In this case the serious initial injury was properly treated by excision and immobilization in plaster, but the quality of the gauze used to promote drainage was very poor and the granulations grew among the open mesh. When the gauze was removed and the wound was found granulating well, skin grafting was thought to be impracticable owing to the great number of foreign bodies which remained. When a skin graft was finally placed on the wound, this was too sclerotic and the remaining strands of gauze were still causing some inflammatory reaction.

This is the only case I have so far seen in Britain of disturbance caused by the use of the wrong type of gauze.

Choice of Graft

Once a wound is found to be ready for grafting, the next step is to decide the type of graft needed. The following general suggestions are based on my own experience:

1. The whole-thickness, one-piece skin graft cannot be used in conjunction with plaster casts, for it should be applied only under guaranteed conditions of asepsis. This is a plastic technique to be used in scar contraction, not a method of covering wounds treated under plaster.

2. For a wound of medium size, say 3 to 6 inches in diameter, the choice is between the Ollier-Thiersch, the "pinch," and the Corachán grafts. The first may be used with advantage in wounds that are absolutely clean, have very healthy granulations and are not unduly large. When the wound has had to be cleansed and prepared before grafting, both the "pinch" and the Corachán grafts are more suitable, and when the sterility of the wound is in question it is probably wiser to use the Corachán rather than the "pinch" graft. With the Corachán graft, which is essentially a graft of reproductive cells, there is a good chance that a certain number of epithelial cells will establish themselves in their new position even if the rest are destroyed by suppuration. On the other hand, if suppuration destroys the "pinch" graft, new epithelium is very unlikely to form, the germinating cells being destroyed with the graft.

3. When the wound is very large I always prefer the Corachán graft, for the amount of skin required is so very much less than in the "pinch" graft. The Ollier-Thiersch graft is of less value in large wounds than in those of medium size; moreover, healing of the large wound caused by removing the amount of skin needed for the graft always takes some time.

All things considered—the size of the wound, the degree of contamination, the quality of the granulations, etc.—the types of skin graft that are on the whole most useful in war wounds treated by the plaster method are the Ollier-Thiersch for small and medium-sized clean areas and the Corachán for large ones.

Techniques of Grafting

The "Pinch" Graft.—After a few days of preparatory treatment carried out through a window cut in the plaster, the cast is removed. The skin of the whole limb is cleansed with soap and water solution, dried, and swabbed over with alcohol. Antiseptics must not be applied to the region of the wound just before the operation. The areas from which the graft is to be taken should have been decided upon previously. If possible, the graft should be taken from the injured limb itself, because the wound made in taking the graft can then be treated under the same plaster as the original wound. Unfortunately, however, an extensive wound of the thigh requires such a large area of skin for the graft that it is generally necessary to take it from the other limb (see Fig. 78). The skin of the region from which the graft is to be cut is cleansed with soap and water solution, shaved, swabbed with alcohol (70 per cent), and surrounded by sterile towels.

If necessary (see p. 293) a strip of skin about 3 mm. wide is excised all round the wound with a fine, sharp knife, and the superficial layer of connective tissue and granulations is scraped away with the sharp edge of the knife laid obliquely to the plane of the wound surface; a uniform layer should be removed and the damage must not extend to the base of the granulations. A piece of gauze soaked in hot saline is laid over the wound and pressed gently with the hand to control the bleeding.

The next step is to take the graft from the previously prepared area. With a long, straight needle the skin is pricked and raised to form a cone. It is then cut with a sharp knife or, preferably, a razor all round the base of this cone, and the piece thus removed (approximately 0.5 cm. in diameter) forms the graft. The first graft taken serves to indicate the thickness of the patient's skin and to guide the surgeon in cutting subsequent grafts. The lower surface of the graft should be free from subcutaneous fat and the section must be through a plane that passes through the deeper layers of the skin only in the center of the graft. This is not difficult to achieve, because if the blade of the knife or razor is held horizontally the section through the cone of skin cuts the various epidermal layers obliquely, and it is only at the center that the deeper cellular layers are included in the cut.

Each graft, as soon as it has been taken, should be transferred immediately to the surface of the wound. The grafts should be placed about 1/4 inch from the edge of the wound and a similar distance from each other. When they are all in position a piece of close-meshed vaseline gauze is laid over the wound, and the whole area covered by a square of felt slightly larger than the wound. The limb is then ready for a new plaster, if this is needed. Similar protective measures are applied to the wound produced by cutting the graft, except that when this is on the other limb no plaster is used. In some cases in which there has previously been a very copious discharge, it is wise to sprinkle some sulfanilamide powder over the wound after the graft has been applied, but this drug should be sparingly used even in such cases, owing to its retarding effect on the healing process.

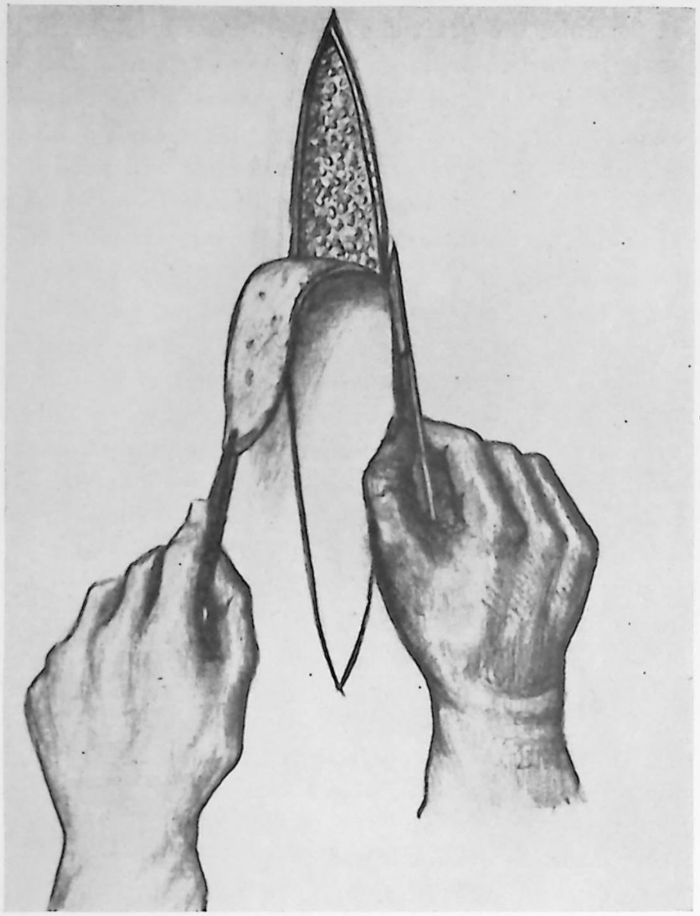


Fig. 72.—Corachán method of skin grafting. A long and narrow strip of skin, free from subcutaneous fat, is cut out. (See also Figs. 73 to 75.)

The plaster should be retained on the limb for eight to twelve days. In very clean cases the plaster may be retained for two or three weeks, when the wound will in some cases be found healed. If the discharge is abundant, a window is cut in the plaster, the felt and gauze are removed, and after the wound has been dried and powdered afresh with sulfanilamide, it is covered again as before and the window is either reapplied or not, according to the amount of discharge. In cases of

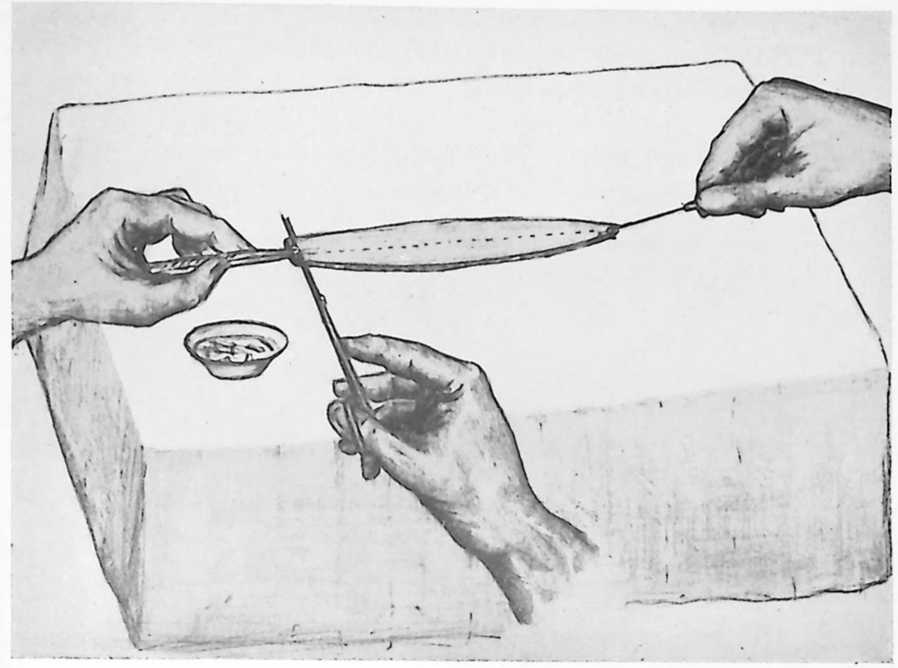


Fig. 73.—The strip of skin is laid out flat on a table and with a fine pair of scissors is cut into as many parallel segments as possible.

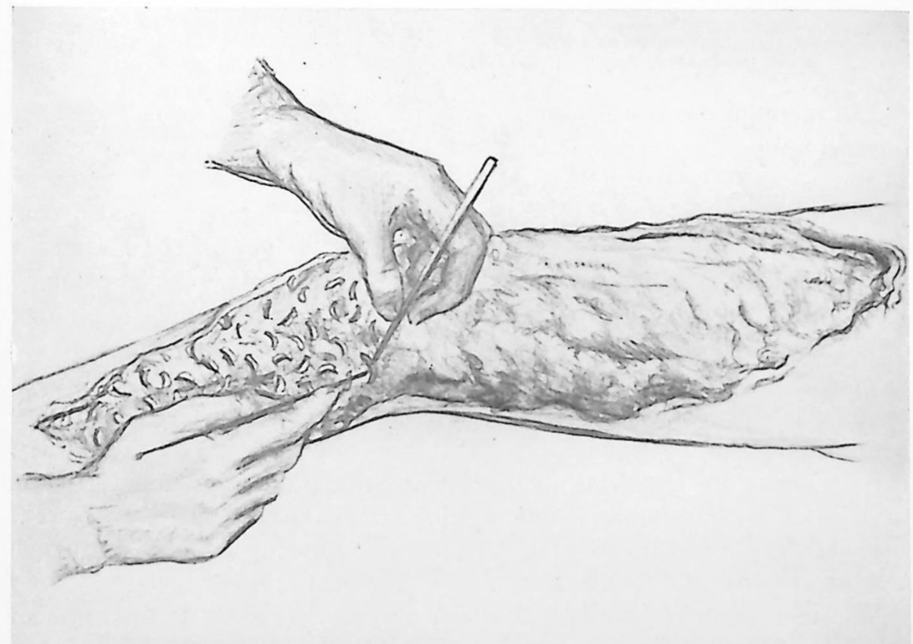


Fig. 74.—The thin slices of skin are placed on the edge of the wound.

fracture the dressing must always be changed through a window, so as to avoid displacement of the bone fragments.

The Corachán Graft.—The Corachán graft has two great advantages: first, the area of skin required for grafting is only half that of the "pinch" graft, and secondly, the wound produced in taking the graft can be immediately stitched up and so heals by first intention.

Fig. 75.—Extensive wound of the external aspect of the thigh and leg. Compound fracture of the external condyle of the femur and patella. Much laceration of the knee joint. Treated after a few hours by the biological technique.

The technique is based on the fact that the epidermal cells which are most capable of multiplication are those of the Malpighian layer, and so the responsibility of new epithelial formation rests mainly with them. The epidermal cells of the sebaceous and sweat glands may also contribute to the new reproductive epithelium. The aim of the method is to implant cells from this reproductive layer only. It is common knowledge that during the epithelization of many wounds a number of islands of epithelium, completely separated from the edges of the skin and sometimes even an inch away, make their appearance on the surface of the granulations. These islands are formed either by the reproduction of individual cells that have been detached from their original seat by the friction of the dressing and have survived and multiplied in their new position, or else by isolated sebaceous and sweat glands. These facts led Corachán (1933) to develop a technique which was afterwards adopted in a number of surgical centers.

The most suitable area from which to take the graft is the anterior surface of the thigh. This is shaved, washed and sterilized with alcohol, and sterile towels are laid around the field. With a knife, a long and narrow ellipse of skin is removed, care being taken that no sub-

cutaneous fat is included (see Fig. 72). The size of the piece of skin removed bears a constant relation to that of the wound to be grafted, a piece measuring approximately one-sixth to one-eighth of the area of the wound being sufficient to graft the whole of the granulating surface. As soon as the graft has been taken, the surgical wound is sutured. The piece of skin to be used as the graft is now taken up by two pairs of fine forceps, one at each end, and laid out flat on the instrument table. While an assistant holds one end, the surgeon takes a pair of fine scissors or a razor and cuts the skin transversely across the line of its greatest length into a series of narrow strips, not exceeding 2 mm. in width (see Fig. 73). In cases in which the piece of skin

Fig. 76.—Freedom from pain and shock after immobilization in plaster.

is more than half an inch wide it must first be divided in two by a longitudinal cut; for the transverse strips should not be more than half an inch in length. Each strip is placed in a small bowl of warm saline, and when the whole piece of skin has been sectioned, the strips are placed one by one on the wound edgewise, that is to say, with one of the surfaces cut by the scissors in contact with the granulations (see Fig. 74). They are placed about one centimeter apart, this spacing being sufficient to allow a good new formation of epithelium in a short time. By applying the strips edgewise direct contact is made between the reproductive layer of the graft and the granulations, with

Fig. 77.—Good quality of the granulation after seven weeks of immobilization in plaster.

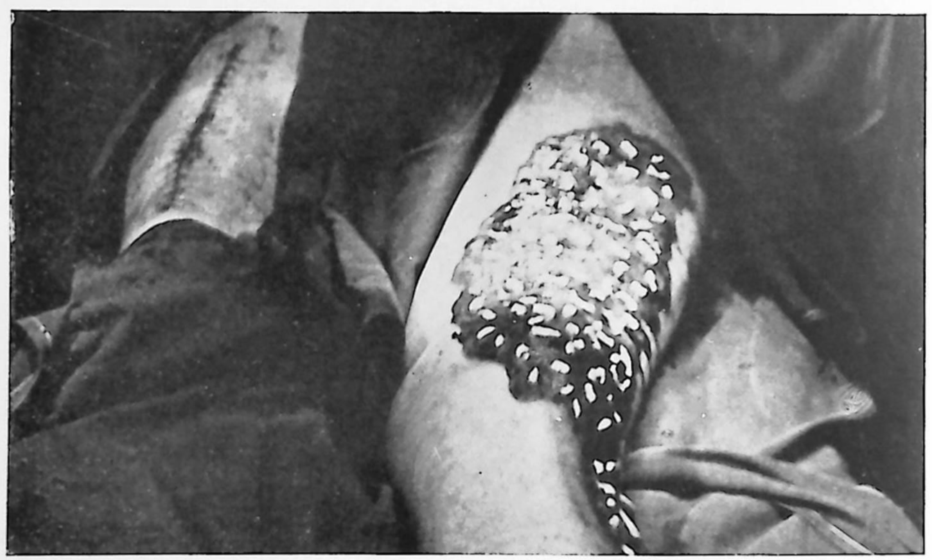


Fig. 78.—Corachán skin graft. Note the sutured wound of the right thigh from which the graft was taken.

the result that many cells are successfully implanted in the wound surface and good healing is effected in about the same time as with a "pinch" graft (see Figs. 75 to 79).

Fig. 79.—End result of the case in Fig. 74, four months after wounds.

The great value of this method of grafting is the ease with which enough skin can be obtained to graft really extensive areas without producing large surgical wounds which sometimes heal very slowly. The skin of the final result is of good quality and does not retract; in many cases it is of better quality than that which results from the "pinch" graft (see Fig. 80).

A.

B.

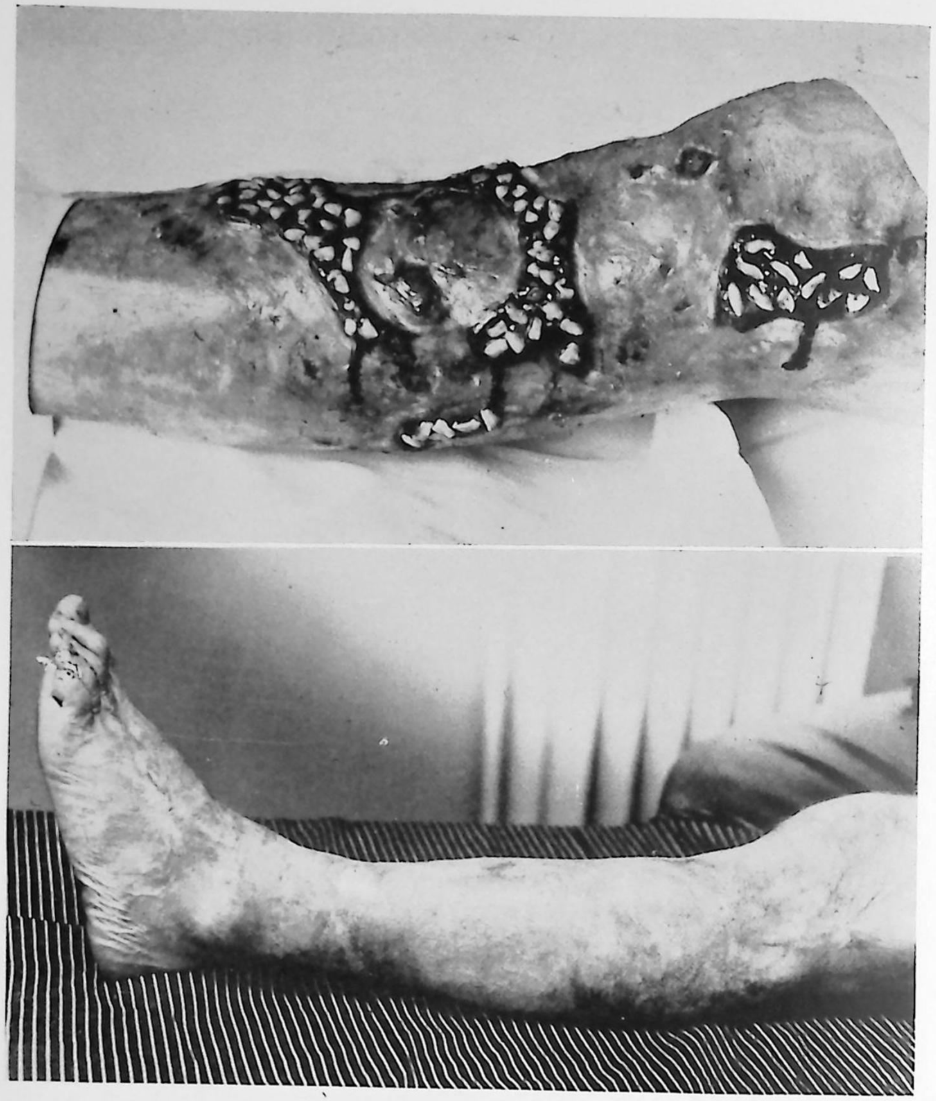


Fig. 80.—*A.* Extensive wound of the leg treated by excision and plaster. Corachán skin graft, five weeks after the production of the wound. *B.* Wound completely epithelized four weeks afterwards.

The wound itself is prepared in exactly the same way as for a "pinch" graft, but in this respect also the Corachán technique has a certain advantage in that it is not so necessary to scratch the granulations to make them bleed. I have often seen excellent epithelization result from a graft placed on their unbroken surface. It is only when the granulations are very sclerotic that they must be scraped.

The Ollier-Thiersch Graft.—In the quality of the final skin and the rapidity with which the wound heals after grafting, the Ollier-Thiersch technique is undoubtedly the most satisfactory. On the other hand, the graft is less resistant to infection than grafts of the "pinch" and Corachán types, and in very large wounds it is sometimes difficult to use owing to the wide area which must be denuded of skin to provide it.

The best region from which to take the graft is the medial surface of the arm, but if a very large graft has to be taken it is better to use the skin of the inner aspect of the thigh, or that of the outer side though this is of less good quality.

Technique.—A piece of transparent paper is laid over the wound and an outline of the opening is sketched upon it. By cutting round this line, a pattern of the shape and size of the wound is obtained, and this is then marked out in iodine on the skin from which the graft is to be taken. It is advisable to mark off an area slightly larger than the actual size of the wound, to allow for the shrinkage of the graft.

Holding the skin level and taut by pressure with a flat piece of wood, the surgeon takes a razor, or one of the many special types of knife such as the Blair, and cuts a superficial and uniform layer of the skin to the shape and size indicated by the iodine line. The section should take only the most superficial epidermal layers; the roots of the hairs should not be included. The graft is immediately transferred to the wound and attached by a few stitches or maintained in position by elastic pressure. The rest of the procedure is similar to that described for the other grafts.

The Dermatome.—The technique of cutting large grafts of intermediate thickness has been simplified, and the scope accordingly extended, by the introduction of the apparatus called by its inventor the dermatome (Padgett, 1939). Its main components are a drum at a predetermined distance from which is fixed a movable knife. By attaching the skin to be grafted firmly to the surface of the drum, using cement or any other suitable adhesive, a sheet of uniform thickness can be cut to an area as large as that of the drum, 4½ in. × 8 in., or smaller.

CHAPTER XXIII

ARTICULAR WOUNDS

The War of 1914 to 1918, which produced such an outpouring of papers on compound fractures, yielded surprisingly few on compound injuries of the joints. An obvious explanation is that penetrating wounds of the joints produced so much more damage in the bone than in the articular tissues that surgeons tended to concentrate on the former, applying to the treatment of wounded joints the principles that were guiding them in the treatment of fractures. Their failure, during the earlier stages of the war, to appreciate the difference between the bony and the articular tissues in their reaction to injury, led in fact to disastrous results. Duval (1918), for instance, cited a mortality of 27.6 per cent and an amputation rate of 30 per cent in knee wounds sustained in France during 1914 and 1915.

In 1915 Delore and Kocher published the first paper recommending primary suture for the treatment of wounds of the knee joint, and in the same year Gaudier adopted this technique (see Gaudier and Hamant, 1916). In consequence of the general acceptance of this practice, results improved, and in 1917 to 1918 the death rate fell to 0.9 per cent and the amputation rate to 2.8 per cent (Duval, *loc. cit.*). After the war primary suture was still accepted. Disagreements arose, however, about the best type of suture and, more especially, about the tissues which should be sutured. Some surgeons recommended the systematic suture of all articular and periarticular tissues, others preferred to suture the synovial membrane only, and some—fortunately very few, but including an authority as great as Böhler (1937)—stressed the advantage of the simple suture of the skin.

In order to obtain a clear idea of the best procedures and the occasions on which they should be employed, it may be of assistance briefly to recall the specific reactions to injury of the various articular and other neighboring tissues, and the important part played by the synovial fluid in the defensive mechanism of the joints.

DEFENSIVE POWER OF THE ARTICULAR TISSUES AND FLUID

From the skin to the articular cartilage, all the tissue layers of the joint, articular and periarticular, have their characteristic response to infection. Three components of the most highly developed joints, namely, the synovial membrane, the synovial fluid, and the articular cartilage, call for special consideration.

The Synovial Membrane

The synovial membrane, which closes the articular cavity in all diarthroses, consists of a continuous stratum of mesenchymatous tissue which varies somewhat in its cellular anatomy from one place to another. In many regions there is only a synovial lining of flattened cells covering a layer of loose connective tissue. In places where the membrane is free from mechanical stresses, the cells are rounded or polygonal and may be disposed in two or three layers. Where the lining of the joint cavity is exposed to much pressure and friction, it is composed of dense fibrous tissue or fibrocartilage. The nature of the cells of the synovial membrane is not yet completely established, but they are generally admitted to be very similar to fibroblasts (Le Gros Clark, 1928). Some of them have a phagocytic capacity and play a defensive part against infections.

Absorption in Joints.—Absorption through the mesenchymatous membrane is relatively slow when there is no breach in the continuity of the superficial layer of cells, but it is very high in the periarticular connective tissue (Le Gros Clark, *loc. cit.*). Le Gros Clark injected trypan blue into the knee joint, and after six hours the histiocytes of the surrounding connective tissue contained no dye; on the other hand, when the dye was introduced directly into the connective tissue, it was taken up very soon by the histiocytes. Some substances, however, are more easily absorbed through the synovial membrane. For instance, Demel (1927) injected 1 to 3 c.c. of 20 per cent sodium iodide into normal joints of dogs, and after varying intervals detected iodine in the saliva by blue tinting of a filter paper impregnated with starch. The time-lag was 35 minutes for the knee, 40 for the hip, 43 for the elbow and 73 for the shoulder. This permeability is probably related to the molecular size of the substance concerned.

The whole of the synovial membrane is concerned in absorption from the joint cavity, but the process is more rapid where the membrane overlies loose connective tissue or is reflected over subsynovial pads of fat. These provide for an increase in the absorption area of the membrane, particularly since the rows of flat cells over them are often thrown into small complicated folds like villi. In the knee joint these pads are especially conspicuous and allow a very rapid absorption, a fact which readily accounts for the occasional appearance of general septicemia in acute traumatic infection of the knee. It should be emphasized that movement accelerates the rate of absorption.

The Articular Cartilage

In diarthrodial joints a simple hyaline cartilage covers the bony ends over the area of friction. This may be regarded as a persistent unossified layer of the cartilage from which the bone has been developed.

Hyaline articular cartilage is completely avascular and has no nerve supply. Cartilage has no absorptive power, and the underlying lymphatics and vessels are absorptive only when the cartilage is ulcerated in areas near the insertion of the synovial membrane.

Articular cartilage is highly resistant to infection, and many days of persistent and intense infection are needed to damage it seriously. It is nourished only by the articular fluid, the contribution of the blood vessels being completely illusory.

The Synovial Fluid

The most important characteristic of joints is their ability to produce fluid. Except for its mucin content, articular fluid is somewhat similar to peritoneal and pleural fluids. The protein in normal human joints varies between 0.4 per cent and 1.6 per cent (Kling, 1938). Irritation and inflammation increase the permeability considerably, and the protein concentration may then reach or exceed that of the blood (8.55 per cent in one case of Kling's). Moreover, the concentration of the diffusible constituents of synovial fluid closely approaches that of blood plasma, and diffusible substances introduced into the circulation rapidly pass into the synovial fluid (Cajori et al., 1926).

The outstanding characteristic of the synovial fluid is its bactericidal capacity. Margolis and Dorsey (1930) often noted the absence of colonization in cultures of synovial fluid in which organisms were present. Forkner, Shands and Poston (1928) found that in infective arthritis cultures of lymph nodes were positive twice as often as cultures of synovial effusions. The bacteria are ingested by macrophages and are mostly disintegrated by proteolytic ferments. Every pathological effusion contains large numbers of phagocytes and nonphagocytic leucocytes which come from the blood stream.

Another characteristic of the articular fluid is its alkalinity, which is commonly increased in most effusions, many investigators giving a figure as high as pH 8.4. Only in purulent arthritis does acidity develop. Synovial fluid is also very rich in agglutinins.

A joint therefore possesses a number of defensive mechanisms lacking in other tissues: first, the hermetic sealing of the joint which excludes contamination from neighboring tissues; secondly, the passive resistance of the cartilage to bacterial invasion; thirdly, the active bactericidal property of the synovial membrane and fluid; and finally, the lower absorptive power of the synovial membrane as compared with the underlying cellular tissue.

In contrast, the defensive properties of the surrounding tissues, from the perisynovial cellular tissue to the deep layer of the skin, are very poor. Not only is their absorption very high, but the slightest movement tends to spread septic contamination through the cellular spaces

or the tendon sheaths to the lymphatics. In war injuries the tissue which bears most responsibility for the onset of septic processes in the joints is the bone. Any intra-articular fissure of the bone in compound injuries of the joints increases much the danger of infection, both because of the difficulty of stopping intra-articular bleeding and because of the penetration of pathogenic germs into the defenseless spongy tissue of the epiphysis. Unfortunately the great majority of war wounds in joints include lesions of the bone.

SURGICAL TREATMENT OF JOINT WOUNDS

The treatment is based on the relatively long time for which the injured joint remains free from infection. As in all the tissues, the growth of infection is determined by two factors, one highly variable—the number and virulence of the invading organisms—and the other more constant, the individual resistance of each tissue to infection. As the first must be considered an unknown quantity, surgical treatment can be influenced only by the second—the known ability of the synovial membrane to resist infection. Duval and other French surgeons gave a very optimistic estimate of the defensive capacity of the joint tissues, stating that the synovial membrane remains free from bacterial colonization for twenty-four, forty-eight, and sometimes even sixty hours before septic arthritis develops. This may be true of some clean "through-and-through" wounds produced by bullets fired at long range, but it is not a reliable rule for most war wounds, especially those produced by shell splinters or bombs. The majority of these missiles remain either in the joint or in the surrounding tissues, particularly inside the bone; and surgeons know well how much worse the prognosis is when a foreign body remains impacted in a joint. A further complicating factor is the speed with which infection develops in the periarticular connective tissue: an average of six hours has been fully confirmed. A joint can be relied on to remain aseptic for 12 to 16 hours, with a maximum of 24 hours; and this ought to be the basic consideration in determining the surgical technique.

