perforated in 7 out of Moore's 8 cases, either alone or in association with a large intestine rupture; in Wakeley's 16 cases of bowel perforation, the caecum (9 times) was the portion of the intestinal tract most frequently damaged, and the large gut in no fewer than 12 cases (75 per cent.).

Solid viscera have also been injured in those exposed to under-water explosion; liver, testicles, pancreas, suprarenals, kidney. Haemorrhage into the tunica albuginea of the testis was not infrequent, and the pancreas underwent rupture in a case reported by Air Vice Marshal Geoffrey Keynes.

The gall-bladder and urinary bladder were seldom affected.

Some have suggested that air embolism follows acute disruption of the pulmonary capillaries and materially contributes to early death (Gouze and Hayter), but Wakeley and his co-workers found no evidence of air embolism in their experimental studies.

SYMPTOMS

The onset is most frequently characterised by a sharp pain in the back at the moment of the explosion; some victims described it as a 'sharp kick', others a 'sudden electric shock', while yet others compared it to a string tied round their waist and suddenly tightened. Other descriptions likened the blow to a 'kick in the stomach', and one felt it as a blow on the back of the pelvis. This dramatic initial symptom is probably due to spinal concussion and is often followed by paralysis of the legs, which gradually passes off. By only one was complaint made of a sensation of water rushing up his rectum and urethra. Some were unconscious or stunned; one exhibited immediate psychogenic symptoms, which were transient.

The clinical picture of 'Immersion Blast' varies in degree of severity and perhaps six clinical types may be recognised.

(*a*) *The mildest cases* suffer from abdominal pain which commences a variable time after the initial sensation of a stupendous blow; some degree of resistance to palpation of the abdominal wall and a varying amount of associated tenderness are also present. The pulse may be slightly raised, although most observers commented on its unaltered rate; slight abdominal distension and very slight elevation of temperature sometimes ensue. All these phenomena have subsided in 48 to 96 hours in these mild cases, and convalescence is speedily established.

In another series of mild type, colicky abdominal pain associated with vomiting and frequent bowel evacuations precede the period of meteorism.

Far the most frequent lesions encountered at operation are retroperitoneal haemorrhages; the clinical picture produced by these may be severe enough to simulate a perforation.

(*b*) *A more severe variety.* In addition to the above clinical phenomena blood is evacuated from the bowel, and haematuria may also be present; on rare occasions haemorrhage from the nose and ears has occurred. The blood from the rectum is usually bright, and submucous haemorrhages may be seen through a sigmoidoscope; at other times, the blood is dark and tarry, and doubtless comes from haemorrhages in the tunics of the colonic wall. Bleeding from the bowel occurs more often in those whose abdomen alone has been immersed than when the thorax is immersed as well.

(*c*) *Contusion and Secondary Abscess.* Lieut. Colonel d'Abreu and his colleagues specially emphasise that in their cases of pelvic abscess and subphrenic abscess, opened about the eleventh day after the incident, the pulse was always under 100, the temperature never over 100°, and the white-cell count never exceeded 14,000. In other victims an extra-caecal or extra-colic abscess developed (vide Kernohan's case): surgical evacuation of the purulent collection may lead to a fistula, which usually closes spontaneously. In these cases the contused bowel permits the permeation of micro-organisms through its damaged tunics.

(*d*) *The classical type where perforation of the intestine takes place at the time of injury.* The perforation is invariably associated with other lesions, such as subserous, mesenteric or retroperitoneal haemorrhages. The intestinal rupture may be single or multiple and may involve small and large bowel separately or together.

This group exhibits a very severe degree of shock, and diagnosis may not be easy when there is the added possibility of a blast injury to the thorax. The rigidity of the abdomen is well marked, but the pulse and facial appearance of the victim may be such as to lull disastrously the observer's apprehensions. Testicular pain is not infrequent, but is not diagnostic of a perforating intestinal lesion; it is due to the presence of small haemorrhages under the tunica albuginea (Wakeley, Breden, d'Abreu and King), and such haemorrhages have been produced experimentally.

(*e*) *Cases of Secondary Intestinal Perforation or Secondary Peritonitis.* These cases exhibit the early signs of injury to the alimentary canal, such as those described in (*a*) and (*b*); then, after a period of time which varies from sixteen hours after the 'incident' (Gill and Hay) to ten days (Wakeley), signs of intra-abdominal catastrophe suddenly make their appearance. These cases for the most part do badly.

Somewhat allied clinically are those cases where urgent symptoms compel a late laparotomy; diffuse peritonitis is present, but no perforation is found. Such cases may be due to the permeation of organisms from within the lumen of the gut through the damaged bowel wall, or there may be some perforation which defies identification. This type, so far as aetiology is concerned, is comparable with the more favourable localised type described under (*c*).

(*f*) *The most severe form where the initial shock is so great that death instantaneously or rapidly follows.*

Such patients are rarely rescued from the water; they are doubtless the victims of rupture of abdominal viscera and severe internal haemorrhage; many have probably additional injuries to the lungs and even the brain.

DIAGNOSIS OF BLAST INJURY OF THE ABDOMEN

Clinical phenomena and experimental methods confirm the frequency of the involvement of thorax and abdomen and very occasionally the head, although the severity of the injury may be felt very unequally by the viscera in the respective cavities.

(1) When the clinical signs are confined to the upper abdomen the *probability of a thoracic cause is very considerable*. (2) When the clinical signs, at first confined to the upper abdomen, spread downwards to the lower belly, an *abdominal lesion is certain*. (3) When the clinical signs are from the first most marked in the lower abdomen, there can be *little doubt of intraperitoneal damage*. Testicular pain is not infrequent, but is not itself an indication for surgery.

INDICATIONS FOR LAPAROTOMY

The following symptoms and signs, especially if present together, suggest the desirability of surgical exploration:

(i) severe, unremitting, and especially increasing abdominal pain;
(ii) tenderness of the lower abdomen, particularly when there is accompanying melaena;
(iii) frequent bowel evacuations and difficulty in micturition.

Too much reliance should not be placed on the pulse-rate which may even fall despite the existence of grave intestinal lesions.

The more severe the injury, the clearer are usually the indications for laparotomy. Where the clinical picture is less dramatically clear, secondary perforation may sometimes supervene disastrously.

The appropriate treatment is more readily apparent in those cases which come under the surgeon's notice late than in those who reach him in the early hours after an incident.

The sagacity of Lieut. Colonel T. Moore, who was confronted during the North African Campaign with 18 cases brought ashore between 16 and 20 hours after an incident, was shown by the fact that in the 8 cases in which a perforation of the bowel was forecast the diagnosis was duly confirmed at operation, while the ninth laparotomy rectified the diagnosis of a severe retroperitoneal haematoma.

If these cases are seen *after twenty-four hours* from the time of exposure to under-water explosion, a conservative attitude should be adopted: thus only two cases out of ten seriously injured men treated expectantly developed an abdominal abscess, and neither case demanded urgent surgery. Gage admitted 23 seriously injured men thirty-six hours after an incident, of whom 5 were moribund; of the remaining 18, who were treated by food-abstinence, morphine, intravenous fluids and gastric suction, 9 developed abdominal masses, of whom only 3 required drainage of an abscess. Palma and Uldall admitted 14 survivors five days after an incident presenting signs and symptoms of severe abdominal injury; two out of six recovered after surgical intervention.

The possibility of a late perforaton of the intestine from the sixth to tenth day must never be forgotten.

ANAESTHESIA

In choice of anaesthetic, the probability of a concomitant blast injury of the lung must not be forgotten, and ether should be avoided. Intravenous anaesthesia and regional methods are best, but may have to be supplemented.

PROPHYLAXIS

There is no doubt from experimental and clinical observation that protection to thorax and abdomen with suitable buoyant material can be achieved.

Victims of shipwreck who are in the water in the vicinity of depth-charges should be instructed to swim on their backs; the greater the distance from the explosion, the less severe are the effects likely to be, and those with their backs directed towards the explosion will suffer less than when the front of the belly faces it.

LATE COMPLICATIONS OR PERSISTENCE OF SYMPTOMS

The abdominal pain has on occasion persisted for three months and in a few cases melaena has lasted for an even longer time. Of 32 survivors who were sigmoidoscoped several months after the incident, only two showed any abnormality: some scattered petechiae were seen high up in the rectal and lower sigmoid wall, but subsequent inspection a month later showed that these had disappeared. In other isolated cases, however, petechiae in the rectal mucosa have been observed much later.

It would appear that survivors who recover from 'immersion blast' very rarely suffer any permanent effects although a few have had their convalescence interrupted by such complications as volvulus, disruption of the abdominal incision, etc.

(See also Chapter 11, part (ii), in the Medical Research Volume of this series.)

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CHAPTER 19

CRUSH SYNDROME

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1ST PERIOD, 1940 TO 1941

FORMATION AND DEVELOPMENT OF THE NOSOLOGICAL CONCEPT

THE conception of 'crush syndrome' as a distinct entity took place in September 1940 during the early part of the big 1940–1 air-raid attacks on London. It was developed mainly as a result of observations made at the British Postgraduate Medical School, where, during the spring and summer of 1940 the staff had already started to familiarise themselves with the problem of shock, both clinically and by research on various aspects of blood-loss and replacement, in patients suffering from haematemesis or the results of accident.[1] [2] In addition the English, American and French literature on 'shock' dating from the last war had been studied, together with the later investigations on the subject, mainly American, dating from Blalock, 1927,[3] onwards. No one seemed at this time to have consulted the German literature on the subject. When the 'blitz' started, although casualties were far fewer than had been anticipated, yet many of the more centrally situated London hospitals were inundated with casualties: patients were taken to the nearest hospital, whereas other hospitals only slightly further from the incident had nothing to do. As a consequence, observations on these early air-raid casualties were extremely sketchy except from those hospitals so situated that only a moderate number of casualties were admitted, mainly on the outskirts of London. Most of the early data of any value were collected either by workers on 'shock' especially detailed by the Medical Research Council (Grant and his colleagues at Guy's, Pochin at University College Hospital, and McMichael and his colleagues at the British Postgraduate Medical School), or by blood transfusion officers under the Emergency Medical Services scheme (Miles, Gavey, Solandt). Later this situation was remedied by establishing quotas for each hospital; after the fixed number of casualties had been admitted to a particular hospital, the remainder were switched over to a neighbouring hospital. By this better distribution of the patients, both therapeutic and research conditions were improved.

The British Postgraduate Medical School and the adjoining Hammersmith Hospital are rather more isolated from main roads and built-up areas than the neighbouring hospitals, and thus it happened that the first batch of air-raid casualties received on September 16, 1940 was relatively few (14 in all) and it was possible to make detailed observations on many of them. Furthermore, as hospitals nearer the incident became full, casualties recovered later from among the fallen débris were sent to Hammersmith. Thus, as well as the usual cases of fright, abrasions, laceration and fracture admitted soon after the incident, there arrived later four patients who had been buried for many hours before release. Two of them, buried for thirteen and twenty-four hours respectively, died rather mysteriously, despite transfusion, within the first few hours; the two others, buried for eight and twelve hours, died on the fourth and eighth day. The first admitted of these was a young man with little in the way of external injuries and a rather high blood pressure (140 mm. Hg.). As he was not considered to be shocked, he was sent directly to the surgical receiving ward. The resuscitation team concentrated on other injuries of a more ordinary type, but in the afternoon were called to see this young man who had fainted on getting out of bed. His blood pressure had fallen to an extremely low level (40 mm. Hg.) and his blood was concentrated (Hb. 19·3 g. per cent.). This was thought to be an example of the classical shock following trauma, which had been described in the writings from the last war in which haemoconcentration had been repeatedly stressed. He responded well to plasma transfusion so far as the circulation was concerned, but on the next day the compressed limb became ischaemic with impending gangrene, apparently as a consequence of a tight oedema. It was noted that the urinary output was poor, but when he died in anuria this was simply ascribed to shock. At post-mortem examination by the coroner's pathologist the kidneys showed no very gross lesion and were actually discarded when taking material for section, but it was noted that the muscles were oedematous and necrotic. A second case from the same incident ran a similar course, dying four days after the first case with a blood urea of 345 mg. per cent. and potassium 33 mg. per cent.; it was observed that the scanty urine was bloodstained. At post-mortem, muscle necrosis was found and the kidneys microscopically showed changes resembling those of a mismatched transfusion. These are Nos. III and IV of the article by Bywaters and Beall.[4] Perplexity and doubts on this unfamiliar clinical sequence led to inquiries among other hospitals as to whether anyone else had had any similar experience. Miss Margaret Louden of the South London Hospital for Women stated that she had seen similar patients who had no external injury and who died with oliguria, what urine was passed being like 'lysol'. In an effort to get others to communicate their experiences McMichael and Douglas wrote a letter to the *British Medical Journal*,[5] describing briefly the first case. No information was forthcoming as a result of this. At the Postgraduate School, plans were made to deal in greater detail with any further cases which might occur. The similarity of the clinical and biochemical findings of the pathological changes in kidney and muscle to those already observed in the first two cases suggested a clearly defined clinical and pathological entity, although the mechanism of its production was yet far from clear (Plates I and II).

Much difficulty was experienced at this time in obtaining permission to perform necropsies, as it was uncertain whether the bodies came under the coroner's direction or whether permission from the relatives had to be obtained—often a lengthy process and sometimes, with unidentified bodies or if all relatives had been killed, quite impossible. In one instance of crushing injury in January 1941 a necropsy was performed with encouragement from the Ministry of Home Security, but without relatives' or coroner's permission, a procedure which caused much distress to the hospital authorities. It later emerged that although the bodies were the concern of the coroner, yet permission to perform a post-mortem examination could not be granted by him, but had to be obtained from the nearest relative. It is undeniably true that this early confusion, the practical difficulties and the later ruling were responsible for the loss of many excellent opportunities for investigations; many workers felt that the great need for more exact knowledge of such war wounds would have warranted a more helpful attitude on the part of the authorities concerned.

The first communications on the subject were to the Medical Research Society in December 1940 and February 1941 by workers from the British Postgraduate Medical School. From the discussion on these communications, it became evident that no nomenclature could be agreed upon without further knowledge of aetiology; the term 'crush syndrome', proposed by the Hammersmith workers because they felt that the syndrome was intimately connected with crushing by heavy masonry, was thought by some open to objection on the grounds that one case at least, though inadequately recorded, appeared to follow multiple lacerations rather than prolonged crushing injury. The term 'lesion of multiple injury' was propounded, and other proposals ranged between 'traumatic oedema', 'traumatic anuria', 'post-traumatic uraemia' and 'compression syndrome'.

When the early case-notes were first presented to the Medical Research Council, rather more interest was taken in the fact that the patients had shown haemoconcentration and traumatic oedema than in the renal death. A sub-committee of the M.R.C. Shock Committee was established to study this matter under the title of 'Traumatic Oedema Sub-Committee'. It held its first meeting on December 30, 1940. Senior surgeons from various parts of the country were asked if they had ever had any experience of the condition, for example in mining accidents, but they were sure they had never seen the syndrome. When the details of the morbid histology were discussed, some pathological experts thought they were non-specific and took the very conservative line that the syndrome might not be of any special importance. In the early part of 1941, however, a striking instance of the syndrome occurred in a central hospital not far from Whitehall, which was demonstrated to the senior surgical administrators of the sub-committee. Thereafter it was agreed to publish a circular as soon as possible so that the salient features of the syndrome might become better known, since it was obvious at this time that the gravity of the illness which developed in a patient who had been compressed under wreckage was not generally appreciated by the profession. In the less well-equipped hospitals it was found that cases were nearly always overlooked for the same reason as the first two cases were missed in Hammersmith Hospital. After an incident, a large number of casualties requiring immediate surgical attention were admitted to hospital, keeping the staff fully occupied for many hours. Following this first wave of admissions there was an interval in which the buried were dug out; these arrived in hospital several hours later, were quickly looked at by the staff who noted that, though crushed there were no external injuries requiring operation, and were left to be dealt with by the nursing staff (morphine and heat). A transfusion might perhaps be given for shock or on the rare occasions that the blood pressure was taken and found to be low, but it was only after a day or two that the oliguria compelled attention and sometimes it was only the vomiting of terminal uraemia which aroused anxiety.

At the second meeting of the sub-committee on February 28, 1941, it was decided to publish six cases which had been fully observed together with any other case-reports which should be received by the sub-committee. Thus, 16 clinical case-records appeared in the *British Medical Journal.* [4] [6] [7] [8] Bratton,[9] in the *Lancet* had also recorded briefly a case coming to post-mortem with pathological changes in the kidneys similar to those found in a series of 10 cases of septic abortion. Most of these first 17 recorded cases had occurred singly in various hospitals; it was the alertness and willingness of the various observers to contribute data that enabled the M.R.C. to present at this comparatively early period of the 'blitz', a reasonably well-rounded picture of the condition, since any single case recorded by itself would have been more mystifying than helpful. The injury as seen in these first 16 cases was described thus:

> The patient has been buried for several hours with pressure on a limb. On admission he looks in good condition except for swelling of the limb, some local anaesthesia, and whealing. The haemoglobin, however, is raised, and a few hours later, despite vaso-constriction, made manifest by pallor, coldness and sweating, the blood pressure falls. This is restored to pre-shock level by (often multiple) transfusions of serum, plasma, or, occasionally, blood. Anxiety may now arise concerning the circulation in the injured limb, which may show diminution of arterial pulsation distally, accompanied by all the changes of incipient gangrene. Signs of renal damage soon appear and progress, even though the crushed limb be amputated. The urinary output, initially small, owing perhaps to the severity of the shock, diminishes further. The urine contains albumen and many dark-brown or black granular casts. These later decrease in number. The patient is alternately drowsy and anxiously aware of the severity of his illness. Slight generalised oedema, thirst and incessant vomiting develop, and the blood-pressure often remains slightly raised. The blood urea and potassium, raised at an early stage, become progressively higher, and death occurs comparatively suddenly, frequently within a week. Necropsy reveals necrosis of muscle and, in the renal tubules, degenerative changes and casts containing brown pigment. (Bywaters and Beall, 1941.)[4]

Recovery occurred in 5 cases of the series with a diuresis on the fifth to eighth day and, in one case, almost complete return of normal renal function, judged by the clearance of urea. Muscle necrosis was the one aetiological factor common to the cases at the British Postgraduate Medical School and to those competently observed elsewhere. (Claims that muscle was not involved were based mainly on inadequate examination.) In view of the similarity of the kidney changes to those following mismatched transfusions, the rôle of transfusion fluids was discussed; 9 cases had had plasma and serum, 4 cases had had blood, and 2 had received neither. But there was no evidence, even in those that had had plasma and blood, of transfusion reaction, and plasma samples taken at 17½ and 40 hours after transfusion showed no increased colour. Moreover, no such condition occurred in any of 25 shocked and injured patients without severe muscle-crush treated by blood or serum transfusion. It was suggested that the pigment found histologically in the renal tubules might possibly be bile pigment, haemoglobin or myohaemoglobin. (Bywaters and Beall, 1941.)[4]

The last-named possibility, suggested by the blanched appearance of necrotic muscle at post-mortem examination was also emphasised by Gilmour, 1941,[10] citing the similarity to paralytic equine myohaemoglobinuria, and had been proposed as long ago as 1923 by Minami,[11] (as was pointed out by Bywaters[12] in July 1941, when the temporary cessation of large-scale air attacks had made available enough leisure to study the German literature of the last war). This condition, thought originally by Bywaters and Beall to be a 'hitherto unreported condition', was first described by Frankenthal in 1916[13]; he cited three buried cases, two of these released after six hours, with multiple lesions such as pancreatic necrosis, fractures and ruptured viscera, together with ischaemic necrosis of muscle and enlarged kidneys (1 case); later (1918),[14] he briefly reviewed 30 cases and in the same year Kuttner[15] reviewed the whole subject pointing out that this condition did not occur before the 'bomb' phase of the war. He described 7 cases well and referred to similar cases of muscle-necrosis due to prolonged pressure occurring in the Messina earthquake of 1909, studied by Von Colmers.[16] Wieting,[17] in 1918, described a case with incipient gangrene treated by multiple incisions. Thereafter several authors studied the condition and were adequately reviewed in 1923 by Minami,[11] who published the most complete of these early accounts based on three original cases, as well as three previously described by Bredauer[18] and one by Hackradt.[19] This was the last paper published on the subject until the War of 1939–45. While Minami suggested the possibility of myohaemoglobinuria, whose spectroscopic absorption bands had just been differentiated from those of haemoglobin by Gunther (1921),[20] he had no further opportunity of verifying this hypothesis.

It is worth noting that while the Germans devoted a section to the subject with 126 cases in the official *Handbuch der ärztlichen Erfahrungen im Weltkriege*, [Kayser, 1922,[21]] none of six English books on war surgery published in 1918 and 1919 mentioned its occurrence, nor any since until 1941. To suppose that the syndrome did not occur in the Allied ranks would be charitable but untrue, since one case dating from the War of 1914–18 was retrospectively diagnosed by Albert and Mitchell in 1943,[22] and one possible example appears to have been described as a case of gas gangrene without organisms in the official American History of the War of 1914–18.[23]

2ND PERIOD: LATER 1941

DEVELOPMENT OF AETIOLOGICAL THEORIES

Following the first publication in 1941, the correspondence columns of the medical journals furnished much criticism, both helpful such as that of Cohen,[24] Franklin and Douglas,[25] and otherwise. Cohen pointed out that in one of the cases described the limb ischaemia was probably due to arterial spasm, a subject of which he had made a special study. Franklin and Douglas,[25] thought 'compression syndrome' would be a more appropriate name, since crushing suggested to surgeons massive destruction of muscle and bone, in which they had not seen the development of renal failure such as characterised these air-raid casualties who had been buried. Some letters suggested that the patients would have recovered if less attention had been paid to the investigation and they had been left alone: such injury was not new but was 'commonly seen on the coalfield where the treatment is careful nursing and non-interference rather than physiological and biochemical assay'.[26] Other theorists[27] [28] stressed 'anoxia' as the possible cause of renal damage, and suggested the giving of oxygen by B.L.B. mask.

During this period (late 1941 and 1942) the main hypotheses put forward were:

(1) that the renal ischaemia and anoxia (due to the diminished blood volume and blood flow and/or to vessel spasm) damaged the kidney: analogy with blackwater fever and the kidney of mismatched transfusion was made (Foy).[29]

(2) that substances necessary for renal functioning were lost into the damaged area: such loss being prevented by tight bandages (Patey and Robertson, 1941 and 1942).[30] [31]

(3) that toxic substances escaped from the ischaemic muscle and damaged the kidney via the blood stream. Haemolysis in the damaged area was suggested by Longland and Murray, 1941,[32] to explain the jaundice and anuria of their case. Workers at the Postgraduate Medical School had drawn attention to the clinical and histological similarities with mismatched transfusion kidney. Urine from cases seen in May 1941, was shown by them, and by Rimington and Smiles from the

National Institute for Medical Research[33], to be acid and to contain oxy- and metmyo-haemoglobin and acid haematin, thus substantiating beyond doubt the association with muscle damage and at the same time strengthening the analogy with intravascular haemolysis. Opinion as to the mechanism of renal damage in the latter condition was still undecided: the generally favoured view was that put forward by Baker and Dodds in 1925,[34] that mechanical blockage of the tubules occurred, due to precipitation of acid haematin in acid urine of high salt concentration. Against this view various objections had been raised,[35] [36] [37] the most significant being that at necropsy an insufficient number of tubules were found to be 'blocked'. However, no other satisfactory hypothesis had been put forward, despite Hesse and Filatov's[38] efforts to incriminate arterial spasm and the vague theory of a specific nephrotoxin. The treatment usually adopted was the alkalisation suggested by Baker and Dodds.[34] Its failure on many occasions could always be excused because theoretically it should prevent but not reverse acid-haematin precipitation.