When a wound is treated within twelve hours of its infliction, a primary suture should be attempted; this is only contraindicated by the presence of conditions which make effective suture impossible, e.g., extensive destruction of synovial membrane. But before the suture an exploratory arthrotomy must be performed, as the only means of cleansing the joint of all foreign bodies, a term which includes not only the missile and small pieces of clothing, wood and the like, but also retained blood. As for the other tissues, soap and water is the best means of cleansing the synovial membrane and eliminating clots from the depths of the joint.

Excision

The soft tissues should be excised to the same extent as in wounds of other regions: the surgeon should be conservative with the skin and radical with the connective tissues. With the bones, however, he must be conservative in the most extreme sense of the term, and replace as many fragments as possible in position; but to do that without undue risk the operation must be performed within eight hours, preferably within six hours of the production of the wound. Bone, unlike the synovial membrane, cannot endure twelve hours' contact with bacteria without being colonized; nor can the periarticular tissues. If, therefore, time is lost the operation has to be more drastic. If the delay has been longer than eight hours, bone must be eliminated, with consequent intra-articular bleeding and serious risk to the functional future of the joint.

Fig. 81.—Extensive bruised wound of the anterior aspect of the ankle joint, with dislocation of the talus and severance of tendons. Operated on eight hours after production of the wound. Cleaned with soap and water; wound excised. Primary suture of the synovial membrane; sulfanilamide powder in the remaining wound. Drainage with dry gauze and plaster from toes to above the knee. (See also Figs. 82 to 84.)

Delay in operation causes similar troubles in the periarticular tissues; so here too the principle of operating within six to eight hours ought to be maintained. If more than eight hours have elapsed, all free fragments of bone must be removed, the synovial membrane closed after excision of a narrow strip of its edges, and the periarticular tissues left open. Fortunately, in many wounds involving the more im-

portant joints, such as the knee, ankle and wrist, there is little or no damage to muscles, and so provided that the excision has been thorough, primary suture of the skin may be performed, without the same danger as in other regions.

Suture.—The suture of the synovial membrane must always be continuous and preferably made with catgut. When the skin is sutured at about the time limit of eight hours, the periarticular spaces should be drained by passing some threads of silk between the stitches at one corner of the wound. I prefer to close the wound with a few separated stitches so as to allow the blood and lymph to escape.

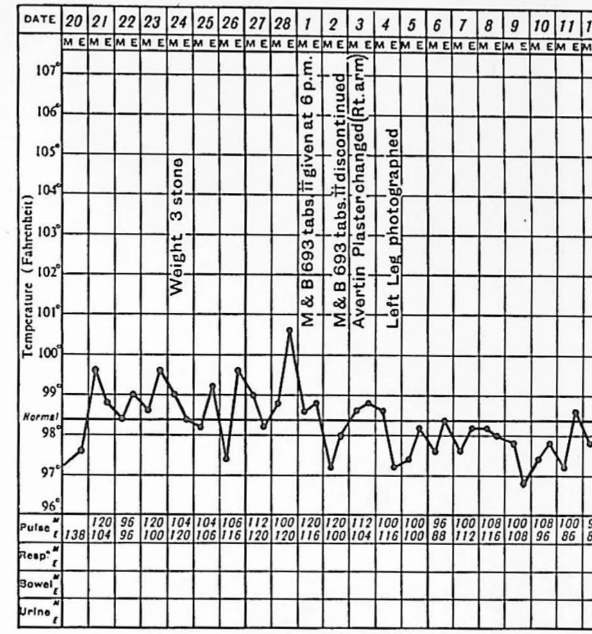


Fig. 82.—Temperature chart of the patient in Fig. 81. (M. and B. 693, sulfapyridine.)

In bruised wounds treated after eight hours the synovial membrane only should be sutured and the skin left completely and freely open. The same must be done in cases where the excision of soft tissues makes it impossible to reunite the edges of the skin without causing undue tension. The case illustrated in Figs. 81 to 84 shows the excellent result that can be obtained by suture of the synovial membrane only.

The patient, a well-developed boy of eight, was knocked down by a van on the morning of February 20, 1941. He was transferred to the Wingfield-Morris Orthopaedic Hospital 7½ hours after the injury. On admission he was very anxious and had a pulse of 120/130 and blood pressure of 104/64. He had a fracture of the right humerus, a wound above the right knee, and a bruised and extensive wound on the anterior aspect of the ankle with compound dislocation of the talus. He underwent immediate resuscitation and operation under gas and oxygen anesthesia. The skin and wound were cleansed with soap and water, and the edges of the skin were excised. The skin had been completely denuded over a wide area, the tendons were damaged and the foot was inverted, with a tear through the capsule of the ankle joint through which the articular surface of the talus protruded forwards (see Fig. 81). All necrotic tissue and some of the long tendons were removed. The ankle joint was closed with continuous plain catgut. The wound was smeared with sulfanilamide powder, a dry gauze was applied and the limb enclosed in plaster from the toes to the knee. The

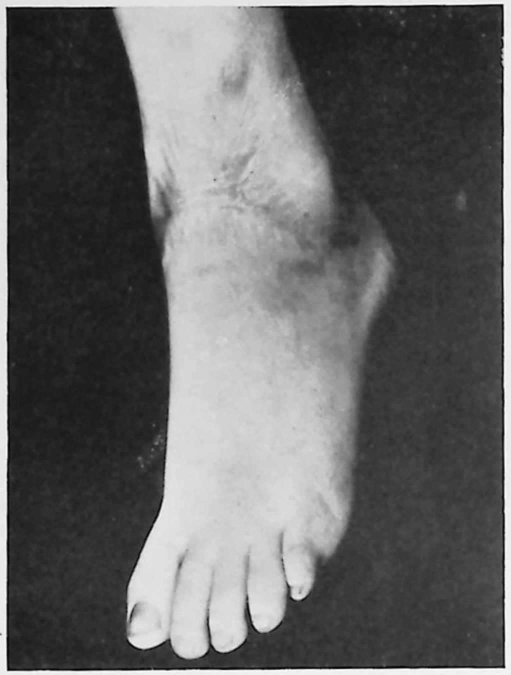


Fig. 83.—Condition of the ankle four months later, when the patient was walking and regaining full range of movement.

postoperative course was uneventful. For some days the temperature slightly exceeded 99° F. except for one day, but at the ninth day it settled down to 99° F. (see Fig. 82). On March 27 the plaster was changed under general anesthesia. The wound looked very clean; it was powdered with sulfanilamide and a new plaster was applied. The plaster of the right arm was removed and the arm placed in a collar-and-cuff sling. On April 17 the plaster was renewed, the wound being markedly reduced. The plaster was finally removed on May 17 and a bandage of elastoplast was applied to cover the small remaining wound. He started walking, but as he found it very difficult he was given massage and progressive re-education. On June 29, he was discharged having recovered full movement of the ankle (see Figs. 83 and 84).

This case is one in which the surgical technique was carried out with all the necessary care. The perfect result, in spite of the initial delay

in sending the patient to the hospital, was undoubtedly due to the correct technique employed.

Order of Excision.—There are two schools of thought on the best order of excision. Some surgeons prefer to do the arthrotomy first and then to treat the periarticular wound; others hold that it is better to treat the periarticular wound first and gradually proceed to the joint. I think the second is the correct method, provided that the surgeon takes the precaution of changing the instruments when the articular stage of the operation starts. I feel it is illogical and dangerous to deal with the joint first (as, for instance, Pierre Duval recommends) and to close the synovial membrane and treat the contaminated part at the end of the operation. The logical technique, and that which my experience has shown to be safe, is excision of the damaged tissues layer by layer, careful hemostasis, and cleansing of the joint through an already clean wound.

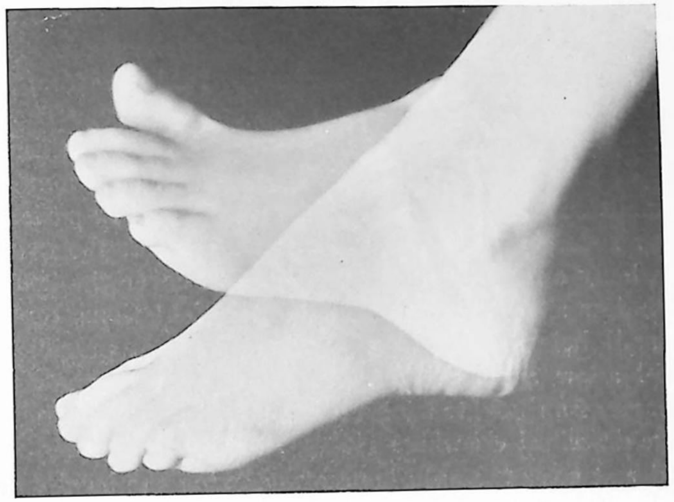


Fig. 84.—Complete recovery of movement by the patient in Fig. 81.

Drainage.—Cases which arrive too late or are too badly damaged for primary suture of the joint should be treated by the principles which have been repeated over and over again in this book, special care being given to drainage. Ogilvie (1941) has given firm support to these views. Generally speaking, a joint should never be drained through the wound. The wound hardly ever coincides with the most dependent part of the joint, and drainage of a joint from other than the most dependent part is worse than useless. In Chapter XXV, which deals systematically with war wounds of different regions, I shall come back to this point and fully specify the place selected for each articulation.

Immobilization

In the last stage of the treatment, when the operation is finished, the surgeon has two alternatives: mobilization or immobilization. Joint surgery is one of the few branches of the art in which a technique of mobilization in the treatment of wounds has been described and at one time, at any rate, widely accepted. This method was advocated during the last war by Willems of Ghent, and made so great an impression that even surgeons who believed in the good effects of immobilizing infected limbs accepted the principles of early mobilization under certain restrictions. This procedure has now been completely forgotten—without, I think, any prejudice to the victims of this war.

Plaster.—The best fixation for a joint treated by primary suture of the synovial membrane and skin is a plaster-of-Paris cast immobilizing both it and the neighboring joints; but in this special group of cases a window must be cut at the level of the affected joint. The purpose of the window is to avoid any tension inside an articulation and also in periarticular tissues closed by primary suture, to permit the aspiration of any articular fluid retained under tension. This aspiration should be performed through undamaged skin far from the wound, and in some cases must be repeated twice or more. The Thomas splint is also useful for knee wounds. The impossibility of securing drainage by means of absorbent gauze in cases in which the wound is closed makes it inadvisable to apply a closed plaster cast. In patients treated by primary suture of the synovial membrane with the overlying tissues left widely open, the plaster cast should cover the whole wound, and no window should be cut. In large articulations, especially the knee, a small hole made in the plaster as far as possible from the wound will allow aspiration of the synovial membrane as required. The drainage of an infected joint should follow the general principles of drainage described elsewhere (see p. 228). Drainage of the articular cavity and rest offer the only hope of arresting the local disturbances and averting danger to life. Once the lining cells of the synovial membrane have been destroyed, and still more when its whole thickness has been eroded, there is great absorption of bacteria and toxins and the patient's general condition deteriorates very rapidly. The only way to diminish such absorption is, of course, the most complete immobilization, not only of the joint itself, but also of the surrounding tissues. Hence a plaster should be applied to fix not only the neighboring joints but also the segment of the body immediately beyond those joints. The position of the limb is of the greatest importance, not only to allow good drainage but also to secure a normal circulation and prevent edema. In the great majority of cases the plaster should cover the wound; but in an infection of the knee joint with very profuse discharge it is sound at first to cut a small window through which the pus

can be drained off without much soaking of the plaster. After a few days the window may be closed, and then the plaster may be kept in position for more than three weeks without any great discomfort.

Factors Determining Successful Treatment

Clearly, then, for articular wounds as for all others, early treatment is the foundation of success; the only distinction is that good results can be obtained even if operation is delayed for a few hours. A cause of failure—unfortunately the most frequent in war wounds—is the technical impossibility of suture owing to damage to the articular tissues, especially of bones and of the synovial membrane. I have only in exceptional cases been able to close the synovial membranes of the shoulder, elbow, wrist or ankle. The hip and knee joints can be stitched up more often—fortunately, because these are the two joints in which infection is most serious.

These general considerations apply to all diarthrodial joints; but every joint has its own particular reaction to infection and its own way of healing, depending on its anatomical disposition.

Lastly, I must stress the enormous difference between peacetime articular wounds and those of war. At all times conservative treatment and primary suture should be carried out to the full; but war casualties make one more sceptical and less dogmatic about the quality of the results. The impressive statistics of Ferguson and Dangerfield (1940) compiled among South African miners bear no relation to the results obtained in cases of articular wounds caused by small splinters of aerial bombs. The difference lies in the rarity of bony injury in the South African workers.

The use of sulfonamide compounds in general treatment has recently improved the results in articular wounds. Patients should be given a prophylactic course of sulfonamides, and local application after excision may also be of some help.

CHAPTER XXIV

AMPUTATION

Amputation is probably the oldest operation in war surgery, and the least affected by progress. The guillotine method was the earliest and for many centuries the only method used. Bleeding was controlled only by cautery until, in the 16th century, Ambroise Paré first employed ligatures. From his time until the 19th century, when Liston introduced flap-amputation, there were no important technical advances; though it may be recalled that Cheselden in 1756 had recommended the division of skin and fat at a lower level than that of the bone. Liston was also one of the most outstanding of the surgeons who described regional techniques (e.g., Larrey, 1808; Syme, 1831; Gritti, 1857; and Pirogoff, 1854).

For many centuries the safest operation for compound fracture was considered to be amputation, and this radical procedure was so widespread that in 1761 the German surgeon Johann Bilguer attacked it in a book entitled *De membrorum amputatione rarissime administranda aut quasi abroganda*. This was a plea for conservative surgery directed to a surgical world that amputated limbs as a preventive measure. In 1842 William Fergusson (1808-1877), Bilguer's most enthusiastic follower, published a strong recommendation of conservative surgery; and Brodie and Syme, following Fergusson, proposed the revision of surgical criteria along very conservative lines.

At first sight, amputation seems to be a plain confession of surgical failure to save a limb. This may have been true in the past, but is certainly not so today. Amputation in war surgery has been progressively relegated to cases in which, as a consequence of trauma, the limb has already been lost through destruction of its blood supply, or rendered useless by extensive injury to its anatomical structures. Limbs are very rarely amputated nowadays for infective complications in the extremities. The amputation rate in war surgery has therefore decreased enormously in the last century and a half.

It is interesting to compare figures of the Napoleonic Wars with some of those recorded during the Spanish War. Whereas Larrey mentions 365 amputations performed among 8,000 wounded of all sorts, during the last year of the War, in Catalonia only 342 amputations were required among a total of over 42,000 wounded, most of whom were injured by artillery fire and aerial attacks, which, it is well known, produce the greatest damage to limbs. The diminution in the number of

amputations is undoubtedly a consequence of improvement in surgical technique, and is one of the most eloquent proofs of the advance of surgery.

INDICATIONS FOR AMPUTATION

The aim of the surgeon is to preserve the injured limb as far as possible, unless it endangers the patient's life or is unlikely to be of any more use. In deciding whether or not to remove a limb, the main point to notice is its circulation. The temperature of the hand or foot and the color of the skin give useful information, and the oscillometer readings help in cases of doubt. Experience and practice enable the surgeon to distinguish accurately a limb that needs immediate amputation from one that can be treated conservatively.

Another factor is the condition and site of the wound. The extent of excision has a limit that cannot be passed without endangering the life of the patient and the utility of the limb. Imagine, for example, a bruised compound fracture caused by a shell or bomb splinter in the upper part of the thigh. The excision of dead tissues might have to include not only a large amount of muscle, thus leaving the femur without protection, but also a large portion of that bone. The surgeon knows from the start that at best many months will be necessary to heal the wound, and that in the end the femur will probably be left with a pseudoarthrosis. The knee and possibly the ankle will be stiff, and the pseudoarthrosis will need still further operations. Thus, after a long illness, the patient will have a stiff leg, with the unavoidable shortening that follows great loss of tissue in a single long bone. Taking into account the initial danger to life, the long convalescence, the number of the operations required and the final result, it seems better to do an immediate amputation, provided that the remaining stump will be long enough to take a suitable artificial limb.

Clearly only experience can give the surgeon sufficient knowledge to support his decisions, and it is therefore almost impossible to draw up a system on which he should act. Some guidance, however, is necessary for young surgeons who have not yet acquired much experience of war surgery, and it is for these that the following observations are intended.

Criteria for Amputation

It is difficult to distinguish between the limb that will be useful to the patient, and that which will later require amputation for functional reasons. The criteria for the arm differ from those for the leg. Broadly speaking, the important need for the arm is the preservation of movement, whereas for the leg it is the maintenance of a strong support. Conservative treatment is far more often desirable for the upper limb than for the lower, because even deformed stumps of fingers, hands contracted by scars, and fingers rendered stiff by adhesions are more useful than the best artificial hand. Re-education clinics and spontaneous adaptation by patients produce quite unexpectedly useful upper limbs. Furthermore, conservative treatment is essential to prevent as far as possible the development of feelings of inferiority and disability, with their social consequences, in patients invalided with war wounds in the upper limb. The lesser danger to life caused by injury of the upper limb allows amputation to be rejected in many cases that at first sight seem to need it.

In the lower limb there need be less hesitation. In the first place it is possible to provide a useful artificial limb, and in the second place deformed feet often remain painful, and there may be harmful ankylosis for which the foot may later have to be amputated. Thirdly, injuries of the leg are generally more dangerous to life than those of the arm. For these reasons conservative treatment cannot be carried out to the same extent as in the upper limb.

Three things must be taken into account when amputation is essential: the site of the wound, its characteristics, and the arterial, nervous and bony damage. The general condition of the patient may contraindicate an immediate serious operation, and if so, initial conservative treatment should be carried out until the patient is fit for amputation.

Amputation in some cases might leave so short a stump that an artificial limb could not be fitted. Whether this would be so naturally depends on the place of the injury. In suitable cases conservative treatment may facilitate a secondary amputation at a selected level, once the granulation of the wound allows the conservation of all soft tissues necessary to cover the stump.

The task of the surgeon, then, is to strike a balance between the following requirements:

1. The need for extreme conservatism with the upper limb.

2. The need for conservatism also in the great majority of extremities which can be saved in some shape, the possibility of a precarious functional result being given, within reason, second place. A delayed amputation may eventually solve the problem.

3. The importance of leaving a stump long enough to take a prosthetic apparatus. In all cases in which the stump would be too short conservatism should have first place.

4. The desirability of reserving amputation for limbs whose blood supply has been seriously affected, or which have undergone so extensive a destruction of tissue, including nerve and bone, that conservative treatment would not only be long and difficult but would offer no hope of future useful function.

5. The need for amputation when the wound is so large and bruised that excision is out of the question.

THE TECHNIQUE OF AMPUTATION

Much has been said against the guillotine amputation—that is to say, the transverse cutting through of all the tissues at the same level, which was the only technique in use before Liston. The criticisms have in general been well founded, but quite a number of war wounds require a guillotine amputation. In the first place, flap-amputation requires the bone to be shorter than the soft tissues by a distance as great as the radius of the limb. Thus in the femur, for instance, an overlap of some three inches would be necessary. In wounds of the thigh a shortening of the bone by three inches might destroy all hope of fitting an artificial limb. In such cases the only possible technique for amputation is the guillotine.

One other type of case needing guillotine amputation is that in which the operation is carried out because of gas gangrene. The always precarious nutrition of the flaps makes them particularly liable to gangrene, so here also the technique that gives the best results is the guillotine. In all other cases the flap technique should be preferred.

Level of the Amputation

The widespread use of artificial limbs has in recent years introduced a new factor into the amputation problem. In planning an amputation the surgeon must remember that the stump will be useful to the patient only in so far as it is fit to carry an artificial limb. Surgeons have recently been relegated to a second place by engineers and limbmakers, who know better than they where the limb should be amputated to make it easiest to wear an artificial limb. Their work has been of great advantage to the patient. Until recently the guiding surgical idea was to keep as much of the limb as possible, often leaving the epiphysis in the amputation stump. Now, thanks to the limbmakers, we know that the length of the stump is important only in relation to the ease with which it will carry the prosthetic apparatus. A good stump should work as a lever: it should be long but not too long, with a regular slightly conical shape.

By the collaboration of surgeons and limb-makers, the points of election for the division of the bones have been determined and are now universally accepted. The agreement reached seems to be contrary to the principles of conservative surgery, because it establishes that any portion of the stump beyond the length necessary to carry the artificial limb is not only useless but harmful, especially in the leg.

The Length of the Stump

The following are the best lengths for the various stumps:

Arm: As much of the shaft as can be saved; the metaphysis, however, should never be conserved.

Forearm: As much as can be saved.

Hand and Fingers: As much as can be saved.

Thigh: At least seven inches below the top of the great trochanter. The femur should never be left shorter than 6 inches: when this would be unavoidable it is better to do a disarticulation at the hip joint. As much of the femur as possible should be saved, provided that the metaphysis and epiphysis are removed —that is to say, the distal 3 or 4 inches.

Leg: The tibia should be divided in the middle, and the fibula shortened by one to two inches more. An amputation should never be done that leaves only three or four inches of tibia, because the rigidity in flexion of the knee will limit the function of a prosthetic apparatus. Instead the amputation should be made above the knee.

Foot: It is necessary to be conservative with the calcaneal region, but not so conservative with the middle tarsal, otherwise the foot will become rigid and in many cases painful. Extreme conservatism is required with the metatarsal bones, on which the wearing of a normal shoe so largely depends.

Except for the hip joint, no disarticulation should be made.

THE TECHNIQUE OF AMPUTATION IN WAR

In war amputation, whenever possible, the tourniquet should be used. It not only prevents hemorrhage in patients suffering from shock and acute anemia, but also to some extent counteracts the shock itself. During the last war, surgeons reported many cases of fulminant shock in patients with seriously bruised injuries when the tourniquet was released; I have seen one such case. This disaster can be prevented, it is said, by amputation before release of the tourniquet. Where the tourniquet cannot be used and loss of blood might prove extremely dangerous, it is best to perform an arterial and venous ligature at the classical points; but this must never be done in amputations for gas gangrene.

The flaps should be cut oblique and unequal, to avoid placing the scar in the weight-bearing area. The common technique is to cut the anterior flap longer than the posterior. This proves convenient in most cases, but in emergency surgery a posterior long flap may be used

when necessary to cover the bone when an extensive wound has damaged the anterior tissues. As the posterior skin has a better blood supply, a posterior long flap is recommended for some wounds with intense concussion of the soft tissues.

Drainage must be provided after all amputations for war injuries. The best drainage material is corrugated rubber when the wound is sutured, and vaseline gauze when it is left open.

All amputations carried out when infection is already developing (in consequence of delay), must be left open. The wound should be packed with vaseline gauze and encased in plaster. Secondary suture may be performed when changing the plaster, from ten to twelve days after the amputation.

PLASTER IN AMPUTATIONS

Plaster is a great help in the postoperative treatment of amputations. In wounds left without suture the plaster is used in the same way as in the treatment of all other serious wounds. Plaster, moreover, makes a further contribution to healing after any amputation. One of the most annoying troubles in amputation is caused by the flexion contracture of the stump, which when the stump is somewhat short is very common indeed. This contracture, if not abolished in time, gives rise to a permanent deformity and in many cases to a stiff joint which makes an artificial limb useless. The best method of preventing flexion contracture is to encase the stump in a well-fitting plaster, in the same way as for any other type of lesion. The stump must be placed in a position of rest. The immobilization in plaster must be maintained for at least three weeks, and in some cases, where the stump is short, for four. From the second week the patient must be told to contract his muscles under the plaster, and these exercises must be intensified when the plaster is removed.

Stumps left by guillotine amputation may be treated in the same way as all other large, granulating wounds and encased in plaster. I prefer this treatment to the use of continuous traction for the skin, which leaves the wound unprotected and in some cases interferes, by the circular pressure of the elastoplast, with the circulation at the base of the limb. Nevertheless, continuous traction with elastoplast is useful in some cases in which the skin is greatly retracted.

If the precaution is taken of dividing the skin an inch below the incision through the other tissues, enough skin will be left in many cases to make a good scar by granular retraction without the need for re-amputation.

CHAPTER XXV

REGIONAL SURGERY

In this chapter war wounds of different regions are considered systematically.

War wounds are caused by missiles of such diverse shapes, sizes, and speeds that classification is very difficult. A rifle bullet fired at point-blank range and one fired from 500 yards, hitting the same spot, would naturally cause entirely different local damage. Nevertheless, the attempt to classify war wounds is worth making, so long as it is borne in mind that in practice the different types may approximate to one another and that each individual casualty must be judged and treated on its merits and not regarded simply as a particular type of war wound requiring some standard form of treatment.

WAR WOUNDS AND FRACTURES OF THE SHOULDER JOINT

The following classification of wounds in the shoulder region is useful in practice:

1. Through-and-Through Bullet Wounds: Rifle bullets or splinters may tunnel right through the head or neck of the humerus or through the shoulder joint.

2. Articular Fractures With Inclusion of Foreign Body: Rifle bullets sometimes, and fragments of light bomb casing always, stay in the shoulder joint if they enter it.

3. Smashing of the Joint: Shell or bomb fragments may cause gross bruising of soft tissues and comminution of the upper end of the humerus, including its head.

Treatment

The treatment of each of these types is considered separately.

Type 1.—If the head of the humerus is tunnelled by a rifle bullet which emerges from the body, the damage to skin, muscles, and bone may be so slight and the skin wounds so clean that simple immobilization of the limb in plaster may be a sufficient treatment. This, however, is the only type of case which can properly be so treated; it occurs very seldom in air raids. If the shoulder joint is similarly transversed by a bullet, the articular surfaces may break up into fragments, but no surgical treatment beyond fixation is required.

Type 2.—If the wound of the soft tissues is irregular and a fragment of the missile remains in the joint, the wound must be opened and the

foreign body extracted. Most bad results in injuries of the shoulder follow this type of wound, because many surgeons believe that only a small operation, if any, is necessary. Loose fragments of bone should be removed and the joint sutured if possible. When the damage to soft tissues hinders suture of the synovial structures of the capsule, the wound should be packed with gauze and the arm immobilized in a thoracobrachial cast.

Fortunately, in many wounds of the anterior side of the shoulder joint—which are the most frequent—stitching-up of the divided infraspinatus muscle permits the closure of the joint without great difficulty.

In cases which need a wide exposure of the anterior part of the shoulder joint, the best approach is either through the wound itself, when this is large and bruised, or by one of the standard surgical approaches, if the wound is small and a fragment of metal remains in the joint.

If the first approach is used, incision-excision is carried out as described in Chapter XVI (see p. 214); the surgeon progresses into the joint after excising successive layers of tissues. To explore the whole joint a transverse incision is made following the upper insertion of the deltoid from the outer third of the clavicle to the acromioclavicular joint and continuing to the posterior part of the shoulder—to the spine of the scapula if the posterior side of the joint is to be explored. A longitudinal incision is now made downwards, passing through the wound of entry if this is in the anterior portion of the deltoid. When the wound is smaller and situated in the posterior part of the deltoid, it is better to make the longitudinal incision on the inner border of the deltoid, separating this muscle from the pectoralis major in order to avoid any damage to the circumflex nerve or the anterior circumflex humeral vessels. Care should also be taken not to damage the cephalic vein, which lies between the deltoid and pectoralis muscles. The whole anterior and lateral part of the deltoid is now retracted downwards and backwards. Access to the joint is obtained through an incision in the capsule at the place judged most convenient for exploration—anterior, posterior or transverse over the head of the humerus. In the anterior incision—undoubtedly the best—the subscapularis is sectioned together with the capsule. At the end of the operation the capsule is closed by continuous suture; the fibers of the deltoid are replaced in position and either completely sutured or not, according to the amount of muscular damage and the time of operation. When bruising of tissues and the time factor are against primary total suture, the transverse incision of the deltoid is the only one sutured apart from the capsule, and drainage of the periarticular spaces is established through the longitudinal incision. The skin is sutured as in the deltoid.

In cases of suppurative arthritis, drainage is provided either anterolaterally or posteriorly. In the former case the drain is inserted along a straight incision three inches long starting at the anterior border of the acromion and continuing downwards over the head of the humerus. The fascial layers are incised with the knife, the fibers of the deltoid are separated with a spatula and the distended capsule is opened up. Posterior drainage is obtained through an incision which begins at the spine of the scapula and follows the fibers of the deltoid downwards and outwards. These fibers are separated, and by blunt dissection the capsule is approached between the fibers of the infraspinatus and teres minor. For the anterior and posterior drains alike, corrugated rubber is the best material.

Type 3.—Grave and extensive wounds in the shoulder region produced by shells and bombs must be examined with great care to see whether the gross mutilation produced by a hurried disarticulation can possibly be avoided. If the auxiliary vessels are intact, even if the patient has lost more than half the humerus, it is best to cleanse the wound carefully, leaving the periosteum. This may not be capable of regenerating all the humerus that has been lost, but it will later provide the arm with some rigidity. The wound must on no account be closed. The prognosis is incomparably better than when disarticulation has been carried out, for even though the arm will be loose-swinging, the patient will have a normally functioning hand. In more limited fractures early excision of the destroyed head of the humerus gives the best immediate and also functional prognosis.

Immobilization of the Shoulder Joint

There are two means of immobilizing the shoulder joint properly: first by a large thoracobrachial plaster cast, and secondly by an abduction apparatus of the well-known "aeroplane" type advocated by Böhler.

An aeroplane splint made of Cramer splinting is sufficiently light to be worn without great discomfort, but its use should be restricted to special cases, as it has several disadvantages. In my experience it is inefficient and even harmful when used to immobilize the scapulohumeral articulation and the upper third of the humerus; the immobilization is incomplete, for even when it is properly applied and maintains the bone ends in adequate position, it fails to immobilize the soft tissues. Displacements are common, especially those caused by the dropping of the apparatus, producing a downward angulation due to lack of support. Indeed, union with downward angulation ("boat-shaped deformity") is common in patients who have been transferred several times from one surgical center to another. When, as often

happens, the apparatus is not applied as carefully as it should be and maintains the arm in the lateral plane instead of at an angle of 40° anteposition, its imperfections are very considerable. An even greater defect, however, is that it does not give the wound any protection, so necessary in such cases.

Fig. 85.—Compound comminuted fracture of upper third of humerus. Excised, drained with dry gauze, and encased in plaster. The photograph shows the second plaster just before its removal. (See also Fig. 86.)

The thoracobrachial plaster cast is superior in every way. It provides the most perfect immobilization, covers the wound, fixes the arm from the first, and does not cause the discomfort of the aeroplane splint. This cast should be applied by using muslin patterns soaked in plaster paste. It permits the most perfect rest until the local discharge necessitates a change of cast or union is complete. The following is an illustrative case:

A soldier 21 years of age, wounded by a splinter at Dunkirk on May 31, sustained a compound fracture of the surgical neck of the left humerus. Next day the wound was excised and drained by gauze, and a plaster spica was applied. On June 10 he was admitted to the Wingfield-Morris Orthopaedic Hospital. X-ray showed a comminuted fracture with the humerus in good position. The general and local condition was good (see Fig. 85). On June 27 the plaster was removed; the wound looked healthy, and the fracture was almost consolidated. The wound was still 3 in. × 2 in. in size. A new plaster was applied and the patient was sent to a convalescent hospital. When the plaster was removed only a small area of granulations ½ in. across remained

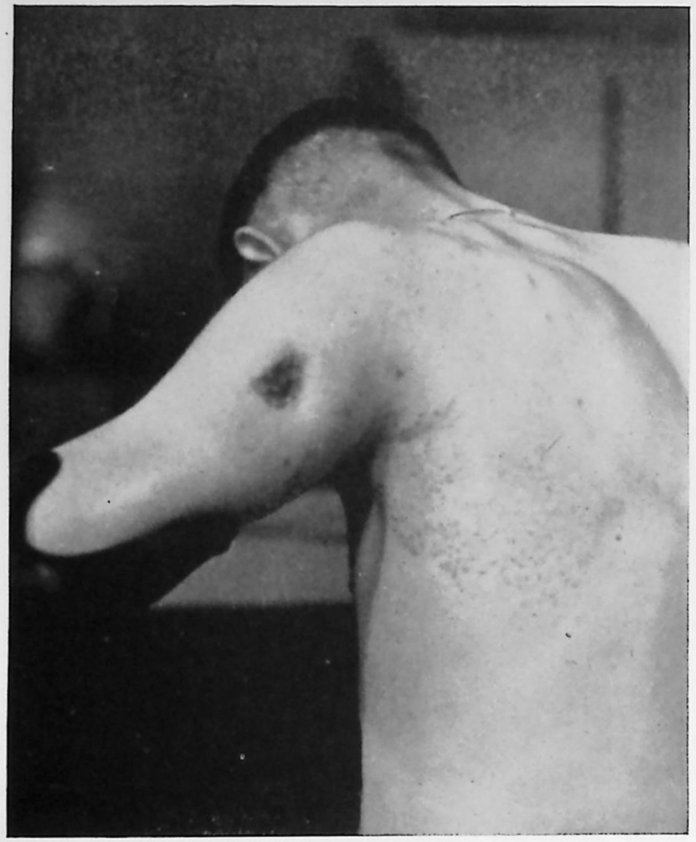


Fig. 86.—When the second plaster was removed, the wound was found reduced to a small area of granulation ½ inch across. The fracture was correctly consolidated.

(see Fig. 86). Movements were started. After two months the patient was re-examined and the movements were as follows:

Shoulder:	Abduction, 10° short of full.
	Flexion, full.
	Extension, full.
	Internal rotation, full.
	External rotation, full.
Elbow:	Extension, full.
	Flexion, full.

There was solid union of the fracture with a very slight external angulation, imperceptible by external examination.

This case was completely normal. All the proper procedures were carried out by the surgeon first in charge of the case.

The best position for the arm is 35° abduction and 35 to 40 ° anteposition, with the forearm horizontal. In ankylosis of the shoulder this is also the most useful position.

FRACTURES OF THE SHAFT OF THE HUMERUS

Fractures of the shaft of the humerus are common in war surgery. If there is no associated damage to blood vessels or nerves, treatment is not difficult. The anatomical structure of the arm does not facilitate the spread of infection like that of the leg. There are no large cellular spaces to harbor and maintain germs. The blood supply and the collateral circulation are free, and conservative measures succeed in a high proportion of cases. Immediate primary amputation is justified only if there has been so much destruction of the blood supply as to endanger the viability of the hand; it should never be undertaken simply because of the gravity and extent of the damage to the humerus. A flail arm with a normal forearm and hand is far more useful than any artificial arm—indeed, so much more useful that it is even justifiable, when necessary, to excise the whole humerus rather than sacrifice the limb itself.

It is useful to divide fractures of the humerus according to their situation in the upper, middle or lower third.

Upper Third

Fractures of the upper third, in the absence of neurovascular damage, have the best prognosis. Chronic osteomyelitis and pseudarthroses are not frequent. The case illustrated in Figs. 87 and 88 is a good example of this type of injury.

Middle Third

Certain complications of gunshot fractures of the middle third of the humerus make their prognosis worse than that of fractures of the upper third. The radial (musculospiral) nerve is often damaged—usually at the time of the injury, though sometimes later by the pressure of fibrous or bony tissues on the fractured ends. The blood vessels of the arm, the brachial artery and its collaterals, are easily damaged by shell or bomb fragments, and the damage may be so extensive that the circulation to the forearm and hand becomes insufficient. So long, however, as there is evidence that the supply to the hand is adequate, an attempt should be made to save the arm. Moreover, it is only very

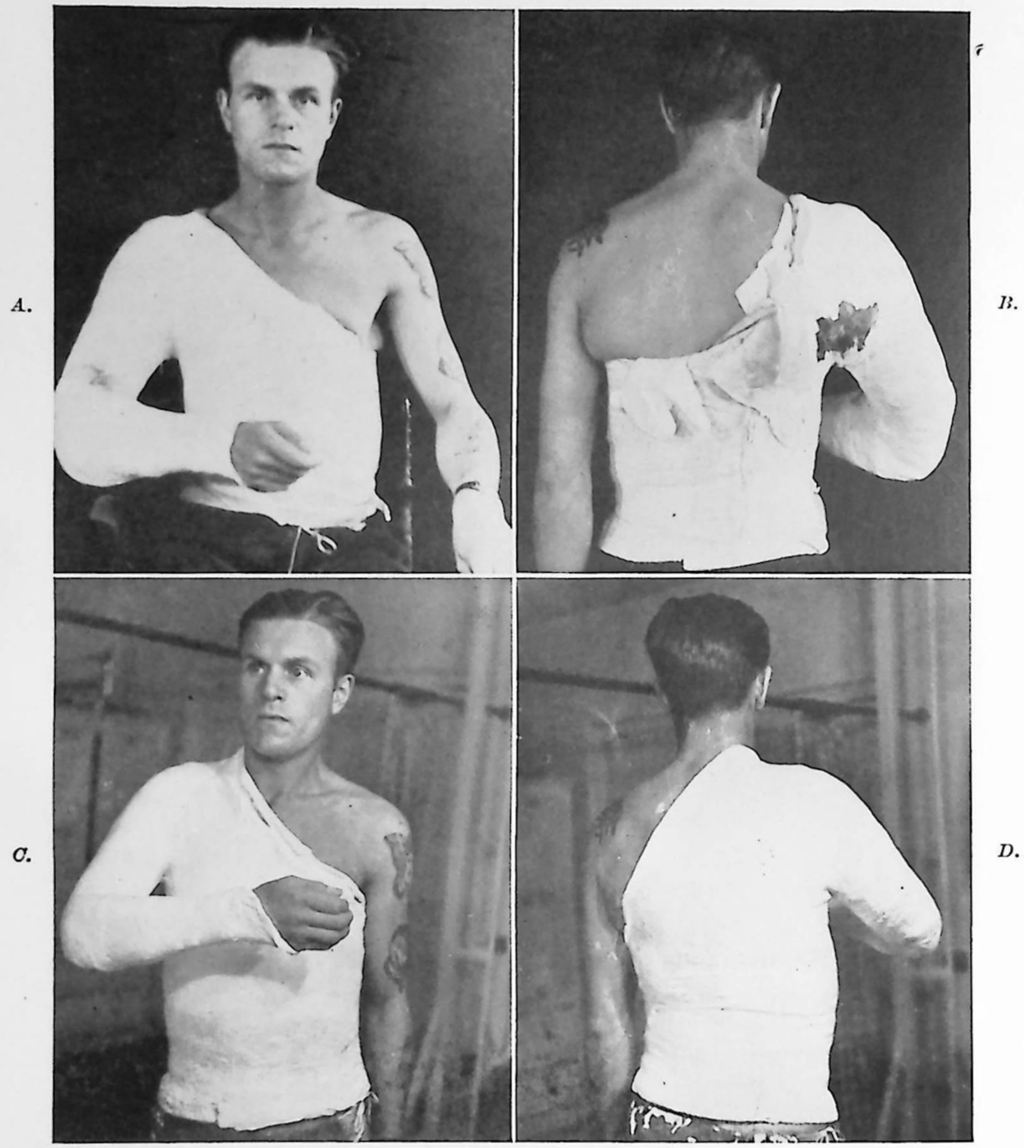


Fig. 87.—Compound fracture of the upper third of the humerus, caused by splinters. *A* and *B*. Incorrect thoracobrachial plaster; the shoulder is not properly immobilized. *C* and *D*. Correct immobilization in plaster. (See also Fig. 88.)

occasionally permissible immediately to suture a radial nerve that has been divided by a splinter, for later a suture usually gives better results, and if the nerve has been irreparably damaged a tendon transplantation is eventually required. In a wound without a fracture, primary suture of divided nerves can be performed only if the skin may be sutured; that is, in clean lacerated wounds operated on within six hours.

Fig. 88.—The same wound at removal of first plaster.

The fracture is best controlled in a thoracobrachial cast. Reduction is not difficult. The whole cast can be made of a prepared bandage, but it is quicker and easier to cut a preliminary muslin pattern. As soon as the cast has been applied and before it has set, traction should be made, either manually over the plaster at the elbow or by a Kirschner wire through the olecranon, and maintained until the plaster is hard.

Deformity occurs very easily in a badly adjusted splint—so easily, indeed, that a splint should never be used for fractures of the upper and middle thirds of the humerus. Similar deformity will occur within a thoracobrachial cast unless traction is maintained until the plaster has set.

Another complication is failure of the fragments of bone to unite, but this risk can be mitigated if great care is taken to preserve every

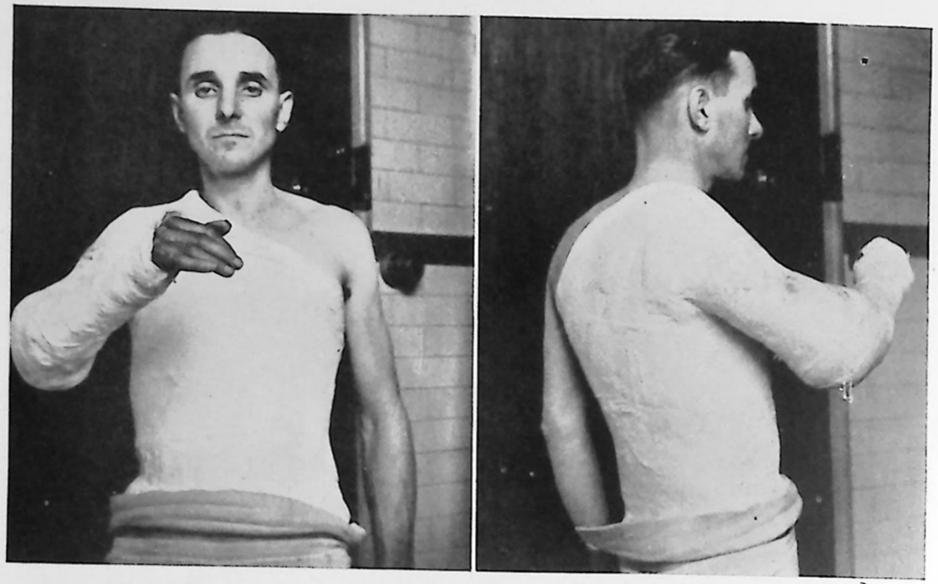


Fig. 89.—Gunshot fracture of lower third of right humerus. The whole of the inferior part of the biceps and the greater part of the tendon of the triceps were destroyed. (See also Figs. 90 and 91.)

Fig. 90.—Radiographs of the same patient taken four months after the injury. In spite of the persistence of many foreign bodies the fracture consolidated in good position. No sign of osteitis.

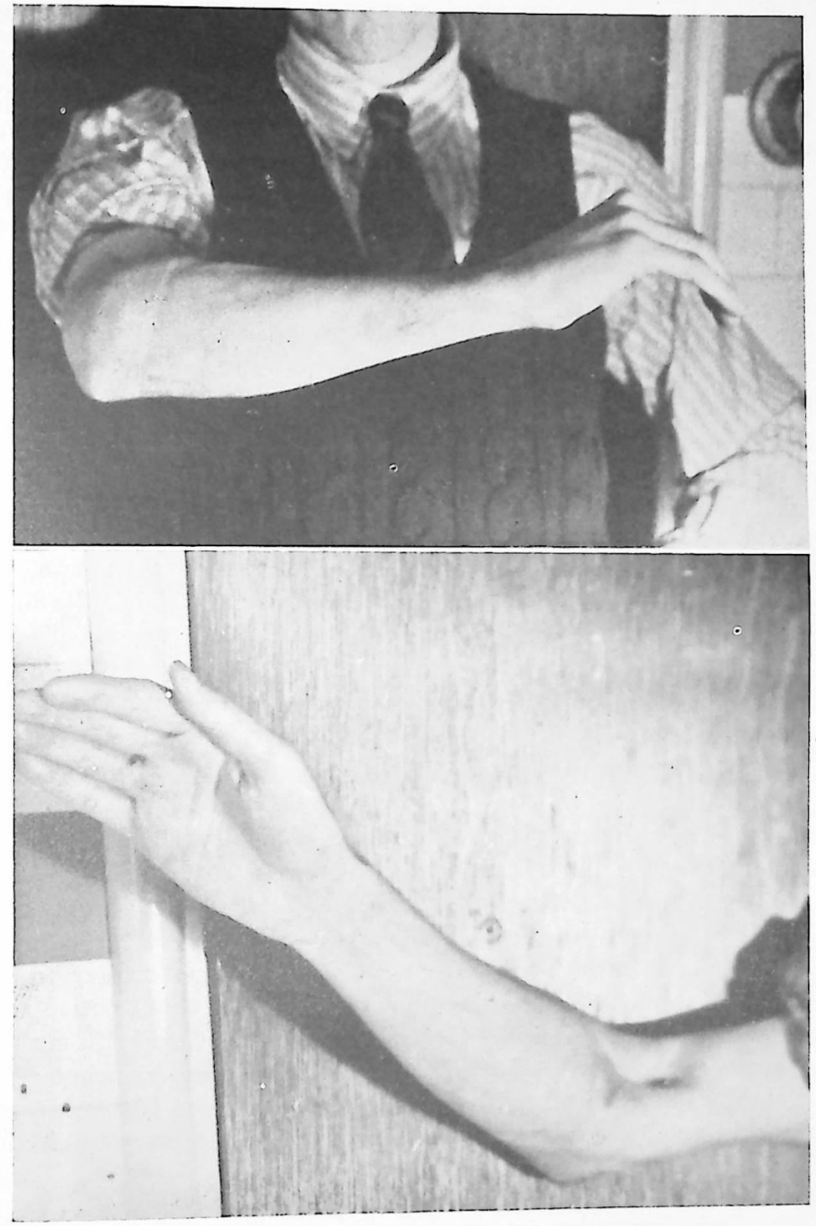


Fig. 91.—The same patient at the end of treatment.

portion of the bone that may survive. Owing to its limited blood supply, the regenerative power of the bone in the middle third of the humerus is poor.

Lower Third

Wounds of the lower third of the humerus are even more serious than those of the middle third—in fact, the prospect of saving the limb diminishes with the distance of the wound from the shoulder. The blood vessels are anterior and easily damaged; the nerves are frequently divided; there are several muscles and tendons close together, with corresponding intermuscular cellular spaces which permit infection to spread easily through the numerous folds unless the first surgical treatment of the wound has been well done; and the drainage of the wound is more difficult because the lower end of the humerus is interposed like a flat plate between the anterior and posterior compartments of the arm.

In cases of chronic osteomyelitis which need an extensive exploration of the humerus the best approach is either through the old scar, if this is long, or through an anterolateral incision. This may be made from the medial border of the deltoid downwards to its inferior insertion, and following the lateral border of the biceps to a point two inches from its lower insertion. The deltoid is divided in its upper part and the biceps and triceps in their lower parts; the brachialis is incised longitudinally. The cephalic vein should be preserved, and in stripping the periosteum of the humerus care must be taken to avoid any damage to the radial nerve. That good results may be obtained when a proper technique is used is shown by the case illustrated in Figs. 89 to 91.

In some fractures of the lower third of the shaft and of the lower articular region of the humerus I have found an abduction apparatus valuable. In all fractures of the upper and middle thirds and in many of the lower third, the thoracobrachial plaster cast provides a better type of immobilization. The position of the arm is similar to that advised for fractures of the shoulder, the degree of anteposition varying with the characteristics of the fracture. In fractures with multiple fragments of the upper third of the humerus a large fragment of the medial side is often displaced inwards by the contraction of the pectoralis major. In these cases an anteposition of 90° is necessary to obtain a sufficient reduction by relaxing the contraction.

FRACTURES OF THE ELBOW JOINT REGION

Many of the compound fractures of the lower end of the humerus are extra-articular, in spite of the radiological appearance. The elbow joint is so compact that any fracture actually within it must necessarily involve one or more articular surfaces. Moreover, in elbow wounds the joint surfaces are very often fragmented or even pulverized; the head of the radius is the surface which seems most often to escape intact even when the condyles of the humerus, the olecranon and the coronoid processes are converted into a shapeless mass.

Classification and Treatment

For treatment, fractures within the elbow joint can be usefully classified into five groups:

1. Fractures produced by bullets fired at long range, making small wounds of entrance and exit in the skin.
2. Fractures in which there has been more severe damage to the skin and other periarticular soft tissues than to the bones of the joint, and in which some part of the joint surface remains intact.
3. Fractures in which there are gross comminution of the joint surfaces and severe wounding of the soft tissues.
4. Comminuted fractures of the lower articular surface of the humerus without gross soft tissue damage.
5. Posterior penetrating wounds with fracture of the olecranon process.

Fractures Made by Through-and-Through Bullet Wounds.—If the two skin wounds are clean, the damage to the internal soft tissues is probably not severe, and immediate immobilization will allow the soft tissues and bone to heal without troublesome complications.

Fractures With Severe Damage to the Soft Tissues.—In these fractures the essential problem is that of infection, for provided that infection does not develop, some mobility of the joint can be regained later. A posterior arthrotomy should be performed along either the outer or the inner border of the olecranon process, according to where the largest surface wound is situated. Sometimes, if there is a wound on both sides, both wounds will have to be enlarged and explored and devitalized bone fragments removed through them. Very occasionally the synovial membrane or the capsule can be sutured, but more often the wound has to be packed with sterile gauze and the skin left unsutured.

Fractures With Gross Comminution of the Articular Surfaces.—In such fractures the joint contains many devitalized bone fragments and often metal splinters, clothing, and other foreign bodies. All these predispose not only to local but also to generalized infection. It is necessary therefore to proceed on a well-designed, clearly defined plan from the first moment. True, it is almost hopeless to try to save the elbow joint; but it is certainly possible to save the arm. The guiding idea is to attempt a resection of the elbow joint. The whole joint must be exposed, i.e., by detachment of the external epicondyle of the humerus, which can be removed with a chisel and turned downwards with its attached muscles (Corachán, 1928). By this means the whole elbow joint may be so exposed and dislocated that all loose fragments of bone and foreign bodies may be easily extracted. In some cases the surface wound is such that the external epicondyle has already been detached by the shell or bomb fragment. When possible, the external epicondyle should be replaced after the operation, and the wound either closed, or drained and packed with gauze, according to the extent of damage to soft tissues and the time since the wound was made. Generally speaking, the elbow joint is one of the most difficult to close by sutures, owing to the disproportion between the sizes of the bone surfaces and that of the synovial membrane and capsule. In either case the arm must be fixed in plaster. In a fairly high proportion of cases some mobility will ultimately return to the joint.

In certain cases in which there has been gross destruction of the external epicondyle and capitellum, the procedure should be to remove all loose fragments and then to excise the internal condyle and trochlea, even when these have not been severely damaged. Removal of the external part of the lower articular surface of the humerus after severe injury is usually followed by a cubitus valgus deformity; if, however, the whole lower articular surface is removed, a flail elbow results, which is fundamentally more useful to the patient. Moreover, the additional drainage secured by the removal of the internal condyle and trochlea is valuable.

Comminuted Fractures of the Lower Articular Surface Without Gross Soft Tissue Damage.—These fractures do not require widespread removal of bone, and, as in fractures of the lower end of the shaft of the humerus just above the elbow joint, can be effectively treated by a combination of abduction splint, plaster cast, and traction. The plaster cast is applied to the arm extending down to the wrist; the arm is abducted and flexed at the shoulder. The abducted arm is supported additionally by an abduction frame made of Cramer splinting. In order at the same time to secure traction, an extension is applied to the arm, exerting traction on the plaster by means of a loop made with a plaster bandage and attached to a continuation beyond the elbow of the Cramer splint supporting the upper arm. The tension is produced by attaching the plaster loop to rubber tubing, the tension of which is increased by means of a windlass. This is one of the few occasions on which I find any sort of abduction frame of any use.

Posterior Penetrating Wounds with Fracture of the Olecranon Process.—These wounds constitute a difficult problem through the increased separation of the olecranon due to the contraction of the triceps. Suture of the olecranon process is in many cases technically impossible and

A.

B.

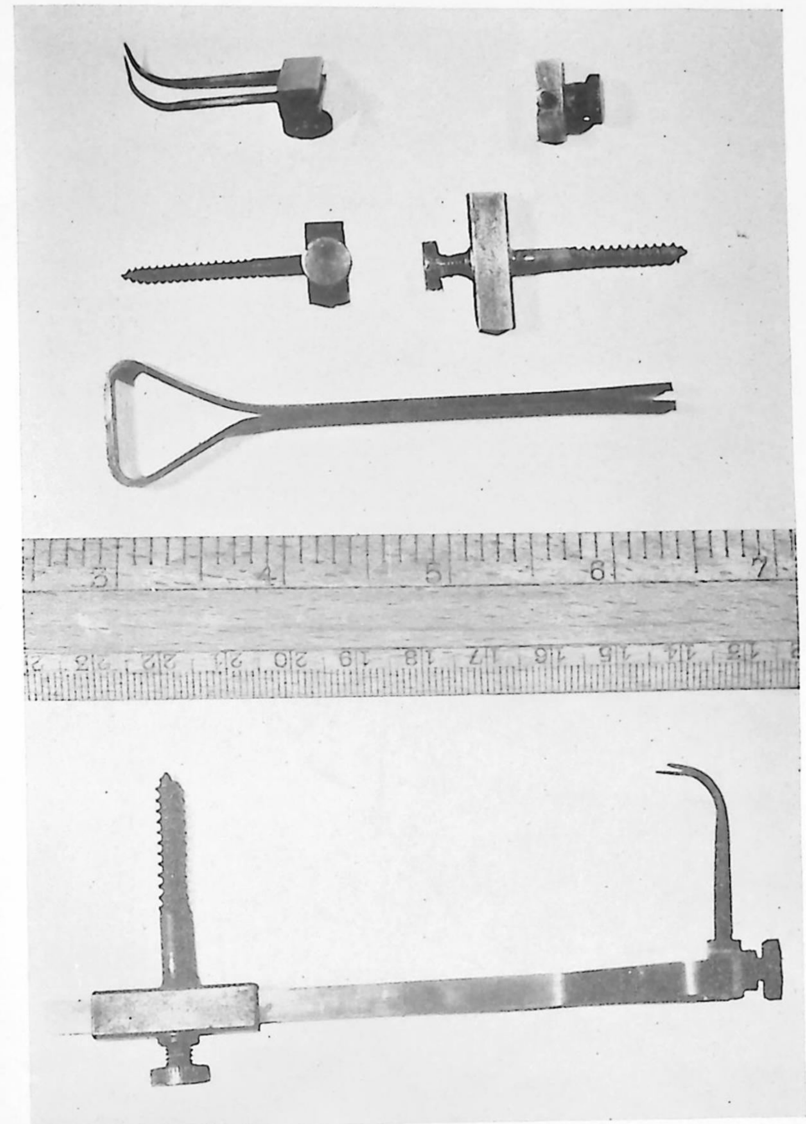


Fig. 92.—*A.* Small apparatus for treating displaced fractures of olecranon. *B.* Apparatus ready for use. (See also Figs. 93 to 98.)

A.

B.

Fig. 93.—*A.* Radiograph of a compound fracture of the olecranon. Eighteen hours after the injury the wound was excised, and the olecranon reduced by the apparatus shown in Fig. 92. *B.* Radiographic appearance twenty days after operation.

frequently dangerous. For treating simple fractures of the olecranon process where for some reason the operation is contraindicated, I use a simple apparatus consisting of a light metal bar 4½ inches long, having fixed at one end a screw for the upper fragment of the olecranon, and, free to slide along it and locking at any desired point, a somewhat larger screw for the ulna, to be inserted an inch or two from the line of the fracture. To reduce the fracture, the two screws are approximated by sliding the ulnar screw along the bar and locking

Fig. 94.—Device for fixing the olecranon in position.

it when the fragments are in satisfactory contact. If the upper fragment of the olecranon is too small for a screw or the process is comminuted, a pair of small re-entrant prongs like goats' horns can be clamped to the end of the bar instead. These pass easily through the skin and engage on the small upper face of the olecranon process just where the tendon of triceps is inserted (see Fig. 92).

A plaster cast fixes the elbow for the required time, and if the fracture is completely reduced, a window can be made over the fixation apparatus. If, on the other hand, there is a gap between the fragments it is better to cover the wound with plaster below the apparatus. In simple fractures the plaster may be kept on for three weeks, after which it should be removed and the elbow mobilized. After another fortnight the apparatus may be removed. In compound fractures the apparatus is kept in position up to 8 weeks but never longer, and movements are permitted as soon as the condition of the wound permits (see Figs. 93 to 98).

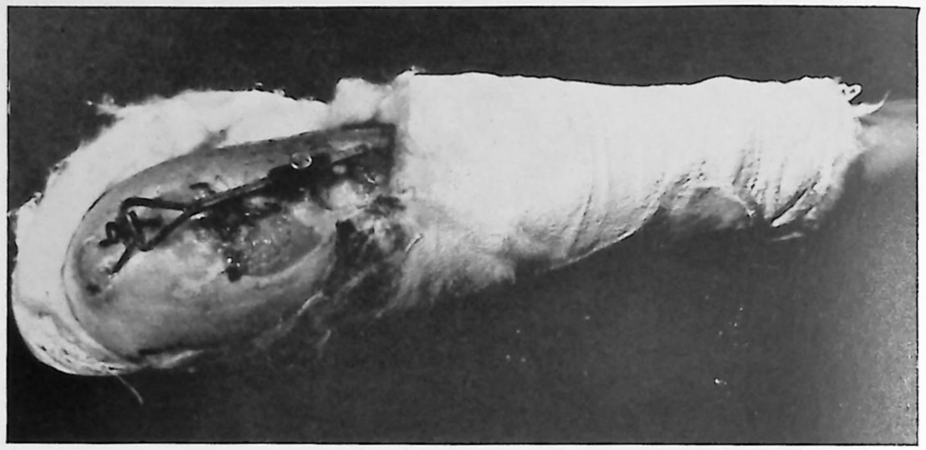


Fig. 95.—Condition of the wound three weeks after operation.

Fig. 96.—Condition of the wound three months after its production.

In some clean fractures of the tip of the olecranon operated on within the optimum time, the best procedure is the excision of the fractured olecranon and attachment of the tendon of triceps to its base. Suture of the skin is necessary to protect the underlying stitches. Immobilization with plaster is maintained for three weeks and followed

by progressive mobilization of the elbow joint. For the drainage of an infected elbow joint either a lateral or a medial posterior incision is the best approach. If the internal incision is made, the ulnar nerve must be carefully avoided. The best way to prevent harm to this nerve is to make an incision two or three inches long following the insertion in the olecranon of the triceps muscles close to the olecranon process; the superficial and deep fasciae are incised and the capsule is opened up. The nerve is displaced internally.