Attention was also drawn by Dunn and his colleagues[39] to the similar location of renal lesions in experimental phosphate and uric acid poisoning: both substances could possibly be liberated from damaged muscle.

3RD PERIOD: 1941, 1942 AND 1943

THE PERIOD OF EXPERIMENTAL INQUIRY

During the latter part of 1941 and in 1942, while air-raid material was scanty, experimental animal work was started. Pochin (1942)[40] studied the effects of occluding the circulation in the rabbit's ear: he found that the damage, manifest clinically by oedema and gangrene, was intensified by heat. The oedema fluid contained 5 per cent. protein and capillary permeability was increased. Eggleton, Winton and their colleagues[41] from University College studied the acute disturbances in renal function after hammering bound ischaemic limbs of dogs. They felt that the depression in creatinine clearance found by them was not in any way due to blockage. Their experimental procedure produced flaccid kidneys, whereas, if blockage, as postulated by Morrison[42] or tubular poisoning was involved, tense swollen kidneys should be found. They noted also that this depressed creatinine clearance could not be prevented by preliminary bicarbonate infusion. They concluded that disturbance of no single mechanism could account for all the observed phenomena. A further interesting observation was made by Eggleton[43] upon the anaesthetised cat. Following release of the compression the creatinine clearance fell 50 per cent. but if the circulation was readmitted slowly to such ischaemic limbs there was no change. Later experiments suggest that the liver, given time, was able to detoxicate the blood returning from the damaged area. It is uncertain, however, whether the renal damage thus produced in cats and dogs is analogous to the human condition since in the latter the criteria are clinical, whereas experimentally the criterion was chiefly that of creatinine-clearance changes during the first few hours only.

At the British Postgraduate Medical School it was found (Bywaters and Popjak, 1942)[44] that ischaemia of the thigh of the rabbit for three hours or longer produced irreversible muscle necrosis, and that the functional changes resembled very closely those seen in man: there was haemoconcentration, fall in blood pressure and acidaemia, with the production of small amounts of acid urine containing protein, creatine and casts. These changes were proportional to the amount of muscle damaged. Biochemical analysis of such ischaemic muscle showed changes exactly similar to those found in human muscle (except in regard to pigment). There was loss of creatine, phosphate and potassium, a large gain in chloride and water, and after a slight initial increase a large decrease in hydrogen-ion concentration. These changes were marked by two hours and complete by six hours after release (Bywaters and Stead, 1943).[45] The local swelling due to muscle-oedema could account approximately for the decrease in blood volume calculated from the change in haemoglobin. The small rise in blood urea, however, was not accompanied by any gross irreversible change in renal function, and this was thought to be related to the absence of pigment in the muscles selected for trauma and in the urine after injury. Where this was remedied by injecting a solution containing human myohaemoglobin after release of compression, considerable uraemia with decrease of urine urea concentration was produced (Bywaters and Stead, 1944)[46]. If the urine were rendered acid by administration of ammonium chloride by mouth, fatal uraemia could be produced even in uninjured animals. This lesion resembled that of crushing injury functionally, but anatomically it differed in several respects from that seen in man, resembling rather the effects of acute ureter-blockage in the rabbit. The conclusion of these workers was that 'myohaemoglobin excreted in acid urine such as occurs in the crush syndrome may play an important rôle in the genesis of renal failure'. Another experimental approach was that of Keele and Scarff (1933)[47] who produced renal damage in rabbits by compression of the renal artery for periods of one to two hours. A proportion of the animals died of uraemia, and this was thought to support the theory that the renal damage of crushing injury was due primarily to renal anoxia or ischaemia. But as these authors pointed out, and as may be seen from their illustrations, the first convoluted tubules were the most severely damaged—becoming completely necrotic with later calcification, whereas in the crush-injury kidney seen on the sixth day, the most severely damaged portion of the nephron was the thick portion of the loop of Henle, and the first convoluted tubules showed merely a slight catarrhal change. The only other experimental work in England bearing on the subject was that of Bielschowsky and Green[48] who

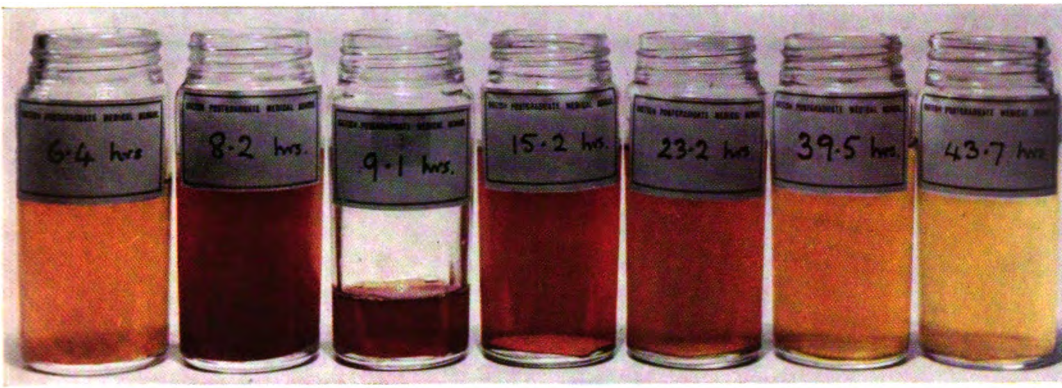

PLATE I. Urinary changes in crush syndrome.

PLATE II. Appearance of affected muscles in a patient suffering from crush syndrome.

Colour photographs by Hennell of the Metal Box Company, Ltd.

[*Facing Page* 680

found that substances extracted from muscle and giving rise to 'shock' on injection into rats were potentiated by myohaemoglobin. The significance of this as regards clinical crush injury was difficult to evaluate, since part of the reaction was apparently due to pyrophosphate, producing death from acute hypocalcaemia (Bywaters and Stead, 1943).[49] No such clinical state is seen in man with crush injury.

In the United States, however, a large volume of experimental work on the renal injury was produced from 1942 onwards—chiefly by A. C. Corcoran and I. H. Page at the Lilly Laboratories[50] and by Bing at Baltimore,[51] [52] but also later by the New York group working with Donald Van Slyke,[53] and by a group at Yale.[54] [55] The accounts of these investigations were available in this country only in the form of unpublished abstracts of reports to the Committee for Medical Research, 'confidential and not to be quoted publicly in any form' except as 'personal communication'; most of them have been subsequently published. In addition, the production of 'shock' with haemoconcentration by methods simulating crush syndrome, either with plain compression (Bywaters and Popjak, 1942)[44] or using some form of percussion by blunt instrument as well (Eggleton, Richardson, *et al.*,[41] Duncan and Blalock[56] [57]) has been studied extensively by various workers in the United States, especially with reference to the use of heat or cold, of compression bandages, lactate infusion (Fox[58]), etc., in prevention and treatment. As with the English work, uraemia could not be produced in animals by 'tourniquet shock' and the method has been useful chiefly in reproducing the initial 'shock' phase of crushing injury. Uraemic death has, however, been produced, as in the English studies, by pigment injection. Bing (1943 and 1944),[51] [52] found that methaemoglobin was the most effective substance; this was confirmed by the Yale group (Bunting,[54] Ordway, Harrison and Albrinck[55]), who noted that oliguria and acidosis were important and predisposing factors, and further, that the impairment of renal function occurred immediately after injection. If such immediate impairment does not occur, renal damage will not later become evident. Some evidence was also forthcoming from the experiments of Van Slyke[53] and others designed to investigate the usefulness of haemoglobin as a transfusion agent. A temporary fall in urea clearance was found in bled dogs retransfused with methaemoglobin but not with haemoglobin or plasma. Van Slyke, Page, and others, have investigated experimentally the effect on renal function of decreased renal blood-flow produced by renal artery compression or by graded haemorrhage: many have thought this to be an important factor in the genesis of the renal injury of human crush syndrome, but as there is no direct evidence, argument is largely by inference from animal experiments. A detailed treatment of this aspect does not come within the purview of the present work, which is limited to the war period.

Page[59] and his fellow workers, having been able by such methods to reproduce the renal damage, turned their main attention to prevention and treatment. They concluded that intravenous gelatine lactate solution and pressure bandaging were the most effective measures under experimental conditions. The use of a reducing agent has also been suggested—ascorbic acid or sodium sulphoxylate by them and methylene blue by the Yale group,[55] on the grounds that formation of a met-compound seemed to be an essential step in the process.

4TH PERIOD: 1943–45

THE EFFECTS OF TREATMENT

As bombardment of this country diminished, the number of aetiological theories and advocated methods of treatment almost exceeded the number of cases: many cases passed unrecognised and untreated. At this time the 'Baedeker' raids were in progress—one provincial centre after another being hit. An M.R.C. investigator visited some of these incidents, but transport was difficult and by the time he arrived some patients were dead, valuable data on the early period was often entirely lacking, and treatment if attempted was uncoordinated. More important still, the fact that renal damage was done in the first few hours, the 'shock phase', after which all treatment was ineffective, was not generally appreciated, if indeed the diagnosis was made at all until the late stages of uraemia. Some hospitals of course presented a welcome contrast, but the difficulties of making observations without clinical responsibility in outside hospitals were immense—despite the kindest and most intelligent reception. It was decided, therefore, to set up a mobile team, with particular reference to the early detection and treatment of such cases and to the evaluation of such treatment. This team, composed of two surgeons and three physicians, was not limited to observations on crushing injury but was to make observations on trauma generally. It set out immediately upon notification by the Ministry of Home Security to incidents within a radius of 100 miles of London. There were of course many fruitless trips—the injured being found on arrival to be 'safely tucked up and asleep—not to be disturbed', but a few cases were collected. More useful material from this point of view was obtained with the resumption of raids on London in early 1944 and during the period of the flying bomb (June to September 1944) and the rocket (September 1944 to March 1945). Observation of the 1944 cases was best when they could be admitted to our own hospital, but this was rarely possible. A similar investigation of industrial accident cases in Newcastle, from January 1944 onwards, provided useful controls and occasional pointers, but interfered severely with the collection of cases in London. Despite this, a series of crush-syndrome cases were seen in that final year, during and after the conclusion of the Newcastle period, which could be observed closely enough, thanks to the kindness and hospitality of the clinicians concerned, to draw tentative conclusions on the effects of treatment.

The problem was difficult since the evaluation of therapeutic efficacy demands first and foremost that the course of the untreated illness in any given case should be adequately known. Very minor degrees of injury produced no renal failure: almost all severe degrees produced renal damage and uraemia even though a proportion of such cases recovered without treatment.[60] The degree of severity depended on the amount of muscle-damage; this was assessed clinically (often difficult in fat people and with trunk involvement) and also by the amount of plasma loss (haemoconcentration and amount of transfused fluid needed to restore blood-pressure to normal) and by the amount of pigment and creatine put out in the urine. Nothing but the complete prevention of renal failure was felt to be of any significance, and that only in patients so severely damaged that untreated they would certainly have developed uraemia. It was felt that one agent alone should be tried at a time, and that chosen was the alkaline fluid, since from experimental work this seemed probably the most useful.

Only five patients fell within this category, but in them it seemed that early forcing of fluid and alkali bicarbonate by mouth, and lactate by vein in conjunction with plasma transfusion if necessary, was really effective judged by the above criteria (one published, case III, Bywaters, Crooke and Morris[61] and four unpublished cases). Numerous cases were reported where alkaline fluid had been given too late or in insufficient quantity to affect the result; as Maegraith and Havard[62] have rightly pointed out, in such patients with already developed renal damage, not only is there no reason for giving alkali but also alkalosis will more easily develop. This was seen in several patients treated with rather more enthusiasm than logic. Other advocated methods of preventing renal damage have been insufficiently tried. Patey and Robertson recorded two recovering cases treated with intermitted positive pressure, but neither satisfy any of the above criteria. Marshall (1944)[63] records four cases given pulsator treatment in a Both respirator, two of which showed no uraemia on the sixth day; one of them was severely injured and evidence is inconclusive since early data are lacking. No trial was made of reducing agents such as ascorbic acid or sulphoxylate (Page).[59] The treatment of established renal damage is difficult; claims have been made on cases who recovered for bicarbonate (Blackburn and Kay),[64] mersalyl (Bradley),[65] sodium sulphate (Henderson),[66] and eucortone with protein privation (Maitland).[67]

INCIDENCE OF CRUSH SYNDROME

It is of interest that we have found only three cases of this condition yet published in this war, from other than British[68][69] and Canadian[70] sources. No Russian, Japanese, French, Belgian or Italian references have been seen despite the certain occurrence of such cases in these countries. In Germany, apart from the two reports mentioned above, the only information comes from the Roosevelt Survey (Bauer, F. K. 'The Nature of Air Raid Casualties' in *Effect of Bombing on Health and Medical Care in Germany*, Morale Division, U.S. Strategic Bombing Survey: Medical Branch Report, War Department, Washington, 1945, chap. 3, p. 17) culled largely from two official reports on the causes of death in air-raid casualties published in March and October 1944.

> Severe contusions with the typical decompression shock syndrome occurred in practically all bombed cities. From estimates of the Luftgau physicians it can be stated that the mortality rate for this condition was about 90 per cent. The remainder recovered without permanent damage. Kidney function returned to normal in a surprisingly short period of time. Dr. Karl Scriba, pathologist in Hamburg, published reports of three and saw 50 of these cases. All died despite vigorous measures, including the liberal administration of whole blood, plasma and vasoconstrictor drugs. All were feeling well and conscious when liberated from the rubble.

In air raids on large towns, estimates of the incidence of crush syndrome ranged between 0·9 per cent. (a figure derived by Douglas[(71)] from an analysis of 764 hospital admissions from 12 raids in 6 towns) to 3·7 per cent. (a figure derived by Bywaters from an analysis of 1,182 admissions into 5 hospitals in 3 towns.[(72)]) The latter figure was claimed to be more accurate, as all the cases were seen by one or both of two observers specially qualified to recognise 'crush syndrome'. The number of crush-syndrome cases officially noted under the more comprehensive heading of crushing injury during 1942–3 was given by Stocks[(73)] (1943) as 5 in a study of a one-fifth sample of those two years. The Medical Research Council has records of about 200 cases of whom 30 occurred in 1942–3. Since the air-raid series, a few cases have been recognised in mining accidents—McLelland (1941)[(74)] and Caplan and Dunkerley (1945)[(75)] and four unpublished cases of our own. Under field conditions, cases of traumatic anuria were an important cause of death in the Services, but they formed only a very small percentage of the total casualties. Only a few cases of crush syndrome proper were observed, usually occurring under the same circumstances as in civilian life, as a result of buildings containing soldiers being hit by flying bombs (Lieut. Colonel Copping's 10 Canadian cases from Liége)[(76)] or by high explosive (Major Ruscoe Clarke's 8 cases from Italy).[(77)] The majority of cases of traumatic anuria occurred under obscure circumstances and the data given on the recorded cases (Darmady, *et al.*, 1944,[(78)] Parsons, 1945,[(79)] Hamilton, Lathe and Cleghorn[(80)]) are too scanty to enable one to judge whether 'shock', muscle ischaemia, sulphonamide blockage, haemolysis from burns, clostridial toxins or iso-agglutinins, or some unrecognised condition was the aetiological agent.

It is certain that muscle ischaemia caused not by prolonged external pressure but by arterial spasm or rupture can cause myohaemoglobinuria and death from uraemia; such cases have been studied in industrial and traffic accidents (Barlow, Bywaters and Stead, 1945),[(60)] (Glen, 1941),[81] (Bywaters, Belsey, Graham, Magner, Williamson, *et al.*, 1942,[82] (Moloney).[83] It is also true that almost exactly the same clinical course and histological findings may be seen following a mismatched transfusion, except that jaundice is commoner and haemoglobin derivatives appear in the urine. Similarly following sulphonamide crystal blockage at the renal papilla (Maisel, *et al.*, 1944),[84] death after six days will occur from uraemia and the kidneys will present a lesion distinguishable from that of crushing injury or mismatched transfusion only by the absence of pigment casts and the presence of intratubular crystal masses.

THE POSITION AT THE END OF 1945

These somewhat confusing views may be reconciled by the findings (Bywaters, 1945)[85] that a similar histological picture, except for the pigment casts, occurs in human cases of acute hydronephrosis produced by tumour blockage of the ureters, sulphapyridine blockage, and calculus anuria. A rise in intra-renal pressure is postulated as the factor common to all these conditions. This is mechanically produced in sulphonamide blockage and in hydronephrosis; after a time the tubules rupture into the interstitial tissue and into the thin-walled renal veins. Experimentally the kidney becomes swollen almost immediately after the injection of the pigment; in human crush syndrome the kidneys do not show the characteristic tubular ruptures until twenty-four hours have elapsed; no degenerative changes are seen in patients dying early. A possible mechanism is that pigment in the glomerular filtrate is deposited on the lining epithelium in that portion of the tubules where acidification takes place and prevents re-absorption of filtrate. In support of this it is to be noted that pigment casts are almost invariably hollow, and that in cross-section the characteristic appearance in the second convoluted tubules is that of a necklace of pigmented beads. It may be that, for this to take place, other accessory factors besides acid urine are necessary—such for instance as an initially low filtration-rate or a poor tubular blood supply. Once re-absorption stops, the renal pressure rises and leakage occurs later producing the characteristic 'tubulo-venous lesions': polyuria itself is stopped after a short initial period by the rise of pressure. In this the lesion is analogous to other conditions of tubular damage (mercury and cyanide poisoning) where oliguria rather than theoretically probable polyuria is ultimately seen.

Present knowledge, therefore, of crush syndrome leads us to prefer the title 'ischaemic muscle necrosis'. As a result of plasma loss, a period of 'shock' ensues, followed in inadequately treated cases by uraemia. The renal lesion is the same as that seen in mismatched transfusion and is associated with a rise in intra-renal pressure. The mechanism of the latter is not yet definitely known. Direct blockage of the tubules by pigment is probably not the correct explanation: one hypothesis is that haemoglobin derivatives produce a specific interference with re-absorption of glomerular filtrate by that segment of the tubule concerned with acidification.

The problem has been of interest for its own sake and for the light it has thrown on 'shock', but, as with all such war studies, it has wider implications for peace-time medicine; such diverse conditions as hydronephrosis (Bywaters, 1945),[85] blackwater fever (Skipper and Haine, 1945),[86] lipoid nephrosis, limb embolism (Bywaters and Stead, 1945),[87] arterial spasm (Cohen, 1944),[88] liver necrosis (Bywaters, 1945),[89] obstetric anuria (Young, 1942),[90] (McMichael and Young, 1941),[91] gas gangrene (Jeffrey and Thomson, 1944,[92] Cutler and Sandusky, 1944),[93] and potassium poisoning acquired relevance, and a fresh significance in the process. Apart from this, if we are to learn anything from this part of the medical history of the war other than that which we apparently did not learn from the medical history of the previous war, three points should be re-emphasised:

(1) Surgeons who have to be fully occupied with technical procedures cannot be expected to give the necessary attention to patients who become severely ill as a result of trauma and when in immediate need after operative intervention. The close co-operation of physicians and surgeons in the management of the injured seems more than ever justified.

(2) The common habit of omitting post-mortem examination in the severely injured and limiting it to the coroner's brief search is to be deplored. Detailed study should be made of both the immediate direct effect of trauma and also of the more remote effects whenever these are suspected from the clinical and biochemical findings.

(3) Although experimental work may suggest solutions to problems already defined by clinicians, the final testing of the 'solution' lies with the trained clinical investigator.

Addendum. Since the above was written a comprehensive account of the anatomical changes in the kidney in this and allied conditions, together with an excellent general review of work to date, has been published by Lucké of the United States Army Institute of Pathology. ('Lower Nephron Disease', Lucké, B., 1946, *Military Surgeon*, **99**, 371.) (See also Chapter 3 in the Medical Research Volume in this Series.)

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CHAPTER 20

IMMERSION FOOT

By R. L. RICHARDS and W. BLACKWOOD
M.D. M.B., Ch.B., F.R.C.S. Ed.

THE term 'immersion foot' was coined during the early part of the war to describe a syndrome occurring in survivors from shipwreck, whose extremities had been exposed for considerable periods to the effects of cold sea-water. The identity of the originator of the term remains a mystery, but 'immersion foot' was rapidly assimilated into the medical vocabulary as a simple and descriptive title for a complex syndrome. It must be stressed that the term is neither accurate nor adequate because the condition may arise without immersion and may affect the hands. The comprehensive 'peripheral vasoneuropathy after chilling', suggested by Ungley and Blackwood, is more accurate but has not met with general acceptance. While the name 'immersion foot' is new, the syndrome which it describes is among the oldest known to medicine; the injurious effect of cold upon the tissues was known to Hippocrates and since the days of Xenophon 'frostbite' has been recognised as a cause of invalidism in armies.

As knowledge of the effects of cold upon the tissues has increased, it has become apparent that they are independent of the nature of the exposure (i.e. to dry cold or to wet cold) but depend upon its duration and severity; at one end of the scale is the reactionary vasodilatation with which everyone who has thrown snowballs is familiar, and at the other true frostbite in which the exposed tissues are frozen solid. Immersion foot occupies an intermediate position between these two extremes, and is associated with chilling rather than freezing of the tissues. It is believed that there is no significant difference between immersion foot and other conditions such as trench foot, which are the result of prolonged exposure of the extremities to cold insufficient to freeze the tissues. The term 'immersion foot' has by some been used to include all such cases, but in the present paper it will be used in its original and more restricted sense.

AETIOLOGICAL FACTORS

The essential causative factor is prolonged exposure of the limbs to cold. Experiments carried out by the late Sir Thomas Lewis and others have shown that exposure for periods longer than a few hours to temperatures lower than 15° C. is harmful to the tissues. In northern latitudes sea-water temperatures are rarely, if ever, above this level, and during winter frequently approach freezing point (—1·9° C.). At this latter temperature a very brief period of exposure (less than two hours) may be sufficient to produce vasoneuropathy. Immersion has no specific action apart from its effect in increasing the rate of heat-loss and is not an essential factor—cases of the syndrome have been observed where the only moisture was provided by condensed perspiration; but prolonged immersion may cause maceration and thus increase tissue damage. In individual cases important contributing causes may be such local factors as immobility and dependency of the limbs and constriction by footwear, puttees or the edge of a seat, and such general factors as malnutrition, low morale, the effect of cold upon the whole body, and haemorrhage and shock from wounds.

CLINICAL FEATURES

During the period of exposure the affected limbs are numb and powerless. At this stage pain is absent. Swelling occurs; boots may have to be removed and later cannot be replaced. The feet are usually of a whitish or sickly yellow colour, but in very cold water they may be bright red. Minor injuries may seriously damage the chilled, sodden and friable tissues.

After rescue the typical case of immersion foot passes through three phases which have been called pre-hyperaemic, hyperaemic, and post-hyperaemic.