Fig. 97.—Radiograph three months after the injury.

FRACTURES OF THE FOREARM

When the Fracture Is More Important Than the Wound

Fractures of both bones of the forearm are usually produced by rifle bullets or small splinters, and are therefore seldom accompanied by great destruction of the soft tissues. The prevention of sepsis is consequently not difficult, but nerve lesions are common, especially of the ulnar nerve. It is important not to overlook this possibility, in order that the damaged nerve may be treated as soon as possible. If the wound receives early treatment, and if the soft tissue injury is clean, a nerve suture may be performed at the time of reduction of the fracture. But these circumstances are rare, either because more than six hours have elapsed since the occurrence of the wound, or because there is little prospect that the wound will remain completely clean. The treatment of the nerve damage must usually be postponed, therefore, until after the fracture of the ulna has consolidated and all possibility of inflammation has disappeared. The nerve can then be repaired in whatever way seems proper, preferably by an end-to-end suture, the sclerotic ends being first excised and the nerve transposed to the anterior compartment of the elbow.

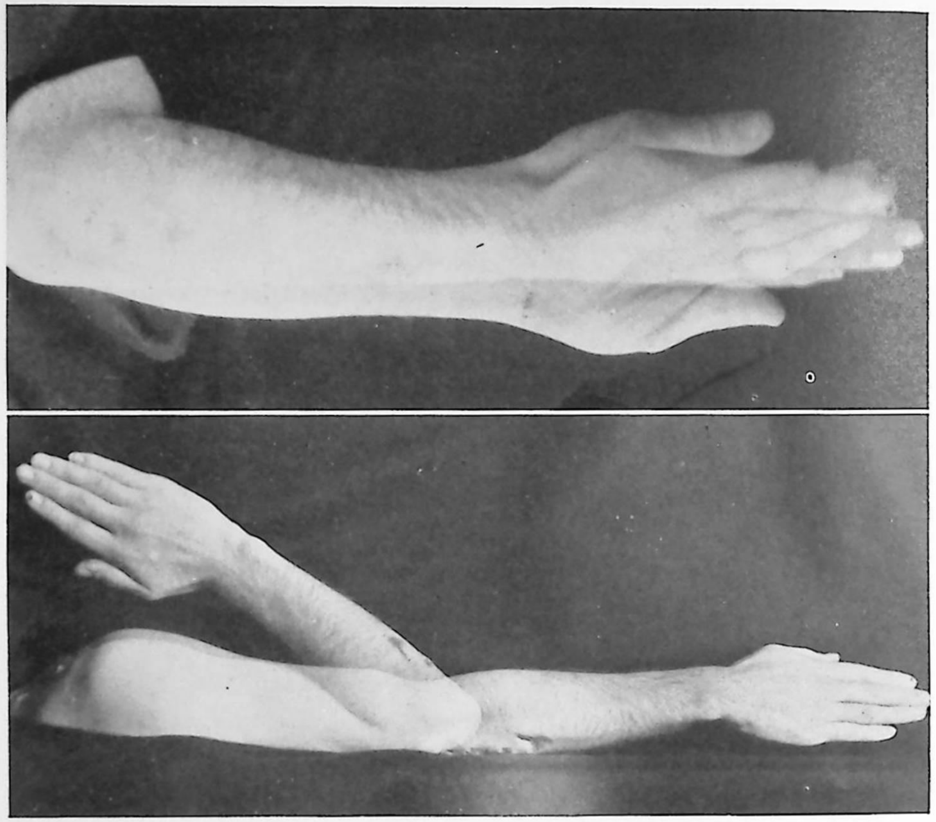


Fig. 98.—Range of movement three months after injury. Complete functional recovery.

When both bones are fractured, reduction must be effected as rapidly as possible; if the wound has been made by a bullet fired at long range and the cutaneous perforation, especially the wound of exit, is small and regular, the forearm may be immediately encased in plaster with extension of the hand and counterextension of the flexure of the

elbow. If the fracture is high, the hand must be partially supinated; if the fracture is towards the lower end of the radius and ulna, it is advisable to place the wrist in pronation. The plaster should run from the heads of the metacarpals to a point about four inches above the flexed elbow. It is better not to change this cast until six to eight weeks have elapsed, in order to avoid late movements of the fragments; the slightness of the discharge from the wound in these cases allows the cast to be kept on until the fracture is firm. Few fractures of the forearm need external fixation with wire, owing to the ease with which reduction is maintained in very comminuted compound fractures.

Fig. 99.—Infected compound fracture of both bones of the forearm. Photographs taken three weeks after injury, at the first change of plaster. (See also Figs. 100 to 103.)

When the Wound Is More Important Than the Fracture

If the fracture of both bones is produced by shell or bomb fragments, the destruction of soft tissues by the splinters of metal and their removal after resection of the edges of the skin makes skin or nerve

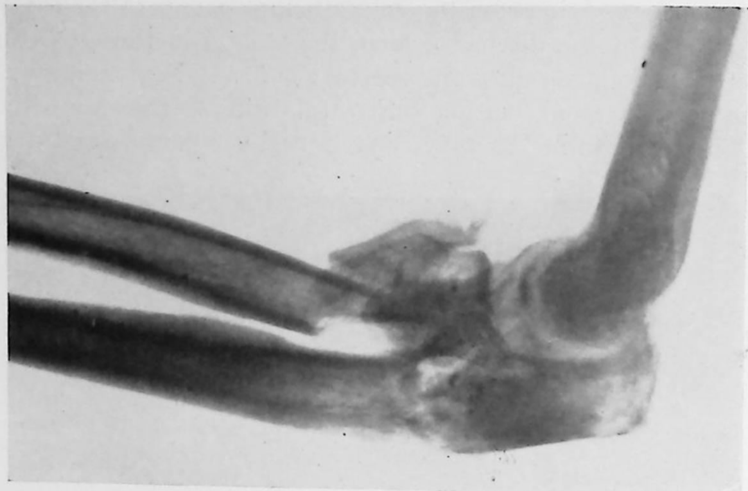


Fig. 100.—Lateral radiograph showing the same infected comminuted fracture of radius and ulna, after six weeks' treatment.

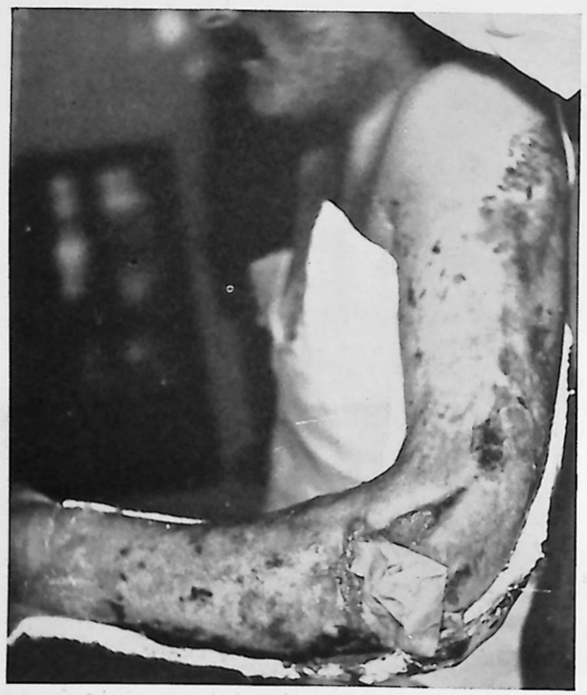


Fig. 101.—The same wound at the second change of plaster, six weeks after injury. Note the gauze still draining the wound.

suture impossible. In these cases, after the site of the fracture has been carefully cleansed, the muscle and skin wounds must be left open; sterile gauze should be the only padding between the wound and the

Fig. 102.—Wound healed three months after injury.

Fig. 103.—Complete consolidation of both bones without osteitis. Radiograph eight weeks after Fig. 101.

plaster. When the operation has been performed too late, these wounds discharge copiously, and it will be found difficult to maintain the first plaster long enough for union. At any time between the third and fourth weeks, therefore, this plaster may be changed for a fresh one, which should be the last. Unfortunately, however, many wounded in the front line do not receive surgical treatment until a serious infection is established. Osteomyelitis may be very extensive and discharge so copious that it is necessary to change the plaster cast more often, sometimes every two weeks. In such cases, owing to the proximity of the arm to the face, the patient may find the stench barely tolerable. Very often at a change of plaster it is possible to remove sequestra, thus facilitating the normal granulation and scarring of the wound. The following is one of these cases treated when infection was making alarming progress:

On Oct. 17, 1939, a man 49 years old had his left arm deeply cut just above the elbow by a circular saw. The main vessels and nerves escaped, and he managed to walk more than a mile through the woods to a road where he was picked up and taken to a hospital. There his wound was cleaned under anesthesia, many small fragments of bone were removed, the muscles and fascia were sutured as far as possible, and the skin was sutured with drainage. The arm became increasingly swollen, painful and inflamed. His temperature rose, he became seriously ill and on Oct. 20 he was transferred to the Wingfield-Morris Orthopaedic Hospital.

On admission he looked ill and anxious. His left arm was painful and swollen, with edema of the forearm and hand. His heart sounds were faint, his temperature 101.2° F. and his pulse rate 96. Radiographs showed a comminuted fracture of the radius and ulna just below the elbow. He was operated on the same evening. When the dressings were removed the whole elbow region looked angry. The wound was tightly sutured and the skin edges were in a state of moist gangrene; the wound when opened was full of offensive pus. The necrotic edges of the skin and subcutaneous tissue and the exposed muscular surfaces were excised, wherever they were dirty or avascular, to the level of good bleeding, and a pocketed and inflamed area above the wound was laid open by a vertical incision. The wound was now deep but widely open; a fine layer of vaseline gauze was applied, then a few layers of ordinary dry gauze, and finally a plaster. The arm was put up with the elbow fixed to a right angle and the arm making an angle of 45° with the side. There was a visible depression in the surface of the plaster where it followed the contour of the wound.

Next morning the patient was better, his arm was comfortable and the edema of his hand had disappeared. Proseptasine 1 gram was given every four hours for twenty-four hours. His temperature fell to normal by Oct. 24 and remained below normal, except for one evening rise to 99.8° F. On November 9 he was given omnopon, grain ⅓, the plaster was bivalved and the dressings were removed (see Figs. 99 and 100). The wound was redressed and replastered as before. He was discharged on Nov. 13. The plaster was changed again on Nov. 30 and an x-ray film taken (see Fig. 101); another was taken on December 21, when the wound was almost healed. This time the plaster extended from the axilla to the metacarpal heads. On January 18, 1940, the plaster was left off, the arm was put up in a collar and cuff, and move-

A.

B.

Fig. 104.—*A.* Compound fracture of ulna correctly treated in a small country hospital. Photograph taken a few days after the injury. Complete absence of pain and edema. Movements of shoulder and fingers are encouraged.

B. The same patient two months after the injury. The wound had been grafted three weeks before. The wounded man was back with his unit less than nine weeks after being wounded.

ments and light active use were ordered. Figs. 102 and 103 show the moderate scar and the radiographic appearances on February 21. On April 12 the range of movement was 80°-135°. There was no radio-ulnar movement. Radiograph showed good consolidation. The shoulder movement was almost full and the man was using his hand naturally. He is known to have improved still further since discharge and is working as before.

The lesson of this case is clear. All the trouble was due to primary suture and probably also to insufficient excision. Although the local condition was serious, simple arrangement and immobilization saved the arm and gave a relatively good functional result.

Fractures of Only One Bone

When only one bone is fractured the general technique is the same, with this difference in detail: that the undamaged bone can serve as a splint for the other and so make reduction unnecessary. The fragments can be maintained in position by a slight deviation of the hand in the direction of the undamaged bone, with a varying degree of supination or pronation corresponding to the distance of the fracture above or below the middle of the forearm, respectively. This type of wound should be encased in plaster in the same way as any other fracture of the forearm (see Fig. 104).

Retention of Fragments of Bone.—In all these fractures it is essential to conserve every possible bone fragment which is attached either to muscle or to periosteum, removing at later changes of plaster those fragments which have died as a result of sepsis or of secondary deprivation of blood supply. In other words, only completely free fragments should be removed, for a lack of continuity of bone easily prevents union. The power of the periosteum in the bones of the forearm to proliferate is limited, especially at the junction of the upper and middle thirds. On the other hand, if all the small fragments which keep their periosteal and muscular attachments undamaged are preserved, they stimulate the regeneration of bone; this stimulus is invaluable even if they are very small.

Drainage of Deep Infection.—In many cases the best approach to deep infection is through the wound itself. In other cases either lateral or posterior drainage should be provided; only rarely should the anterior spaces be incised. A collection of pus from a suppurating ulna must be treated differently from one coming from a radius.

Suppuration of the Ulna.—Drainage should be provided through an incision of the skin following the posterior border of the bone. When it is necessary to open up the interosseous space, the best way is to separate the anconeus from the posteroexternal side of the ulna in the upper part of the bone, and the extensor carpi ulnaris in the middle and lower thirds. A forceps is introduced into the dissected space and the opening enlarged with it.

Suppuration of the Radius.—Drainage should be provided through a posterior incision for the upper third and an external incision for the middle and lower thirds. The most difficult part to drain is the junction of the upper and the middle third, owing to the relatively deep situation of the bone and the thickness of the muscle between it and the skin. In fractures at that site it is better to drain the bone either through a posterior incision, if the osteomyelitis is mostly in the upper third, or through a lateral incision, displacing the extensor and dissecting the supinator, if the lesion extends down to the middle third. The latter incision should be slightly posterior in its upper part.

FRACTURES OF THE WRIST AND HAND

The anatomical disposition of the wrist and its articular spaces make it clinically one large joint. Lesions of the wrist may be divided into three groups:

1. Wounds caused by bullets fired at long range, with small regular wounds of entry and exit that heal rapidly; the bone lesion is usually a simple clean tunnel if no foreign bodies, especially bits of clothing, remain in the wound. This type of lesion may be treated by immediate immobilization in plaster without any recourse to surgery; its progress demonstrates that there is no sepsis, for healing commonly follows within two months, usually leaving as the after-effect a permanent rigidity of the carpus, and in other cases loss of function in the fingers as a consequence of lesions in tendons or nerves.

2. The second type of lesion is produced by small shell or bomb fragments that remain embedded in the depths of the narrow wound. The edges are bruised and the base is often filled with particles of foreign body. Under such conditions it is not surprising that painful and persistent arthritis of the wrist is common, though a spreading infection with septicemia is rare. With the disastrous possibilities of an infection of the wrist in mind, the surgeon should apply prompt treatment, enlarging and excising the edges of the wound, separating the tissues, and removing every kind of foreign body from the bottom of the wound; bone fragments should be removed if possible. If the loss of skin or the appearance of the lesion does not permit suture, a gauze pack should be inserted after the wound has been powdered with sulfanilamide. A plaster should then be applied from above the elbow to the head of the metacarpals, with the wrist in slight dorsiflexion. Primary suture, however, is preferable whenever possible, owing to the tendinous nature of this articular region.

3. The third type of lesion, in which great crushing of the entire articulation is caused by a soft bullet or by a shell or bomb fragment, is seen very often. To save the hand it is necessary to adopt very extreme measures, even the resection of the whole wrist.

Drainage.—A lateral incision two inches long is made on the anatomic snuff-box. The tendons of the abductor pollicis longus and extensor pollicis brevis are separated from the extensor pollicis longus, the radial artery is retracted and the lateral ligament and synovial membrane are incised. A medial incision two inches long is made over the head of the ulna slightly posterior to the medial side of the wrist. The extensor carpi ulnaris is separated posteriorly and the medial ligament and synovial membrane are incised.

In some cases of infection of the carporadial and ulnar joints, better drainage is obtained through a double posterior incision two inches long which approaches the joint through the dorsal carpal ligament between the tendons of the extensor pollicis longus and the extensor indicis proprius on the outer side, and between the extensor carpi ulnaris and the extensor digiti quinti proprius on the inner side.

Infection of the Tendon Sheaths.—Involvement of the tendon sheaths in infections of this region is a very grave complication which seriously jeopardizes the future functions of the wrist and hand. In war injuries produced by firearms and explosives the tendons must never be sutured, for suppuration almost invariably occurs, with breakdown of the suture line. Only lacerated wounds in tendons caused by glass may sometimes be sutured. An attempt should always be made to place the hand and—if owing to the destruction of the tendon no ultimate mobility is expected—the fingers in a plaster cast as soon as possible. This technique, combined with proper surgical treatment of the wound, may avert infective complications of the hand and wrist.

Fractures of Metacarpals and Phalanges

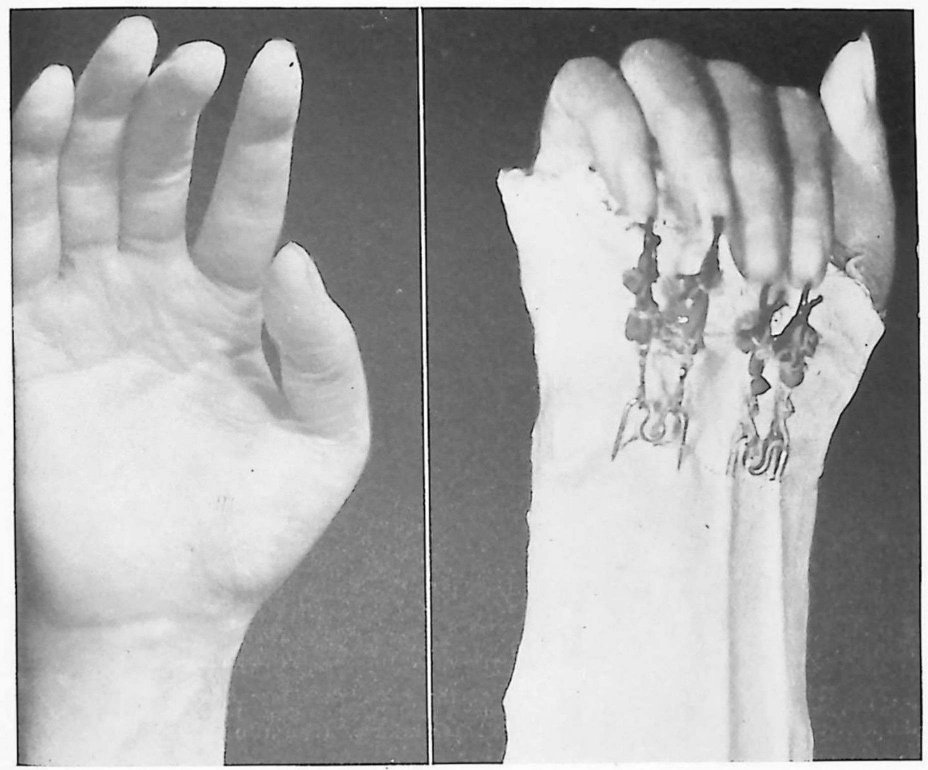
In fractures of metacarpals and phalanges, as in all surgery of the hands, the most conservative treatment should be used. Excision of bruised tissues must be carried out with extreme prudence, avoiding further damage. Infective complications in the hand are not frequent when correct treatment is employed in due time. Thorough hemostasis, cleansing of the wound from foreign bodies and especially from hematomas, and excision of lacerated subcutaneous cellular tissue, followed by primary suture of the skin whenever possible, form the basis of success.

From the point of view of immobilization it is very important to distinguish two types of cases, for the patient's functional future mainly

depends on the fingers and hand being placed in a more or less correct position within the immobilizing apparatus or plaster. These two types are:

1. Wounds of the metacarpals and phalanges associated with oblique or comminuted fractures which require continuous traction at the same time as immobilization; and

2. Wounds associated with transverse fractures which need only fixation.



A. *B.*

Fig. 105.—Continuous elastic traction to combat stiffness of the fingers in extension. Note the transfixion of the nails. *A.* Maximum flexion obtained one year after an infection of wrist and lower third of forearm. *B.* Range of flexion after three weeks of continuous elastic traction by rubber tubes fixed in the nails.

For cases of the first type, in which traction is required, it is best to employ a combination of plaster and wire, making curved splints of the wire for palmar support and keeping these in position by turns of plaster bandages round the wrist and lower forearm. To make an extension for the fingers, one of many methods may be used, e.g., traction either by a wire or by a modified safety pin through the pulp of the finger, or better still through the free end of the fingernail (see Fig. 105).

In rifle bullets or splinter wounds of the fingers, the damage to the bone is less important than the destruction to the tendons; even if the fingers are saved, they are in most cases useless. It follows that fingers in which tendon as well as bone lesions have been produced by bullets or splinters need immediate amputation, for the slight possibility that function may be restored is not worth the risk of conservative treatment.

Injuries of the metacarpals, on the other hand, demand conservative surgery if this is at all possible. A plaster cast fixing the hand in a position of useful function, with the thumb opposed to the fingers, gives good results if combined with traction of the fingers in flexion.

Fig. 106.—Laceration of the dorsum of the hand with loss of almost the whole third metacarpal and the extensors of second and third digits. Photographs taken at the first change of plaster, fourteen days after injury. (See also Figs. 107 to 109.)

On July 14, 1941, a man of 58 was seriously wounded in the right hand by a machine. The wound extended from the carpal region to the metacarpophalangeal joints and involved the whole width of the hand. The whole of the third metacarpal bone was missing except its base, and the contents of the second and third interosseous spaces were scooped out and hanging to the distal part of the wound. The second metacarpal bone was bare, and a slice was missing from the dorsomedial aspect of the head. The metacarpophalangeal and carpometacarpal joints were open. The extensor tendons of the second and third digits were beyond repair; that of the fourth was only partially interrupted. Operation was performed three hours after the injury, 3,000 units of antitetanic serum being given. Under general anesthesia with gas and oxygen the skin and wound were cleansed with soap and water and an antiseptic was applied to the skin. The wound was excised as completely as was con-

venient and the flexor tendons were found bare in its depth. All the structures attached to the base of the first phalanx were excised. The rest of the skin of the dorsum was in narrow strips, which were largely removed. The distal lateral angle of the wound was closed with three interrupted silkworm-gut sutures along a line continuing the fourth interdigital cleft. The lateral angle of the distal flaps was held in place with one stitch; sulfanilamide powder was blown on the wound. A dry dressing and a plaster-of-Paris cast were applied with the hand in relaxation.

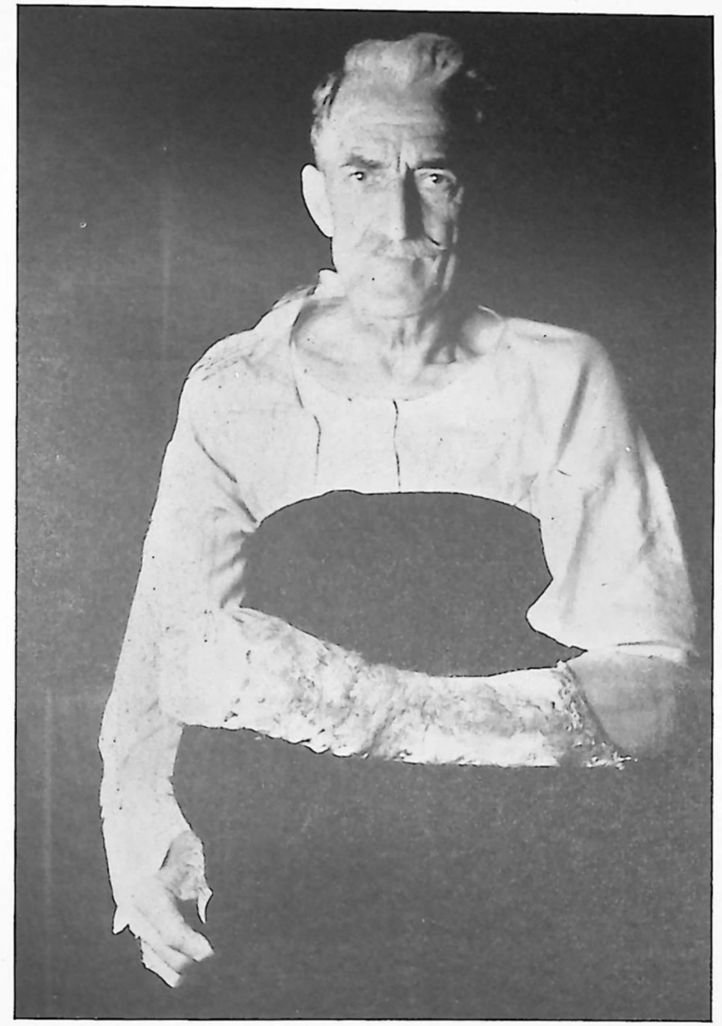


Fig. 107.—Good local and general condition throughout the whole treatment. Note absence of edema of forearm.

The postoperative course was uneventful, the temperature never rising as high as 99° F. (see Fig. 106). Fourteen days later the plaster was removed and the wound was found dry and clean (see Figs. 107 and 108). The second metacarpal was covered with granulations, the

Fig. 108.—At the removal of the first plaster the plain gauze used for drainage is dried. Note the two different qualities of gauze.

Fig. 109.—Ten days after the skin grafting; only a small area is still uncovered by epithelium.

remaining extensor tendons being clean and without any sign of infection. The place of the lost bone of the second and third metacarpals was filled with granulations. Dry gauze and new plaster were applied. On August first the plaster was removed and a Ollier-Thiersch graft was applied to the dorsum of the hand, after cleaning with soap and water and saline. Vaseline gauze and a new plaster were applied. On August 10 the plaster was removed and the graft was found satisfactory; only a small area over the second and fourth metacarpals was still uncovered by epithelium (see Fig. 109). On August 13 the patient was discharged from the hospital. On September 9 he showed some increase in the range of movement of the fingers, except that of the third and fourth digits, which had lost their extensor tendons and also had had their flexor sheaths damaged.

Wounds of the second type, i.e., transverse fractures, are rare in war. All that is needed is plaster for immobilization, care being taken to flex the fingers.

Drainage.—The utmost care should be taken in draining the palmar spaces. The surgery of industrial accidents during the last twenty years has shown the great responsibility of errors of surgery for deformity and crippling of the hands. The teaching of Bunnell, Kanavel and Iselin has made it clear that certain definite lines of incision should be followed to avoid permanent disability due to scar retraction and lesions of the nerve supply.

In war injuries of the hand, three incisions are particularly useful. The first, for drainage of the middle palmar space, is the long, curved incision that follows the first flexion crease from outside to inside, then upwards to the base of the thenar region and on to the inner part of the annular ligament. It avoids the thenar nerve branch, provided generally by the median nerve.

The second incision, for the drainage of the thenar space, passes immediately above the thenar crease and should end just where this reaches the thenar muscles so as to avoid damage to the thenar nerve.

The third incision, in the thenar space in the dorsum of the hand, must be external to the first interosseus muscle and must stop short of cutting the radial artery as it passes through the first cleft.

WOUNDS AND FRACTURES OF THE HIP

Injuries of the hip region constitute one of the greatest problems of war surgery, not only because of their gravity but also because of the technical complexity, and in many cases the unsatisfactory outcome, of their treatment.

If the general statistics of casualties treated in different hospitals are examined, war injuries of the buttock and especially fractures of the hip are found to be relatively rare in comparison with fractures of other bones and joints. This fact at first sight seems surprising, for from its size and position the hip might be expected to be injured more often than other joints. But the comparative rarity of lesions of the hip in war hospitals is misleading, for the number of wounds in this region is actually rather large; the majority of the patients, however, never get to a hospital but die somewhere on the way. Fatal complications are favored by the proximity of vital organs, such as the bladder, the intestines and the iliac and femoral vessels.

In hip wounds without fracture two anatomical factors contribute to the serious prognosis: the large muscular mass of the gluteus, and the subperitoneal connective tissue spaces. Behind many little skin wounds in the gluteus maximus caused by splinters from an aerial bomb, there is an enormous destruction of the deep muscular structures mixed with contaminated blood and often with portions of clothing and other foreign bodies. A further danger in hip wounds arises from proximity of the anus and, in soldiers on campaign, from the dirty condition of the skin of the gluteal region.

Classification of Wounds of the Hips and Buttock

1. **Fractures in Which the Joint Lesions are the Only Important Ones.**—The cause of these fractures is usually a bullet fired at long range, and the wounds of entry and exit are mere punctures. Unless an important organ or vessel is hit, the danger is slight and healing usually proceeds without infection. When the bone damage is serious, all the complications and difficulties are related to the formation of excessive callus, which commonly causes total ankylosis of the hip joint.

2. **Wounds in the Buttock Without Bony Lesion, but With Inclusion of a Foreign Body.**—These are always serious, even when the wound of entry is relatively small and clean. It is common to find an area of mortifying subcutaneous fat soaked with blood, and some debris of dead muscle; and obviously, unless a radical operation is performed at once, the prognosis is very serious. In other cases the worst damage is in the musculature, the aponeurosis of the gluteus maximus being perforated and having immediately behind it a great mass of bruised muscle and blood. The commonest cause of these wounds is a fragment of an aerial bomb, a shell or a hand grenade.

3. **Wounds of the Buttock With Fracture of the Ilium, Head of the Femur or Both.**—In some serious cases there is not only a destructive wound of the soft tissues, but the bones of the hip are also damaged. Vessels and nerves, especially the sciatic nerve and superior gluteal artery, and less frequently the inferior gluteal artery, are often damaged. Gas gangrene and subperitoneal infections are the most common and dangerous complication of these wounds.