The *pre-hyperaemic stage* is a direct continuation of the events occurring during exposure. For a period which varies from six to twenty-four hours according to the severity of the exposure, the feet remain cold and numb and feel heavy. The peripheral pulses are impalpable, toe and ankle movements are absent, there is a 'stocking' type of sensory loss to all forms of exteroceptive stimuli, the ankle jerks are frequently absent, and swelling may extend as high as the knee.

A remarkable and usually sudden change follows when the limbs enter the *hyperaemic stage*. The cold pulseless feet rapidly become hot and flushed, and the peripheral pulses become full and bounding. In the majority of cases a distinct centrifugal spread of the hyperaemia may be observed. The hyperaemia is attended by pain; except in mild cases the pain is severe, burning or throbbing in quality and it increases in severity to reach a maximum in twenty-four to thirty-six hours. For the first forty-eight hours of the hyperaemic stage the feet are hot and of a deep red-blue colour; swelling tends to increase; and blisters, ecchymoses and petechial haemorrhages may appear. Areas that are to become gangrenous do not warm, blister extensively, and around their margins the general hyperaemia is intensified to form a distinct line of demarcation. In this acute hyperaemic stage the appearance of the feet may be most alarming. Within a day or two, however, the intense hyperaemia and swelling subside; the feet are now pale, though still warm, and areas of gangrene become more clearly defined. Massive gangrene leading to loss of toes or portions of the feet is rare, but superficial necrosis with shedding of thimble-like casts of the digits is not uncommon. In the early stages pain is continuous and diffuse, but later (seven to ten days after rescue) shooting or stabbing pains may develop. These pains tend to occur in paroxysms, are aggravated by heat, by movement, and occasionally by emotional factors, and radiate from the centre of the foot towards the toes. They may last for several weeks and tend to disappear by a process of 'recession' (i.e. pains shooting from the foot into the toes recede gradually until they are felt only in the tips of the toes). Seven to

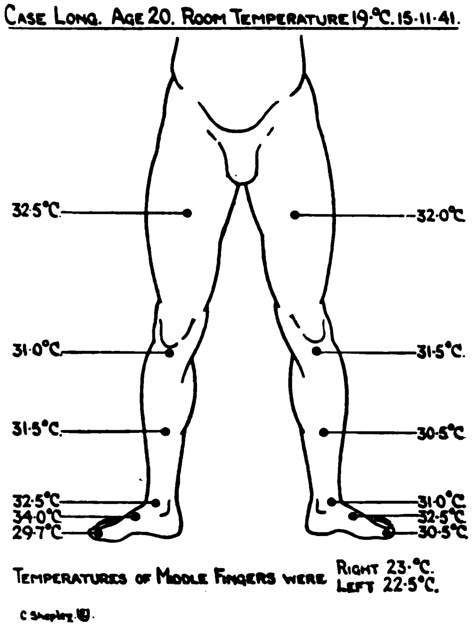

Fig. 1. Skin temperature gradients in a case of immersion foot 4 weeks after exposure. Note the abnormal warmth of the feet.

ten days after rescue a relatively stationary sensory picture is obtained; there is usually a 'sock' or 'carpet-slipper' type of sensory loss with analgesia slightly more extensive than anaesthesia. Thereafter sensory recovery is slow and associated with the usual phenomena which accompany nerve regeneration. At first swelling hampers movements of the ankle and toes, but as swelling subsides wasting of the intrinsic muscles of the foot becomes apparent. This results in a flat-footed, springless type of gait. Clawing of the toes and other contractures of the foot are apt to occur in severe cases. Radiography reveals marked osteoporosis of the bones of the foot.

The duration of the hyperaemic stage varies from a few days to eight weeks. In all but the mildest cases it is succeeded by a post-hyperaemic stage. The transition is never abrupt. It is noted one day that the previously warm feet are cold (see Fig.). At first this is usually the result of exposure to some cooling influence (e.g. a tepid bath, a walk in the open air, or standing on a cold floor), but later the feet become permanently cold and if exposed to moderate degrees of cold they cool excessively. Associated with this cold-sensitivity there is a marked hyperhidrosis. Recurrence of stabbing pains is another frequent complaint. These late sequels persist for a long time and may be the cause of serious disability. Patients who do not have these symptoms and are apparently well while leading a sheltered life ashore, may have further trouble if they return to serve in northern latitudes.

Immersion Hand. In approximately 50 per cent of cases the hands are also affected, although less severely than the feet. The essential features of immersion hand are similar to those of immersion foot. Wasting of the intrinsic muscles of the hand may be very prominent and presents an appearance similar to the 'claw hand' of progressive muscular atrophy. Occasionally a hand may be more severely affected than the feet if the patient has used it for bailing, scooping up water to drink or some other purpose which has resulted in prolonged exposure. In the late stages, cold sensitivity in the hands may manifest itself by attacks of the Raynaud phenomenon (Plates V–IX).

PATHOLOGY

All tissues of the limb are affected, to a variable degree, the degenerative changes being most marked peripherally. In early cases the skin may show cellular and intercellular oedema, separation of the epidermis from the dermis, or coagulative necrosis. The capillary loops in the dermis show dilatation and tortuosity, may be obstructed by agglutinated red blood cells, or may show thrombosis. In late cases marked fibrosis may be present in the dermis and in the atrophied subcutaneous adipose tissue. Following exposure, skeletal muscle may show patchy Zenker's hyaline necrosis. In the rat this initial lesion is followed by absorption of damaged muscle and regeneration of muscle fibres. It is possible that this process occurs in man, but suitable material for study has not been obtained. In late cases the muscles may show the changes of partial denervation.

Initially the nerves show partial or complete degeneration, affecting especially the smaller fibres, followed by regeneration which spreads distally. In the arteries and veins thrombosis and organisation of thrombi have been found by some workers and not by others. British investigators have failed to find them either in animal or human material, but pathologists from America and other countries have found these changes even at some distance proximal to regions of necrosis. The explanation of the difference may well be the probability that while a mild state of 'peripheral vasoneuropathy after chilling' can exist without organic vascular obstruction, severe cases are often accompanied by this change.

Bone, usually the least damaged tissue, may show decalcification, even necrosis and later regeneration (Plates I–IV).

PATHOGENESIS

Immersion foot is the sequel to prolonged exposure of the extremities to low temperature; the pathogenesis of the syndrome must therefore be considered in relation to the known effects of cold upon the tissues. Experiments with tissue cultures have shown that tissue death from the effects of cold *per se*, if it occurs at all, takes place at temperatures much lower than those which cause immersion foot. It is therefore believed that tissue damage in immersion foot is due to the indirect effects of cold, and in particular to its effect upon the blood vessels.

If an extremity is exposed to cold for a brief period, the physiological response is vasoconstriction, succeeded by vasodilatation when the extremity is restored to the normal environment. If the exposure to cold be more prolonged, vasoconstriction of the larger vessels (arteries and arterioles) is maintained, but the minute vessels of the skin and subcutaneous tissues become dilated. Prolonged constriction of the larger vessels tends to a condition of relative ischaemia of the peripheral tissues. This is partly offset by a reduction in metabolism brought about by the low temperature; cessation of metabolism does not take place until tissue temperature reaches zero centigrade. In the majority of cases of immersion foot it is unlikely that tissue temperature will fall as low as zero and the chilled tissues are therefore in a state of unbalanced metabolism in which anabolism has ceased but katabolism continues. The effects of this are: first, certain tissues which are susceptible to lack of oxygen suffer damage; and secondly, products of tissue katabolism accumulate in the chilled and ischaemic tissues. The minute vessels (capillaries and venules) are particularly susceptible to anoxia; they become widely dilated, their walls are damaged, and plasma leaks through them.

After rescue, when the circulation through the main arteries is restored and blood enters the chilled tissues, the accumulation of vasodilator metabolites causes an initial intense hyperaemia. Blood enters the damaged minute vessels under considerable pressure, more plasma may leak through their walls and the red cells remain stranded in the lumen—a phenomenon to which Kreyberg has given the name of 'stasis'. In some cases actual haemorrhage may occur, giving rise to blood-filled bullae or haemorrhage into muscle. This stasis of blood in the minute vessels is of considerable importance since the life of the tissue cells depends upon the diffusion of oxygen, salts and other substances through the capillary wall. The greater the damage to the minute vessels during the period of exposure the more carefully must the restoration of circulation to the chilled tissues be controlled. Any additional trauma will increase the damage to the vessels and may precipitate gangrene (e.g. the application of heat will increase metabolism beyond the resources of the available blood supply, cause greater anoxia and further tissue damage). Stasis is not necessarily an irreversible process but if normality is not restored the stranded red cells become 'conglutinated' and form hyaline thrombi which permanently block the vessels.

This picture of what takes place in the tissues during exposure and the immediate post-rescue period is based largely upon experimental work by Lake, Kreyberg and others, but accords well with clinical and pathological findings. The extent of tissue damage is almost certainly determined during this period.

Later findings can for the most part be attributed to the effects of chilling and ischaemia. Damage to peripheral nerves accounts for the abnormalities of sensation which are observed. Pain in the early stages is attributed to anoxia of nerve endings and in the later stages to constriction of nerves by interstitial tissue and collagen resulting from organisation of the oedema fluid of high protein content which permeates the tissues during the acute phase. The prolonged hyperaemia and anhidrosis of the later hyperaemic stage are due to the interruption of post-ganglionic sympathetic neurons in the peripheral nerves. Motor paralyses and contractures are the result of denervation and the direct effects of ischaemia and cold upon the muscles themselves. The late vascular phenomena are as yet inadequately explained, but the evidence is in favour of the hypothesis that they are related to the denervation and subsequent re-innervation of the peripheral blood vessels.

PREVENTION AND TREATMENT

Official instructions were issued (M.R.C. War Memo. No. 8) regarding the procedure to be adopted by men who have to abandon ship in latitudes where immersion foot is liable to occur; these need not be repeated here. Boots may afford some protection during a short period of exposure, but when swelling occurs they are liable to cause constriction and should be removed. Rubbing the feet may be of value during the early stages but is apt to do more harm than good when the tissues are sodden and friable. The wearing of stockings impregnated with vaseline has been advocated and may be of some value.

When rescued the patient should not be allowed to walk. Stripped of his wet clothing, he should lie with his feet elevated and exposed to the air. Warmth may be applied to the trunk and hot drinks given, but the direct application of heat to the affected limbs is forbidden. At this stage sympathectomy and other similar measures designed to increase the peripheral circulation should not be employed. It has not been proved that there is any advantage in maintaining chilling of the tissues during the pre-hyperaemic stage, and there is a certain amount of evidence that such treatment may be harmful.

Once the feet become hyperaemic, cold therapy by ice-bags, or by dry cooling with a fan, in a refrigeration cabinet, or by exposure of the limbs at an open window is of definite value for the relief of pain, and by reducing metabolism may help to minimise tissue damage. If cold therapy is employed, it should be controlled by observations upon skin temperature; the latter should not be allowed to fall below 21° C., the optimum temperature for protracted therapeutic cooling. At this stage large doses of sedatives and analgesics may be required.

The feet must be kept scrupulously clean; they should be cleansed daily with soap and water followed by spirit, the toes dusted with sulphanilamide powder and separated by pledgets of sterile gauze. A prophylactic injection of antitetanic serum should always be given. Blisters should be snipped aseptically, but apart from this an attitude of surgical conservatism should be adopted. Later, minor amputations of the trimming variety may be required; rarely, severe pain may necessitate a more radical amputation than would otherwise have been necessary.

In the treatment of the late cold-sensitive state and hyperhidrosis, preganglionic sympathectomy may be of value. Arch supports should be worn until such time as power is restored in the muscles of the sole.

(See also volume on *Medicine and Pathology* in this series, Chapter XI.)

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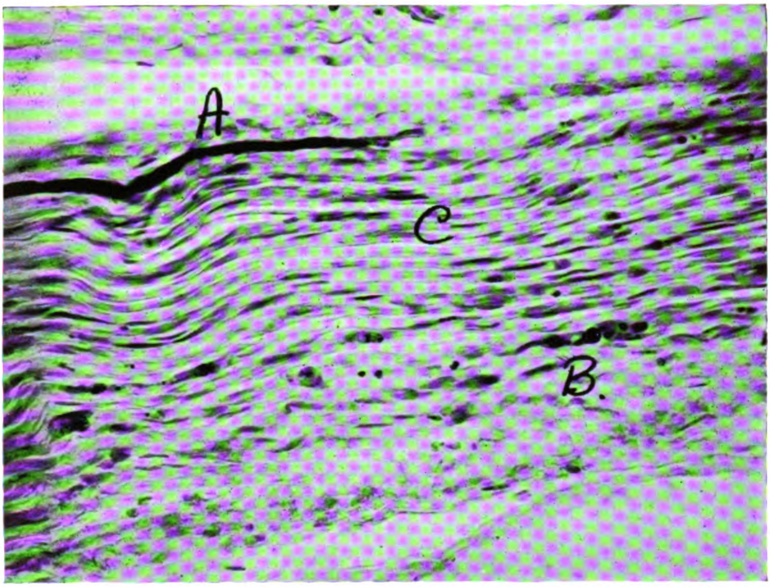

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PLATE I. Interdigital nerve, ten weeks after exposure, showing intact myelin sheath (A), degenerated myelin (B), and proliferated Schwann cells (C) in the degenerated region. L.S. Myelin sheath stain (× 225).

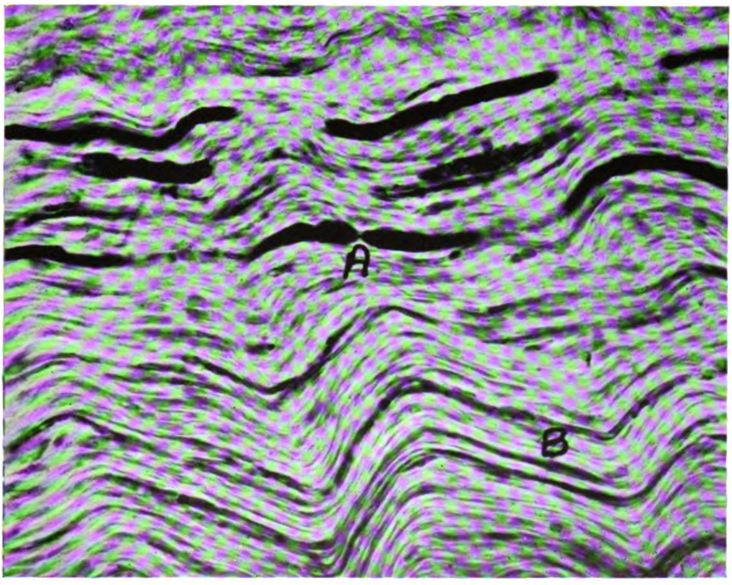

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PLATE II. Tibial nerve, mid-leg region, ten months after exposure, showing large myelinated nerve fibres (A) which were not irreversibly damaged, and six fine regenerating myelinated fibres (B). L. S. Myelin sheath stain (× 225).

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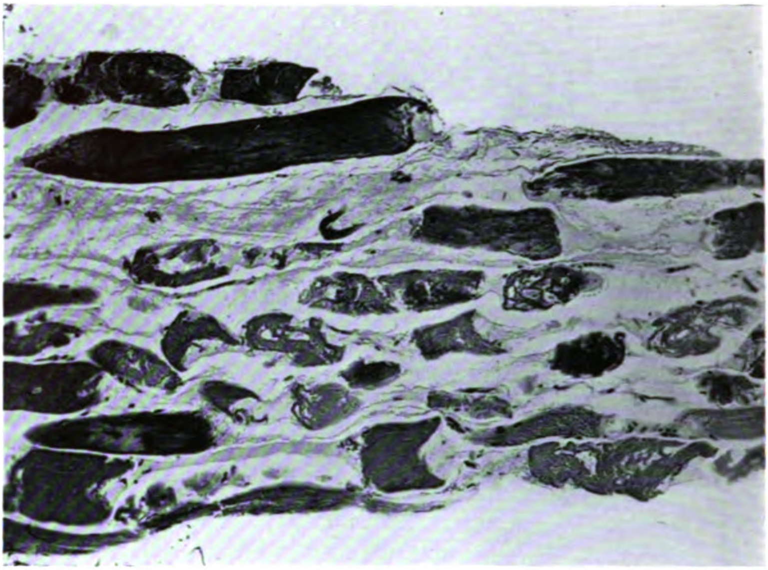

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PLATE III. Extensor digitorum brevis muscle from a man who died half-an-hour before rescue, showing severe, subtotal, degenerative changes. L.S. H. & E. (× 90).

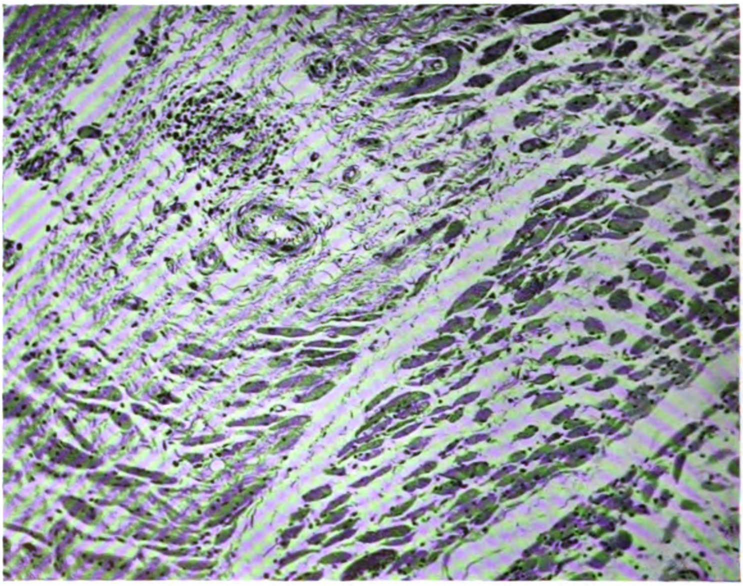

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PLATE IV. Muscles and vessels from the posterior compartment of the leg, four months after exposure, showing perivascular chronic inflammatory cells, œdema and small hypernucleated muscle fibres. Having recovered from the initial damage, these now await re-innervation. T.S. H. & E. (× 80).

PLATE V. Appearance of feet twenty-two days after rescue in a severe case of immersion foot.

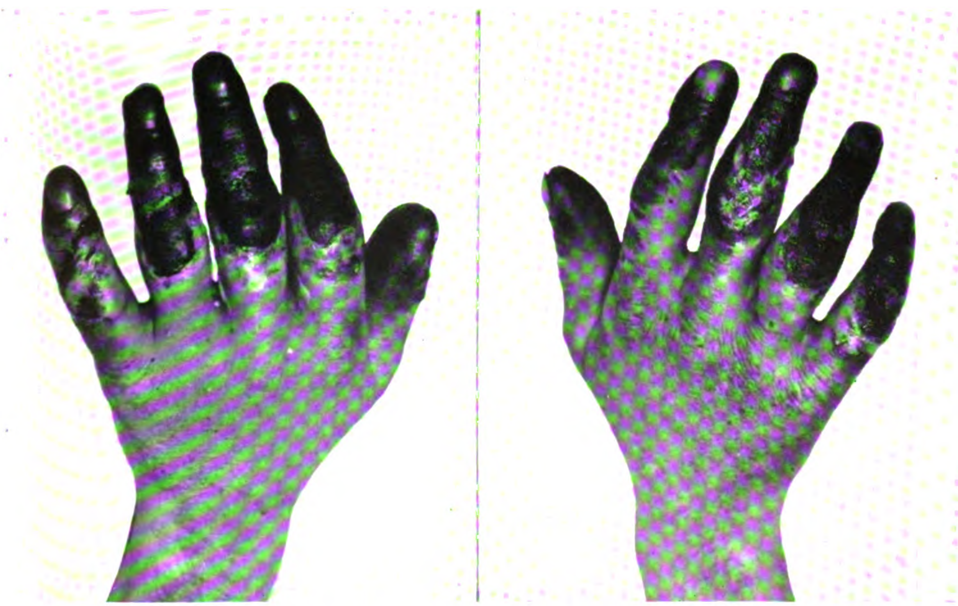

PLATE VI. Appearance of hands twenty days after a severe exposure to cold and wet.

PLATE VII. (1) Immersion Foot. Ten days after rescue.

PLATE VIII. (2) Immersion Foot. A month after rescue.

Colour photographs by Hennell of the Metal Box Company, Ltd.

PLATE IX. (3) Immersion Foot. Two months after rescue.

Colour photograph by Hennell of the Metal Box Company, Ltd.

CHAPTER 21

AMPUTATIONS AND ARTIFICIAL LIMBS

(i)

Amputations

BY G. PERKINS
M.C., M.Ch., F.R.C.S.

AT the beginning of the war it was accepted by most British surgeons (1) that patients were unable to bear weight on the end of their stumps for more than a limited number of years; (2) that limb-makers found it easier and more satisfactory to fit artificial limbs to amputations done at certain levels, which were called sites of election; (3) that an amputation stump that had healed *per primam* gave far less subsequent trouble than one complicated by sepsis. The war brought these axioms under review.

END-BEARING STUMPS

With regard to end-bearing stumps British surgeons were influenced by the views of the limb-fitting surgeons of the Ministry of Pensions. All amputees of the War of 1914–18 became the responsibility of the Ministry of Pensions which appointed a small staff of doctors whose duties were chiefly confined to ordering, fitting and approving artificial limbs supplied to pensioners by the Ministry's contractors. Experience taught them the attributes of a good stump, and they also learnt which amputations gave least trouble. From a study of the life history of thousands of amputees they came to the conclusion that end-bearing stumps tolerated weight-bearing for only a limited number of years. Longitudinal transmission of stress from the artificial limb to the stump, though unimportant in the upper limb, is of the utmost importance in the lower limb. Two amputations—the Syme and the Stokes-Gritti—were designed for end-bearing. The Ministry's limb-fitting surgeons saw a certain number of unsatisfactory end-results of both these operations, which were not in favour with the British military authorities. Very few Syme and practically no Stokes-Gritti amputations were done. Transatlantic surgeons hold different views; the Canadians and the Americans approve of both amputations, particularly the Syme.

It is probably going too far to condemn Syme's operation altogether. A Syme—well done, under favourable conditions—gives a stump that may continue, as the Toronto surgeons have shown, to take end-bearing for many years. A badly done Syme will not tolerate end-bearing.

During the War of 1939–45 double amputations were relatively common, and a man with a bilateral Syme was much less disabled than a man who had lost both legs at a higher level. At the end of the war opinion was veering round to the belief that a Syme should be done in preference to a below-knee amputation whenever the surgeon was familiar with the operation and could expect primary healing. The greater likelihood of primary healing brought about by the use of penicillin was responsible for this change of view.

The Stokes-Gritti amputation still remains out of favour on this side of the Atlantic. Like the Syme, it is more difficult to do than an amputation at the site of election. There is less certainty than in the case of the Syme that the stump will stand up permanently to weight-bearing; the Canadians and the Americans may in the future produce more concrete evidence on this point.

Partial amputations of the feet were not favoured by the limb-fitting surgeons of the Ministry of Pensions, but, provided that the remnant of the foot was plantigrade, i.e. that the foot was at right angles to the leg and lay flat on the ground, function could be excellent. The sole of the shoe needs to be rockered to prevent undue stress falling on the extremity of the stump. Feet that are not plantigrade can usually be made so by orthopaedic surgery. At the beginning of a future war surgeons will probably be advised to conserve as much of the foot as possible and to leave the question of re-amputation for later consideration. This has always been the advice given in cases of injury to the fingers.