4. **Fractures With Inclusion of the Metal Fragment.**—Many different types of these lesions may be seen, from comminution of the hip joint to less serious injuries such as fracture of the trochanter or acetabulum. These fractures respond much better than the others to surgical treatment.

Treatment of Serious Wounds of the Buttock

In serious buttock wounds the factors of time and excision largely decide the patient's future. The region is usually dirty, much fat and muscle are damaged, the layers of the tissue are closely superimposed, and important organs and other anatomical structures lie near the wound. Operation should therefore be carried out as early as possible, certainly before six hours and better still before four. The excision should be adequate, the depth of the wound exposed, and the drainage carefully performed. For this a very thorough enlargement of the wound is necessary. *No wound in this region should ever be closed by primary suture.*

Technique of Drainage of the Hip Joint.—In all serious infections of the hip joint, operation on the following lines is essential:

If the patient is seriously ill, transfusion with both plasma and blood is required before operation. Because of the depth of the hip joint socket and the very close approximation of the opposing articular surfaces, drainage of infected fractures is difficult to establish by any approach. Excision of damaged tissues, however radical and deliberate, never really exposes the joint, as the head of the femur prevents the exit of fluid by acting as a plug. An operation which does not include resection of the head of the femur is essentially extra-articular, and though such an operation may defeat the septic process when the lesion of the bone is not serious, it usually fails to drain the joint itself in a seriously infected fracture. Indeed, the only really radical method of draining the hip joint is excision of the head of the femur, the best approach being the anterolateral along the upper border of the neck and head, by an incision that runs from the anterior superior iliac spine downwards and slightly laterally. The fasciae are divided, the sartorius is separated inwards and the space between it and the vastus lateralis opened up by blunt dissection. This approach is not as easy as Smith-Petersen's, but gives good drainage after the operation; it has the added advantage that it can if necessary be enlarged upwards into a Smith-Petersen approach.

In some cases the extent and gravity of the wound, especially when it extends to the upper third of the femur, make any attempt at conservative treatment not only useless but dangerous, as even the best of drainage and the widest resection will then not arrest the septic process. The only chance of saving life in such cases is to perform a disarticulation at the hip joint, giving blood transfusion before and during the operation to control shock. The mortality is very high, but always lower among those who have been operated on early than among those on whom conservative treatment has been first attempted. Chemotherapy may possibly help to save some of the seriously infected cases.

When hip casualties occur in the front line, the real difficulty lies in performing a rapid and efficient operation in an advanced surgical station, for on account of the gravity of their wounds the patients cannot be transported far from the front. The outlook is better for air raid casualties, as valuable time is saved by efficient transport and the proximity of good surgical facilities.

Treatment in Less Serious Cases

When the fracture of the hip joint is produced by a long-range bullet, the wounds of entry and exit are usually small and there are no serious lesions of the soft tissues. Such cases may be treated by immobilization without any other surgical treatment, and progress will be similar to that of a closed fracture.

In cases of multiple fracture and more severe damage to soft tissues caused by high-velocity bullets, fragments of bone must be removed and/or the head of the femur resected for drainage. In many cases the capsule may be sutured.

Immobilization must follow immediately. The plaster cast, for which I always use the pattern technique, should extend from the axilla down to and including the foot (see Fig. 69).

In cases operated on too late, in which the head of the femur has been resected or much splintered bone has been removed, the plaster cast quickly becomes saturated and cannot therefore be left on for long. Twenty days is about the maximum period for the first cast. The patient should lie on the injured side. When drainage is effected by means of corrugated rubber, the drain may be led through a hole bored in the cast as soon as it is applied, and the cast can be kept on a few days longer than it would without this form of drainage. In other cases vaseline gauze inserted in the plane of intermuscular cleavage and changed with every new cast will serve to drain the discharge.

Operation should be performed at the earliest possible moment, owing to the rapid intoxication of these patients when excision is delayed. The following is an example of the course of a wound in the hip region when operation is not carried out within the first few hours.

A doctor's wife was wounded by an aerial bomb splinter which caused a perforating wound of the buttock with the outlet in the external part of the groin. Great bruising of the soft tissues was produced and she suffered immediately from shock of some severity, the blood pressure being 90/60. Blood transfusion, morphine, glucose saline and heat were employed to combat the shock. A hopeful reaction appeared after the first blood transfusion, but this was maintained for less than one hour. Twelve hours later the shock was still pronounced, and there was a slight rise in temperature, toxic excitement and a blood pressure of 105. Within forty-eight hours of receiving the wound the patient had a pyrexia of 104° F. and died in advanced toxemia.

The only opportunity in this case was lost when the patient responded to treatment during the first hour of resuscitation. Excision and drainage should have been performed there and then.

FRACTURES OF THE SHAFT OF THE FEMUR

The great destruction of the thigh muscles caused by bomb and shell fragments, and the extensive splintering of the femur produced by rifle bullets or by the casing of modern light bombs, contribute to the gravity of wounds in a region in which gas gangrene is common and osteomyelitis is serious. Owing to the anatomical structure of the thigh, drainage in case of infection is difficult; the stratification of the muscular masses with the dividing fascial layers may make even the boldest longitudinal drainage incision inadequate. Fortunately, sepsis can be averted by proper treatment within a few hours of the injury.

Transport of the Patient

Except for the star-shaped fractures caused by rifle bullets, in which the muscular damage is slight and the skin lesion negligible, all wounds of the femur must be treated as rapidly as possible.

The first urgent problem is the transport of the patient to the nearest surgical station under provisional but effective immobilization, for movement of the fracture increases the muscular damage and sometimes the nervous and vascular damage as well; the prevention of further shock depends likewise on the conditions of transport. These, however, with the methods of splinting normally available, are seldom all that they should be. Splints that can be easily applied to the thigh have the serious disadvantage of being badly adapted to the trunk, especially to the pelvis, and unless the tip of the splint extends beyond the thigh, immobilization is wholly unsatisfactory. In the War of 1914 to 1918 widespread use was made of the Thomas splint, which enables the leg to be kept in extension by traction from the foot and countertraction from the pelvis. This apparatus, though inefficient if employed with the idea of treating the fracture, has the great advantage that it can be applied as a first-aid splint to the patient where he lies wounded. The Thomas splint is also ineffective as a means of immobilizing fractures of the upper third of the femur. These high fractures can be immobilized by two Cramer splints, well protected with cotton wool: one is placed at the back of the leg and thigh, reaching just to the lower border of the buttock; the other, a long one, covers the leg, thigh and abdomen. Here again, however, no splint is comparable with a well-fitted plaster-of-Paris cast, provided that sufficient elevation of the foot is secured during transport.

Treatment

Reduction.—In the relatively few cases in which shock is not too severe, fractures of the shaft of the femur may be reduced under general anesthesia with ether (see p. 165); but for most patients local anesthesia is necessary. The next step is to reduce the deformity by traction, the details of the procedure varying according to the site of the fracture. In fractures of the upper third, the pull should be in the direction of flexion and abduction of the hip; in those of the middle third a straight pull in slight abduction is needed. If the fracture is at the lower end of the femur, both hip and knee must be flexed to prevent backward rotation of the lower fragment.

To ensure proper reduction some form of orthopedic table should be used. If traction in a straight line is required, the foot should be bandaged to the extension screw on the table; if a flexed position of the knee is required, a Kirschner wire may be passed either through the crest of the tibia or through the lower epiphysis of the femur (see Fig. 27). Any other form of skeletal traction apparatus, such as a Steinmann pin or an ice-tong caliper, can be used. The purpose of the traction is to reduce the fracture and maintain it in reduction, so that, after the surgical treatment of the wound has been completed, a plaster cast may be applied directly to the leg and the Kirschner wire or Steinmann pin either removed or maintained. Sometimes the number of cases requiring treatment exceeds the available supply of orthopedic tables and traction apparatus; and in such circumstances trained assistants can effect and maintain reduction by gripping the leg behind the knee.

Treatment of the Wound, Fixation of the Fracture, and Application of the Plaster.—When the deformity has been partially corrected by traction, the skin of the entire thigh and the raw surface of the wound should be scrubbed quite clean with a nail brush, soap and water. The wound is enlarged longitudinally both above and below and the skin edges are excised. This is followed by careful removal of such muscular bundles as do not bleed freely or respond to stimulation with forceps, in order to eliminate what would otherwise become a culture medium for anaerobic bacteria.

The next step is completely to remove all organic and inorganic foreign bodies, and all damaged and unattached fragments of bone encountered during the exploration of the wound. After hemostasis, the fractured ends should be aligned as accurately as possible, sulfanilamide powder spread in the wound, and a sterile gauze pack applied with another layer on top of it, and the whole leg plastered from the lower ribs to the toes. When the plaster is dry, the traction may in some cases be released, the fracture being held in correct alignment by the cast.

It must be remembered in planning drainage that the thigh is divided by fascial planes into an anterior and a posterior part, and that an infected wound of the anterior part does not drain well from behind, and *vice versa*. In most cases it is necessary to make separate openings in front and behind, so as to drain both compartments.

Fixation of the Fracture Under Plaster.—In extensive injuries of the soft tissues which have been treated by thorough excision of muscular tissue and fascia, the plaster alone may be sufficient to maintain the reduction. In these cases the decreased tone of the muscles permits the bone to be kept in correct position. The plaster must be well moulded and extend high up the body. When the wound is not very large it is necessary to counteract the contraction of muscles inside the plaster, which in all simple fractures may produce secondary deformities.

There are three successful techniques for combating loss of reduction inside the plaster:

1. A loop made of a plaster bandage is attached at the level of the flexed knee, and from it is suspended a weight of 15 to 25 pounds. This method is especially convenient for shocked or infected patients, who need the benefit of immobilization in plaster but whose plasters, owing to the profuse discharge, must be changed three or four times during the treatment. When a plaster is removed the patient is placed on the orthopedic table and anesthetized, traction is exercised by the handle fixed on the table leg, and the plaster is cut circularly just above the knee to allow the traction to be maintained. The whole plaster covering the body, leg and thigh is removed. After the dressings have been changed, a new plaster is applied to the body and thigh and fixed to the old plaster of the leg, through which the traction is exerted. By this technique traction is not lost and the fracture does not suffer any displacement.

2. For cases without soft tissue damage, a better method of keeping the fractured femur in position is to transfix the lower metaphysis with a Steinmann pin or, better, with two. The longer and lower pin transfixes the bones, passing right through the soft tissues to emerge at the inner side of the thigh. The shorter pin, placed parallel with the longer one and about 2 in. proximal to it, also transfixes the cortex but does not emerge at the inner side (Anderson, 1939). To fix the upper frag-

ment, two more short pins are inserted into the trochanter, making a right angle between them, and fixed together with a plate. The four pins and the plate are included in the plaster and solidly held together. The only serious objection to this technique is its lavish use of Steinmann pins. Inflammatory reactions sometimes occur, especially round the upper pins: in a small number of cases so treated I have seen three of these reactions, one of them serious.

3. The best of these three procedures is without doubt the use of Kirschner wires, which have the advantage that they do not produce bony rarefaction or inflammatory processes, and are easily placed in position and fixed—as least as easily as Steinmann pins. The only drawback to their use is the clumsy stirrup which is needed to keep the wire taut and without which it is wholly inefficient. Either the patient must be kept in bed to allow the traction to work, or the stirrup must be fixed to the plaster. To avoid this difficulty I use a simple device with which the wire can be fixed to the plaster without using the stirrup to maintain lateral tension (see Fig. 43). The technique is as follows:

The Kirschner wire is placed in position by the ordinary method, or, better still, by an electric drill if one is available. The stirrup is fixed with the appropriate lateral tension and the plaster applied, care being taken to make it strong enough to take the tension of the wire later. When the plaster is completely dry a simple plate is affixed firmly to each end of the wire inside the stirrup by means of a device similar to that which ordinarily holds the wire in the stirrup (see Fig. 44). The stirrup is still in position, keeping the wire taut. The plates lie flat on the surface of the plaster and are solidly attached to it by a plaster bandage (see Fig. 45). When the bandage is completely set, the stirrup is removed and the ends of the wire cut short; the patient is then ready for removal if necessary (see p. 238).

The upper fragment of the femur may be fixed through the great trochanter by a wire passing right through from front to rear. A large stirrup is necessary here, because in many patients there is not enough room between the soft tissues and the ends of an ordinary stirrup to allow the plates to be kept in position. The upper plates are fixed to the plaster like the lower ones.

With this technique the Kirschner wire may be kept in place for many weeks without complication. In some cases I have left it on for twelve. The bones are maintained in perfect position, and the patient may walk as soon as the wound is sufficiently healed.

Treatment by Continuous Traction.—Until recently a common treatment of a fractured femur was continuous traction after primary surgical treatment of the wound. Extension was maintained by some form of skeletal traction through Steinmann pins, with the limb supported

on a Braun or Thomas splint suspended from a Balkan frame. This method has admittedly been successful: the fracture can be reduced and the ends maintained in position until the bone unites; the exact position of the fragments can be checked and controlled by adjusting the apparatus, and inspection of the wound is easy. Immobilization, however, is not complete, and slight movements must take place whenever the patient alters his position. Probably in simple fractures very little movement of the fragments occurs even when the patient lifts and lowers himself, because the muscles around the fracture act as an additional splint. On the other hand, in an open fracture caused by a fragment of shell or bomb there is frequently very considerable muscular destruction and the splinting action of the muscles is decreased. Continuous traction is therefore never completely effective in immobilizing a compound fracture of a femur, and, unlike the plaster cast, it does not immobilize the wounded soft tissues.

Good results from traction treatment depend on constant watchfulness and adjustment of the apparatus. Such conditions are attainable easily enough under peacetime conditions, but not so easily when a limited staff has to deal, as it often must after aerial bombardments, with a large number of cases. Moreover, traction treatment calls for a large stock of various kinds of apparatus; the plaster method requires nothing more than plaster of Paris, muslin, and bandages.

The last but not the least inconvenience of the systematic use of continuous traction for compound fracture of the femur in war is the difficulty of transporting wounded in troublesome and complicated apparatus. The surgeon should remember that treatment with the Thomas splint is not efficient unless it is correctly fixed in bed with a Balkan beam.

To sum up: treatment of open fractures of the femur by plaster of Paris secures good control of the fragments; when correctly placed and fixed the cast immobilizes the wound and so helps to prevent the spread of infection; many patients can be treated at the same time by a relatively small surgical staff; and only the simplest of apparatus is needed. Under war conditions these are considerable advantages, but yet another must be emphasized: its value when the wounded have to be moved.

Advantage of Plaster in Transporting Casualties

In civil practice there is no evacuation problem; in wartime the transport of patients is necessary, and the conditions of transport may make all the difference between life and death. To illustrate this fact it is only necessary to describe the procedure followed in Catalonia, which reached its maximum efficiency during the fierce battle of the river Ebro. Military casualties underwent wound treatment—complete or otherwise—reduction of the fracture, and fixation in a plaster cast at the first casualty surgical station—often the No. 1 hospital or mobile unit. The risk of the wound being irritated by movement of the fracture being thus averted, the patients were transported to the base in comfort, and many of them, by the time they were on their way from the casualty station, had already started their final treatment instead of being temporarily patched up until treatment proper could be instituted at the base hospital. If excision had not been performed and the cast was used merely to facilitate transport, a mark was made on the plaster to indicate the urgency of evacuation to a surgical unit.

In the treatment of air raid casualties the benefits of the system are even more apparent, but in these excision may almost always be performed before evacuation. I have already explained why bomb wounds are easily infected, and why, unless treatment is energetically started within six hours after the wound is inflicted, the incidence of gas gangrene is high. Thus the best results are obtained when full surgical treatment of the wound, reduction of the fracture, and the application of plaster are all carried out as soon as possible, even while the raid is still continuing. After the raid, or in the lull between the raids, many casualties can be evacuated with a copy of their notes to a base hospital in the country. On arrival the condition of the fracture can be observed radiologically and if necessary, the plaster can be removed and replaced after correction of the deformity at the most convenient time.

Cases Not to Be Treated by Plaster in the Initial Stages.—In two groups of cases it is better to delay the application of the plaster. In some very severe wounds of the thigh and leg it is uncertain whether the distal part of the leg will survive. It is therefore best to set the leg up in some traction apparatus for a few days so that the circulation can be watched. Amputation may then be performed if necessary, but if, on the other hand, it becomes apparent that the leg will survive, a plaster should be applied and the patient evacuated to a base hospital. The other type of casualty which should be kept under direct observation is the one who arrives too late at the operating table, after more than eight hours, and has suffered great damage to the muscular tissue. The wound should be opened up and excised as radically as possible, sulfanilamide powder placed in it, drainage established and the thigh immobilized by traction in a Thomas or Braun splint. If in forty-eight hours no anaerobic complication has arisen in the wound, the injured limb should be placed in the plaster spica and the patient prepared for evacuation if necessary.

Surgeons who have no experience with the plaster technique are advised to start practicing it on upper limbs, to progress to the foot and leg, and only when they know enough of the details to apply the full method to the thigh.

Injuries to the Femoral Artery and Sciatic Nerve

Few patients with the femoral artery severed survive the initial dramatic hemorrhage. I have, however, seen three patients with the femoral artery damaged for whom there was time for resuscitation and who survived the first danger. In all three cases a tourniquet was applied. Conservative treatment of the limb was planned, after ligature of the artery in two cases and lateral suture of the artery, which was two-thirds severed, in the third. In all three cases a secondary gangrene appeared and amputation was made necessary. Bastos (1937) had the same disappointing experience in Madrid. In one of his cases the femoral vein was ligated, but without any better result.

Injuries to the sciatic nerve are commonly caused by bullets or small splinters. Secondary suture of the nerve as soon as the condition of the wound allows, is always preferable, because of the extensive and laborious operation needed in these cases; the speed and pressure of emergency work do not provide proper conditions for a correct operation at the advanced station.

FRACTURES INVOLVING THE KNEE JOINT

Of all fractures of joints, no class has given rise to so much discussion among surgeons as those involving the knee joint. During the last war a point was reached at which some surgeons advocated immediate amputation as a prophylactic measure in cases of any severity—a pessimistic view that was justified only by the number of disasters which had occurred with some of the conservative techniques that were then being employed.

Classification

As with all gunshot wounds, it is necessary to consider separately (1) the type produced by a rifle bullet fired at long range which transverses the joint and comes out on the opposite side; (2) the type produced by a shell or bomb fragment which penetrates into the joint and lodges in it; and (3) the type in which actual crushing of the whole joint occurs, with great damage to the skin and muscles and often to the blood vessels and nerves.

Type 1.—In this type, even when the bullet causes a comminuted fracture of the articular surface of the femur, the case follows an entirely favorable course when it is treated immediately by complete immobilization in a plaster cast from pelvis to toes. General treatment with one of the sulfonamide compounds should be given. Healing is complete within three months, some mobility of the joint is usually preserved, and gross permanent stiffness of the knee rarely persists.

Type 2.—In this type, however, grave complications follow unless the case is properly treated from the start. On inspection a small or medium-sized wound of entry is seen in the region of the joint, but no wound of exit; the skin wound made by a fragment of modern light bomb may be very small. If more than two hours have elapsed since the wound was made, the joint will be found distended with blood. This apparently harmless wound, with a slight contusion round its edges, is the gateway through which numerous foreign bodies besides the projectile have passed; and if it is not properly treated at once, acute and fatal suppurative arthritis may result.

It is a great mistake in such cases to adopt immediate immobilization on the assumption that the same treatment is applicable as in the first type of case with its punctiform entrance and exit wounds. When cases of the second type are so treated, it is found necessary to remove the plaster cast on the second or third day because of the great pressure on the knee or because of the manifest development of signs of a general infection.

Varying with the direction from which the missile has come, the surgeon finds extensive lesions of the articular surface of the femur (usually in only one condyle), or of the upper surface of the tibia, which may be almost pulverized. The ultimate movements of the joint depend on the degree of bone destruction.

Type 3.—In the third type there is usually, in addition to the damage to the bone and soft tissues, much loss of blood, and patients are admitted in a state of intense shock. The majority of these grave cases—and, needless to say, of all cases in which there has been serious vascular damage—seem at first sight to call for mutilating surgery, but boldly conceived conservative treatment may often save not only the patient's life but his leg as well.

Treatment

Type 1.—Wounds produced by high velocity bullets which have transversed and emerged from the joint may be treated simply by cleaning the edges of the wound and immobilization in plaster. A sulfonamide compound should also be administered.

Types 2 and 3.—These should be treated as soon as possible, but not with haste. If sepsis of the joint sets in, chemotherapy is only of limited value. All open fractures of the knee must therefore receive efficient surgical treatment, which must consist of a broad exploratory arthrotomy, directed towards the elimination of all foreign bodies and of devitalized soft tissues, which may in themselves be potential sources of infection.

The best approach for examining the knee joint is by way of a large curved exterior incision, with displacement of the patella. But this large incision, though good for exploratory purposes—for it gives a good exposure of the articular surface of the knee in flexion—is very bad for purposes of drainage, and in many cases causes stiffness. In those casualties in which operation is performed within twelve to sixteen hours of the injury, extraction of foreign bodies from the joint may be followed by suture of the synovial membrane; the skin wound should generally be left open. On the other hand, in cases seen when infection is already established, and in those in which destruction of the soft tissues is so great that suture except under tension is impossible, a fair-sized drain of vaseline gauze should be inserted down to the joint. In cases of empyema the joint must be opened (see p. 333).

In recently wounded patients excision of large displaced fragments is not recommended, for it does not confer any immediate benefit and endangers not only the movement but also the future stability of the joint. Nor is a formal resection of the knee advisable in these cases, the problem being how to treat the synovial membrane rather than the larger fragments of bone.

When the patella is broken into a number of fragments, the best procedure is to resect the entire bone. It is sometimes difficult to suture the capsule in front of the joint, but in many cases the suture of the capsule perfectly closes the joint. The late functional results of excision of the patella are satisfactory. The following is an illustrative case:

An army officer 29 years old, while riding a motorcycle on March 27, 1941, received injuries to the face and head and a compound fracture of the patella. He was transferred to the Wingfield-Morris Orthopaedic Hospital and examined more than twenty-five hours after being injured. Just above the patella was a transverse wound less than an inch long; he had a fracture of the right maxilla. Owing to the delay and the relatively good local condition (the situation of the wound and its clean edges suggesting that the patella had protected the joint from contamination), the wound was superficially cleansed with soap and water and powdered with sulfanilamide and the leg was put in a protective plaster with a window over the wound, to avoid pressure on the joint and to facilitate aspiration if any infective complication appeared. Excision of the patella was indicated by comminution and lack of reduction of the fragments, but it would have been dangerous to excise too soon, on account of the small external wound.

The course was uneventful. A secondary suture was made on April 18 and healing went on normally. Massage and mobilization of the knee joint were carried out for over six weeks to prevent stiffness due to excessive immobility. After that time the patella was excised and quadriceps exercises were started next day. The postoperative course was normal and the patient was discharged in September, 1941, when his knee showed a flexion of 90°. In March, 1942, he wrote that he was only 5° short of full flexion and that he was on full duty again.

This case would have had a shorter history if there had been less delay in sending the patient to the hospital. When he came in it was too late to risk a large intra-articular operation, owing to probable sepsis in the small wound of the patellar region.

The only cases in which a formal resection of the knee appears to be indicated are those in which an old suppurating sinus is kept up by a local osteomyelitis; for relapses may result from a flare-up of the septic focus, and a planned resection offers the only means of ending the attacks and achieving a stable and useful leg.

Drainage of the Knee Joint.—The great area of the synovial membrane of the knee joint, with its many blind pockets extending in various directions, impedes systematic treatment of the large collections of infected fluid. It is therefore impossible to drain the joint in every case through the same approach, and the surgical technique should be adapted to the varying conditions of the infection. The superficial arrangement of the knee joint makes the aspiration of fluid very easy; and, by combining aspiration with immobility and general sulfonamide treatment, some infections may be controlled without opening up the joint. This conservative treatment is useful in cases treated by primary suture of the synovial membrane which show the initial signs of infection—increasing pain, distention of the synovial cavity by fluid, increasing heat in the skin of the joint region, and some fever. Aspiration of the synovial fluid through a small window in the plaster, repeated every time the joint refills, and a course of chemotherapy, may in some cases resolve the infection in a few days.

When a wound left open from the beginning becomes infected, the drainage of the cavity depends on the site of the principal collection of pus, and the initial wound may be a way of approach. Wounds treated by primary suture which need much drainage may be treated by an anterior incision on each side of the patella, extending the whole length of the suprapatellar pouch, as high up as convenient. But the position of these incisions in a patient lying in bed is completely opposed to drainage by gravity, and so in many cases posterior counterdrainage must be performed.

Three different approaches may be followed for the drainage of the posterior compartment of the joint.

1. **The Lateral Approach.**—The knee is placed in flexion to relax the biceps tendon. An incision three inches long is made in the lateral aspect of the knee at the anterior part of the head of the fibula, following the anterior border of the tendon of biceps. This tendon protects the common peroneal nerve. The incision is continued by blunt dissection to the posterior compartment.

2. **The Medial Approach.**—This is a similar incision made in the median aspect of the joint; the only difference is that the tendons of which the incision passes the anterior border are those of the semimembranosus, semitendinosus and gracilis muscles.

3. **The Posterior Medial Approach.**—A longitudinal incision of four inches is made in the central part of the popliteal space, slightly internal to the midline. The popliteal vessels and tibial nerve are carefully preserved and retracted outwards. The ligaments and capsule are incised transversely.

Immobilization of the Knee Joint.—The best immobilization for the knee joint is the enclosure of the whole limb from foot to pelvis inclusive in a plaster cast. It is commonly admitted that the foot should be fixed by the plaster, but it is not so common to see wounds of the knee joint immobilized by plaster extending to the lower ribs. It is impossible to fix the knee with a plaster supported in its upper part solely by the muscles of the thigh. The knee must be placed in semiflexion (15°-25°) in the first plaster, and should be fixed in the second (if a second is needed) in only 10° of flexion.

When a window is cut to ascertain the amount of fluid, the best place is the external aspect of the suprapatellar region. Through this window the fluid can also be aspirated.

In other cases which have been sutured under doubtfully favorable conditions a Thomas splint or a long and well-moulded plaster splint can be useful. In either of these splints the joint may be explored without delay, and this advantage partly compensates for the inferior immobilization.

Cases with extensive bone damage, minute fragmentation of the joint, and wide destruction of the soft tissues usually require amputation, especially if operated on after twenty-four hours, for the sepsis is then probably too widespread to justify any attempt at conservative treatment. They combine the worst dangers of both types of injury, namely, serious fracture and extensive articular wounds.

The following cases of infected articular fracture show the importance both of complete excision and of perfect immobilization:

A patient 24 years old had a compound comminuted fracture of both condyles of the femur and the patella treated by excision and plaster, but from the beginning the wound was insufficiently excised and drained. Ten days after the operation the drainage was improved and a collection of pus evacuated, but the patient already had an osteomyelitis which made necessary the removal of several sequestra on different occasions. Three weeks after the injury, after an incision had been made to improve drainage, he had a fresh rise of temperature. The whole lower limb was at that time covered by plaster. A course of sulfapyridine by mouth was given, and the day after the first dose the temperature fell from 103° F. to almost normal. The sulfapyridine was discontinued after four days, and the next day the temperature rose again to nearly 103° F. A new course of sulfapyridine and improvement in drainage brought the temperature under control next day, and the drug was continued for five more days; but 24 hours after it was stopped the temperature rose again, and this time the fever could not be controlled by sulfapyridine. After three days of administration without effect, it was discontinued and the temperature persisted for four more days. Under general anesthesia the plaster was removed and a careful incision of all the pockets of the wound gave good drainage of the pus produced by the osteomyelitis. A new plaster was applied. Next day the temperature was normal without any drug.

After two months of trouble caused by diffused osteomyelitis, consolidation of the fracture was obtained. An examination made eleven months after injury showed consolidation with a shortening of the femur by 1½ in., ankylosis of the knee joint and free movement in hip and ankle.

The difficulties arose from the deficient exposure of the fracture, which led to insufficient excision and drainage, as was proved by the fact that the temperature started nearly three days after the injury, when a large collection of retained fluid had been formed. Recovery followed the establishment of complete drainage when all dead tissues had been eliminated.

A soldier 23 years old was wounded in France on May 28, 1940. He had a shrapnel wound over the upper border of the left patella, and was admitted to a hospital in England the next day. The wound was excised and found to penetrate the knee joint, and the patella was comminuted. The wound was tightly packed with gauze and the joint immobilized with a plaster from the toes to the upper third of the thigh. He was admitted to the Wingfield-Morris Orthopaedic Hospital on June 10 and was then comfortable with a normal temperature. X-ray showed comminution of the patella. In spite of his good general condition, the insufficient immobilization of the knee joint, by a plaster of which the upper part was supported by the thigh muscles, indicated the need for a new plaster. The plaster was changed on June 13. A clean excised wound 3 in. × 1 in., packed with flavine gauze, was found at the external part of the patella region. Granulations looked healthy, and, to avoid damage, the packing was left in place and a new plaster was applied immobilizing the thigh.