SITES OF ELECTION

Apart from partial amputations of the hand and foot, and the weight-bearing Syme and Stokes-Gritti amputations, there was at the beginning of the war agreement on sites of election; and this has remained more or less unchanged. The limb-fitting surgeons of the Ministry of Pensions lay down four sites of election: the ideal length for an above-elbow amputation stump is 8 in., measured from the tip of the acromion to the end of the humerus; for a below-elbow stump 7 in., measured from the tip of the olecranon to the end of the ulna; for an above-knee stump 11 in., measured from the top of the trochanter to the end of the femur; and for a below-knee stump 5½ in., measured from the line of the knee-joint to the end of the tibia. These lengths are based on the fact that the shorter the stump the easier it is to fit, but that it must be long enough to contain the insertion of the muscles that control the joint above and long enough to remain inside the socket when the joint is flexed. The shortest useful length varies with different individuals. There was general agreement that a joint should be retained whenever possible. Re-amputation at the next site of election can always be done at a later stage if the length of stump below the joint proves insufficient to control a prosthesis.

On one point opinion is in a state of flux. Early in the war it was accepted that an amputation through the wrist was undesirable because the stump was too long and because, being bulbous-ended, it could not be fitted into the ordinary conical socket. However, with an amputation through the wrist the patient retains strong active rotation of the forearm whereas the below-elbow stump when fitted with an artificial limb loses the power to rotate. Rotation of the forearm is very useful, more useful even than wrist movement. Recently an artificial limb has been designed for an amputation through the wrist that preserves active rotation. Before the war the limb-fitting surgeons urged re-amputation in all cases of amputation through the wrist; they do not now insist on this.

DEFINITIVE AND PROVISIONAL AMPUTATIONS

Because the stump that had healed by first intention gave far less trouble afterwards than the stump that had healed by granulation tissue, surgeons were advised not to do a definitive amputation at a site of election unless they were reasonably sure of primary healing. At the beginning of the war it was considered unlikely that an amputation done near the battlefield would heal by first intention. Accordingly it became the rule to do a provisional amputation at a low level with the intention of doing a definitive re-amputation at the site of election when all sepsis had been overcome. The practice of the American Army surgeons differed from ours in regard to the provisional amputation. They were advised to perform a guillotine amputation, not to suture the skin, and to apply traction to the skin edges. When the soldier reached a hospital in the rear the skin edges were trimmed and sewn together. Our surgeons were advised to amputate as low as possible through viable tissue but to cut skin flaps and partly to close the wound; a few days later the skin was sutured completely. The introduction of the sulphonamides and penicillin so lowered the incidence of sepsis that many of these provisional amputations after secondary suture yielded perfect stumps—except that they were too long. The fiat then went forth that provisional amputations should be done at a low level certainly, but at least three inches above a joint. This gave room for the fitting of an artificial limb if the stump healed satisfactorily. Towards the end of the war British surgeons grew bolder, and under a penicillin 'umbrella' amputated at sites of election and closed the skin, as for a definitive amputation. If a future war is fought under the same conditions, namely, if there are facilities for doing clean surgery on men within a few hours of their being wounded, it is probable that the need for provisional amputations will disappear.

TECHNIQUE OF THE DEFINITIVE AMPUTATION

This has been simplified and standardised so that the same technique can be applied for all four amputations. Antero-posterior skin flaps are cut, each equal in length to half the diameter of the limb. The deep fascia is cut through at the same level, and the two flaps consisting of skin and deep fascia are dissected up to where the bone is to be divided. The muscles and bone are cut through transversely at this level. Neither the nerves nor the periosteum receive any particular attention, the nerves being cut through with the muscles, and the periosteum with the bone. In the below-knee amputation the end of the tibia is bevelled in front and the fibula is cut one inch shorter than the tibia; in all the other amputations the bone is sectioned transversely. As in all surgery, careful haemostasis is important. Drainage is optional; many surgeons are coming round to the view that a drain never avoids a haematoma. Moreover, drainage sets at nought one of the great surgical lessons of the war, namely, that however careful the precautions an open wound almost invariably becomes infected.

REHABILITATION

The war emphasised the importance of rehabilitation, and surgeons have been reminded that their duty to their patient does not cease with the healing of the stump. The stump has to be prepared for the reception of a prosthesis, and the patient after being fitted has to be taught how to use his mechanical limb. Both tasks should be supervised by the surgeon. The penalty for neglecting the first task is a waste of time only, but unless the second task is properly undertaken the amputee suffers a permanent loss. In the case of the arm, the patient must patiently teach himself how to use his new limb; he cannot learn this any more quickly or easily than a righthanded man can learn to write with his left hand. In the case of the leg, instruction in balancing and walking will enable a co-operative patient to walk without a limp. The rehabilitation of the amputee is one of the noteworthy features of the War of 1939–45.

KRUCKENBERG OPERATION

The Kruckenberg operation—separating the forearm into two prongs—was favoured by the Russians and the Germans, possibly on account of the paucity of prostheses. No British or American accounts of this operation were reported.

CINEPLASTIC OPERATIONS

The fingers or the appliance of an artificial arm are controlled by the movements of the two shoulder blades. Cineplastic operations afford additional motive units, and on that account should appeal to surgeons. The war has reinforced the opinions of German surgeons that cineplastic operations are worth while, and they have been championed by a few American surgeons. British surgeons feel that cineplastic amputations have a future but they have refrained from performing them pending the production of a suitable prosthesis, which is not yet forthcoming.

PAINFUL STUMPS

The war did not solve the problem of the painful stump. Experience confirmed the belief that previous sepsis in the sacrificed limb rendered likely a painful stump, but clean amputations performed on the day of wounding were not immune. British surgeons thought it wise to interfere as little as possible with the main nerves at the time of the amputation. Attempts were made, particularly by the Americans, to prevent traction on terminal neuromata by imbedding them in bone, but the advantages of this procedure were not apparent. Local excision of neuromata rarely gave any permanent relief. Sympathectomy helped some patients.

(ii)
Amputations and Limb-Fitting

By R. LANGDALE KELHAM
O.B.E., M.R.C.S.

PREPARATION FOR LIMB-FITTING

One of the most important facts that has emerged in connexion with the rehabilitation of those who have lost a limb in the last decade is the realisation of the importance of preparing the patient after amputation for his future as a limb-wearer and, after the provision of a suitable prosthesis, the giving of adequate training in the use of it.

Neither a perfect stump provided by the surgeon, nor the most modern and highly-mechanised prosthesis supplied by a limb-maker will, combined together, enable the patient to use the stump and the limb to the best advantage unless a carefully-thought-out system of preparatory treatment intervenes between amputation and limb-fitting. Further, a perfect stump fitted with the best type of limb will not guarantee the best functional result without training in the use of the limb after its application.

In order that a patient shall approach the subject of limb-fitting and limb-wearing in a co-operative and optimistic spirit, it is necessary to counteract as much as possible the psychological trauma resulting from amputation. Many of those who suffer amputation are subject to anxieties and fears of certain kinds which are detrimental to mental and physical recovery. These are usually found to be of a domestic and financial nature, while the fear of dependence upon others, so prevalent in the early stages, is often a dominating factor which can be relieved only by information given to the patient concerning his probable future capabilities and by allowing him to associate with those who have been successfully rehabilitated; the fact that war service casualties, and now all British people, can be provided with limbs and receive all medical and surgical treatment free of cost to themselves for the rest of their lives relieves the mind of financial worries; the fact that, should the patient be unwilling to return to his previous occupation, or unable to do so through his disability, he may be trained in any new work he desires and enabled once more to become a self-supporting citizen, relieves his mind on this aspect of the matter. By informing the patient of all these points as soon after the amputation as possible, if not before, he will approach his future with hope and determination to overcome the disablement.

Much has been done to instil a hopeful outlook by showing, to all primary amputees in Ministry of Pensions' hospitals, films which portray successful limb-wearers; by assembling cases in special amputation hospitals; by the attitude and approach to these patients by hospital staffs who have knowledge of the particular requirements of this class of disabled person, and who will permit and encourage the development of a spirit of independence.

Those who have been confined to bed for some time before and after amputation are in no fit state when they leave their beds to be fitted with prostheses. Attention is given to the general toning-up of the muscles by remedial exercises applied particularly to the spinal and abdominal groups, and to the mobilisation of all joints; joint flexion and other deformities are eradicated.

The muscles of the stump itself are given re-development exercises on specially-designed apparatus and the stump bandaged by a technique devised to remove terminal oedema. By such methods is the patient prepared mentally and physically to withstand the stresses and strains of limb-wearing.

STUMP LENGTHS

During the decade 1930–40 the number of primary amputees fitted with limbs by the Ministry of Pensions' Limb-Fitting Service was small by comparison with the 1919–29 period. Moreover, these cases were, in the main, the result of deliberate surgery. The limb surgeon had, therefore, to deal largely with 'ideal' stumps. The ideal stump had been defined in the light of experience gained in the years following the War of 1914–18, and it was aimed for by the surgeon performing the primary amputation in the years 1930–40. This was proved by a review of primary amputations performed in 1933–4 when, out of thirteen primary above-knee cases, only two could be regarded as long stumps, that is, 12 in. measured from the tip of the great trochanter. Out of twenty-five below-knee cases only one could be regarded as a long stump, the remainder being, for all practical purposes, ideal. A stump below the knee was regarded as long if it exceeded 6 in. of tibia.

The result of this was that the limb surgeon had come to expect perfection of stump from the prosthetic aspect, and re-amputation due to breakdown was very rare. War conditions necessitated the reconsideration of peace-time policy in these respects. The policy of H.M. Forces, and that of the majority of surgeons dealing with amputations among air-raid casualties, was to conserve all possible tissue at primary amputation, leaving it to a later stage to perform a definitive operation at the site of election. The result of the advent of chemotherapy was that many long stumps, which were expected to become infected and require re-amputation, healed up so satisfactorily that the patient would not consent to re-amputation merely for prosthetic reasons; nor, indeed, could the surgeon feel justified in insisting upon such a course.

It follows that the limb surgeon's approach to limb-fitting underwent a radical change. He had to fit the stump as he received it. A high proportion of the stumps received were not ideal and, therefore, more and more emphasis came to be placed upon the preparation of the patient and the stump for limb-fitting by exercises and bandaging, coupled with extremely accurate limb-fitting; thus, out of 265 below-knee cases presented for limb-fitting, 15·5 per cent. had long stumps and 25·7 per cent. had stumps which were other than ideal apart from length. Out of 235 above-knee cases, 37·5 per cent. had long stumps and 26 per cent. had stumps which were unsatisfactory in other ways. These considerations, when regarded in the light of past experience with long stumps, gave rise to some modification of fitting principles, as will be described later.

CAUSES OF AMPUTATION

The commonest causes of amputation other than trauma among those who present themselves for limb-fitting are thrombo-angiitis obliterans, diabetic gangrene and osteo-myelitis, the two former conditions being responsible for many of the double amputations. Contrary to opinions formed by limb surgeons in earlier years, further experiments have shown that, in thrombo-angiitic and diabetic cases, if the pulsation of the dorsalis pedis and posterior tibial arteries can be felt and yet amputation is necessary for gangrene of the toes, it is justifiable to attempt to conserve the knee-joint. A below-knee stump of about 3 in. but not exceeding 4 in. has been found to give the best chance of tolerating limb-wearing. It is of inestimable value that one natural knee joint be retained in cases which may become double lower-limb amputees.

GENERAL PRINCIPLES FOR FITTING ABOVE-KNEE PROSTHESIS

CONTROL AND SUSPENSION

No modification of the basic principle of ischial bearing is considered to be anatomically possible. Suspension and control, however, allow of more variation. It has been found that the optimum gait is obtained from a prosthesis activated and controlled by the stump; the attachments to the body, either by means of a suitable pelvic belt or by any other means, being merely for suspensory purposes. The limb normally prescribed to provide for this is suspended by the double swivel pelvic band with or without a single shoulder-brace. The knee joint is fitted with an adjustable knee-brake to prevent over-action of the knee, together with some device to secure rapid extension of the shin on the knee. The shoulder-controlled prosthesis, on the other hand, has an entirely free knee, the shin being extended on the knee by a movement of the shoulders which is transmitted through suspenders and leather cords acting upon an eccentric pulley fitted to the knee spindle. This type of limb, though permitting a less natural gait, is more readily manipulated over rough and hilly country and in certain occupations. This is borne out by the fact that out of 235 cases only 15·5 per cent. were fitted with shoulder-controlled limbs and, of these, 77 per cent. were fitted to patients residing in predominantly hilly country. This compares with the figure of 53 per cent. of patients of the War of 1914–18 from all districts who still use the shoulder-controlled method. These figures confirm the modern tendency to prescribe a stump-controlled limb whenever possible.

SPECIAL SOCKETS

It has been found that above-knee stumps of a certain character are liable to circulatory troubles through traction on adherent scars or to the formation of sebaceous adenomata. It was believed that these difficulties were aggravated if not actually caused by the piston action of the stump within the socket when walking, and efforts were made to devise a socket which, while maintaining ischial bearing and causing no pressure on the femoral vessels, would reduce piston action to the minimum.

A New Zealand limb-fitter, who came to Britain on a liaison visit, introduced to the Ministry's limb-surgeons and contractors a socket of his own design. The object was to maintain the ischial tuberosity on a flat seat by the pressure of a boss fashioned upon the antero-internal aspect of the socket in front of the tendons of the adductor longus. This socket was made out of willow in view of the technical difficulty of using sheet metal. Forty-nine cases for which the usual shape of socket had proved unsatisfactory were fitted with this socket. The initial results appeared good and, after twelve months of experimentation, out of thirty-nine cases then supplied, twenty-five were satisfactory with only five failures. Eighteen months later the failures amounted to fourteen out of forty-nine cases, while eleven were uncertain and appeared likely to fail.

Shortly after this experiment a somewhat similar appliance was devised with the object of providing a flat-seated socket in sheet metal. This, called the 'X' socket, was built on similar principles, but the adductor boss was omitted, this structure being thought to cause pressure on the femoral vessels. The ischial tuberosity was to be maintained on this seating by the general pressure of the front of the socket. One hundred and one cases were fitted with the 'X' socket. After trials lasting two years there were fifty-two failures and only thirty cases which could be considered successful. As with the first socket, so with this, metal had to be abandoned as a medium. With both these sockets there was found to be almost invariably an initial improvement in the stump. Piston action was clearly reduced and the symptoms tended to decrease. The main cause of failure was the fact that the tendinous origins of the hamstring muscles arising from the ischial tuberosity became intolerant to pressure on the edge of the seating. If the socket were adjusted for this, the tuberosity dropped inside the socket with the resultant weight bearing upon the pubic ramus and perineum. There was also a marked tendency for a roll of flesh to appear between the top of the socket and the perineum despite efforts to accommodate this by increasing the middle diameters of the socket, and adenomata occurred in this roll. Efforts have lately been made to preserve the undoubted benefit of reduced piston action while at the same time eliminating the other harmful effects of this socket. A new modification has been introduced which incorporates a comparatively flat seat with exaggerated adductor angle without the harshness of the flat seating as shown in the 'X' socket. This socket is now on trial and can be viewed with but guarded optimism in default of further and longer experiment.

Suction Sockets. The principle of a prosthesis being attached to a thigh stump by suction, and used without any other form of suspension, was introduced shortly after the War of 1914–18. A number of patients were fitted with suction sockets in this country at that time. Some still continue to wear these without detriment to their stumps, but the majority of the original test cases had to discard that method of fitting on account of the harm resulting in the stump. The principle of suction sockets has, however, been revived and a new type of two-way valve introduced by the Ministry's Research Department. This has now been tried in a large number of cases. While it is too early to indicate a final verdict upon the modern suction socket, experiments carried out to date fully justify continuation on the lines now being adopted.

VERY SHORT ABOVE-KNEE STUMPS

The difference in performance between that of the normal above-knee leg-wearer and that of those who have been forced to use the 'tilting table' is so great that every effort was made to fit the shortest stump with the former type of leg. It can now be said that any stump having any functional length of femur below the level of the perineum can be fitted with an above-knee type of leg. This is achieved by setting the axis of the hip joint at a very low level, carrying the socket higher laterally, accommodating the marked adduction and flexion of the socket (which is a common feature in these cases), and adding a housed roller cord medially, which forms an artificial adductor. Stumps less than 4½ in. measured from the tip of the great trochanter have been successfully fitted in this way, giving better function than would have resulted from the use of a tilting-table leg, which was the only alternative in earlier days.

THE FITTING OF ABOVE-KNEE STUMPS IN WOMEN PATIENTS

The fitting in these cases is a problem of its own. Not only is there a variation anatomically, but the aesthetic problem is greater. The ischial tuberosity is more difficult to palpate, so much so, that in many cases the fitting thereon is more approximate than accurate. Aesthetic considerations make any form of mechanical hip joint undesirable. Suspension is normally provided by means of cords from a waist-belt passing over housed rollers on the sides of the socket, or by means of a surgical corset. The prosthesis is controlled by the stump. Shoulder control is contra-indicated in most women for anatomical reasons. It has been found that the majority of women, even with short stumps, can control legs with this suspension without any mechanical hip joint. The effect of the hip joint is reproduced by the use of a medial roller which acts as an artificial adductor. In the past the suspension of an artificial limb to the patient's own corset has been undertaken in a large number of individual cases, but the issue of corsets for the suspension of a prosthesis is now available to all women amputees, the corset now being regarded as an integral part of the limb. A special corset, suitably extended and reinforced, has been designed for limb suspension, but it is not always to be recommended for patients who would not otherwise wear a corset. This form of corset has also been used for men in certain cases, either to incorporate a back support, or as an abdominal support for men with unduly prominent abdomen who have to wear artificial limbs. A maternity corset has also been designed for limb suspension and may be used by pregnant women for whom, in any case, a maternity corset is an obstetric necessity. The usual suspension in pregnancy is a loose-fitting and easily adjustable belt with shoulder straps fitted in such a way as to avoid the mammae. The psychological trauma of amputation is much more noticeable in women than in men, as would be expected, and this entails greater care in the handling and rehabilitation.

CHILDREN

The practice in vogue at one time of fitting children with peg legs during early growth was discontinued some years ago and, except in very rare cases, is no longer in use. Fully articulated limbs are fitted as a routine. A high proportion of the amputations in infants and adolescents now fitted are the result of congenital deformities, and in such cases the limb is supplied at a time when the child would naturally begin to walk. For infants wood limbs having a rigid ankle and felt foot are the most suitable for above-knee amputation. They are hand-made and the various parts are specially constructed to the size required. As growth proceeds the wooden limb can easily be lengthened as required and can easily be made to last several years. In young children with an above-knee stump of useful length, the most suitable type of control is a three-point elastic suspension with an elastic patella-strap. At a later stage, or dependent upon the rate of growth and general development, metal limbs with all the modern mechanical refinements can be supplied. Children learn very rapidly to walk on an artificial limb but, their main desire being to move from place to place as quickly as possible, it is difficult to ensure or teach a good gait, but bad habits developed can be corrected in later life.

PROSTHESES FOR AMPUTATION THROUGH THE KNEE

Though this type of prosthesis is somewhat clumsier and relatively heavy, the patients wearing it walk well when trained despite the fact that for the time being, for mechanical reasons, it has not yet been found possible to incorporate an adjustable knee-control. A stump resulting from disarticulation at the knee is not subject to the circulatory defects found so often among long above-knee and transcondylar stumps, and this amputation is sometimes advised in cases where there has been an old osteo-myelitis of the femur or other condition which renders bone or muscle-section inadvisable; also when dealing with elderly patients for whom speed and absence of shock are important factors. Unfortunately, the type of limb that must of necessity be prescribed for disarticulation at the knee, transcondylar amputations, or very long femur stumps in which there is a bulbous end to the resultant stump, must also be fitted with a blocked leather adjustable socket which increases the weight of the limb and is hot to wear. Owing to the length of the stump no internal knee mechanism can be fitted, the knee-joint being of the external free-swinging variety.

THE FITTING OF BELOW-KNEE AMPUTATION STUMPS

WEIGHT-BEARING

In the case of below-knee stumps the choice of the weight-bearing area is more open, the alternatives being tibial-bearing, part tibial and part thigh, and ischial-bearing. From past experience and because the stumps which were dealt with during the War of 1939–45 were, in a high proportion, not ideal, it has generally been found necessary to distribute the weight between the tibial-bearing and the thigh in all cases in which the stump was capable of tolerating a moderate degree of tibial-bearing. By this means it was hoped to ensure that the stumps should last the patient's lifetime, in contrast to the many stumps of the War of 1914–18 which became intolerant to full tibial-bearing after a few years. The use of the ischial-bearing corset is confined to cases in which there is a definite risk of a breakdown of the stump, should any tibial-bearing be permitted.

CHOICE OF MATERIAL

The choice lies between a metal and a wooden leg. The difference in weight between these two is very small indeed. The longer the stump below the knee the more suitable is the wooden leg because the leather socket which is customarily fitted to a metal limb proves unhygienic for long stumps. However, in practice it is found that in provincial limb-fitting centres of the Ministry, where the surgeon has the services of only one fitter at his disposal, he very often has to be guided in his choice as to material by selecting that with which the fitter is most skilled. The satisfactory fitting of a wooden socket requires a higher degree of craftsmanship. Out of each hundred legs supplied to below-knee amputees, thirty are wood. For the short below-knee stump a metal leg has the advantage by virtue of its detachable leather socket.

WOMEN

Materials for below-knee amputations among women are dealt with on similar lines, with the exception that ischial-bearing corsets are avoided whenever possible. The wooden limb is preferred by many women as giving a better cosmetic result and causing less damage to stockings. It entails, however, most skilled craftsmanship, both in the fitting of the socket and the external finish, the latter being important to ensure that an exact copy of the outline of the natural calf is reproduced.

CHILDREN

In the past when dealing with children it has been the policy to avoid as far as possible full tibial-bearing owing to the risk of dislocation of the upper tibial epiphyses, a number of such dislocations having occurred in years gone by. It is now found, however, that this risk is much reduced, if not eliminated, by scrupulous attention to the correct adjustment of the back check ligament fitted to the prosthesis, which is designed to prevent hyperextension at the knee-joint. The result is that now it is possible to fit young children at the earliest age of eighteen months and upwards with a long semi-soft tibial-bearing corset.

SUSPENSION

The alternatives are to attach a limb to suspenders passing over both shoulders or over one shoulder, or to a waist belt. A corseted form of waist belt has been used with success in some cases. There is, however, a strong tendency to fit women in particular without shoulder or waist suspension, the limb being retained on the stump by means of a leather soft-lined strap, riveted to the upper steels above the knee joint, which passes across the lower end of the thigh immediately above the patella.