Next day the temperature rose progressively, in three days reaching 102.5° F. A course of sulfapyridine by mouth had no effect. Ten days later the wound was re-examined and fluid was found in the joint, which was drained through two lateral incisions, and a large old hematoma with white fibrous tissue and some purulent spots was eliminated. Plaster was re-applied and the temperature progressively improved. A new plaster was put on four weeks later, when the wounds were found healthy and granulating well, and the fracture of the patella was consolidated. Soon active movements and massage of the quadriceps were instituted and the patient was discharged. On October 16 he was re-admitted to the Wingfield-Morris Orthopaedic Hospital: the wounds were completely healed, and the knee movement limited to 25° of flexion but improving.

This is a typical example of the disturbance caused by a change of plaster even when well tolerated. In spite of the most careful precautions, the slight movement damaged the granulations and produced the hematoma and resulting infection.

INJURIES OF THE LEG

War injuries of the leg form a group in which the surgeon's capacity may be of the greatest profit to the patient. The leg indeed is perhaps the region in which surgery has made its most outstanding progress during the last few years. The commonest spectacle of postwar misery used to be the old soldier with one or both legs mutilated. The constantly increasing possibilities of conservative surgery have allowed the surgeons of our generation to save many legs which would have been considered already lost by the surgeons who preceded us. We are still obliged to amputate a number of legs, but it is no exaggeration to say that the only type of lesion in which amputation is life-saving and thus necessary is smashing of the extremity or severance of the main artery —a certain cause of necrosis in a war injury.

The chief indications for amputation of the leg in past wars were two: (1) prevention or treatment of infections in muscles, joints, bones or connective tissues, or (2) permanent disabilities which made a clean amputation preferable from the beginning of the treatment. Now, provided that the blood supply is not interfered with, many legs may be saved and much permanent deformity may be prevented by performing the operation and the subsequent treatment in accordance with the fundamental principles set out in this book. Even where the blood supply is impaired, the surgical treatment of accidental wounds does not differ in general principle from the treatment of any tissue damaged by an external agent. In this connection the following case note is highly instructive. The italics are mine.

"A surgeon operated on a compound fracture of tibia and fibula and found that the anterior tibial vessels were lacerated at the site of the fracture. The vessels were sutured. A small protruding fragment of the tibia was removed, and the wound was irrigated with hydrogen peroxide and left widely open. The fracture was reduced by manipulation, and a plaster cast was applied over wool packing extending above the knee. A window was cut over the wound and the plaster was bivalved. A prophylactic dose of 12,000 units of anti-gas gangrene serum and 1,000 units of antitetanic serum were given. The wound was examined every two hours.

"Twenty hours later a minute bubble of gas was expressed from the lower aspect of the wound and a faint smell of gas gangrene was present. A specimen of the discharge from the wound was taken, and the pathologist reported that *Cl. welchii* were present. The wound was explored immediately by a cruciate incision, each limb of the cross being about six inches long. The corners of the skin flap were sutured back to the skin. *Several muscles were seen to be discolored,* and bubbles of gas were present. *The muscles particularly affected were the tibialis anticus and the extensor digitorum longus.* These and all suspicious muscles were completely excised throughout the length of the wound. Twelve hours later the patient's general condition had improved, and four days later there was no evidence of gas gangrene."

This case is a clear demonstration of the possibility of saving not only life but also the leg when the devitalized tissues are excised without hesitation. In this case the proper excision was performed only after gas gangrene had become established. Nevertheless, removal of the dead muscles was sufficient to stop the progress of the infection. If the muscles left without blood supply by the severing of the anterior tibial artery—particularly the tibialis anticus and the extensor digitorum longus—had been excised at the first operation, it seems very probable that no complication would have arisen. This case also shows the ineffectiveness of such preventive measures as the administration of anti-gas-gangrene serum, cutting windows to allow air to "oxygenate" the wound, or irrigation with hydrogen peroxide, as substitutes for excision of tissues deprived of their vital blood supply.

FRACTURES OF THE TIBIA AND FIBULA

Wounds of the lower leg produce a far higher proportion of lesions of bone than do wounds of the thigh. In the lower leg the proportion of bone to soft tissue is over 1 to 5; in the thigh it is about 1 to 20. The problems in the two regions are therefore quite distinct, and, as is well known, the thigh and the leg react differently both to anaerobic and to pyogenic infections. The great mass of muscle and fascia in the thigh facilitates the development of anaerobic infections, and pyogenic infections of the cellular tissues is also frequent there. On the other hand, the relative smallness of the shaft of the femur limits the incidence of infective complications in the bone; though when a pyogenic colonization is established in the femur, its special structure, with its strong and compact cortex, facilitates persistent suppuration which diffuses through the connective tissue spaces and causes great toxic and bacterial absorption.

The lower leg contains fewer muscle planes, and most of these are situated in the calf. On the other hand, the greater amount of bony tissue and the less compact structure of most of it give a special character to injuries and complications in the lower leg. The development of gas gangrene infection in the thigh is determined by local interference with the individual blood supply of every muscle of the upper part (see

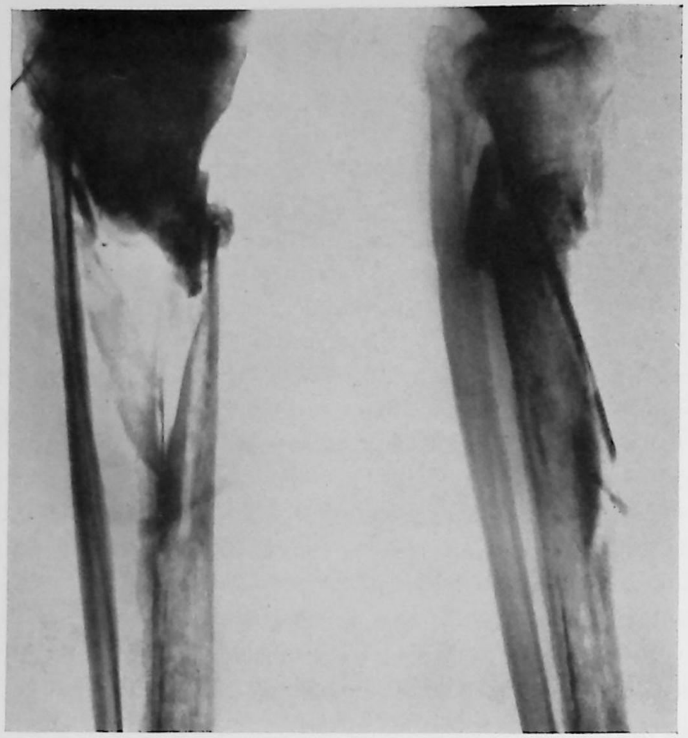
p. 98). In the leg the same cause may produce a similar effect, but the high incidence of gas gangrene in the leg is due to a different type of interference with the blood supply. It is the severance of the popliteal artery which causes initial ischemia and so leads to infective gangrene.

As gas gangrene mostly depends on an interruption of the main blood supply, the infection can be prevented in the great majority of wounds of the leg if the integrity of the main arteries is preserved. The best method of investigating arterial integrity is to place an oscillometer on the ankle and compare the systolic and diastolic pressures and the amplitude of the oscillation in the two legs. The surgical decision depends on the readings. An attempt to save a leg which has lost its main blood supply exposes the patient to a very serious danger without any substantial hope of satisfactory recovery. At best a secondary delimitation of the ischemic part of the leg necessitates a delayed amputation after endangering the patient's life for some days.

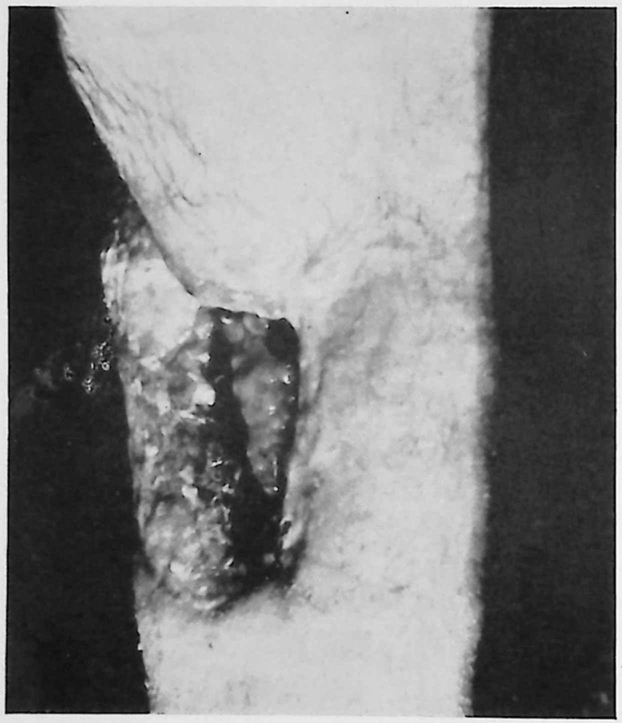
When a bruised wound in the muscles of the calf is not associated with damage to the main arteries, local muscular excision should be performed with care and enterprise. Wounds of the calf should never be sutured. Septic processes arising in the leg as a result of fracture principally affect the tibia, owing to the lack of muscular protection along its antero-internal face and its proximity to the surface. The poor blood supply of the superficial part of the tibia, due to its close connection with the skin, tends to make these infections chronic with the formation of sequestra. On the other hand, cellulitis or septicemia resulting from absorption from badly drained foci in the bones may occur as a result of unsuitable treatment.

It is particularly necessary to prevent infection of the tibia, for though in the majority of cases this does not endanger life, the stability of the limb may be jeopardized by the loss of an excessive amount of bone, not only from too drastic a removal of fragments at the first operation, but more frequently from later removal of sequestra due to infection. The following is an illustrative case:

A soldier 42 years old, riding a motorcycle on March 1, 1941, was hit by an army lorry and sustained general concussion and a compound comminuted fracture of the upper third of the tibia and fibula. Four hours after being injured he was operated on in a hospital near by. The limb was encased in plaster from toes to groin. Owing to a rise of temperature he had sulfanilamide for five days and 1000 units of anti-tetanic serum. The pyrexia subsided on March 12, and two days afterwards the plaster was removed. A large area of skin was found sloughed on the outer side of the leg just below the knee. On April 1 the plaster was changed, some sequestra were removed, and the wound was dressed with bismuth iodoform paraffin paste. On April 22, May 3 and May 30 the plaster was changed again. The wound was healing but several sequestra were not yet loose.



A.



B.

Fig. 110.—*A.* Radiograph of an infected compound fracture of tibia and fibula admitted to hospital for treatment, possibly amputation.

B. Characteristics of the wound at the time when the radiograph was made. Note the black sequestrum. (See also Fig. 111.)

On June 12 the patient was transferred to the Wingfield-Morris Orthopaedic Hospital. On removal of the plaster a large irregular triangular-shaped wound 5 in. × 3½ in. was found in the upper half of the left leg. It was suppurating and filled with unhealthy granulation tissue; at its periphery there was extensive dermatitis. The center was occupied by two long sequestra of black bone. The ankle was very swollen. Radiography showed two large sequestra and several smaller ones (see Fig. 110).

Fig. 111.—Wound clean, granulating and appreciably reduced.

A back splint was applied from the groin to the toes and the leg was placed on a Braun splint, the wound being left uncovered except for a single layer of gauze. Zinc oxide was used for the dermatitis. On June 23 sequestrectomy was performed, three large blackened sequestra being removed. The upper medial sequestrum was mobilized with a chisel and broken off through healthy bone. The marrow cavity was found to be continuous with the infected area. The incision was enlarged progressively downwards to three inches from the ankle, the medullary cavity being laid open with forceps. The bone lining the cavity was necrotic and was all excised. Finally, healthy fatty marrow was reached. The wound was packed with vaseline gauze and a plaster applied to mid-thigh. The leg was replaced on a Braun splint. The patient had a considerable reaction after the operation and pyrexia persisted for ten days. The plaster was soaked with discharge and on July 16 it was removed. The fracture was found clinically consolidated. Fig. 111 shows the condition twelve weeks later.

Gunshot fractures of the leg differ widely in importance and progress. It is therefore essential to divide them into two groups according to their situation. The first group includes fractures of the condyles of the tibia and of the upper third of its shaft without joint involvement; the second includes fractures of the lower and middle thirds of the leg.

Treatment of Fractures of the Upper Third of the Tibia

The lack of soft tissues over the upper third of the tibia makes it very difficult to maintain anatomical position of comminuted fragments after operation. It is necessary, therefore, to proceed on the following lines in operating on all fractures in this region except those produced by a bullet fired at long range with punctured entrance and exit wounds. The loss of substance caused by excision of the contused edges of the skin and subcutaneous tissue, as well as the displacement of the bony fragments, however slight, prevents suture except under great tension. The area of excision should therefore be left open, though the initial enlargement incision may be reduced in size by some stitches at each end. The tibia remains exposed, but by operating at once and immediately afterwards applying a well-fitting cast from the upper third of the thigh down to and including the entire foot, sequestration may be prevented (see Figs. 112 to 114). The cases I have treated in this way first in Catalonia and afterwards in England have all followed the same uneventful course. Even cellulitis is rare in this region, and when it does occur it is only superficial.

Results

Union in these fractures is extraordinarily slow: in many cases casts must be kept on for three or four months, and as soon as the soaking of plaster ceases, the patient must be made to walk in the cast in order to stimulate the formation of callus. It is necessary to add to the plaster a heel or metal stirrup so that the patient's weight will fall on the axis of the tibia. In the great majority of cases a well-fitted plaster maintains the reduction without the internal fixation with pins or wires.

Treatment of Fractures of the Lower Two-Thirds of the Tibia

There is more rigidity between the tibia and the fibula in their lower two-thirds, and there are a number of intermuscular cellular spaces

Fig. 112.—Compound fracture of tibia and fibula treated by the principles laid down in this book. Note the small window for bacteriological examinations. (See also Figs. 113 and 114.)

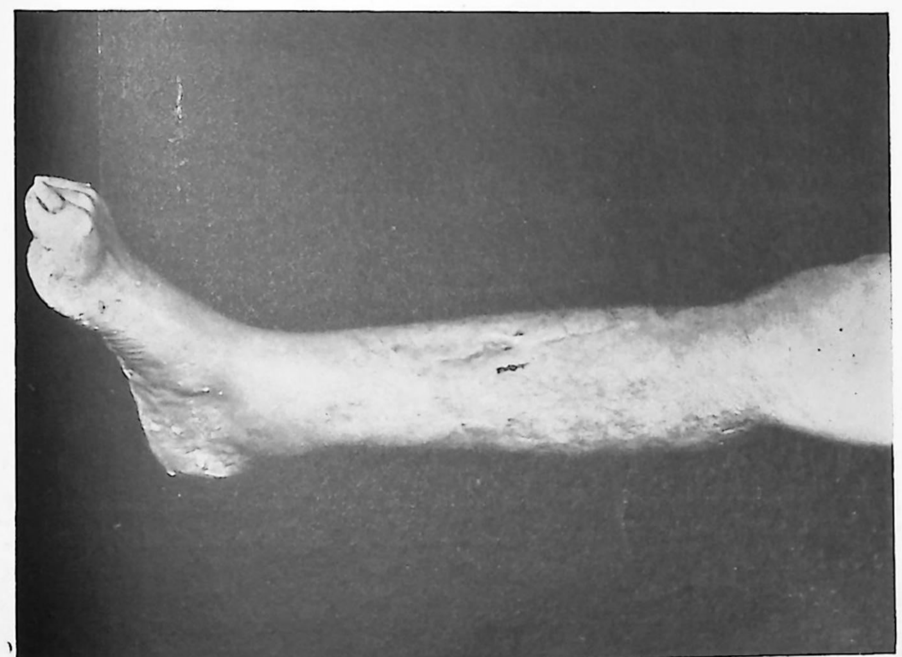


Fig. 113.—Same case at the removal of the last plaster. The fracture has consolidated slowly, owing to the removal of several detached fragments. Photograph taken nearly five months after injury.

which are liable to become inflamed. The lower the fracture (so long as it does not involve the ankle joint), the more covered with soft tissues are the fragments and the better the alignment of bone ends that can be obtained; overlap must be reduced by skeletal traction. The muscles and tendons assist in reducing fractures of the lower end of the tibia, but fractures of the middle third need to be fixed by permanent bony

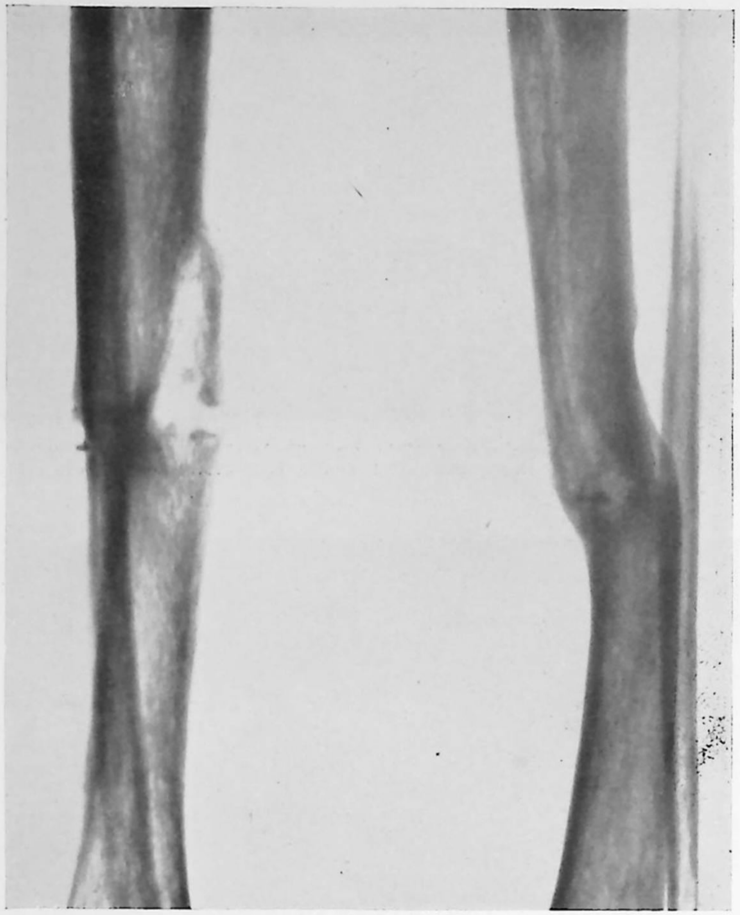


Fig. 114.—Radiographs showing callus formation filling the gaps caused by the removal of detached fragments.

transfixion, except when excision of soft tissues and fragments of bone has been exceptionally extensive. The general lines of the operation are as follows:

The operation is performed on an orthopedic table. When the patient is anesthetized, the whole leg is cleaned with soap and water and a nail brush, and the skin is further sterilized with an antiseptic. When possible a Kirschner wire should be inserted in the lower part of the tibia near the ankle joint, or in wounds near this joint through the calcaneus.

The stirrup is fixed to the traction device of the orthopedic table and the fracture is provisionally reduced by turning the traction screw. A second Kirschner wire is passed through the upper part of the tibia near the tubercle, care being taken to place it well into the bony tissue and not too near the anterior border of the tibia. This can be fixed to the pelvic support of the orthopedic table.

The field is isolated by sterile towels and the operation begins along the lines described in Chapter XVI (see p. 214). The fracture is completely reduced under direct vision, drainage is applied and the leg is encased in a plaster cast. As soon as the plaster is dry the patient is ready for removal from the table, but when there is no hurry it is preferable to wait a few minutes. When the plaster is completely set, the plates for fixation of the wires are placed in position, the stirrups are removed, and the ends of the wires are cut short. Not only is the actual wound now placed in the best conditions, but orthopedic success is also secured. After six to eight weeks, at the time of the change of the first dressing, the Kirschner wires are removed, an x-ray examination is made, and the wound is encased in a new plaster if this is necessary. Steinmann pins can also be used when Kirschner wires are not available.

The following case was treated on these lines:

About 2 A.M. on May 3, 1941, a pilot, aged 40 years, had a compound fracture of the right tibia and fibula with great contusion in the back of the leg. At 3 A.M. his wound was dressed and grain 1/3 of morphine injected. At 4:15 A.M. he was admitted to the Wingfield-Morris Orthopaedic Hospital. His general condition was fairly good. He had abrasions on his face and a compound fracture of the lower third of the right leg, with the upper fragment of the tibia protruding through a wound 6 in. × 2½ in. on the anterior aspect of the lower and middle thirds of the leg. There were large ecchymoses and abrasions in the calf. The circulation of the foot was good. At 6 A.M. the patient was operated on under gas, oxygen, and ether. The wound and leg were thoroughly cleansed with soap and water solution. Two pins were placed, one in the region of the tibial tubercle and the other through the calcaneus: the wound was too low for a pin to be inserted through the inferior epiphysis of the tibia. The leg was placed on a Böhler frame, the skin sterilized with antiseptic and the field isolated with towels. The wound was then explored by extending it by longitudinal incisions above and below the original opening. A narrow edge of the skin and a large portion of fascia were excised. Very extensive damage was found in the muscles, especially in the tibialis anticus, the tendon of which was completely severed, and in the medial part of the gastrocnemius. The bruised parts of these muscles were excised, the bony ends were cleaned; and some small portions of detached bone were removed. The fracture was now reduced by traction and some manipulation. The wound was powdered with sulfanilamide and plain gauze drainage was applied; the two ends were closed with stitches, the central portion being left completely open. A closed plaster was applied (see Fig. 115). Three thousand units of antitetanic serum were given during the anesthesia.

Postoperative radiography showed satisfactory reduction (see Fig. 116). The leg was placed on a Braun splint. On the following day the condition of the patient was completely satisfactory. He had a single

Fig. 115.—Compound comminuted fracture of tibia and fibula with extensive wound. No toxemia. Photograph taken four days after injury. (See also Fig. 116 to 120.)

Fig. 116.—Radiographs taken through the plaster.

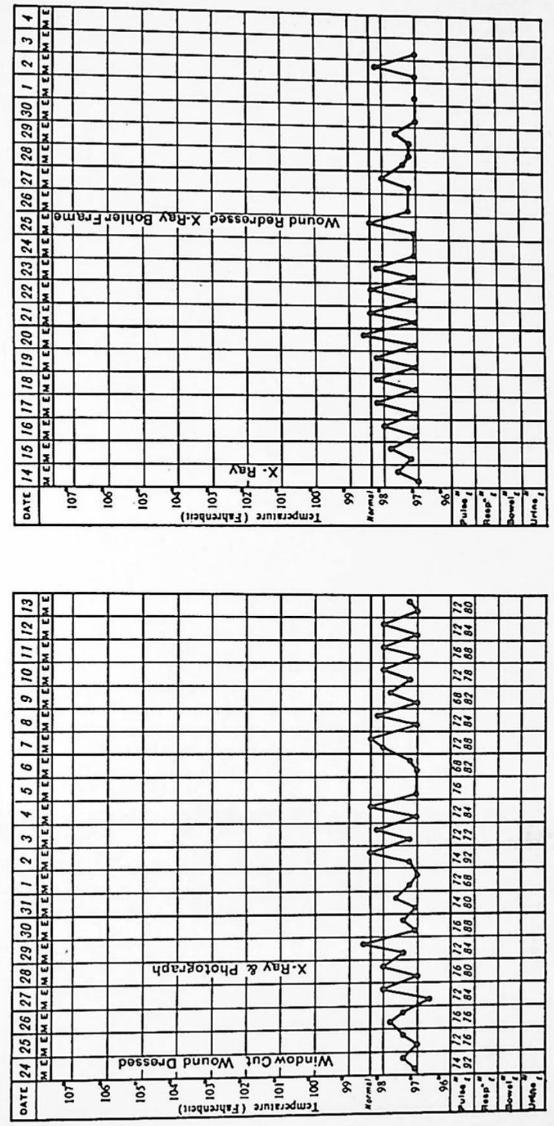


Fig. 117.—Temperature chart in the first six weeks, showing complete absence of fever.

injection of morphine on the evening of the first day after operation and since then had no pain. On the second day the plaster was stained with blood, and a glass window was applied to investigate the bacterial flora. Recovery was completely apyrexial (see Fig. 117), and two sedimentation rate tests, one on the fifth day and the other on the ninth, gave, respectively, 80 and 64 mm. in one hour. On June 25 a window was cut in the plaster and the gauze removed; healthy granulations then completely filled the wound (see Fig. 118). An x-ray film showed that the callus was not strong enough, and the window was therefore closed again with plaster. On July 11 the plaster was cut off, the pins were removed, and the wound was found to be smaller. A new plaster was applied and the patient walked on a Böhler iron. He was then discharged.

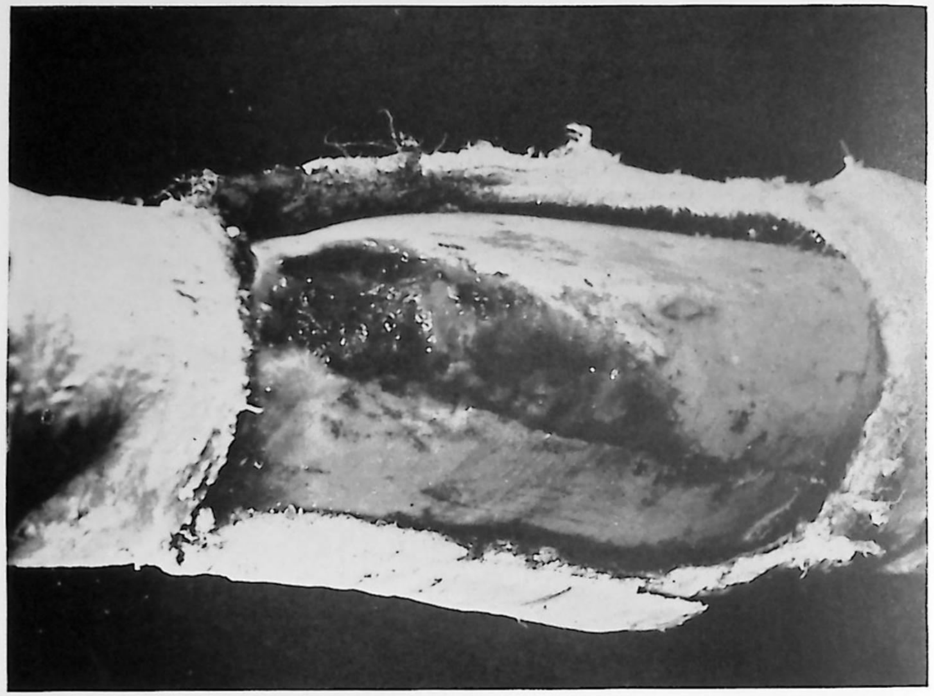


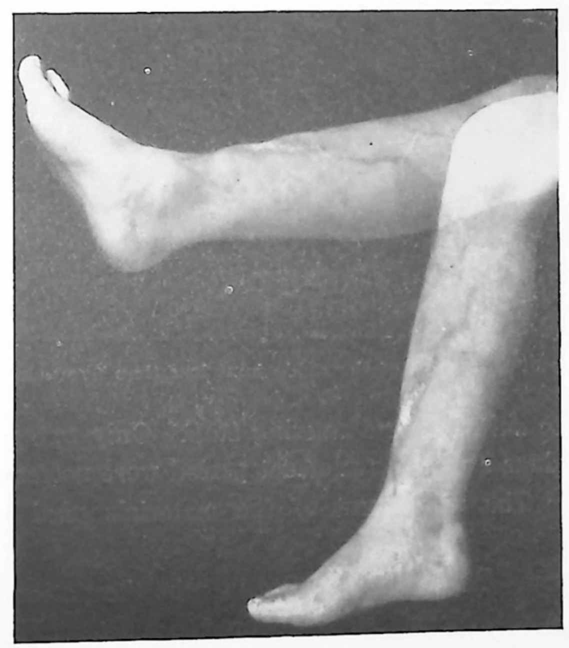
Fig. 118.—Wound reduced to less than half its original size, six weeks after the application of the first plaster.

On August 16 x-ray examination showed full consolidation in good position; the plaster was removed and the wound was found covered with epithelium. A compression bandage was applied and the patient discharged to a convalescent hospital for exercises and re-education of articular function. On September 27 he was again examined and found to have a good consolidation of the fracture without any shortening of the leg or other deformity (see Fig. 119). Movement of the knee joint was from 0° to 120° and still improving. Foot movements were full and the condition of the scar was satisfactory: it was narrow and not adherent (see Fig. 120). The patient was returned to his unit.

The bacterial flora of this case were as follows:

On the 5th day after operation: enterococcus.

A.



B.

Fig. 119.—*A*. Fractures completely consolidated. *B*. Photograph taken five months after injury, when the patient was walking about normally.

On the 45th day: *Staphylococcus aureus,* diphtheroids and enterococcus.