SHORT BELOW-KNEE STUMPS

As with short above-knee stumps, which are fitted wherever possible with some form of above-knee limb rather than with a tilting table leg, so with short below-knee stumps it is desired to fit a limb which retains the movement of the natural knee-joint rather than immobilise it in what is termed a 'kneeling limb'. A new type of knee-joint known as the polycentric knee-joint was introduced, this joint approximating more nearly to the movement of the natural knee, but while it was found to be of great benefit in the fitting of these short stumps it was found to be mechanically unsound. Fortunately it was realised that results could be obtained equal to those found when using the polycentric joint by a careful fitting of the leather detachable socket in the metal limb, the careful positioning of the artificial uniaxial knee-joint, and the use of a four-point elastic suspension between the socket and the corset. By this means stumps having but 2 in. of tibia have been successfully fitted with below-knee prostheses, the shortest stump fitted to date having but 1¼ in. of tibia.

THE SYME STUMP

Many of the Syme stumps presented for limb-fitting during the past few years continue to exhibit all the defects of long stumps. Full end-bearing, therefore, is no longer practised as a routine. It is customary in the modern Syme prostheses so to construct the socket that a considerable part of the body weight if not all can be carried upon the tibial-bearing surfaces rather than on the stump end. Nevertheless, when the stump is good the wearers of Syme prostheses walk extremely well and the stumps give little trouble. The appliance is, however, on account of the necessary bulbous extremity of the stump, of bad cosmetic appearance and relatively heavy.

SPECIAL DEVICES

A number of special devices have been introduced in recent years. With some, the results have been inconclusive. Among these is what has been termed the 'free-wheel' knee control for above-knee prostheses. This is a device in which the braking effect of the control operates only on flexion at the knee. It has been used with success by a number of patients.

Several patterns of lateral ankle joint which permit of an inversion and eversion of the foot have been introduced. Medically this device should prove of great benefit since the foot adapts itself to cambered surfaces. It has proved very popular among a limited number of test cases; others, however, complain of a feeling of instability. Mechanically, the joint is not yet perfect. For those having an above-knee amputation who are fitted with a pelvic band incorporating steel, a hinged pelvic band steel has been devised. This has proved of benefit to a number of patients; it gives more comfort in the sitting position.

PLASTER PYLONS

The policy of the Ministry's surgeons concerning the use of plaster pylons continues to be summarised by the phrase 'fit for pylon, fit for limb'. Thus, pylons are now used only occasionally and then either for the purpose of obtaining shrinkage of the stump preparatory to limb-fitting, which shrinkage is not obtainable by bandaging for various reasons, or where there may be a delay in the manufacture of the permanent prosthesis and it is desirable for psychological reasons to render the patient ambulatory at an early stage. When considered in relation to the below-knee stump it has been found that a number of stumps in earlier days have suffered harm as the result of the too-early fitting of a pylon, a device which should not be fitted to a below-knee stump when tibial-bearing is clinically contra-indicated.

AMPUTATION OF UPPER EXTREMITY

GENERAL

The variation in stump lengths and in conditions among stumps of the upper extremity has been found to be as marked as in the case of the lower extremity, but this is of less consequence to the surgeon and to the subsequent limb-wearing, except in so far as the long stump may interfere with the fitting of useful mechanical devices to the prosthesis. Circulatory defects of the long stump continue to present themselves but are less obtrusive.

Pain in the arm stump and in the phantom limb is more than twice as common with arm cases than with lower limb amputees, being present in 50 per cent. of the arm cases reviewed, and in only 20·5 per cent. of the leg cases. There was no significant difference in frequency between the above- and below-elbow amputations. The high incidence of pain in arm cases is probably due to the greater psychological trauma suffered by the man whose arm has been amputated, and who regards his disability as a greater mutilation and his prosthesis as an inferior substitute for what he has lost. For this he has every justification.

ARM PROSTHESES

Arm prostheses in use by the Ministry have been improved and simplified and, to some degree, a mechanical standardisation has been achieved, the best features of several makers' productions being incorporated. The Ministry has stressed the policy of retaining the artificial hand for dress, and for carrying and writing purposes, special appliances having been designed for specific tasks. Many new appliances have been devised and improvements made to older appliances. The modern policy of supplying arm prostheses at the earliest possible date after amputation, together with energetic instruction in the use of the prosthesis after supply, has resulted in a considerable improvement in the numbers successfully equipped both during and since the War of 1939–45 as compared with the War of 1914–18.

APPLIANCES AND MECHANICAL HANDS

When the arm amputee has been fitted with his first prosthesis he is given an opportunity of using and trying out a large number of appliances in the Arm Training Centre, eventually choosing a few of those which will be most suitable to him for his future occupation and daily life. He is encouraged to make each appliance serve as many functions as possible, as indeed they do, thus reducing the number he has to carry about with him. In many cases special appliances have been designed to meet the individual requirements of a patient, either at his work or in his recreation, such as for golf, fishing or shooting.

Much thought and experimentation have been devoted to improving the lot of the double-arm amputee with a view to making him less dependent on other people. These experiments have met with success. New office appliances, a desk-telephone appliance and a number of other improvements have been introduced. Rubber sleeves have been made to fit over the bare arm stumps and to these can be attached all the articles necessary to enable a double-arm amputee to perform unaided his toilet, bathing, shaving, etc.

MECHANICAL HANDS

While, since the close of the War of 1914–18, the Ministry has concentrated upon the use of appliances with artificial arms because the mechanical hands of those days were found to be too heavy for the average arm user, the production of a more efficient and lighter mechanical hand has not been lost sight of. Within recent years two new mechanical hands have been designed and are being tested by a number of patients. These hands are both lighter and of greater functional value than any previously produced in this country.

VERY SHORT ABOVE-ELBOW STUMPS

The very short above-elbow stump has been successfully fitted with the standard above-elbow limb by the incorporation in the socket of an extended shoulder-cap and the use of a Bowden cable control attached to a waist-belt for one of the motors. In practice it is desirable that there be a minimal projection of humerus beyond the lower level of the axilla for this limb to be a success. Although this arm has been fitted to stumps having as little as 1½ in. of humerus, measured from the tip of the acromion process, the old through-shoulder type of prosthesis continues to give satisfaction in many very short above-elbow cases. The above-elbow prosthesis issued to patients with humeral stumps of satisfactory length has an automatic elbow-locking mechanism which is controlled by shoulder movements. This has been found satisfactory, though many patients continue to operate the locking mechanism by means of the sound hand.

SHORT BELOW-ELBOW STUMPS

In earlier days short below-elbow stumps were fitted with a prosthesis incorporating jointed steels at the elbow, to which was attached an upper-arm corset, but recently increasingly successful results have been obtained with a new form of harness known as the 'non-corset type appendage' which obviates the need for upper-arm corsets and side steels. This is now in regular use for most below-elbow cases, whether the stumps be short or long.

THE GAUNTLET ARM

The prosthesis designed for a disarticulation at the wrist has always been a somewhat unsightly and heavy appliance; and, though it still continues to be used by those performing heavy work, for those engaged in lighter occupations a 'gauntlet' arm has been evolved which has proved very satisfactory and is favoured by many double amputation cases, especially those who are, in addition, sightless, because the extremity of the gauntlet is open and patients can derive benefit from the tactile sensation of the stump which remains.

MUTILATED HAND APPLIANCES

Much development has taken place in the provision of appliances for the partially mutilated hand, very many such cases having to be dealt with from the War of 1939–45 through the explosion of hand-grenades, etc. There can, however, be no form of standardisation in the prostheses designed to meet this disability and each individual case requires special consideration and special design.

CHILDREN

It is customary to supply a prosthesis to a child before school age begins. There is a clear psychological advantage in doing so and functional benefit is obtained through accustoming the child to limb wearing at an early age, preventing him from becoming 'one-hand minded'. At a very early age the simplest type of prosthesis is prescribed. Later the child is given a more mechanised arm at a time appropriate to his mental and physical development.

TRAINING IN THE USE OF THE LIMB

LOWER-EXTREMITY PROSTHESES

The patient receives some initial instruction from his limb-fitter during the fitting stages of limb-making. When the prosthesis is completed and has been accepted by the limb-surgeon, the patient starts training in the walking school. Hand-rails, except for elderly people, are no longer used, the patient being trained while using two walking-sticks. For double-leg amputations and those who tend to acquire a lordotic stance a system of overhead parallel bars is used. With these, the patient walks within the rails, sliding his hands along the overhead bars, his arms being fully extended above his head and thus producing an erect stance. The training is so arranged as to teach balance, confidence and rhythmic walking, for which latter purpose the use of music from a gramophone is a great advantage. During the course, the patient is taught to perform all the usual movements associated with progression such as turning, stooping, sitting down, rising from a chair, and walking over various surfaces and stair-climbing. At the end of the course the pupil has become accustomed to his prosthesis and has developed confidence in his ability to use it.

UPPER-EXTREMITY PROSTHESES

In the arm-training school the pupil first learns how to control the prosthesis. He then begins to use various types of appliances while doing some elementary carpentry until he discovers which appliances are most suitable for performing the various functions he will have to carry out in his normal daily life. Woodwork gives the best opportunity of learning the use of appliances. If, during the training stage, the patient has decided his future career he can practise with those appliances most suited to him. Apparatus is provided in the training school to enable the pupil to practise upon taps, levers, door handles, light switches, etc. He may practise writing and typing, and sports are not neglected.

The time taken for carrying out the training in average cases is: one week for below-knee amputation, and two weeks for thigh amputation. For double-leg amputations it varies from three to six weeks. The time spent in the arm-training school averages from ten days for single amputation to a month for the double amputation.

(For further details of the arrangements made for limb-fitting centres see the Ministry of Pensions Contributions, Chapter 5, in the Second Volume of the History of the Civilian Health and Medical Services, in this Series.)

CHAPTER 22

PHYSIOTHERAPY AND REHABILITATION

(i)

Physical Medicine: The Clinical Side

By Sir ROBERT STANTON WOODS
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LOCALISED AND GENERAL ACTIVITY

In the application of the methods of physical medicine, there was an outstanding clinical advance during the war.

For many years, especially in conditions following trauma, in addition to the more 'passive' therapeutic measures—massage, thermotherapy, electrotherapy, actinotherapy and hydrotherapy—movement at the joints of the affected region formed part of the technique of physiotherapy. Formerly, the effort activating this movement was supplied by the technician—passive movement. That this might lead to abuse was obvious; the movements might readily become too forcible and too prolonged, and undoubtedly a certain amount of harm did result. Gradually, therefore, the technique changed to 'active' movement; thus making use of pain as a brake on either too violent or too prolonged kinesitherapy; passive movement was replaced by a combination of 'activity' on the part of the patient and 'assistance' by the technician. This method has not only the negative advantage of increased safety, but the active movement of muscles is encouraged.

Very early in the war years there gradually occurred a further and much greater advance in the use of activity. Even before the war certain progressive hospitals had been practising and teaching the enlistment of general body activity as a therapeutic factor in the restoration of health, but this practice underwent wide extension during the war. This was not by any means confined to cases of trauma. General body activity was increasingly employed in rehabilitation after almost any illness in which it was not definitely contra-indicated. The effect sought was two-fold. Physically, on the one hand, it was calculated to stimulate the circulation in locomotor tissues, thus helping to restore the function of these at a much earlier stage than formerly. A similar influence was brought to bear upon the circulation in thoracic and abdominal viscera. On the other hand, there cannot be much doubt that the resumption of such activity had, in the majority of patients, a profound influence upon morale, especially where day-to-day progress could be demonstrated.

War conditions, with the very great extension of facilities, and the interchange of ideas and encouragement of inter-hospital visiting on the part of medical staffs, gave opportunities to many more medical men for the practice of an almost revolutionary innovation.

The use of early general body activity was also extended to abdominal surgery, obstetrics, head injury, thoracic injury, etc. One of its really spectacular applications, practised to a limited extent before 1939, was to be found at centres for spinal injury. In these institutions, four days after a vertebral fracture it was common to see groups of air-pilots and commando troops undertaking the most strenuous back-exercises with only a close-fitting plaster for security.

GYNAECOLOGY AND OBSTETRICS

The principles laid down in the following extracts from a statement by a gynaecologist and obstetrician at one of the teaching hospitals in London apply equally to the majority of these institutions:

> Extensive use is made of physical medicine in the obstetric department at this hospital. There are classes for ante-natal exercises and for instruction in relaxation during labour. Even more important are the post-natal exercises which begin soon after delivery with small movements of the hands and feet and deep breathing, and which progress to really strenuous exercises including pelvic tilt and pelvic-floor movements before the mother gets up. There is no doubt that this régime is of both physical and psychological benefit. . . . At a later post-natal stage there are exercises for the correction of incipient prolapse and weakness of bladder control.
>
> On the gynaecological side, in the bed-fast stage, deep breathing and early post-operative mobilisation, with the exception of the actual operation site, have proved of great value. The incidence of thrombosis and embolism is lower to-day than it was ten years ago, and mobilisation is an important contributary factor in the reduction of these complications. Patients get 'up' much earlier than formerly, even on the fifth day after major operations, and hitherto there have been no untoward results.

This régime of very early post-natal activity was introduced even before the war, but only at exceptional institutions; war conditions, with the wide dispersal of advanced teaching and the evidence of the benefit which accrued from early general bodily activity after trauma in E.M.S. hospitals, led to an extension of this practice to obstetrics. It was, therefore, a common experience to see the patients in a maternity ward carrying out bed-exercises under the leadership of a physiotherapist, and testimony was very generally expressed to the resulting benefits, mainly in respect of hastened convalescence and to the much more fit final condition of the mother.

GENERAL SURGERY

The introduction of this régime in obstetrics and gynaecology had its counterpart in general surgical practice. A senior surgeon on the staff of one of the teaching hospitals in London provides an account of his own practice and views in the following terms:

> *Breathing exercises* constitute a most excellent régime, both before and after laparotomy, in all abdominal operations. This applies with special force where

general anaesthesia is called for. The exercises should be carried out at least thrice daily, and it is of the greatest moment that inspiration should be deep. It is obvious, therefore, that the régime, to be effective, must be supervised.

General exercises. Systematic, active movements of the limbs during the bed-fast stage are almost certainly a powerful factor in lowering the incidence of post-operative thrombosis. This applies with special relevance to the lower limbs. Unless there is contra-indication, body activity drill is instituted almost immediately after the first effects of the operation and of the anaesthetic have passed. The earliest movements involve only a minimum of activity but very rapidly their extent increases and in combination with regulated and supervised breathing will soon merge into general class exercises in bed. Experience has shown not only that such a régime is safe but that it has a profound effect upon physical and psychological recovery. There are of course certain conditions, as for example, thyrotoxicosis, in which systematic and increasing body activity may be entirely contra-indicated or must at least be modified.

'MEDICAL' (NON-SURGICAL) CONDITIONS

This therapy of general body activity had its part to play in the restoration of physical and psychological well-being at equally early stages of recovery from non-surgical somatic illnesses. Nor was psychological rehabilitation by means of the therapy of organised activity limited to the psychological accompaniment of somatic illness. At all the E.M.S. centres for the non-complicated neuroses, supervised and organised exercise formed an essential part of the régime.

REFORM IN THE APPLICATION OF PHYSIOTHERAPY

For some years, observers in control of departments of physical medicine in hospitals have been conscious of a major defect in the application of physiotherapeutic methods. The basis of these forms of treatment is fundamentally an activation of the local circulation. The custom therefore which has for long been current in hospital out-patient practice—namely, a visit three times a week for treatment which lasts on an average forty–forty-five minutes—would appear to be so inadequate as to be almost useless. Half-an-hour's application of massage, electrotherapy or thermotherapy with an interval of forty-eight hours between the visits has been stigmatised as farcical— a description which it would be difficult to refute. Indeed, a not uncommon routine is for these visits to be reduced to twice a week; once in seven days is occasionally met with and certainly does deserve the stigma of farce. Recent experience has provided overwhelming evidence in favour of a routine in which physiotherapy is administered three or even four times daily. It is true that, even with the great extension of facilities introduced under the E.M.S., daily treatment would be impossible without a drastic reduction in the numbers of patients receiving this treatment. There is little doubt that the numbers of patients attending departments could with advantage be considerably reduced; partly by curtailing courses of treatment which tend to be protracted indefinitely and partly by a more experienced and realistic and less empirical selection of cases.

(ii)

Application of Physical Medicine to Disease and Injury of the Chest

By F. S. COOKSEY
O.B.E., M.D.

During the fourth decade of this century physical educationists paid little attention to the mechanism of breathing. This was partly owing to the generally accepted view that respiratory function develops as a physiological response to physical activity, and partly due to the vogue for free activity in preference to formal physical training. Nevertheless, the expansion of the Armed Forces before the outbreak of war revealed a high proportion of physically defective recruits in whom flat chests, round shoulders and low vital capacity were common findings. The Army established physical development centres to deal with this problem and found that, while it was possible to improve the physique of these recruits, structural defects could not be reversed at an age when growth had almost ceased. Subsequently it was recognised that these defects started early in childhood and could be prevented only by adequate physical education from the commencement of schooling. During the same period it was customary to treat disease and injury of the chest by rest in bed and local rest for the affected lung until inflammatory changes had resolved. Commonly this period extended over several weeks and the combination of toxaemia and immobility led to loss of weight, fixation and deformity of the thorax, incomplete aeration of the affected area of the lung and reduced vital capacity. Breathing and chest-mobilising exercises were employed in convalescence, but often months of treatment failed to restore full function because inflammatory exudates had reached an advanced stage of organisation before the start of remedial therapy. The efficacy of prolonged rest in the treatment of phthisis was the main reason why rest was favoured in the acute stage of all respiratory disorders, and even when remedial exercises were used the approach was over-cautious for fear of lighting up infection.

Before the war the Brompton and London Chest Hospitals began to employ remedial exercises earlier in the treatment of thoracic disorders and found thereby that the rigidity of the thoracic cage could be prevented or corrected more easily and that aeration of the affected lung accelerated resolution of the inflammatory changes, provided the patient was on top of the infection. The introduction of the sulphonamides and advances in surgical technique led to more speedy control of infection and this enabled remedial exercises to be started within a few days of the onset of illness or early in post-operative treatment, so that it was possible to expand the affected lung and mobilise the thorax before exudates had time to organise. Thus the outbreak of war coincided with awakening interest in the prophylactic and therapeutic use of remedial exercises in thoracic disorders. This field proved second to none in the scope it provided for the methods of medical rehabilitation which were developed during the war.

THORACIC SURGERY CENTRES

At the outset arrangements were made to include physiotherapy. Shortly afterwards other forms of physical medicine and medical rehabilitation in process of development were added. These were group remedial exercises and games; occupational therapy; organised education and recreation especially for children and young adults in the Forces; social service; vocational training and industrial resettlement. The system of medical rehabilitation which was developed for all branches of medicine and surgery is described elsewhere. In this section it is necessary to refer only to those details of special application to disease and injury of the chest.

Breathing Exercises. The restoration of respiratory function being of primary importance, breathing exercises became the predominant feature in the rehabilitation of chest cases. These exercises were not limited, however, to inspiratory and expiratory movements as the name, convenient in its brevity, implies. Breathing exercises alone led to hyperventilation and whenever possible they needed to be preceded by and interspersed with general exercises to increase the demand for oxygen. Moreover, the respiratory excursion necessary to expand lung tissue in the presence of organising exudate was obtained more readily if the patient were rendered dyspnoeic by physical exertion. Such physical activity was found to have the further advantage of preventing the stiffness and loss of weight to which reference has been made. The value of early, vigorous and progressive breathing and general exercises together with early ambulation was soon established. Consequently it was usual to find patients ready for exercises in the gymnasium or out of doors in fine weather within a week or two of operation or infection. In the acute stage, and more especially before infection had localised, physical activity was contra-indicated so that breathing exercises only were used as, for example, to prevent atelectasis in the immediate after-treatment of thoracic and upper abdominal operations or to expand lung collapse by haemothorax. At this time breathing exercises needed to be limited to the minimum which would be effective; but a few assisted movements to prevent stiffness and to maintain posture were included with advantage. The optimum was found to be five or ten minutes' treatment three or four times a day with adequate rest periods to prevent hyperventilation and fatigue. At the same time patients were encouraged to practice their exercises at frequent intervals. In most cases it was possible and beneficial to introduce general exercises within a few days of operation or the onset of infection, and thereafter to increase rapidly the strength and duration of the exercises. However, in the early stages chest cases were prone to exacerbations of infection and the associated toxaemia, so that quite often it was necessary to suspend or modify the exercises according to the day-to-day, even hour-to-hour, condition of the patient. To this end close liaison between the medical and ancillary staff was essential.

Group Exercises and Games. The shortage of physiotherapists made it impossible to give adequate individual attention to all cases in the rapidly expanding thoracic surgery centres until group exercises were introduced. These were known from pre-war experience in the treatment of asthma to stimulate interest and the competitive spirit, so that long periods of remedial exercise could be performed without boredom; but their use had been restricted in the main to ambulant patients. It was found that group exercises could be used with the same advantage for bed patients as soon as they were beginning to convalesce, though in the early stages most patients required some individual instruction as well. Gradually five stages or progressions of remedial exercises became the established practice. Commencing with individual treatment in bed, patients progressed to group exercises in bed, sitting group exercises in the ward, easy group exercises and games in the gymnasium or out of doors, and finally to advanced exercises and games. At each stage the exercises were increased in strength and duration until they occupied thirty minutes or longer twice or three times a day. Further improvement followed the employment of remedial gymnasts for group exercises and games. These remedial gymnasts were women graduates of the physical training colleges, most of whom were qualified also as physiotherapists, and men seconded from the Army Physical Training Corps. Remedial gymnasts have training and experience of class instruction in which they use sustained and vigorous remedial exercises, freely interspersed with games adapted to produce the movement required. The effect of this was seen in the full restoration of respiratory function and physical fitness. For example, it was found in cases of empyema that the cavity could be obliterated rapidly by some fifteen minutes' vigorous general exercises interspersed with inspiratory exercises to expand the adjacent lung, followed by a similar period playing volley ball; the latter game being chosen to mobilise the shoulder girdle. This procedure, often starting within a week of operation, was carried out twice daily out of doors in fine weather with the patients stripped to the waist except for a small dressing to retain the drainage tube. At first, patients and ward sisters objected to the unaccustomed exposure of the chest, but resistance ceased when the advantages were seen in patients of all ages and sexes. The enthusiasm aroused by a capable remedial gymnast was in marked contrast to the apathy so commonly observed in exercise classes conducted by physiotherapists, most of whom lack adequate training in this work.

Specific Remedial Exercises. It was customary to prescribe inspiratory or expiratory breathing exercises according to the need of the case; but, in practice, both were combined. Full inspiration was secured more easily if the lung were first emptied. Full expiration could be obtained in asthma and bronchitis only if inspiration were controlled. Increase in tidal air and thus in vital capacity, required a full expiratory and inspiratory excursion. *Inspiratory* or lung-expansion exercises were used in atelectasis, pneumonia, empyema, after the removal of a lobe or lung, and as a prophylactic before and after operations on the upper abdomen. The classical method of expanding collapsed lung by forced expiration against resistance such as Wolff's bottles or the closed glottis has the disadvantage that the positive pressure is distributed to all parts of the lung and the diseased or injured area usually offers greater resistance to expansion due to fibrinous exudate. This method was discarded in favour of true inspiratory exercises in which use was made of the negative pressure created by the elevation of the ribs and descent of the diaphragm, the effort being localised to the affected area by a combination of posture and manual pressure to restrict movement in the unaffected lung. Localisation of the inspiratory effort was further facilitated by the physiotherapist giving moderate manual counter-pressure so that the ribs had some resistance against which to work. Later on in group work, patients learned to give counter-pressure to expansion and to fix the unaffected lung with their own hands. With skilful instruction it was found possible to localise expansion to any desired area and the range of movement obtained was surprising. *Expiratory* exercises were used in asthma and chronic bronchitis and were combined with relaxation and mobilisation of the thorax. During the war attention was drawn to the value of expiratory exercises combined with postural drainage in lung abscess, bronchiectasis and post-operative basal congestion. When the pathological secretion was tenacious it was found to be efficacious to combine postural drainage and expiratory exercises with chest manipulations known as clapping and pounding, which have the effect of dislodging secretion and stimulating coughing. Patients admitted for operation for bronchiectasis and certain other pulmonary disorders (except phthisis) combined group postural drainage and expiratory breathing exercises to drain the affected area with exercises to increase the vital capacity of the unaffected part of the lungs before operation. Some cases of bronchiectasis improved so much under this conservative treatment that operation became unnecessary. The development of thoracoplasty in the treatment of phthisis required breathing exercises for a few days after each stage to prevent atelectasis of the unaffected base, and postural bed-exercises designed to prevent scoliosis with the minimum of physical effort.