This is a case in which the value of the procedure could be tested, and serves as a demonstration of its merits. In spite of the seriousness of the lesion and the large damage to muscles, the patient was cured with a minimum of:

1. Pain and discomfort. Only a light injection of morphine was necessary.

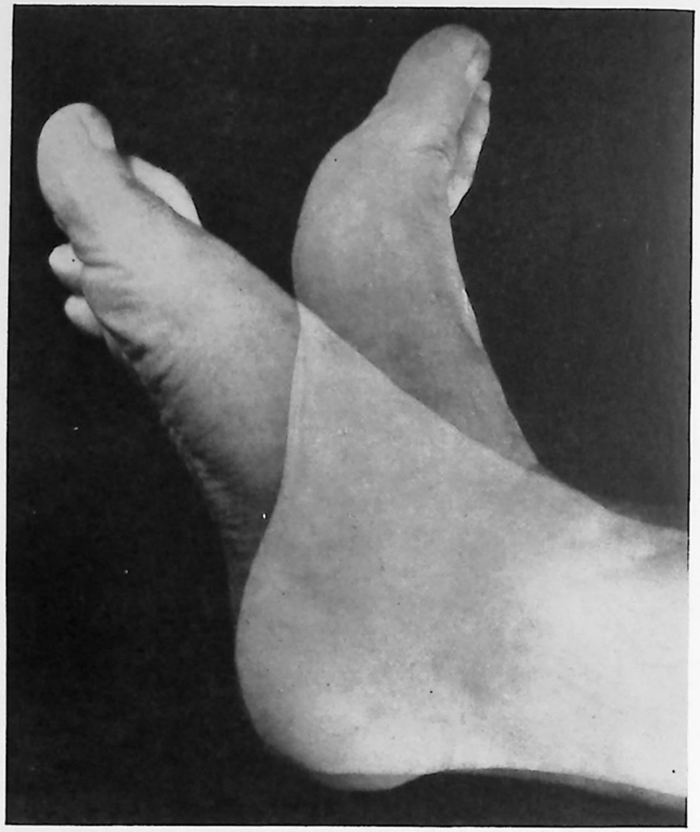


Fig. 120.—Range of movement of the ankle joint less than five months after injury.

2. Trouble to surgeons and nursing staff. Only two plasters and a protective bandage at the convalescent period were necessary.

3. Expense. The whole cost of the materials used ran to a few shillings.

4. Disablement. At the end of five months the patient had the full use of his leg, and the treatment gave him the functional integrity which is so essential to members of the fighting forces.

The following case shows the efficacy of the method in combating serious invasive infections (see also Figs. 121 to 123, illustrating a similar case):

On May 29, 1940, a gunner 24 years old was wounded by a shell fragment, sustaining a compound fracture of the lower third of the left tibia and fibula. The following day the wound was operated on and packed with flavine and paraffin, and the leg put in plaster. A radiograph after the operation showed good position of the fragments. He was

A. *B.*

Fig. 121.—*A.* Compound fracture of the shaft of the tibia and fibula and fracture of the lower epiphysis of both bones. There was a lacerated wound in the foot and the big toe was amputated. The injuries were caused in a plane crash. Amputation of the leg was considered.

B. Consolidation of the fractures shown in radiograph taken four months after injury. (See also Figs. 122 and 123.)

transferred to a new hospital two days afterwards, where the plaster was removed and a new plaster cast applied. He was then evacuated to another hospital, where he arrived on June 10 in fair general condition, with a normal pulse and temperature, and a new x-ray film showed good position of the fragments. On June 14, a fortnight after he was wounded, the leg was jarred and started to ache severely. On June 16 his temperature rose to 102° F. and he had considerable pain and enlargement of the inguinal glands, which were tender. On June 19 the plaster was bivalved and removed; some necrotic bone was excised and the wound was dressed with vaseline gauze and the leg replaced in plaster. Some improvement in the general condition followed, but the ankle was still very painful on movement of the leg. X-ray pictures showed fair position of the fragments but involvement of the ankle joint. On June 26 the plaster was removed under general anesthesia: there was a very considerable discharge of pus from the wound, and many metallic fragments came away with the packing. A collection of pus on the lateral aspect of the joint in front of the malleolus was incised and about 20 c.c. of blood-stained pus were evacuated. The wound was packed with vaseline gauze and a plaster applied.

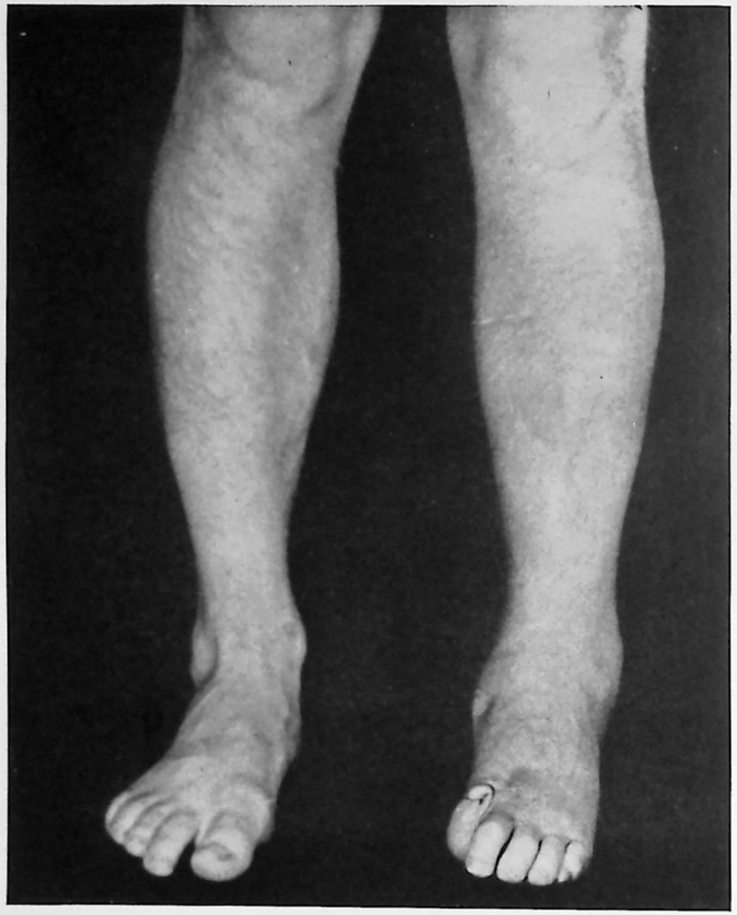


Fig. 122.—Good healing of the wounds. No shortening of the leg. Five degrees of inversion of the foot. The patient is back with his unit and flying again.

On June 28 the patient was transferred to the Wingfield-Morris Orthopaedic Hospital. Until July 5 he was comfortable with normal temperature, but on that day he started complaining of some pain in the ankle, and the nodes in the groin were enlarged and tender. On July 6, under general anesthesia, the plaster was removed, the wounds were reincised on both sides to establish better drainage, vaseline packs

were inserted, and a fresh plaster was applied. The patient's general condition again improved, but he still had some fever. On July 19 the part of the plaster that covered the dorsum of the foot was removed and an abscess in this region was incised. There were edema, redness of the skin, tenderness and discharge from the subcutaneous tissue. Owing to the cellulitis the wound was covered only with vaseline gauze dressings and was not replastered until this had subsided a fortnight afterwards. An examination of the pus showed a mixed growth of diphtheroids and *Proteus vulgaris*. Sulfapyridine was given by mouth for 4 days.

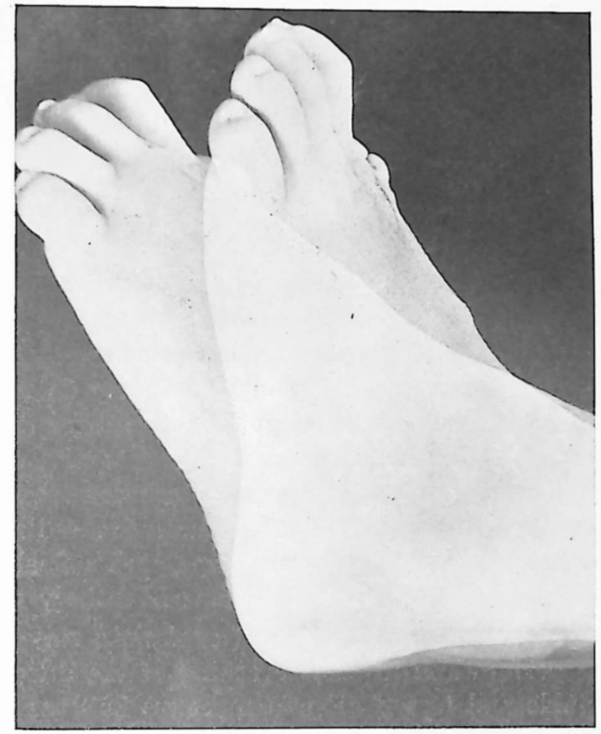


Fig. 123.—Range of movement of the ankle joint eight months after injury.

The course was now uneventful until November 11, when the patient felt cold and shivery and developed a temperature of 103° F.; a node in the groin was enlarged, but there was no pain in the wounds. Sulfapyridine was again administered, the leg elevated in a Braun splint and the condition was normal again in two days. On November 25 the patient started walking on a Böhler iron. On January 21, 1941, the plaster was removed, the discharge being dark brown and having a slight odor. No sinuses were evident, but there were a few small granulating areas. There was no edema. X-ray pictures showed good consolidation of the fracture and no sequestra. The next day an Unna plaster bandage was applied to the leg and ankle and he was transferred to a convalescent hospital. He was seen again on May 29, 1941, having in the interval been treated by massage and active movements. He was able to walk with one stick and had 5° of flexion and 5° of extension of the foot; he had no pain and no edema; and the position of the leg was functionally satisfactory. There was perfect movement of the knee and shortening of the leg was less than an inch.

The complications which arose in this case were in all probability due to the following mistakes:

1. Insufficient incision and excision, especially removal of devitalized bone and foreign bodies.
2. Insufficient drainage.
3. Premature removal of plaster when the patient was in good condition 48 hours after the operation.

In spite of all that the patient kept his leg; the late result is sufficient to justify the avoidance of amputation, which was for a time considered the easiest way to save his life.

FRACTURES OF THE ANKLE AND FOOT

Bullets fired at long range produce in the ankle or foot punctured wounds with tunneling of bone. Such simple traversing wounds often heal cleanly, but the talus and calcaneus react characteristically even to slight damage. Their structure is spongy and they do not, when the wound becomes infected, throw off large sequestra after the manner of long bones; instead a chronic inflammation persists with occasional attacks of flaring acute osteitis, and minute sequestra are discharged through a persistent troublesome sinus. Successive radiographs show only a progressive decalcification of the bone, and a final cure is frequently only effected when the diseased bone is entirely removed.

The lesions produced by bomb or shell explosions may vary widely, from irregular perforations to gross crushing of the articulations and bones of the ankle and tarsus. Septic processes in these regions have little tendency to spread, and signs of serious toxic absorption are seen only in infection of the ankle joint with fracture of the talus and large external wounds. It is more common to find moderate infection of the bones and joints, with the patient always on the verge of general illness and a temperature usually not above 100° F.

Treatment

Fractures caused by rifle bullets may be treated by immobilization in plaster applied directly to the wound with no preliminary surgery. Those produced by fragments of shell or bomb which remain embedded in the base of the wound usually require surgical operation: the foreign body must be extracted and some bone must be removed in order to leave the base of the wound wide open; a sharp spoon manipulated with care is a useful instrument in these cases.

When the destruction of the talus is more severe, and especially when most of the damage is centered in the head of this bone, the resection of a part of the affected bone gives a very satisfactory immediate result. In cases in which the degree of comminution of the bone is still more extensive, it is necessary to excise the whole talus, especially if the associated wounds of the soft tissues and tendons are serious.

In certain cases in which the bone damage is gross but the skin damage comparatively small, it is justifiable to begin conservative treatment with encasement in plaster after a preliminary surgical cleansing. The results are usually good, but when in doubt it is always better to remove the talus.

Since the calcaneus, like the talus, is a spongy bone, it reacts to infection in the same way, and suppurating sinuses are common in the calcaneal region many months after a perforating wound, even though no foreign body is embedded in it.

When a transverse tunnel in the calcaneus suppurates persistently and its track runs through the posterior part of the large tuberosity, it should be opened up and converted into a gutter.

The talus is most easily exposed through an incision on the outer side of the foot, but if the whole of this bone has to be removed it will be found useful to make an additional incision on the inner side, in order to divide the ligaments here attached to the bone. The calcaneus is likewise most easily approached through an external incision; it is important to preserve undamaged the insertion of the tendo achillis when operating on this bone.

The results of total removal of the talus are satisfactory both immediaately and from the point of view of the ultimate function of the foot. On the other hand, total excision of the calcaneus or even a large part of it leaves a foot of very poor functional value.

If there is a great destruction of all tissues in the ankle joint region, the foot cannot be saved and an amputation becomes inevitable. The site of the amputation is still largely a matter of personal preference (see Chapter XXIV).

Application of Plaster.—Whatever the operative treatment adopted, the encasing of the foot in plaster is a good supplementary measure; indeed, immobilization by a closed plaster cast, preceded by surgical treatment directed towards laying open the superficial tissues and draining the joints and tendon sheaths whenever doubt exists about the cleanliness of the wound, has made it possible to save extremities which have appeared at first sight to be doomed (see Fig. 124). The cast should run from the knee—and in some cases better still above the knee—to the foot and should be kept on as long as possible; an operation in proper time permits the maintenance of the plaster for more than six weeks, but in other cases it cannot be maintained for more than a month. Wounds in this region may be closed by primary suture where conditions are appropriate (see p. 285).

Suppuration of the tendon sheaths must be assumed if after the usual initial pyrexia there appears another phase of fever, accompanied by swelling of the toes, inguinal adenitis and pain. The cast must be removed at once and the infected region drained by means of a long incision. Adequate drainage followed by another immobilization in plaster will be sufficient to cure this complication, which is not really as serious as it at first seems.

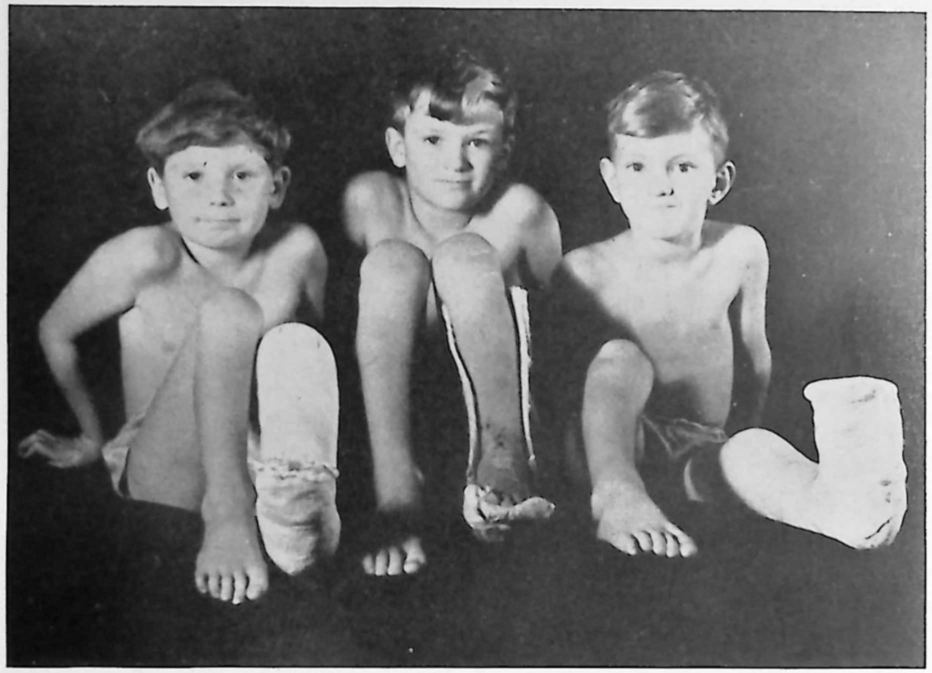


Fig. 124.—Three children treated at the same time at the Wingfield-Morris Orthopaedic Hospital. All had comparable severe injuries of the left leg and ankle joint. The photograph shows their lack of discomfort.

The following cases illustrate some of the problems in the treatment of wounds and fractures of the ankle and foot:

A boy 9 years old was knocked down by a motor bus about 4 P.M. on June 27, 1941, and admitted to the Wingfield-Morris Orthopaedic Hospital within 10 minutes of the accident. He looked very anxious. His pulse rate was 120 and his blood pressure 105/70. There was gross laceration of the anteromedial part of the left foot but no visible fracture (see Fig. 125).

He was treated by morphine, warmth and rest. There was comminution of the medial part of the head of the talus and scaphoid. At 5:30 P.M., under general ether anesthesia the wound was excised after cleaning with soap and water, sulfanilamide powder was sprayed on, and medial

Fig. 125.—Compound comminuted fracture of the ankle (scaphoid and talus) treated on the lines laid down in this book. Operation one and a half hours after injury. This is the child in the center of Fig. 124. (See also Figs. 126 to 128.)

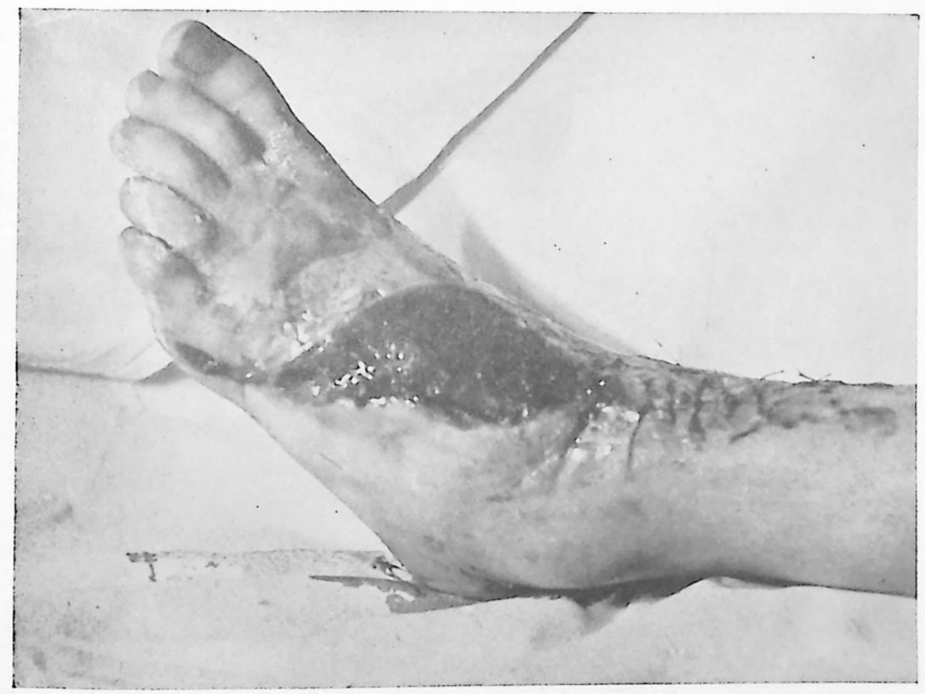


Fig. 126.—Same case as in Fig. 125. Wound at the first change of plaster twenty-five days after injury.

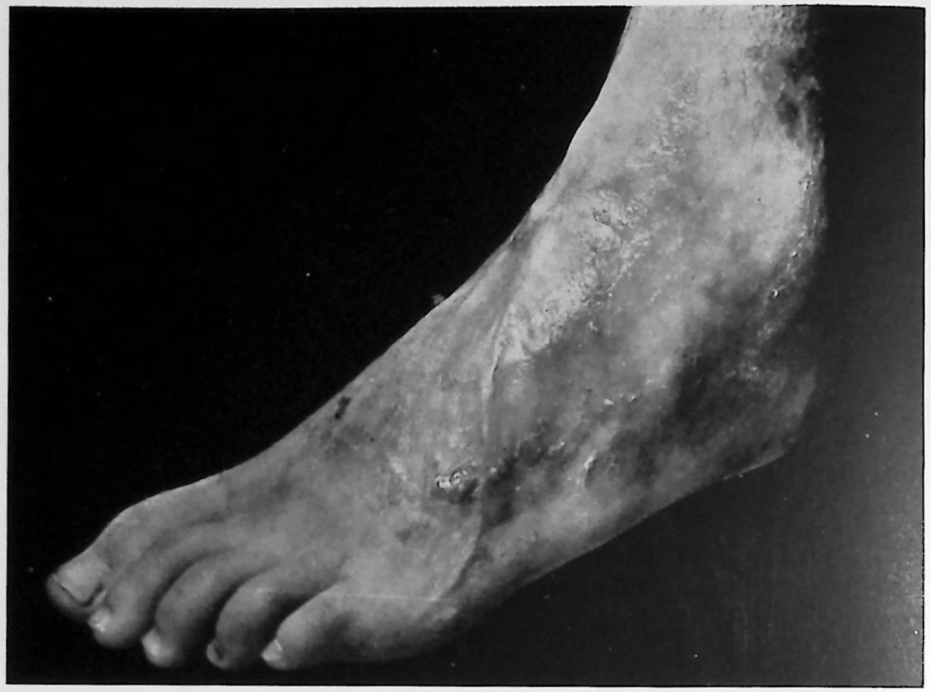


Fig. 127.—The wound completely healed and the fractures consolidated ten weeks after injury. Note the quality of the scar in spite of absence of skin graft.

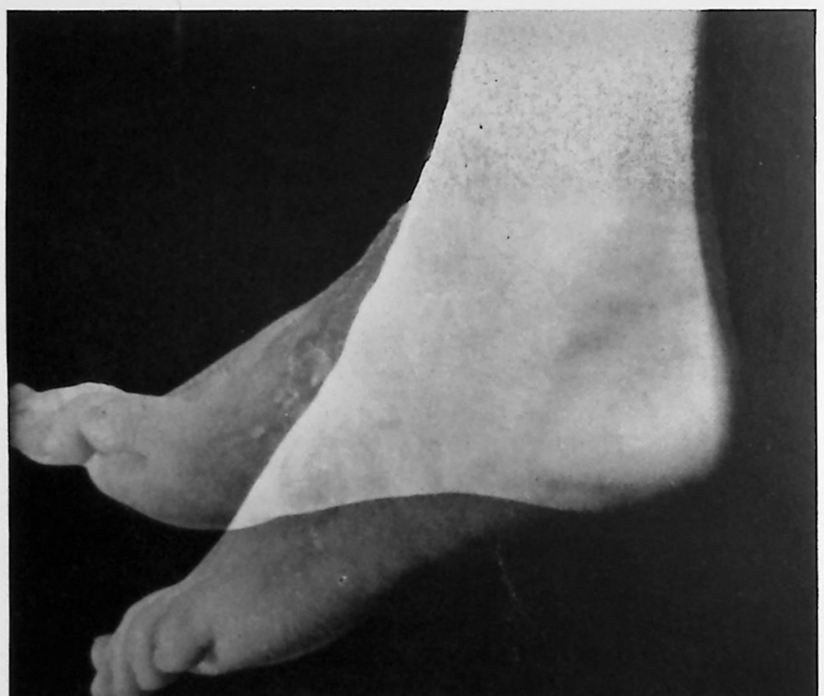


Fig. 128.—Range of movement of the ankle joint three months after the wound.

drainage was instituted with corrugated rubber and drained with plain gauze and plaster to above the knee joint. There was excessive skin laceration with apparent loss of skin from the medial malleolus to the anteromedial part of the dorsum of the upper third of the foot. The skin was avulsed from the deep fascia on the medial side of the foot as far down as the medial border of the plantar surface. The skin edges were excised and all bruised structures were removed. Excision of the medial plantar border of the foot was difficult owing to the bruising of muscles. Only the extreme ends of the skin wound were approximated. The wound was sprayed with sulfanilamide powder, two rubber drains were placed through stab wounds on the medial side of the foot and dry gauze in the rest of the wound, and plaster was applied from the toes to above the knee.

On June 28 the temperature rose to 101° F., and on July 3 some inguinal glands were enlarged. On July 21 the plaster was changed. The wound was granulating well and the tendons were all covered; the rubber drain was removed (see Fig. 126). The plaster was changed on Aug. 18, when the wound was nearly all covered with epithelium. Vaseline gauze and new plaster were applied. No more plaster was used after September 1, when treatment of a small nonepithelized area was continued by dressings of vaseline gauze and streptocide powder. By September 19 the epithelial covering was complete (see Fig. 127). Full movements of the ankle were regained by the beginning of October (see Fig. 128).

A boy 7 years old knocked down by a car on July 29, 1941, was admitted with a severe injury to his left foot. The skin and the wound were cleansed with soap and water and the wound was incised and excised. Gravel was found embedded in the cancellous bone of the lateral malleolus, the body of the talus and the anterior part of the calcaneus. The peroneal tendons were found divided. The extensor digitorum brevis muscle was found destroyed. The wound was powdered with sulfanilamide and a dry dressing and plaster were applied to the foot and the leg, including the knee (see Fig. 129). On August 10 the plaster was removed and the wound was found covered with granulations (see Fig. 130). There was no sepsis. A new plaster was put on, and a third on September 8, when the wound was also powdered with sulfanilamide. On October 5 the plaster was removed and the size of the wound was found appreciably reduced (see Fig. 131). After the granulations had been cleansed with soap and water and dusted with sulfanilamide powder for some days, grafts were placed in the wound. After five weeks more the wound was covered with epithelium. By December 12 the scar was strong and the boy walked with a marked reduction of the extension of the foot (see Fig. 132).

A sergeant gunner in the R.A.F., aged 19, was wounded in the left foot about 1 A.M. on June 13, 1941, while flying over Germany. He had considerable pain. Between 4 A.M. and 5 A.M. he landed at his aerodrome; and there the wound was dressed and he was given 3000 units of antitetanic serum. He was admitted to the Wingfield-Morris Orthopaedic Hospital at 6:15 A.M. in good general condition but with great pain in the left foot. He had an entry wound from about the base of the fifth metatarsal to the cuboid and an exit wound about the middle of the dorsum just distal to the midtarsal joints. An x-ray film showed shattering

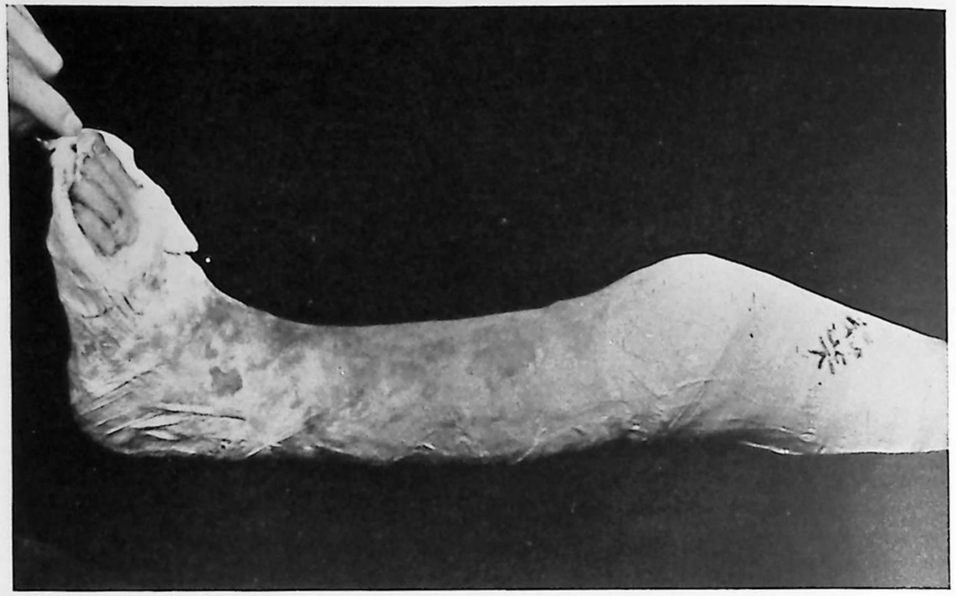


Fig. 129.—Extensive wound of the ankle joint. The plaster is stained with blood and discharge. (See also Figs. 130 to 132.)

Fig. 130.—The wound at the first change of plaster: when the drainage gauze was removed a new plain gauze and plaster were applied.

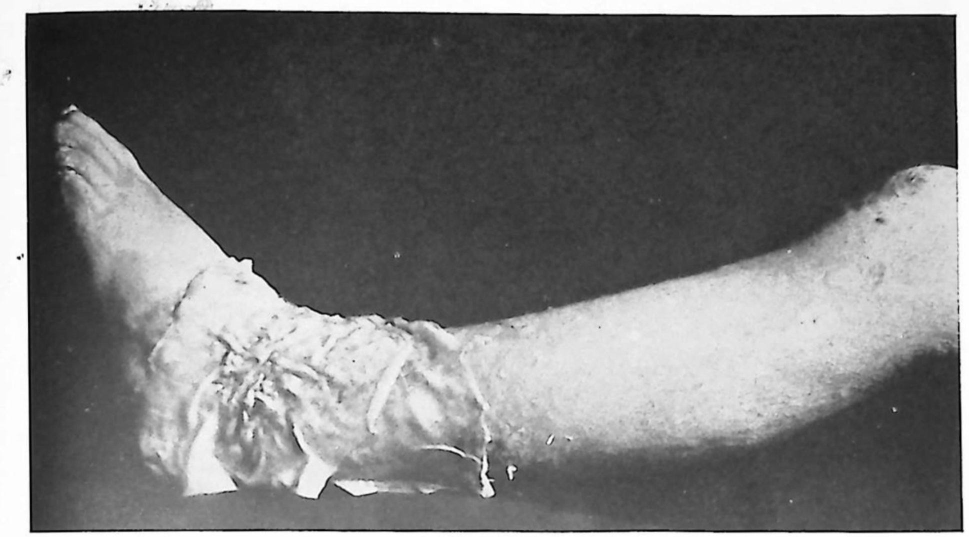


Fig. 131.—The wound covered by the appropriate type of plain gauze. At the removal of the second plaster the discharge has completely vanished.