Massage. Massage for the legs, arms and back was found useful in the early stages of convalescence for patients with marked muscle wasting after severe or prolonged toxaemia; but improvement in surgical technique and chemotherapy together with early ambulation and remedial exercises reduced these cases to a minimum.

Electrotherapy. Heat in the form of radiant heat or short-wave diathermy was found useful to relieve the pain of operative and traumatic wounds, and especially for the capsulitis of the shoulder joint which was a common complication of thoracic disorders. In the early days diathermy was used in the treatment of sepsis; but with the improvement in chemotherapy the need for this largely disappeared. In non-tuberculous cases ultra-violet light, in the form of natural sunlight when conditions permitted, proved a useful stimulant in patients who had been ill for some time. It was noted that irradiation of the chest wall might have a deleterious effect on intra-thoracic inflammation and it was found desirable to shield the chest until the patient had been observed to be responding well to exposure of other parts of the body.

Occupational Therapy. Remedial occupational therapy had little value in the treatment of thoracic disorders; but diversional therapy was appreciated by patients kept in hospital for long periods and was used to prevent boredom and the loss of functional activity. In phthisis light bedside handicrafts were invaluable and often formed the basis of sheltered work in convalescence. The majority of chest cases retained normal mental faculty and manual dexterity so that occupational therapy was limited to the maintenance and restoration of functional activity during their stay in hospital.

Educational and Recreational Therapy. This subject was of major importance in the management of phthisis. During the war organised education and recreation was provided for all young adults in the Services during their stay in hospital; but no special problems arose in connexion with thoracic cases.

Vocational Training and Industrial Resettlement. In chest cases manual dexterity and mental function were seldom affected and the extent to which rehabilitation was possible depended mainly upon the restoration of adequate vital capacity, the arrest of chronic infection, and the degree of incapacity imposed by irreversible degenerative changes. The restoration of vital capacity was secured by breathing and chest mobility exercises at hospital. When this was possible vocational training was unnecessary, and industrial resettlement presented no problem other than the availability of the normal employment of the individual. In some cases of pneumonectomy and bilateral lobectomy it was found impossible to restore adequate vital capacity for occupations requiring considerable physical exertion, and vocational training followed by resettlement in lighter work became necessary. Emphysema and degenerative changes secondary to chronic infection, silicosis and pneumoconiosis result in varying degrees of permanent incapacity and it was necessary to provide work in which the physical requirements and working conditions in respect of dust and exposure were within the residual capacity of the individual. The Disabled Persons (Employment) Act 1944 made provision for the vocational training and industrial resettlement of all disabled persons. In practice difficulties arose with thoracic cases because the patients who needed help were unsuited for vocational training on account of age, and the relatively unskilled alternative work available offered poor financial return in comparison with the skilled work or responsible position to which they were accustomed. In phthisis the disease either became quiescent so that patients were able to resume their accustomed work or they needed continuous medical supervision and sheltered employment on the lines long established by Papworth Village Settlement and Preston Hall. During the war no significant advances were made in the methods for rehabilitation of the tuberculous, although indirectly earlier diagnosis through mass radiography, special allowances and advances in surgical technique improved the prospects of rehabilitating these cases.

(iii)
Physical Medicine for Foot-strain

BY E. J. CRISP
M.B., B.Ch.

Up to 1939 foot-strain was regarded very largely as a feminine complaint, usually the result of wearing unsuitable shoes. The World War of 1939–45 quickly disproved this idea. Whereas the War of 1914–18 was largely static, the later war was one of speed and movement. demanding absolute physical fitness. This meant that all recruits had to undergo a most rigorous training. The consequences were completely unexpected, and the large number of recruits continually reporting sick with foot-strain soon constituted a major problem. In contrast with the mild foot-strain met with in peace-time, the condition was frequently extreme. Though many cases responded to routine out-patient treatment, a considerable number were sufficiently acute to require admission to hospital. The Army had few home-based hospitals, and the majority of cases were treated in E.M.S. hospitals.

Symptoms. Many recruits told a similar story. Their feet had given no trouble in peace-time and had stood up well to preliminary military training, but after a long route march they became painful and never had a chance to recover. Others stated that their feet had always been liable to become painful, and that military training had aggravated the predisposition. Foot-strain was not confined to recruits. Fully trained soldiers, after transfer from motorised transport to infantry, frequently developed acute pain in the feet after prolonged marching. Patients usually complained of acute pain in the plantar fascia and spring ligament, under the metatarsal heads and the external malleolus, and said that the pain was not relieved by a night's rest. For a time the tendency was to suspect malingering, but the clinical picture was so constant that it became obvious we were witnessing an acute fatigue syndrome.

Clinical Picture. When standing the feet were invariably in the valgus position. On examination they were found to be stiff, painful to touch and often swollen or perspiring. A proportion of cases were complicated by spasm of the extensor longus digitorum muscle, causing the toes to be clawed or to stick up in the air. The spasm persisted in the recumbent position, relaxation being impossible. This very interesting condition is best described as '*pes valgus* with clawed toes' and probably develops in the following manner. In consequence of the suppression of the action of the tibialis anticus muscle through sheer fatigue, the extensor digitorum longus muscle attempts to mimic its action as chief supporter of the long arch and dorsiflexor of the foot. The extensor digitorum longus next goes into spasm; so long as the lumbrical muscles remain competent the toes stick up in the air, when that fails they become clawed. This condition, once fully developed, is extremely difficult to treat.

CAUSES OF ACUTE FOOT-STRAIN

Before discussing treatment it will be well to consider briefly the various causes contributory to this epidemic of valgus foot-strain.

1. *Faulty Grading.* Many recruits with defective feet (e.g. short tendo Achillis, high longitudinal arches, etc.) were placed in Category A 1.
2. *Faulty Foot Posture.* The conventional Army posture with the feet turned well out is a contributory cause of valgus strain.
3. *Marking Time.* Prolonged marking time and stamping on hard surfaces bruises the feet unnecessarily.
4. *Weight of Army Boot.* The boot is comfortable and of excellent design, but extremely heavy. The weight of the boot was frequently the direct cause of the fatigue of the tibialis anticus muscle.
5. *Fatigue.* Ill-judged progression of training in faultily graded personnel led to acute fatigue. (Some men are sprinters, others are long distance runners; in the Army they are expected to be both.)

TREATMENT

In the early war years the less severe cases received out-patient treatment only, but in the light of experience it became customary to admit all cases of acute foot-strain to hospital. By this means the soldier was returned to duty with the least possible delay.

Rest. The first essential in treatment was complete rest in bed until all pain and spasm had gone. After this, treatment of the uncomplicated case was comparatively simple. Non-weight-bearing remedial exercises were performed in bed for several days and the patient then allowed to get up. He continued to receive individual attention from the physiotherapist until all faults in function were corrected. After this he progressed through carefully graded remedial classes until fit for discharge to convalescent depot. Cases of this type normally required 3–4 weeks in hospital.

The case complicated by spasm of the extensor digitorum longus required considerable individual attention from the physiotherapist. The first essential was to train the tibialis anticus muscle to contract, and to dissociate its synergist the extensor digitorum longus and teach it to relax. This was done by training the patient to dorsiflex the foot while at the same time plantar-flexing the toes, and vice versa to extend the toes while plantar-flexing the foot. It was often necessary to employ surged faradism to recondition the tibialis anticus and the intrinsic muscles of the foot. Once normal muscle function was restored progression of rehabilitation was the same as for the uncomplicated case, but the whole process meant six to eight weeks in hospital. Treatment was not complete until the case had been regraded and placed in the correct medical category, and where necessary light boots prescribed.

PROPHYLAXIS

Prevention is better than cure and conscription is still with us. Many cases of acute foot-strain in the war would never have occurred if categorisation had been more accurate, and progression of training more intelligent. During the latter years of the war, in consequence of experience, the Army ceased to insist on the soldier turning his feet out at an exaggerated angle when standing or marching, and modified the method of marking time. This considerably reduced the incidence of foot trouble. If training is always suitably graded, and foot inspections are frequently made, the problem of foot-strain should be reduced to reasonable proportions.

SUMMARY

The E.M.S. may be said to have rendered a major service by the way it coped with foot-strain in the Forces. Not only did it treat many thousands of Service cases, but it was able to give the authorities concerned invaluable advice on how foot-strain could be reduced to a minimum. So far as the Services were concerned it was shown conclusively that in-patient treatment was far more effective than a daily attendance as an out-patient.

(iv)

Medical Electrology in War-time

By P. BAUWENS
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It is often said that from the material and strategic point of view a new war begins where the previous one left off. Whatever the truth in this statement, it held good in 1939 so far as physical medicine was concerned. The Second World War began with the issue of instruments of the type which graced physiotherapy departments towards the end of the First World War. Despite this initial handicap relating to equipment, valuable work was carried out in the field of electrodiagnosis and electrotherapy—particularly where the management of peripheral nerve lesions was concerned. From the mass of material available much was learned as to the value of certain treatments and much was initiated which it is gratifying to note is still receiving attention in the post-war period. The Medical Research Council must be thanked for a great deal of encouragement and help afforded.

ELECTRODIAGNOSIS

One of the concomitants inseparable from war casualties is the high incidence of peripheral nerve injuries. From experience gained during the War of 1914–18, it was realised that segregation at centres, staffed and equipped to deal with these cases, ensured greater efficiency and economy in respect of the management of patients with peripheral nerve injury (P.N.I.). Granted the proper organisation and adequate personnel, it also offered better chances of study and scientific advancement and better results could be achieved than when the cases were dispersed. The lesson learnt from this influenced the authorities in 1939 to organise the medical services as regards P.N.I.s on a similar pattern. From the literature which emanated from various centres, it was soon clear that electrical methods of muscle and nerve testing were once more given as adjuncts in the examination of P.N.I. and that advantage was taken of the segregated clinical material to achieve some form of standardisation. On the one hand, by eliciting responses to electrical stimulation, serious attempts were made to obtain quantitative measurements of excitability based on the intensity-duration curve which was accepted as the most reliable index of excitability. On the other hand, the study of potentials produced in muscles was undertaken in the hope that these would prove of diagnostic and prognostic value. In both cases it was the application of thermionic valve techniques which made these developments possible.

MUSCLE TESTING BY STIMULATION

As early as 1941, Bauwens described an electrical circuit incorporating valves, designed to generate single impulses of rectangular wave-form of which both the duration and the intensity could independently be controlled. By using a pentode valve in the output circuit, it was found possible to measure the current delivered, and to ensure that this remained unaffected by fluctuations of resistance within reasonable limits. After experimental work on normal and denervated muscles, it was decided to adopt, for the sake of simplicity, a test with three standard durations: $\frac{1}{1000}$ sec., $\frac{1}{50}$ sec., and 1 sec. The reason for this particular choice was that the durations of $\frac{1}{1000}$ sec. and 1 sec. were of the order of those empirically employed hitherto and known as interrupted faradic and galvanic stimuli. It was soon realised that the fact that both these currents could be measured and were not affected by changes in resistance of the skin, was of considerable advantage—particularly when it was further noted that a fairly constant relation existed as regards the threshold values of current for each duration. In the normal, the current required with a duration of $\frac{1}{1000}$ sec. was less than double that required with a duration of 1 sec.

The addition of an intermediate duration resulted from the appreciation that the point at which the intensity-duration curve tended upwards (*temps utile*) was of significance. The $\frac{1}{50}$ sec. was selected because the current required to evoke a response with this duration in the normal muscle rarely exceeded that required with a duration of 1 sec., while in the case of denervated muscle it was considerably greater. The interpretation of these threshold quantities was based more on their relative than on their absolute values. The table below gives typical readings in column A. The relative values shown in column B could be reduced to two figures since the rheobase was invariably expressed as unity.

TABLE

	A			B		
Duration in seconds	1	$\frac{1}{50}$	$\frac{1}{1000}$	1	$\frac{1}{50}$	$\frac{1}{1000}$
Normal Muscle	2·5	2·5	4·5	1	1	1·8
Complete denervation	4	9	α	1	2·3	α
Partial denervation	6	11	30	1	2	5

In the case chosen as example 1/1·8 denoted normal muscle, while 2·3/α and 2/5 denoted complete and partial denervation respectively.

It was found that a careful physiotherapist aware of the pitfalls of muscle testing would record figures reliable enough to use as a basis for interpretation. Whereas the apparatus employed for the method just outlined provided rectangular impulses of which the current remained constant for the duration of flow, for another method based on similar physiological principles a rectangular impulse generator which kept the output voltage constant for the duration of flow was developed by Ritchie (1944a and b). This apparatus working on the multivibrator principle was much simpler and required only two valves as against five. If precautions were taken to reduce the resistance of the skin under the electrodes to its lowest value, the curves obtained with this generator were claimed to be comparable with those obtained with the constant current generator, as were also the deductions. Ritchie did not abbreviate his results or reduce them to a formula but plotted, on logarithmic graph paper, a curve from the voltage threshold values obtained with five predetermined durations of 0·01, 0·1, 1, 10 and 100 m.sec. The slopes of the resulting curves more than their actual position on the graph determined their diagnostic and prognostic significance.

While working in another peripheral nerve injury centre, J. Doupe (1943) carried out some experiments of a critical nature on the value of electro-diagnostic methods. In the essay on contractibility and excitability of denervated muscle, basing his argument on physiological considerations, he discussed the clinical value of strength duration curves. From this it was clear that even the most carefully plotted curve, after a painstaking test, could not be considered infallible. In the light of the doubt he cast on the absolute accuracy and reliability of even complete curves, it remains to be shown that they offer an advantage over the more concise forms of expression in order to compensate for the greater amount of time and paper consumed in their preparation and the tedium involved.

The advances both in the technique and safety factor of local anaesthetics encouraged some authorities to resort to general anaesthetics for examinations of great importance. This expedient was particularly valuable in the presence of excessive pain or oedema, when nerve conduction could be tested by stimulation of nerves over nerve motor points in preference to muscle motor points. It afforded the added advantage that, if necessary, needle electrodes could be introduced through the skin. For this purpose a special stimulator was designed. It delivered pulses of 50 cycles alternating current which could be measured. This apparatus has since been used by Professor Seddon for tests of nerve conduction during open operation.

MUSCLE TESTING BY ELECTROMYOGRAPHY

As distinct from the clinical application of the physiology of nerve and muscle excitability, Weddell, Feinstein and Pottle (1944) investigated the significance of electrical manifestations in normal and denervated muscle. This work was based on that of Adrian, Bronk and Matthews in the case of normal muscle activity and on that of Denny-Brown and Pennybacker in the case of denervated muscle. Their equipment consisted of a high-gain amplifier capable of magnifying the potentials picked up in muscles by means of concentric needle electrodes, sufficiently to convert them into audible sounds in a loud speaker and reproduce their wave-form on the screen of a cathode-ray tube. In its broad lines their technique enabled them to recognise the diphasic wave-form of the normal motor unit activity on volition and to distinguish it from the characteristic repetitive spike potentials denoting autonomous activity of denervated muscle fibre. They also describe discharges of highly complex wave-form which preceded recovery.

To emphasise the sensitivity of this method, it might be said that theoretically it should detect one single normal motor unit among denervated ones and a single denervated fibrillating muscle fibre among normal ones at rest. Needless to say in practice such accuracy is not achieved, nor indeed is it desirable. Such a delicate instrument proved a valuable aid in detecting small numbers of normal motor units, denervated fibres, and early recovery which escaped detection by methods depending on electrical stimulation. By fitting the output of a similar amplifier with an integrating device such as is commonly used in radio practice for measuring the efficiency of amplifiers at various frequencies, Bauwens (1947) obtained quantitative data which enabled him to record progressive recovery in P.N.I. cases during the last year of the war and in cases which were followed up in the post-war period.

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(v)

Organisation of Occupational Therapy

BY HAROLD BALME
O.B.E., M.D., F.R.C.S.

Prior to the War of 1914–18 the use of occupational therapy was but little known in the United Kingdom outside the mental hospital service, where it was mainly employed as a form of pastime and mental diversion for the patients. With the coming of that war, however, a new conception of the treatment of physical disability was born. The great chain of well-equipped military orthopaedic centres, established by Robert Jones and inspired by his dominant personality, took as their target the complete reconditioning of the wounded soldier, and everything which could possibly contribute to that end was brought into service. A wide range of rehabilitation facilities was provided, remedial exercises and all forms of physiotherapy introduced, and curative workshops for both light and heavy handicrafts established. These workshops were under the care of male handicraft instructors, but, on the entrance of the United States into the war, women occupational therapists were also employed in the excellent orthopaedic centres established by Colonel J. E. Goldthwait of Boston. In these centres occupational therapy was used not merely as a form of mental diversion and interest but as a positive means of restoring physical function. The regular gentle movements of weak muscles or stiff joints, while the patient was busily occupied with the intricacies of rug-weaving or netting or carpentry proved invaluable for their general tonic effect, as well as for the local improvement of the damaged part resulting from improved circulation and muscular movement.

After 1918 the orthopaedic centres were dismantled and occupational therapy again reverted, for the most part, to the mental hospital service. On the outbreak of the Second World War, however, the need for providing the best means of rehabilitation after injury assumed a new significance, for not only were there the Service personnel to be considered but also the large number of members of the civilian community who were in danger of being incapacitated by air raids. It was accordingly decided that at all special centres provided under the Emergency Medical Services for the reception and treatment of disabling injuries—orthopaedic centres, long-term fracture hospitals, spinal and head injury centres, neurosis centres, etc.—occupational therapy departments should be built and equipped as an integral part of the scheme. In the case of hutted hospitals, one complete hut (or in some instances two) was usually set aside for this purpose, often divided into two sections, one for light handicrafts (weaving looms, stool-netting frames, benches for leatherwork, perspex, etc.) and the other for the heavier crafts such as carpentry and metalwork. In older hospitals to which Service and civilian casualties were sent, and in which there was often no available accommodation for an occupational therapy department, the necessary space was secured by the use of disused wards, adjoining outhouses and neighbouring halls.

The equipment of these departments and the supply of the necessary material were all centrally controlled, the Board of Trade making a special concession to allow the purchase of wool, etc. coupon free, on certificate that it was only to be used for therapeutic purposes in hospitals and rehabilitation centres. Grants of necessary apparatus and material were made on loan to hospitals wherever there were trained instructors, subsequent orders for renewal of material being paid for from the sale of finished articles. These were usually bought by the patients themselves for the cost of the materials plus a small percentage to cover wastage. Mr. Rhaiadr Jones, the Ministry's Honorary Consultant Adviser on Rehabilitation, superintended all distribution and personally visited most of the occupational therapy departments in the country. In service hospitals occupational therapy was similarly employed, particularly in centres for long-stay patients. Male handicraft instructors and members of the Educational Corps were chiefly responsible for this work, together with a few trained occupational therapists who had joined the Women's Auxiliary Services. They were greatly helped by welfare officers and voluntary visitors from the British Red Cross Society and the Order of St. John.

The chief difficulty in developing occupational therapy was not the shortage of accommodation nor lack of materials, but the great scarcity of trained therapists. At the outbreak of war there were only three schools of occupational therapy in the British Isles, with a yearly output of about thirty students, and there were not more than 100 qualified occupational therapists on the register of the Association. The leading school in England—that founded in 1930 at Dorset House, Bristol, by Dr. Elizabeth Casson, and continued under her expert direction—soon became untenable, owing to the frequency of air raids, and had to be moved to Bromsgrove. Here it was excellently housed, through the kind co-operation of the Barnsley Hall Emergency Hospital authorities, new buildings being added and an excellent school established, with Miss E. M. MacDonald as its able Principal.* For a time this was the only school functioning in England but before the end of the war five others were added.

Even with this provision, however, the supply of occupational therapists was quite unequal to the demand. The Ministry of Health, with the concurrence of the Association of Occupational Therapists, accordingly arranged to subsidise short courses for those already possessing some knowledge of anatomy and physiology or of handicrafts, such as physiotherapists, nurses, and craft teachers. Other courses were also established for younger candidates who could qualify to act as auxiliaries to fully-trained therapists. Altogether 198 students were trained in those shortened courses, all of which were given at Dorset House School. On completion of the special examinations set by the Association they were immediately appointed to hospital occupational therapy departments, at home or oversea.

In addition to those trained at recognised schools of occupational therapy, large numbers of volunteers assisted in the teaching of handicrafts at Service or E.M.S. hospitals. Many were provided by the War Organisation of the British Red Cross Society and Order of St. John, which also contributed a very large sum of money for the purchase of materials; others again were local teachers from arts and crafts schools. Carpentry instructors and teachers of other heavy handicrafts were regularly employed at all hospitals and rehabilitation centres in which men recovering from the more severe injuries or illnesses were under treatment.

As occupational therapy became more widely used during the war and its advantages more fully appreciated it soon became evident that its range of usefulness should not be confined to the particular handicrafts with which it was at first associated. Embroidery work, toy-making, weaving, netting and carpentry, while providing an excellent means of diversion and exercise for certain classes of patient, did not by any means appeal to all. Other means of employing the leisure time of patients in a profitable and purposeful manner were therefore brought into

* This School was later moved to Oxford.

service. One of the most imaginative and successful departures from orthodoxy in this field was that adopted by the R.A.F. at their finely equipped rehabilitation centres at Hoylake and Loughborough. Here they were dealing with commissioned and non-commissioned officers from aircrews, all recovering from very serious injury, and all of them apprehensive of becoming unfit for further service in the air through losing touch with their special craftmanship. To allay these apprehensions and provide the best possible stimulus for such patients Link Trainers were installed for the use of pilots, while navigation courses, aircraft recognition models and modern engineering works took the place of the ordinary occupational therapy apparatus for other members of the crew. Aircraft recognition models were similarly used at all R.A.F. hospitals at home and abroad.

Among other new forms of occupational therapy which were employed with great success at certain centres, mention should be made of the Art Therapy Scheme, initiated at Midhurst Sanatorium by Mr. Adrian Hill, R.A. for officers recovering from pulmonary tuberculosis; the extensive use of art-design and pottery at the neurosis centres; the use of industrial machines and of ordinary industrial processes in the rehabilitation workshops attached to Austins and Vauxhall Motor Works and in the small factory associated with the East Grinstead Plastic Centre; the wide use of books of every description, from the generous contribution of the Red Cross Hospital Library Service (a contribution totalling over six million volumes during the war years); and the educational and cultural courses introduced into many long-stay hospitals and sanatoria for patients anxious to continue their studies during their period of inactivity.

By this diversity of operations occupational therapy has proved able to make a far wider contribution to physical or psychological recovery than was ever previously imagined. It did not merely divert patients' attention from their disabilities or injuries and give them something pleasant with which to occupy their minds. Its contribution was positive in character, for it stimulated creative and critical faculties at a time when they were apt to become dormant, it promoted general circulation as well as helping to mobilise stiff joints and strengthen weakened muscles, it directed the patient's attention to what they could do and provided them with an incentive to make full use of their powers, and it helped to prepare those who had to be invalided from the Forces for the new vocation in civilian life which they might hope to follow.

CHAPTER 23

NON-PULMONARY TUBERCULOSIS DURING THE WAR

By H. H. LANGSTON
M.B., B.S., F.R.C.S.

Discoveries of great significance and importance were made in many branches of medicine during the war years and the study of large groups of patients suffering from similar conditions which the war made possible led to important advances in methods of treatment.

With the exception of the introduction of calciferol in the treatment of lupus vulgaris, however, no material advance in knowledge and no significant change in the established methods of treatment occurred in the period of the war in the various forms of non-pulmonary tuberculosis either on general lines or in the treatment of the local lesion.

In bone and joint tuberculosis the important principles of general treatment of the patient on sanatorium lines continued to guide British surgeons in their treatment of these forms of tuberculous disease. These principles consisted of rest as absolute as possible for the local lesion until healing was well advanced, followed in selected cases when the disease was arrested by operative intervention to give stability and security to the unstable and insecure joint.

The allocation of considerable numbers of beds in orthopaedic hospitals for the treatment of Service patients led to a serious shortage of beds for the patients with bone and joint tuberculosis, but, even with these disturbances, patients suffering from these forms of tuberculosis continued to be treated in long-stay hospitals according to the methods based on those principles that Robert Jones, Henry Gauvain, Girdlestone and others elaborated in the first three decades of this century.

Similarly the methods of treatment of the various forms of glandular and urogenital tuberculosis remained unchanged.

In 1943 Dowling first noted a dramatic improvement in a case of lupus vulgaris treated with massive doses of calciferol and eleven cases so treated with striking improvement were demonstrated by Dowling and Prosser Thomas to the Royal Society of Medicine in December 1945. (The discovery of this effect of calciferol, it subsequently appeared, had been made independently in France by M. J. Charpy in 1940.)

Although the discovery of the markedly beneficial effect of calciferol in the treatment of lupus vulgaris may properly be described as a most important advance in the treatment of this distressing and disfiguring form of tuberculosis, and one made in this country during the war years, the discovery was made too late in the period under review to influence materially the treatment of lupus vulgaris or to cause any dramatic reduction in the number, or amelioration of the lot, of sufferers from the disease in the period.

It might have been anticipated that the circumstances of war would materially affect the incidence of the non-pulmonary forms of tuberculosis among the population, and a variety of factors that might have influenced unfavourably the incidence of the disease have been studied and the views of tuberculosis officers and surgeons practising in various parts of the country obtained upon them.

Though accurate assessment of the incidence of surgical tuberculosis among the fluctuating populations of both town and country was difficult and notification was not always reliable and statistics incomplete, there was not, and has not been since the war, any evidence of material increase in the various forms of non-pulmonary tuberculosis.

Treatment and after-care on the other hand were materially affected by the circumstances of war. There is definite evidence of increased delay in the initiation of treatment owing to the diminished number of beds available as the result of the demands made by Service requirements on hospital beds; particularly was this so in the case of adult sufferers from bone and joint tuberculosis, and, although it cannot be demonstrated statistically, workers in this field believe that increased hospitalisation and crippling resulted, in an appreciable proportion of cases, from this delay.

After-care was materially diminished in almost all parts of the country. The number of tuberculosis officers and surgeons available to visit after-care clinics was very greatly reduced and clinic sessions were therefore reduced correspondingly. Furthermore, owing to evacuation, bombing and the lengthened hours of work of both patients and the parents of patients, it frequently proved impossible for patients to attend at the clinics when requested to do so. This undoubtedly resulted in an increase in the number of 'return cases' requiring treatment in hospital for a re-activation of disease or the correction on occasions of an avoidable deformity.

Contributing to the diminished efficiency of after-care was the very considerable delay in the supply of both surgical appliances and surgical boots arising from reduced supplies of raw material and the call-up of skilled appliance-makers. It was unfortunate that appliance-making was not regarded as a reserved occupation and a sufficient number of craftsmen retained in the appliance-making firms to avoid the long periods of delay, often running into many months, during which an adult had to wait for an appliance to enable him to get work, or a child to return to school.

While there is no evidence that bombing and shelter life materially influenced non-pulmonary tuberculosis, several tuberculosis officers were of the opinion that, although milk in schools, school meals and the equitable distribution of food materially reduced the incidence of all forms of tuberculosis in childhood in areas described as 'depressed areas' before the war, yet for the child who contracted tuberculosis the protein and fat rations were not sufficiently high, and from more than one source the opinion was expressed that a failure to respond to treatment and to gain weight could be attributed to a lack of high-quality protein

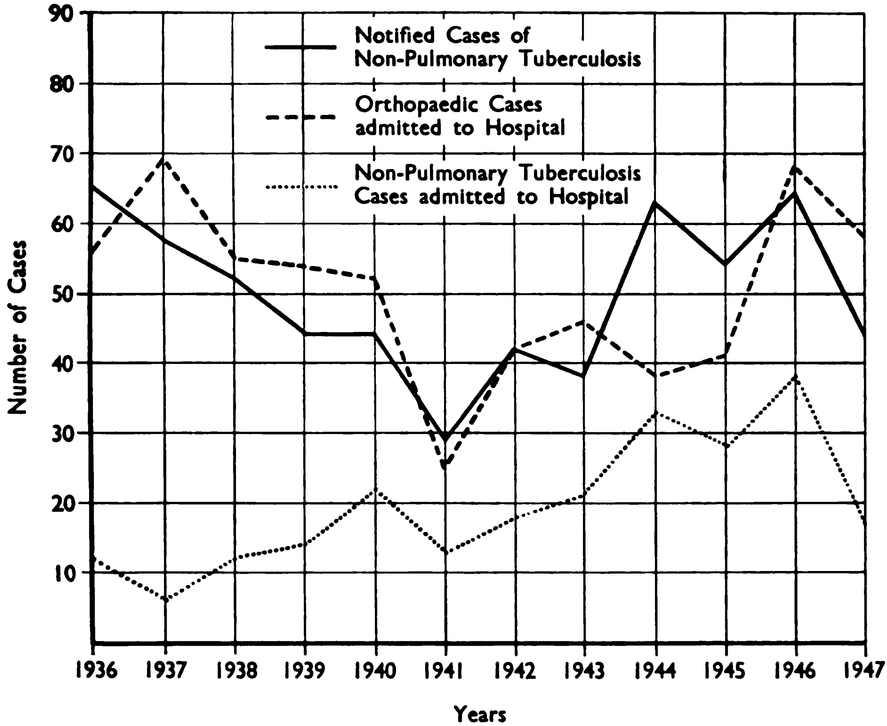


FIG. 1.—Graph indicating number of cases of non-pulmonary tuberculosis notified in Portsmouth, 1936–47.

and fat and that this was more noticeable among tuberculous children in hospital than in pre-war years.

It has been suggested that the evacuation of children from the towns, where they had been accustomed to drinking only pasteurised milk, to the country areas where milk was not so treated, led to a significant number of evacuated children developing glandular tuberculosis and possibly was responsible for some fresh cases of bone tuberculosis.

Statistics relating to the incidence of cases of non-pulmonary tuberculosis have been kindly provided by various authorities. Included in this article are tables prepared by the Medical Officer of Health of Portsmouth, which may be taken as typical of similar information obtained from other towns subject to evacuation and heavy bombing, and illustrate not only the fact that there has been no appreciable rise in the incidence of non-pulmonary tuberculosis during the war years and the year after the war, but also the apparent decline in the years of evacuation due to lessened population (Figs. 1 and 2). The peak in 1944 in which notifications reached 0·4 per 1,000 population is considered to be due to the notification of the disease in patients discharged from the Services.

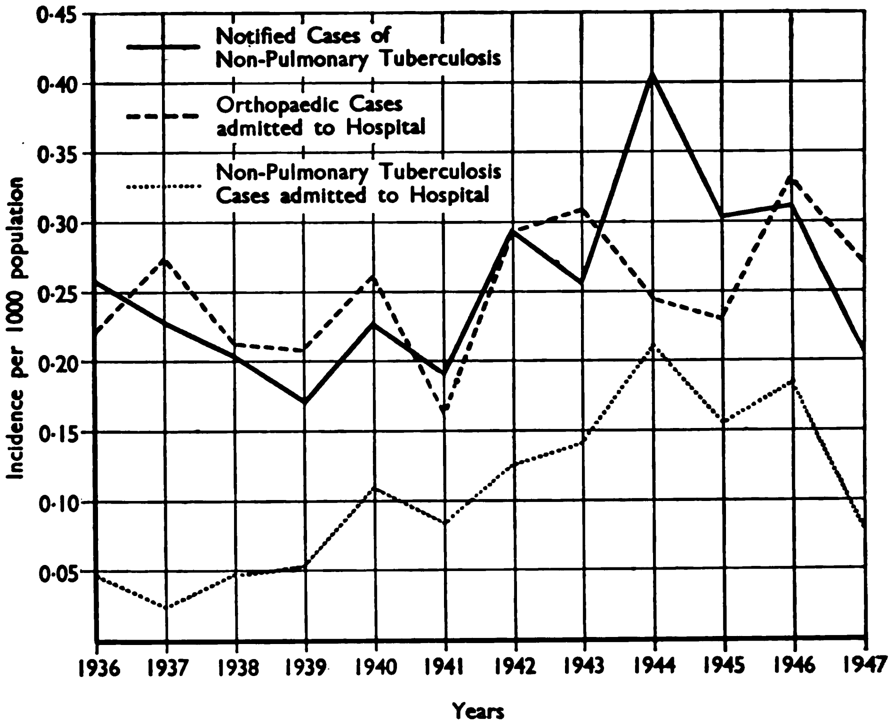


Fig. 2.—Graph showing incidence of non-pulmonary tuberculosis in Portsmouth for years 1936-47.

CHAPTER 24

TRAUMATIC EFFECTS OF THE ATOMIC BOMB

By Sir ZACHARY COPE
B.A., M.D., M.S., F.R.C.S.

Before the War of 1939–45 it was known that the splitting of an atom would release a great amount of energy, and during the course of the war intensive research was carried out, chiefly in America, to find a suitable method of applying this potentially released energy for warlike purposes. In 1945 this effort succeeded and produced the atomic bomb. This bomb comprised a collection of radio-active material in such a critical state that it could easily be detonated with resultant splitting of a large number of the contained atoms and the immediate release of a truly devastating amount of energy. Up till 1951 there were only records of the explosion of five atomic bombs—at Alamorgado, Hiroshima, Nagasaki, Bikini and a fifth which was exploded under water. The dropping of the bombs on Hiroshima and Nagasaki produced such destruction and killed so many people that the Japanese at once concluded that further resistance was useless. Though the British Forces did not make use of this terrible weapon it is necessary to give a brief account of its traumatic effects.

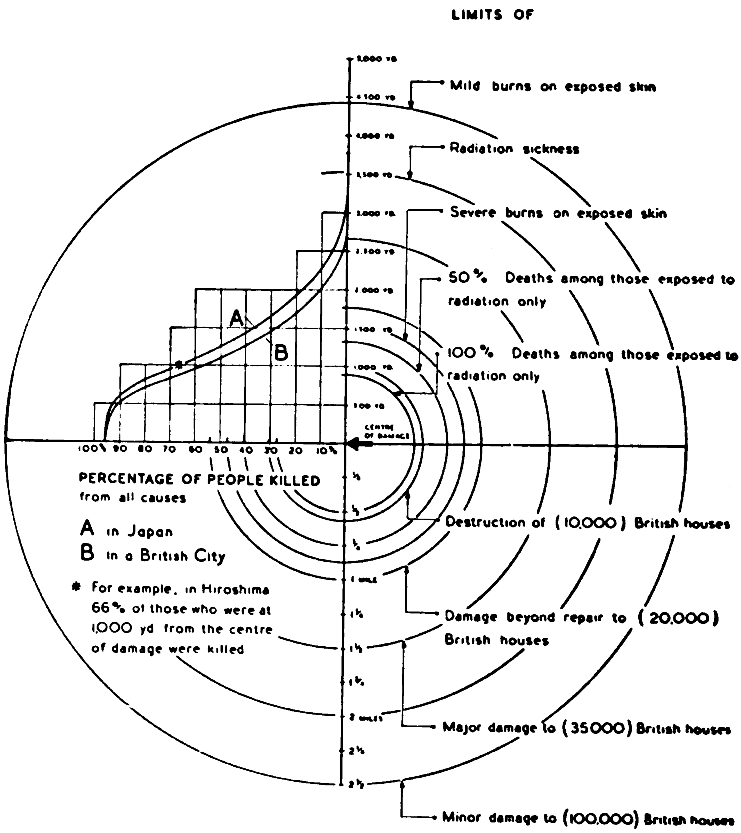
When an atomic bomb explodes there is an immediate generation of an immense amount of every kind of radiation—infra-red heat rays, visible light radiation of dazzling intensity, ultra-violet radiation, X-rays and gamma radiation. The damage to life and property is caused either by the terrific heat and consequent fires, the disintegrating effects of the explosion and the powerful blast-wave which is thus created, or the lethal effects of the gamma and other radiations. The distance to which these effects are felt is very much greater than that with any previously known form of explosion.

The instantaneous flash of most intense heat scorches to death any living thing which is exposed within a few hundred yards of the explosion, and will inflict superficial or 'flash' burns on any person exposed to its influence within a radius of from one to two miles or beyond; at farther distances however a thin protection, clothing or otherwise will prevent these burns. At the same time, the heat-flash will scorch or start fires in any inflammable material within reach, and thus innumerable conflagrations arise within the affected area.

The blast-wave induced by the explosion of the bomb is of much greater power than any previously experienced. Most brick or wooden buildings within a radius of half to one mile of the explosion fall in ruins, but it has been found that strong reinforced concrete buildings can withstand the blast even when close to the explosion. The power of the blast is such that up to a distance of two miles most of the buildings are partially destroyed, and structures even farther away suffer considerable damage. Those who saw the damage at Hiroshima and Nagasaki considered that most of the deaths were probably due to the victims being struck by débris or imprisoned in the falling buildings. There was very little evidence that the blast was the sole cause of death.

THE MORE IMPORTANT EFFECTS OF ATOMIC BOMBS ON PEOPLE AND THEIR HOMES

Explosion as at Hiroshima and Nagasaki



The new and startling factor in the atomic bomb was its radio-activity. At the time of the explosion large quantities of gamma rays were released and exerted their deleterious effect on all living beings within a radius of two miles or more. Those persons within a radius of one mile who survived the heat- and blast-waves were very liable to perish at a later date from what the Japanese called the 'atomic bomb disease'. Milder forms of radiation sickness attacked those who were between one and two miles distant from the site of bomb explosion.

The gamma rays penetrate the body without causing any immediate sensation and a varying time intervenes before symptoms present themselves, depending upon the amount of rays absorbed. Experience showed that, with a severe radiation, nausea and vomiting occurred within a few hours of the exposure, and these symptoms were soon followed by malaise, diarrhoea, thirst and fever until delirium ushered in death. When the patient was more distant and received a smaller dose of radiation, the symptoms came on more slowly, but often led to death within a month or six weeks. If the patient survived beyond that time, recovery often occurred.

The main effect of the gamma rays (as has long been known to be the case with X-rays), is upon the blood-forming tissues, epithelium and the gonads, but the whole body comes under their influence. With each cellular system the immature proliferating cell is more sensitive to irradiation than the adult. Hyperplastic erythroid tissue and reticulo-endothelial cells form an exception to this statement. The bone-marrow, the lymphatic system, and the testes and ovaries are chiefly affected. After that in descending order of sensitivity come the basal layer of the skin, connective tissue, bone, liver, pancreas, kidney, nerve, brain and muscle. There is apparently no direct effect upon the fully developed elements of the blood in circulation and only when these need to be replaced is the severe damage done to the embryonic cells revealed. As the red cells, platelets and leucocytes die off in the normal course of events and are not replaced, serious symptoms develop which are described in the following passage (taken from the report of the British Mission to Japan):

> 'As red cell formation ceased, the patient began to suffer from progressive anaemia; as platelet formation ceased, the blood seeped in small and large haemorrhages into the skin and the retina, and sometimes into the intestines and kidneys. The fall in the number of white cells, which was useful in diagnosing mild cases because it could be detected by taking blood counts, in severe cases lowered resistance so that the patient inevitably fell prey to some infection, usually spreading from the mouth and accompanied by gangrene of the lips, the tongue and sometimes the throat. Death in these cases was the result of a combination of anaemia, internal bleeding and

infection. Deaths probably began in about a week after the explosion, reached a peak in about three weeks and had for the most part ceased after six to eight weeks.'

The anaemia results from a cessation of red-blood-cell formation, with normal destruction of the red blood cells continuing at the usual rate of about 0·83 per cent. of the red cell mass each day. In the early phase capillary fragility is increased before a platelet deficiency develops. At the same time heparin is liberated. Whether there is a circulating 'radio-toxin' has not been determined.

Men who were exposed to the radiation from the bomb (up to a distance of from one or two miles) were usually found to have diminished sperm counts, and sometimes loss of potency or of libido, but as a rule there was a slow and gradual return to normal. In fatal cases there were marked changes in the histological appearance of the testes. The radiation also affected the ovaries and the reproductive process in women. For two months after the explosion at Hiroshima miscarriages, abortions and premature births were five times as frequent as in normal times. Alarming accounts of the long-continuing contamination of the ground by radio-active material have been spread, and the facts should be stated. Careful investigations were made, at both Hiroshima and Nagasaki, on soil specimens taken at various places. Radio-activity was proved around the ground centre but its intensity was very weak, being under ten to twenty times the natural leakage of the electroscope, i.e. below one hundredth of a tolerance dose. The measured radio-activity decreased rapidly and after a week was not strong enough to harm the human body. At Nagasaki there was one area some distance from the ground centre which had considerably stronger radio-active properties. Induced radiation might affect the iron and silicon in a concrete building, and for several days after the bombing a sufficient dose of induced radiation was scattered in the concrete buildings in the central areas to produce damaging but not fatal effects. With the exception quoted above, contamination existed only for about a week and could not be termed very serious. In any case of doubt it would of course easily be possible to establish the presence or absence of radio-activity.

From the foregoing account it will be seen that the effects of gamma radiation from an atomic bomb were very similar, though much more rapid in evolution, to the changes induced by prolonged or repeated exposure to X-rays. In both cases an early indication as to the progress of the disease can be gained by repeated examination of the elements of the blood in circulation. In minor degrees of exposure some indication of the effect on the body may be deduced from the total lymphocyte count. If there be no decrease in the total lymphocyte count in the first forty-eight hours, the exposure will have been less than 25 r. and symptoms probably will not appear. If exposure has been between 25 and 100 r. a fleeting lymphocytopenia will develop and symptoms will be mild. Exposures between 100 and 200 r. will cause serious symptoms and possibly death, and leucocytic changes will be greater. But diagnosis of acute radiation-illness by the leucocyte count in the case of exposure to an atomic bomb is impracticable, except in those cases which survive the initial shock and develop symptoms a few days or weeks later. With the atomic bomb the quantity of rays to which any person in the neighbourhood is likely to be exposed is many times greater than in any other known risk; moreover it would need a considerable thickness of lead, or a still greater thickness of concrete or earth, to afford adequate protection against the intense radiation from the bombs.

Calculations based upon the results of the bombs exploded over Hiroshima and Nagasaki proved that 19 out of 20 people within ¼ mile of the explosion were killed, and 17 out of every 20 within the next ¼ mile radius succumbed. From half to one mile from the centre of explosion just under or over 50 per cent. of people survived its effect. Of those who were more than a mile distant 9 out of 10 survived. Even in the central area a few persons survived; in one instance when at the inner corner of a cave which was covered by a layer of soil just under 10 ft. thick, and in another when in a well-covered inside room in a strong concrete building. (See diagram on page 738.)

The clinical manifestations of atomic bomb disease have been studied by several observers. Keller made a study of 21 patients seen in August and September 1945 suffering from the late effects of atomic bomb radiation at Hiroshima and Nagasaki; he found that anorexia, nausea and vomiting often came on within a few hours while fever began any time from two to twenty-five days after exposure. The haemorrhagic manifestations began in about twenty-five days. Loss of hair commonly occurred within one to three weeks. There was no significant change in the bowel habit. The blood-sedimentation rate was very rapid, often being over 100 mm. for two consecutive hours as tested by the Westergren method. The bleeding time was prolonged and the leucocytic and thrombocytic counts were very low. In severe cases the leucocyte count was under a thousand. A common feature of most of the cases was an unusual tendency to experience fatigue or a feeling of weakness. Occasional symptoms were faintness, dizziness, difficulty in swallowing and unusual thirst. Of the 21 cases only 5 died. Since the distance of the patients from the site of bomb explosion varied from 50 to 4,000 metres, and 11 were actually within 500 metres, it is difficult to be dogmatic about the mortality at different distances.

TREATMENT OF ATOMIC BOMB DISEASE

Prophylactic treatment means the prevention of exposure to the radiation. The Japanese experience was that in the central area within a radius of 1 km. (⅝ mile) one could not escape from the effects unless sheltered in a perfect underground cave trench; in the area between 1 and 2 km. ($\frac{5}{8}$ to $1\frac{1}{4}$ mile) distant one could be protected in a concrete but not in a wooden building. Within 2 km. a protected position, even if taken up soon after the recognition of the explosion, would not help, but outside that distance a quickly taken sheltered position would give protection from the effects of the bomb. Outside a radius of 2 km. ($1\frac{1}{4}$ mile) there was almost no danger to life though wounds and burns might occur. Outside a radius of 4 km. there was comparative safety. To avoid the atomic bomb effects one should live in underground cave-type residential districts, which should be well covered by thick concrete, but this is clearly impossible for a whole nation. The most that could be done would be to afford relative protection by reinforced concrete structures, or deep underground tunnels, to those persons engaged in occupations of the greatest importance.

It should be noted that residual radio-activity in a damaged area is not of importance, when the bomb explodes at a considerable height, though it would be more dangerous if the bomb exploded just above the ground. When a person has been seriously exposed to gamma radiation, the most important lines of treatment are directed towards maintaining a sufficient supply of blood, preventing infection and diminishing the tendency to haemorrhage. The best means to these ends are daily transfusions of blood, the giving of large doses of penicillin ($2\frac{1}{2}$ million units daily), and perhaps the administration of folic acid 25 mg. daily by mouth. Careful nursing and scrupulous aseptic technique are necessary in dealing with these patients. The patient should be given complete mental and physical rest and the greatest care taken to prevent chilling. Mild sedation may be needed and the diet should be low with small residue and of a bland nature. Cronkite states that the use of drugs and vitamins does not rest on a sound experimental background. If recovery occurs, so far as can at present be estimated, it can be complete and leave no untoward after-effects.

It should be the rule that all persons who were within a radius of 4 km. ($2\frac{1}{2}$ miles) at the time of the explosion should be under medical supervision for some weeks; they should be instructed to report at once to the doctor if affected by vomiting, anorexia, sore throat, diarrhoea, loss of hair or a sense of fatigue.

From the military point of view the selection of cases for treatment calls for comment. As Cronkite says, most of the casualties in the central zone will be disabled military liabilities with a life-expectancy of less than a month; all that can be done for these is to give them humanitarian care, for they can never be of military use again. With regard to those farther from the centre some clinical discrimination will be necessary.

It is to be hoped that in the near future there may be devised some simple method of ascertaining accurately the dose of radiation to which each individual has been exposed. Only by this means could accurate segregation be carried out.

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CHAPTER 25

PRISONER-OF-WAR CAMP SURGERY

Surgery in a Japanese Prison Camp on Singapore Island 1942-45

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In December 1934 the Japanese Government ratified its signature to Appendix 23 of the International Convention of 1929 for the amelioration of the condition of the wounded and sick in armies in the field. Among the provisions that it bound itself to observe were: that wounded and sick shall be respected and protected in all circumstances; that they shall be treated with humanity and cared for medically by the belligerent in whose care they may be; that the personnel engaged in the treatment of the wounded and sick shall be respected and protected in all circumstances; that if they fall into the hands of the enemy they shall not be treated as prisoners-of-war; that they shall be sent back to the belligerent to which they belong as soon as a route is open and military consideration permits, and that the buildings and materials of medical establishments shall not be diverted from their purpose so long as they are necessary for the care of the wounded and sick.

The Japanese Government's signature to this Convention seems to have been given with an intention sincerely to adhere to its terms in the same spirit that permeated its peaceful activities in China at the time. Indeed it hesitated only at the paragraph that prohibits the use of the Geneva Cross for trade purposes, instructing its delegates to except this Article on behalf of their country. One might at that time buy almost anywhere in the Far East a packet of Gold Flake cigarettes, the product of Japan, yet identical in every way (other than burning) with that of the B.A.T. Why the Japanese should swallow the Convention but strain at the Cross must be left for answer to the student of the doctrine of face.

In the following pages may be seen the contrast between what should have been and what was. That this contrast was attributable to no failure on the part of the captive medical officers and other ranks was also apparent. The self-sacrificing devotion of all to their patients was exemplary from the collapse in Malaya until the end of the war. While naming neither persons nor units, the writer wishes here to record his respectful and unbounded admiration of the conduct and work of all his colleagues, commissioned and non-commissioned.

In the concluding stages of the war in Malaya, all the wounded and sick evacuated to Singapore during the campaign were still on the Island except those returned to duty, and a few hundred who had been sent away in two small hospital ships. On the day of the capitulation all the wounded and sick were accommodated in Alexandra Hospital—by then in Japanese hands—in a number of improvised military hospitals, in the Civil General Hospital and in Tan Tock Seng Hospital. Immediately after the capitulation the Imperial Japanese Army (I.J.A.) interrupted all communication between the British Army, the Indian Army and Chinese and Malayan troops. British and Australian troops were confined in the same area, but the care of the Australians was left by arrangement in the capable hands of the Australian Army Medical Service. The British and Australian Medical Services thus carried out their work independently in separate parts of the same 'hospital' at Changi.

In outlying camps on Singapore Island, in the Burma, Thailand and other remote camps, and during the last year of captivity at Changi and Kranji camps, British and Australian personnel were treated together or separately, as circumstances demanded, by medical officers and other ranks of both Services. This report is, however, almost entirely devoted to the work of the British Section.

At the capitulation on February 15, 1942, there were over 2,500 British wounded in Singapore; the most seriously wounded who had survived the battlefields were in an improvised hospital in Singapore, and in the Civil General Hospital. All nurses of the Q.A.I.M.N.S. and of the I.M.D. except one, had been sent away on February 13 and from that date the care of the wounded was carried out by male R.A.M.C., I.M.S. and I.M.D. personnel, by the remaining nursing sister and by some devoted civilian women who attached themselves as V.A.Ds. All women were transferred by the Japanese to Changi Gaol, the 'Civil Internment Camp', as soon as it was open.

On February 17, by Japanese order, the civil hospitals were emptied of Service patients who were transferred to military formations, and thus it occurred that all seriously wounded found themselves in one military hospital in improvised quarters. A large proportion of the wounded had not then, and never did have, the ordinary standard of care provided by Army general hospitals in war-time.

By the end of the first week of captivity, on Japanese orders, large numbers of patients were being sent, either marching or in ambulances and lorries, to their Units in Changi Camp. Finally all patients were sent to Changi, the last transfer being made on the 2nd March in spite of a protest that 32 were unfit to move. Of these 32, one was operated upon immediately on arrival for a secondary haemorrhage that occurred on the way, and many died subsequently. Thus, on March 2, 1942, there were in Changi 'Hospital' in Roberts' Barracks 986 wounded, and in their Unit lines over 1,500 more. Immediately an out-patients' department was opened to which regimental medical officers were asked to send patients in whose cases they needed help and consultation. An immediate survey was made of all wounded, and those needing operative or other surgical treatment were transferred to the 'hospital'. In view of the way in which our casualties had been spread by Japanese orders over a large area of the prison camp, the out-patient department was of great value in making possible supervision of the care of the wounded. Further inspections were made at intervals until September 1942. On the last occasion a final list of those suitable for repatriation by the Japanese to the United Kingdom and Australia was submitted to the I.J.A. A tentative one had been prepared soon after the capitulation and the need for repatriation had been pressed on the Japanese. In September 1942 the wounded on the list were inspected by two Japanese medical officers, a physician and a surgeon, and the suitability of most of the wounded for repatriation was accepted by the I.J.A., though no such repatriation ever occurred.

Conditions in Roberts' Hospital (*Changi*). The conditions in which patients were treated were always shocking, though with the passage of time they improved in some ways while deteriorating in others.

1. *Quarters*. The 'wards' were barrack rooms, spacious enough for the 40 soldiers for whom they were designed, but dreadfully crowded for the 140 wounded that had to be packed into each. The water supply had been cut off by earlier shelling, there were no facilities for washing patients or linen, and the lavatories were out of action. There was no lighting available. A water supply was eventually restored by the R.E. by permission of the I.J.A., and months later electric light was laid on.

At the beginning, the plague of flies was such that the appearance of a formidable epidemic of dysentery could be prophesied, and this in fact appeared with punctuality.

2. *Personnel*. From among the medical officers there were assembled seven Fellows of the English and Edinburgh Royal Colleges of Surgeons and a larger number of junior medical officers, a few with some slight surgical experience. There was a consultant anaesthetist, two radiologists, and officers with ophthalmological, laryngological and pathological experience. There was a considerable number of non-commissioned R.A.M.C. personnel and some Assistant Surgeons I.M.D. (British Cadre). On both these groups fell the duties of nursing the wounded and sick, with no supervision or help from sisters.

3. *Equipment*. All equipment except some bedsteads had been saved from Singapore. It had been transported without Japanese knowledge under the sick in ambulances and lorries. Enough instruments for surgery, operating tables, sterilisers, dressings, linen, and large quantities of drugs and dressings were also secretly conveyed to Changi through the efficiency of the administrative branch of the R.A.M.C. To begin with we had some paraffin for heating sterilisers, and much later the

R.E. managed to arrange a steam pipe from the cookhouse. The pressure was never such as to be completely reliable for sterilisation, but this piece of engineering was a great boon to the surgical staff. Later, after leaving Changi, we had to resort to rubber wood fires for sterilising. There was also a portable X-ray apparatus, defective at first, but it was repaired later when electricity became available, and a small store of films and material for their photographic development.

Arrangement of Duties of Available Personnel—Commissioned Officers. We tried to arrange that everyone should have work to do, and work did not appear to be lacking. Accordingly, eight teams each consisting of a chief with responsible Service experience and junior officers, were organised.

Other Ranks. A number of operating room attendants from the R.A.M.C. ran the operating theatre, and very well indeed did they run it. There were orderlies who acted as nurses. The absence of any real experience of nursing was an immediate difficulty, and hard as the non-commissioned wardmasters tried to train the orderlies, the large number of serious wounds made things very difficult. An attempt to use commissioned quartermasters R.A.M.C. was of some use in improving conditions, but in general this was a failure.

Dysentery. Almost immediately the expected outbreak of dysentery, bacillary and amoebic, occurred, and our worst anticipations were realised. In the absence of anything but a precarious water supply the difficulties of nursing the wounded so afflicted were formidable. After many weeks, however, our demands to the I.J.A. resulted in our engineers being permitted to restore a water supply and the use of those water closets in the barracks that could be made serviceable. Bedsores were numerous and severe at this stage.

Linen. The shortage of bed linen, mattresses and pillows was severe, and even those supplies that we had were continually suffering attrition. A sheet, blanket or pillow was to a discharged patient a temptation which he could hardly be expected to resist. As time passed, the increasing shortage and final absence of linen became the greatest of our difficulties in the practice of surgery.

Diet. The diet consisted largely of rice, supplied at first in greater quantities than could be used. It was supplemented by minute quantities of protein, which soon became restricted to a few ounces of bad dried fish every week. Deficiency diseases were soon prevalent and, as was to be expected, all kinds of ill-health were generally attributed to this cause. It is probable that a good many troubles were wrongly so interpreted.

Progress. The early catastrophic epidemic of dysentery and the plague of flies both began to diminish in intensity, but though the flies yielded to sanitary supervision, the dysentery became chronic and never disappeared. Practically all the war wounds suppurated. The early preference for the Winnett-Orr closed methods of treatment gradually faded and open methods were found more efficient.

An important part of the medical orderly's work was the preservation of function in the muscles and joints of the wounded limbs from the earliest hours. Among the pressing calls on their time, including attention to many complaints from officers regarding defective ward cleanliness, the medical orderlies were rarely at fault in selecting those patients that needed their special care. The usual routine was ward-rounds and dressings all the morning, and the carrying out of measures to restore function during the remaining daylight hours. The fact that they did for their patients those things that helped them most towards recovery, disregarding many criticisms that were levelled at them by officers and others who were dismayed at the dirt and frequent untidiness in the wards, is attested by what in the circumstances was a low mortality, and by the rapid return of good function in the wounded limbs of patients throughout the hospital. Indeed, by the latter part of 1942 it was a pleasure to see so little defective function accompanying so many serious wounds all over the camp.

'Clean Surgery'. As soon as the need arose, a separate fly-proof operating theatre for 'clean' cases was constructed by the Royal Engineers, and to this no unhealed wound was admitted. Here nerve suture, herniorrhaphy, bone grafting, meniscectomy, could be carried out when necessary.

Union of Fractures. Among the fractured femurs, all united with less than one inch of shortening, except in the case of one soldier who was treated without splints by the Japanese and was left with three-and-a-half inches of shortening.

The writer remembers only one stiff knee other than this example of Japanese neglect.

Some medical officers considered that the defective diet contributed to delayed union of fractures. This contention could not be supported by irrefutable evidence and the number of ununited fractures was small.

Healing of Wounds. Despite the presence of very severe infection in nearly all the wounds, very few unhealed war wounds were seen by the end of 1942.

Artificial Limbs. In the autumn of 1942 we began the manufacture of artificial limbs. We had a good group of engineers, fitters from the R.A.O.C., R.E., R.A. and other formations. We had the benefit at first of an R.A.O.C. officer and later an R.A. officer to take charge of the mechanical side of the work. None of us had any practical experience of limb prosthesis and we had to learn by trial and error. We found material principally in Thomas knee splints and large aluminium fan blades. The limbs were articulated skeleton frameworks with solid wooden feet or hooked or pincer hands. To imitate knee joints we had a joint with two centres of movement, simulating the movement of the tibia on the femur. We had to learn the necessity for a stiff artificial ankle joint or one with little mobility strongly controlled by springs or rubber buffers.

Casualties from Fighting on Singapore Island, February 1942

(Excluding Australian, Indian, Malay, Chinese Troops)

Total number	Unknown
Deaths in No. 1 Malayan General Hospital, Singapore (Before we went to Changi on March 2)	87
Wounded evacuated to Changi prison camp far exceeding	2,500
Of these died of wounds in 1942 at Changi	40 (1·6 per cent.)
Causes of death: secondary haemorrhage, suppuration, septicaemia, dysentery, avitaminosis	
Possible death rate of wounded arriving in medical formations R.A.M.C. and I.M.S.	(5·6 per cent.)

War Wounds. Summary of Results on 31 *December*, 1942 *in Soldiers Treated in Changi*

Compound fractures	489	Chest—penetrating lung	25
Ununited—Tibia	2	Deaths	2
Humerus	1	Brain	25
Ulna	1	Deaths	3
Radius	1	Spinal cord	5
Secondary haemorrage	26	Deaths from urinary infections	5
Deaths	6	Cauda equina	3
Femur	37	Deaths	0
Deaths	7	Peripheral nerves	72
Hip-joint	3	Nerves repaired	40
Deaths	2	Aneurysms	
Knee Joint	26	Excision of aneurysm in 5 patients, 1 amputation through thigh	6
Deaths	8	Deaths	0
Amputations 18, with survivals	12	Abdomen	28
Artificial limbs—Manufacture proceeding slowly		Deaths	14

Exhaustion of supplies. During 1942 efforts were concentrated on the treatment of war wounds. By the end of this year dressings, rubber gloves and anaesthetics were almost—plaster-of-paris and antiseptics entirely—exhausted. Anaesthetics—i.e. chloroform and a little novocain in crystals—were then strictly rationed. On January 1, 1943 a demonstration was made to surgeons of herniorrhaphy by fascial graft; this was done without gloves and without operating gowns, but instruments, cotton thread and soap and water were available.

Conditions in 1943, 1944 *and* 1945. The problems now became more difficult, war surgery giving place to civil and tropical surgical practice. In the latter months of 1942 large numbers of prisoners had been transferred by the I.J.A. to the notorious Siam-Burma Railway, where the treatment they received from our captors was an uninterrupted horror. The survivors began to come back to Changi in 1943 and 1944 where we tried to bring them back to some sort of health.

In 1944 and 1945 the Japanese concern at the, for them, unfavourable progress of the war, resulted in new camps being opened on Singapore Island where defensive and other works could be carried out by prisoner labour. Conditions deteriorated rapidly and the dietary became worse and worse.

The conditions in these camps varied considerably with the personalities of their (usually) non-commissioned commanders. In many, beriberi, pellagra and dysentery were rife, and the state of the soldiers suffering from these conditions, returned by the I.J.A. to Changi, was pitiable in the extreme. These conditions continued to deteriorate until the end of the war.

In 1944 the Changi 'hospital' was transferred to Kranji, no interchange between the two camps being permitted, except the transfer of sick from the former to the latter and the return of the convalescents in the opposite direction. The consulting surgeon was, however, permitted to visit Changi from Kranji on three occasions.

With the deterioration of living conditions and of diet, and with the increase of crowding, certain maladies that had previously been endemic now made serious ravages.

Diphtheritic Infection of Fauces, Trachea, Wounds, Skin. There was practically no anti-diphtheritic serum available. The I.J.A. would send occasionally minute doses, presumably in response to their peculiar face-saving doctrines, but the total amount supplied was inadequate for one patient's treatment. These diphtheritic infections were recognised by microscopic examination of membrane. Faucial, laryngeal and tracheal diphtheria had a high mortality. Cutaneous and wound diphtheria was treated when possible by wound excision, followed by normal saline dressings changed once or twice daily. Reinfection was, of course, frequently seen and correspondingly dreaded. Nevertheless, large numbers of the patients survived and healed well when this treatment was adopted.

Tropical Ulcers (Tropical Phagedena). These were similarly treated. Many of these unfortunate patients had contracted serious infections of underlying bone, and repeated sequestrectomy was necessary. Eventually healing was attained in the majority of these ulcers. With bone infection healing was very greatly prolonged, with many relapses. There were examples of these wounds being dressed once or twice daily with normal saline solution for many months, even for years, with eventual healing. This, the final and only satisfactory solution reached for the problem, was carried out with the greatest care and gentleness by medical officers and with a success that was a tribute to their skill, gentleness and conscientious devotion. All dressings had to be washed and used again many times.

Amoebic Dysentery. This became once more a scourge and was combined with famine oedema, beriberi, pellagra and other avitaminoses.

The surgical complications of dysentery were not numerous until towards the last year of captivity. Early on they included appendicitis, stricture, especially rectal; later on perforation and hepatic abscesses.

We had little luck with dysenteric perforations. Rectal strictures disappeared eventually if left untreated; one resistant example with intestinal obstruction was treated by colostomy and excision of the upper rectum. Healing was not complete for over a year, when colostomy was closed. Appendicostomy and ileostomy were used many times in the treatment of chronic dysentery, but the results were not impressive.

Hepatic Abscesses. The absence of emetine made the treatment of amoebic dysentery difficult. There were, however, few cases of hepatic abscess until the last year of captivity. They occurred mostly in people who gave no history and had no other symptoms of amoebic dysentery. Such abscesses were treated by surgical measures with uniform success. The operative approach consisted of:

(*a*) Laparotomy to discover whether or not there were peritoneal adhesions walling off pus that might have escaped from the liver into the abdomen.

(*b*) Drainage by tube to the surface, using either an abdominal or thoracic incision whichever seemed appropriate.

The thoracic incision that was suitable was an extrapleural one. The right ninth rib was removed from the tip to the angle. The pleura was pushed up out of the way by blunt dissection, and a tube was passed into any affected part of the right lobe of the liver. Healing was uneventful and secondary infections did not seem to occur. It was noteworthy also that when pus from an amoebic abscess of the liver was coughed up, secondary infection did not occur, but rupture into the lung did not result in healing and thus did not obviate the necessity for operation.

Duodenal Ulcer. Serious duodenal ulcers became a plague. The victims had perpetual and severe pain leading them to beg for some sort of relief. They became emaciated and some suffered perforation and haemorrhage. The ulcers were enormous, bearing in their bases the liver, pancreas, and the structures in the right end of the lesser omentum, They would develop vigorous visible peristalsis in three months from the onset of the symptoms and without duodenal stricture. They also often had palpable tumours. Operation was never done unless such patients were in extreme pain. During captivity partial gastrectomy was performed twenty-two times, three urgently for bleeding that recurred after blood transfusions. Two of the patients died, one of acute oedema of the lungs three days after an operation for haemorrhage, the other from miliary tuberculosis, verified post-mortem.

These patients had very rough passages. To offer gastrectomy to a man when there are no sheets, only mattresses and perhaps pillows, shiny and black with dried shed blood, pus, and sweat, is not a pleasant duty, eagerly though it was accepted. The operations were usually carried out under regional intercostal novocain or chloroform. The only available milk powder was a minute quantity of the Red Cross supplies which arrived, but which the Japanese took mostly for themselves. Impounding the meagre supplies thus issued to the whole camp, we could allow each patient with duodenal ulcer treated by gastrectomy one gallon of milk only during after-treatment.

Convalescence was marred by suppuration in about half the cases, by duodenal leakage once, by perforation of an anastomotic ulcer a month after gastrectomy and successfully closed with recovery, and usually by famine oedema, sometimes with ascites. This last disappeared in a day or so when the end of the war permitted the consumption of all milk supplies in hand.

Before closing this section the writer wishes to pay tribute to the theatre and ward staffs on the surgical side of our prisoners' 'hospital'.

The theatre work was as near perfect as circumstances permitted, and operation was never refused on account of defective theatre technique. Though often considered, no operation for prolapsed disc was ever carried out, but laminectomy for war wounds, craniotomy, excision of cerebral abscess, bone grafting, fascial grafting, joint operations, resections of bowel, drainage of hepatic abscesses, large numbers of appendicectomies, cholecystectomy and gastrectomy were all carried out with confidence, success and greater likelihood of healing by first intention than is seen in some centres in the East. This was largely due to the competent, conscientious and skilful work of the operating-room attendants. The ward work as time passed began to show great improvement and in the end the nursing cannot be described as other than extremely good by any standard. It is to the credit of the nursing orderlies that in spite of the conditions indicated above, in spite of the malnutrition, the thin stretched skins, the fleshless bony backs, shoulders, buttocks, the muscleless legs, without linen and without air rings, with no pillowcases and hardly any pillows, large numbers of patients suffering from grave surgical diseases were nursed to recovery.

The writer wishes to place on record the fact that from early in 1943 until the end of captivity, i.e. during the last two and three-quarter years, not a single bedsore was seen on the surgical side and again he would express his admiration for the nursing orderlies responsible for this remarkable record.

Observations on Operative and Other Surgery. While the above resumé is a skeleton account of the surgical work done in Changi and Kranji, a great deal of surgical work was also done elsewhere in Thailand, Burma, Java, Malaya and Sumatra at various times, and the experiences of surgeons in some of these places have been published.

In some of these other camps the accommodation and facilities for surgery were worse than on Singapore Island, but accounts of survivors suggest that for prolonged diet of low and progressively deteriorating standard Singapore was as badly off as any and far worse than most. In Singapore we had to dispense with many things, but had to improvise little but our operating theatres. In other camps things were different, and certainly in one operations were performed under hypnosis owing to the absence of anaesthetic agents. The absence of rubber gloves and antiseptics was a deterrent to some, but a technique involving the discarding of all clothing except a pair of shorts and a cap and veil and, as far as possible, the adoption of the practice of keeping the fingers out of wounds, was highly successful. It was noteworthy that those operations which could not be carried out without manipulating the tissues with the necessarily bare fingers were those in which we could not expect healing by first intention, as a routine. The most striking examples were naturally the gastrectomies, in which some intraperitoneal suppuration occurred, as has been said, in about half the cases. In the prevention of suppuration sulphonamide drugs, of which we had a sufficiency in the form of 'M & B' tablets, made no difference.

The main operative difficulties were those of Attap roofs full of rat droppings through which the wind would blow and the rain would drip, and increasing scarcity of necessities, especially of ligature materials and dressings. During our last year, for example, we were buying sewing cotton for 60 Japanese Straits dollars a reel. It became clear that with the shortage of normal apparatus and with the absence of a great deal of it, the prime needs for those placed in similar circumstances to ours would be as follows:

1. The devotion to their work and their fellows which characterises nearly all young medical officers and which fortunately remains with them as part of their characters throughout their professional lives.

2. A sufficiency of nursing orderlies to carry out the nursing duties under the supervision of the medical officers. If captivity is prolonged they will be really reliable nurses.

3. The assistance of well trained operating-room attendants from the Services. Though they may have had little experience of responsible work in theatres, such as that carried out by theatre nurses and sisters, yet they are easy to teach, are truly reliable, rapidly learn to be extremely good assistants at operations, and acquire impeccable asepsis.

We would add the following comments on other factors:

4. Antiseptics. With soap and water available, no antiseptics seemed necessary.

5. The absence of bed linen proved the greatest difficulty.

6. Food. Prison diets were deficient especially in proteins and vitamins. Operations were well tolerated however in spite of low dietary. The unfortunate need for gastrectomy in many cases precipitated avitaminosis and aggravated its degree in these unfortunate people. All who survived, however, left prison alive and later rapidly picked up health again.

7. In the future no doubt antibiotics and chemotherapeutic agents will be available, but apart from sulphonomides we had none, and we laid little stress on their efficacy.

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