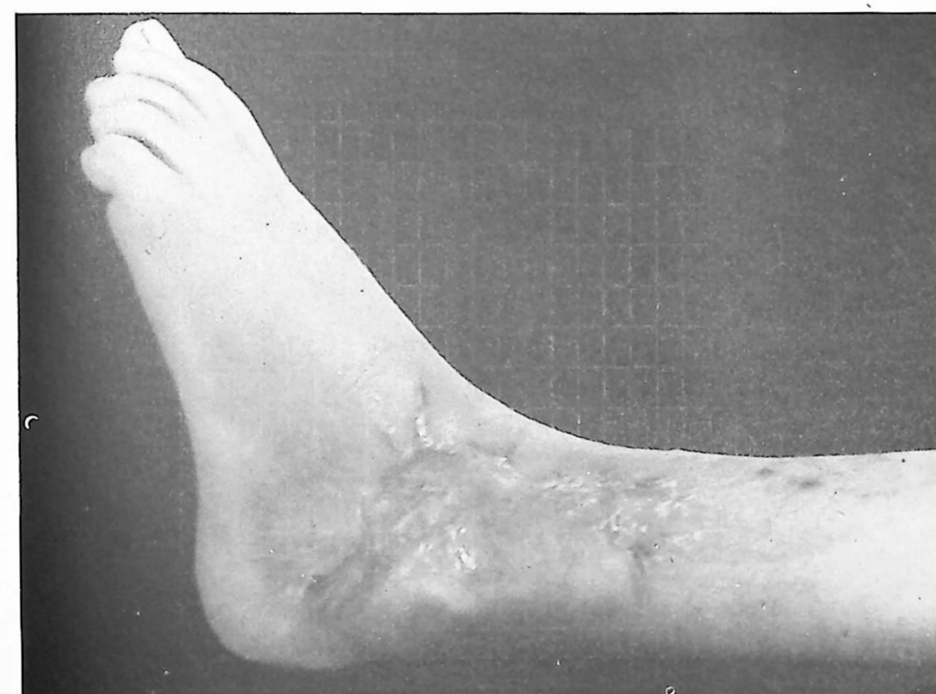


Fig. 132.—The wound is healed three months after the injury. Range of movement of the ankle joint was poor.

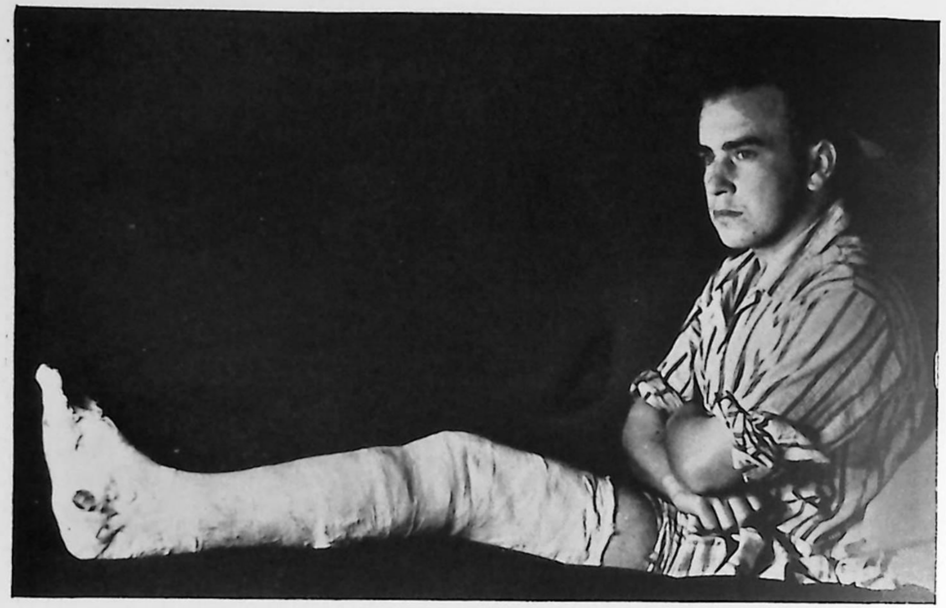


Fig. 133.—Compound comminuted gunshot fractures of the left foot. Treated on completely orthodox lines. Absence of toxemia and pain since the operation. (See also Figs. 134 to 139.)

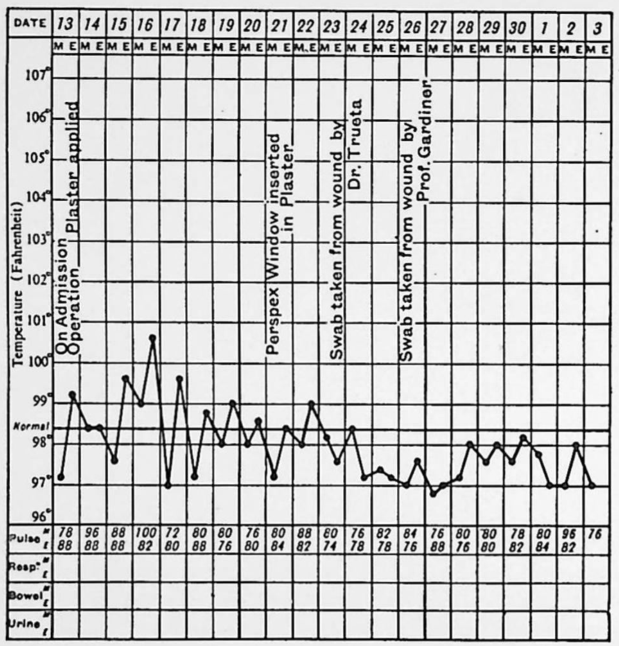


Fig. 134.—Same case as in Fig. 133. Temperature chart shows the reaction caused by the antitetanic injection. Otherwise complete absence of fever throughout the whole treatment.

of the outer two cuneiforms, the distal part of the cuboid and the proximal parts of the bases of the lateral four metatarsals. At 7:50 he was operated on under gas, oxygen, and ether. The skin and wound were cleansed with soap and water solution, the field was isolated and radical incision-excision of the wound was performed. The exit wound of the dorsum of the foot was treated first. The skin edges were excised. All necrotic tissues were removed, and the wound, being in a tendinous

Fig. 135.—The wound at the first change of plaster more than five weeks after injury. The wound is reduced to less than a fourth of its initial size.

region and placed in the upper part of the long tunnel through the bones, was closed completely by interrupted stitches at the end of the operation. The entry wound was explored, being widely enlarged after removal of all bruised tissues from the dorsal wound. A considerable amount of damaged tissue was removed from the abductor minimi digiti and then many pieces of loose bone, so that finally a tunnel was left connecting the two wounds, and this was quite free from any pieces of unattached bone. The wound was washed out with hot soap and water and sprayed with sulfanilamide powder. The upper wound was closed with some stitches. The upward and medial extension of the inferior wound was also closed loosely and then the remaining cavity was packed with gauze. The limb was placed in plaster and elevated on a Braun splint.

The next day the patient had slight pain in the foot but was comfortable. Within forty-eight hours of the production of the wound he was sitting up in bed and reading. Pain had now completely disappeared. The plaster was slightly soaked with blood (see Fig. 133). On

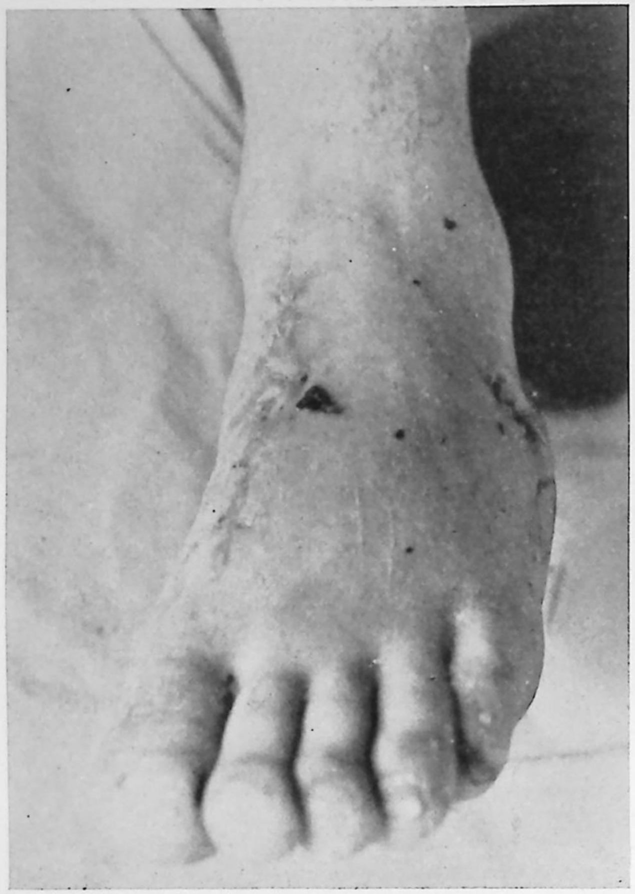


Fig. 136.—The upper wound is completely healed. Photograph taken when the first plaster was removed.

June 16 he had a rise of temperature to 100.6° F., slight enlargement of the right inguinal glands, and pain in the right buttock. Slight local reaction from the antitetanic serum was discovered. This inflammation disappeared in two days (see Fig. 134). On July 21 the plaster was changed. The wound on the medial side of the dorsum of the foot was completely healed, but on the lateral side there was moderate discharge. The skin was growing into the tunnel-shaped wound (see Fig. 135). On July 26, he was able to go on leave for three weeks. On August 28 the plaster was removed. The wound of the dorsal part of the foot showed

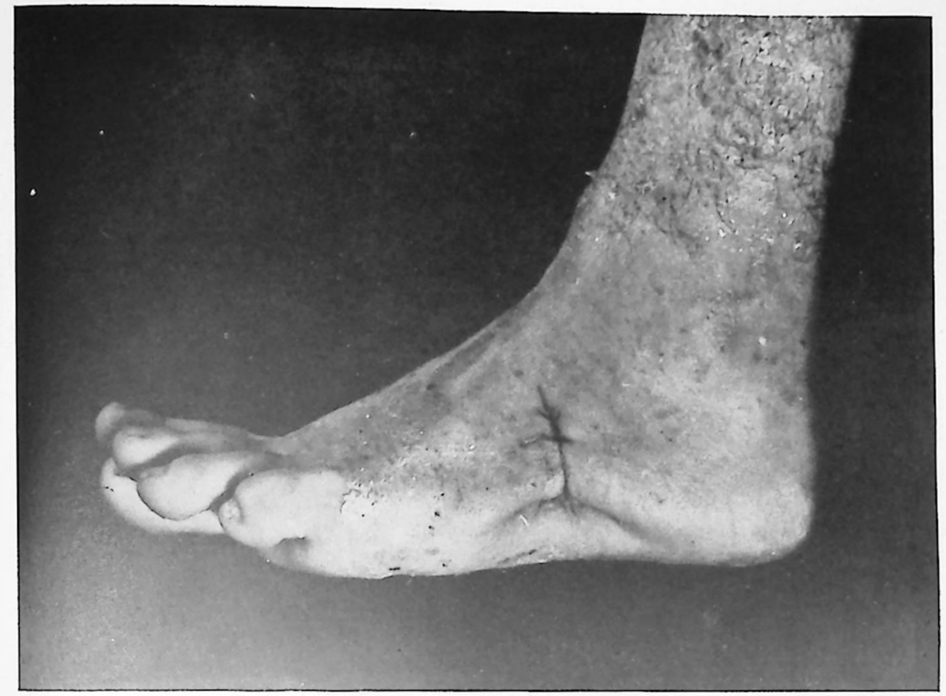


Fig. 137.—Photograph taken three months after injury.

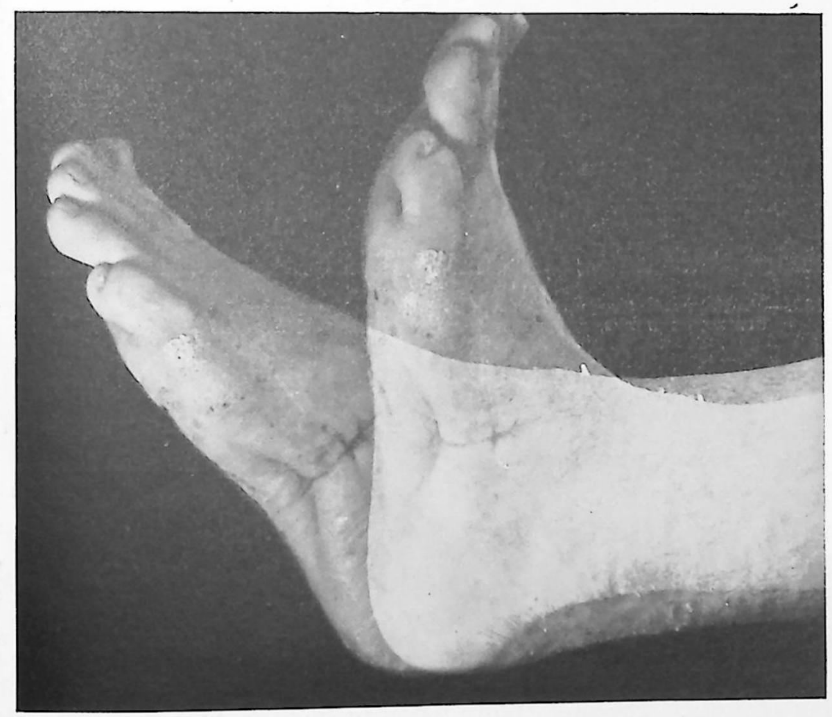


Fig. 138.—End result in the same case. Range of movement of the ankle joint three months after injury.

a very good scar, and the wound of the plantar side was healing well (see Fig. 136). Only a small area, less than half an inch, was not covered with epithelium. New plaster was applied for three weeks, and when this was removed the entry was found completely healed (see Fig. 137). An elastoplast bandage was applied for three weeks. On November 13 the wounds were found to be healed with good scars. The position of the foot was good, with no tendency to flatfoot, and ankle movements were full (see Fig. 138). X-ray pictures showed a callus organized in the place of the cuboid, and the ends of the metatarsals were normal (see Fig. 139). Only a narrow strip remained at the place of the first cuneiform. There was no sign of osteitis.

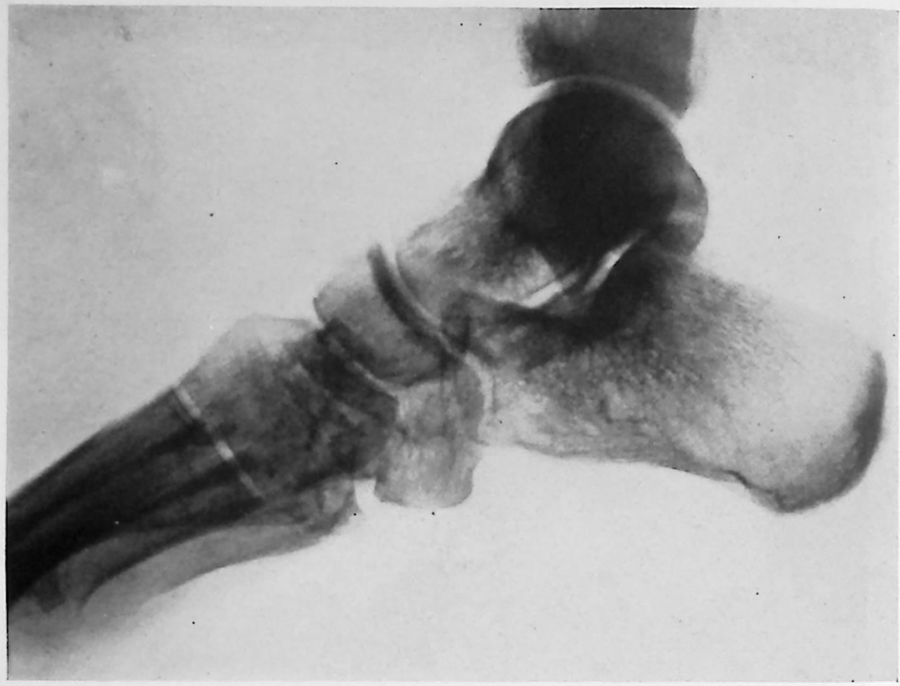


Fig. 139.—Radiograph five months after injury shows complete regeneration of the destroyed bones, in particular the cuboid. No signs of osteitis.

This is another case in which, except for the slight rise of temperature caused by the antitetanic serum, no trouble of any sort occurred. The functional result, in spite of the great alteration of the architecture of the foot caused by the anti-aircraft shrapnel, was as good as could be desired. There was no pain and discomfort for the patient, no trouble for the medical and nursing staff, no expense in the treatment, and a good functional result.

Refractory Cases.—Some cases, after the disappearance of the inflammation, improve very slowly, the suppuration sometimes never ceasing entirely. The underlying lesion in these cases is spongy osteitis, which, unlike osteitis of the long bones, does not produce large sequestra

whose extrusion or removal leaves behind a granulation surface. In chronic osteitis of the calcaneus or talus there is no possibility of the suppuration stopping after extrusion of a sequestrum. Indeed, cases which extrude visible sequestra are very rare; the bone is converted into a suppurating sponge and open sinuses persist for a long time.

The only hope in such cases, apart from performing extensive resections, is regularly to alternate the application of plaster with surgical treatment, keeping the cast on for several days and then curetting the bone with a spoon. The wound sometimes has to be scraped four times before it can be made to heal. In many cases, however, the only treatment is excision of the bone, with the inevitable functional consequences. The widespread use of Steinmann pins for traction through the calcaneus is one of the principal causes of osteitis, which may be very serious (see Fig. 42).

Fractures of the Fore Part of the Foot

With the exception of self-inflicted wounds, which show an exit wound on the sole of the foot, bullet wounds of the foot are very rare. On the other hand, wounds produced by bombs or shells are common and, as in all such lesions, the degree of injury varies widely, from the simple embedding of a foreign body to the avulsion of the entire foot.

Attempts to classify the various anatomical forms of wounds of the foot are of little if any value, and any predetermined scheme of work is rendered impossible because of their great diversity. It is important, however, in this region to apply the general principles of treatment with especial care, for in view of the great number of tissue planes, joints and tendon sheaths, any infection might have such grave results as to endanger the foot.

Surgical Treatment.—Surgical treatment consists in the removal of free pieces of bone, total excision of several tarsal and metatarsal bones, or amputation of the foot itself. When the extent of the wound and that of the fracture are compatible with saving the foot, and when neither extensive arterial lesions nor grave infections are present, a resection of the anterior tarsus or total tarsectomy may be performed.

CHAPTER XXVI

BURNS

With the large-scale bombing attacks on the civil population, and with the widespread use of petrol for the operation of aircraft, tanks and other military machines, burns are a very frequent injury of war today. Generally speaking, the type of injury produced in the bombing of towns and villages is largely determined by the nature of the buildings in the locality, since the kind of bomb used for any given area is chosen according to the general type and constructional materials of its buildings. This fact was very noticeable in the Spanish War. In their raids on the towns and villages of the Basque country, where the houses contained a high proportion of woodwork, the bombs used by the Germans and Italians were mostly incendiary, combined with a certain number of high explosive bombs of small and medium size (50 to 300 pounds). Guernika, Durango, Ochandiano and Eibar were all attacked in this way and the damage was largely caused by fire. On the other hand, in Catalonia, and particularly in Barcelona, where the buildings were constructed mainly of stone, steel, and concrete, incendiary bombs produced little effect and were entirely replaced after the first few raids by high explosive bombs, mostly of large size.

ETIOLOGY

The lesion of the tissues which is caused by excessive heat may be produced either by flames or by a heated fluid (a scald). In wartime today, however, the vast majority of burns are produced by flames, scalds being largely confined to accidents in ships. The greater seriousness of the flame burn makes treatment more difficult. Moreover, the large number of persons who may be burned at the same time, when a closely populated area, a factory or a ship is bombed, further increases the problem.

CLASSIFICATION OF BURNS

From the point of view of pathology, burns were classified by Dupuytren into six types, or degrees, according to the depth of the tissues involved. In the first three degrees the burn is confined to the skin, while burns of the fourth, fifth and sixth degrees involve the cellular subcutaneous tissue, the muscles, and the whole structure of the limb, respectively. More recently, however, British surgeons have adopted another system (already in use in Germany and America), according to which burns are divided into three types, or degrees. This classification

is undoubtedly more logical and more satisfactory from the clinical and therapeutic aspects. The difficulty of determining the exact degree of a recent burn is well known. Moreover, as will be seen presently, the treatment employed must be chosen in relation to other factors besides the depth of the burn. The problem of recognizing at an early stage the particular degree of a burn still remains.

1st Degree.—In this type of burn only the most superficial layer of the skin is damaged. The skin is reddened, slightly swollen, and painful. Dilatation of the capillaries produces an exudate. There is some inflammation, which leads to an increase of cells in the Malpighian layer, and in many cases the epidermis eventually becomes detached.

2nd Degree.—A burn of the second degree is characterized by blisters, which contain serum and may appear either at once or a few hours after the burn. The horny layer of the skin, the epidermis, is detached from the Malpighian or mucous layer, and the fluid which escapes from the capillaries is collected in the space between. The Malpighian layer itself usually remains intact, and, provided that no further damage is caused and no infection develops, a new epidermis will be formed in 8 to 10 days. When the blister has been broken or removed, the area is extremely painful, because the nerve endings in the Malpighian layer lie exposed.

3rd Degree.—These are the burns which form scars. This group includes all cases in which the inner layers of the skin are destroyed, as well as those cases in which the deeper tissues are also damaged. The destruction of the skin may vary from a charring of the epidermis, papillae, and sweat and sebaceous glands to the loss of the entire thickness of the skin. Where the Malpighian layer has been destroyed, considerable suppuration will be caused by the dead tissues, and this will lead to granulation and healing by the normal second intention process. If, on the other hand, the burn has only charred the epidermis and part of the papillae of the Malpighian layer, the elimination of dead tissue will be slight and a new epidermis will quickly be formed by what still remains of the Malpighian layer and of the cutaneous glands.

In an extensive burn the three degrees are often found combined, and it is almost impossible to determine the particular degree at any given point, especially in the first few hours.

For treatment I prefer to classify burns by yet another system, which is similar to that used for fractures. It divides burns into two groups, closed and open.

Closed Burns

This group includes all first degree burns and those of the second degree in which the blisters have not been broken. The horny layer of the skin, being still intact, prevents bacterial contamination and protects the cells of the Malpighian layer from possible further damage. The nerve endings are not exposed, and consequently the pain is not very severe or persistent.

Open Burns

An open burn is one in which the inner layers of the skin have been exposed and which, as Zeno (1938) pointed out, must therefore be considered as a wound. When the whole thickness of the skin has been charred and the nerve endings have been destroyed, the pain is less severe than when the superficial layer only has been burned and the nerve endings have been exposed. Once the dead tissues have been eliminated, a layer of granulation tissue forms, and if this is very profuse, the regeneration of the epidermis is a slow and difficult process. This is the type of burn which, if not properly treated, may lead to serious scar contraction.

FACTORS AFFECTING THE GRAVITY OF BURNS

It is commonly believed that the danger of a burn lies in the extent of its surface area rather than in its depth. A first degree burn involving more than half the total surface of the body is supposed to be necessarily fatal. This is not strictly true, for the gravity of the burn depends mainly on a combination of four different factors: its extent, its depth, the region of the body affected, and the treatment employed. These factors, combined with one or two others of lesser importance, such as the age of the patient, provide the basis for prognosis.

Shock

All seriously burned persons are faced with the risk of two different complications at two different stages. The first of these complications is that of primary shock, which in some cases is immediately followed by secondary shock. The shock which results from a burn is not of quite the same type as that found in wounded patients, for the burned patient tends to have a normal or even high rather than a low blood pressure much more persistently than in traumatic shock, together with a higher concentration of red corpuscles. As in traumatic shock, however, there is an extravasation of plasma, producing edema, and a diminution of blood volume. Extensive dehydration takes place throughout any area which has lost the protection of the horny layer of the skin. Glycogen is often given off by the liver, producing hyperglycemia and acidosis, or there may be an increase of chlorides in the burned area, leading to hypochloremia. Proteolysis occurs in the burned tissues and the blood will show an excess of nitrogen. A marked rise in the blood sedimentation rate is frequently observed.

After a few days the picture of shock may change, giving way to signs of the second possible complication. This is due to toxemia and is characterized by fever, dyspnea and collapse, followed in some cases by delirium and finally death. The new clinical picture is probably due to the absorption of proteolytic products and perhaps of bacterial toxins, which in their turn produce still further proteolysis. Necropsy of patients who have died as a result of burns has revealed the frequent presence of degenerative lesions in the liver and of acute nephritis, and to a lesser degree of intestinal ulcers, pneumonia, and cerebral thrombosis.

The order of frequency of the causes of death in burned patients is as follows: shock, toxemia (hepatitis, nephritis, intestinal ulcers), pneumonia, cerebral thrombosis.

COSMETIC AND FUNCTIONAL RECOVERY

As in the compound fracture, the surgeon's primary object is to save life. Immediately following this comes the urgent need to secure for the patient the best functional use of the affected region and a good esthetic recovery. The natural reparative process of the tissues is, in burns, seriously hampered by several factors, chief of which are the adhesions formed by the scar tissue with the deeper structures, the lack of elasticity in this tissue, and its tendency to a progressive contraction which gives rise to functional disturbances in such areas as the face, neck, axilla, and hands. The wide area involved in many serious burns, moreover, increases the risk of the development of secondary deformities. All these difficulties must be constantly borne in mind in the treatment of burns.

TREATMENT

I do not intend to give a detailed description of all the countless techniques that have been evolved for the treatment of burns. The very existence of so many different forms of treatment is a proof that the ideal method which can be adapted to any type of burn has not yet been discovered. The various recently used methods can, however, be grouped in four categories, each of which corresponds more or less to a certain period of time in which it was predominantly if not exclusively employed: (1) antiseptics; (2) emollients; (3) coagulants; and (4) the most recent development of all, saline baths.

Antiseptics.—Shortly after antiseptics had been adopted for the treatment of wounds, the technique was extended to treatment of burns, for which it is still employed today, although to a markedly lesser extent. The substance most commonly and persistently used was picric acid, which appears to have achieved only a limited success. In severe or extensive burns, moreover, the toxicity of the substance tended to produce lesions in the liver and kidneys. Some of the antiseptics in use today are also coagulant, for which reason I prefer to include them in that group. The treatment of burns by antiseptics is wholly illogical, since it does nothing to prevent shock or the development of deformities, and introduces a definitely harmful factor by its toxic effects.

Emollients.—Emollients were widely employed in the treatment of burns during the War of 1914 to 1918 and to a lesser degree they are still in use. This method was introduced as a reaction against the antiseptic technique and with the object of protecting the burned areas from irritation and friction caused by dressings and from further bacterial infection. The substances most frequently used were a liniment of calcium and olive oil, and ambrine, both of which produced improved results—particularly the ambrine for burns of the face; since, when the wax of which this substance is partly composed sets, there is no need to use bandages. With this method the contraction of the scar was less marked and the toxic effects of antiseptics were avoided; but like the antiseptics, it did nothing to prevent shock and infection.

Coagulants.—The idea of coagulating the dead tissues and so forming a thin film on the surface of the burn is an old one. Billroth (1871) used silver nitrate and recommended it in the following words: "Another plan of treatment is with a solution of nitrate of silver ten grains to the ounce of water; this is to be painted over the burned part, and compresses wet with the same to be kept constantly applied. At first the pain from the cauterization of the parts denuded of epidermis is occasionally very great, but a thin blackish-brown crust soon forms and the pain then ceases entirely. I recommend to you this plan of treatment when all three degrees of burn are combined."

This accurate description of the coagulant treatment was entirely forgotten until 1925, when Davidson published the principles and details of the tannic acid technique. Davidson was dealing with burns in the Ford factories in Detroit, and his aim was to find some form of treatment which would both impede the onset of shock and, as far as possible, prevent infection and deformities. The industrial process of tanning leather with tannic acid suggested to him the possibility that a similar procedure could be applied to burns. He started by using the same solution of tannic acid (at first 2.5 per cent, later 5 per cent), but to ensure complete coagulation of the burned area he found it necessary to apply the solution continuously over a period of several hours. This was a serious disadvantage, but not one which could be avoided by using a more highly concentrated solution, for the thicker the layer of coagulation the greater the destruction produced in the tissues. To overcome this difficulty Bettmann recommended 10 per cent silver

nitrate combined with 5 per cent tannic acid, and with this combination it was possible to obtain an adequate layer of coagulation in half an hour of continuous application.

A more recent development is the use of the triple dye (crystal violet 1 in 400, brilliant green 1 in 400, and acriflavine 1 in 1,000) first introduced by Aldrich in 1933. For this it has been claimed that it is more analgesic than tannic acid, more effective in promoting the resistance of the burned area to infection, and more likely to result in a soft scar without extensive contraction and deformity. Undoubtedly the mixture of dyes, as such or in combination with tannic acid and silver nitrate, is valuable in emergency treatment, particularly of patients who, for the full surgical treatment described below, would have to be transported far from the place of the accident; but for patients who can receive such treatment within the six-hour time lag I do not recommend it. It should be recalled that the danger of sepsis from the contaminated and devitalized tissues increases as time goes on, and accordingly that the application of triple dye (or any other coagulant) in the late stages is not only ineffective but, by limiting drainage, may even be dangerous.

To sum up: The coagulation technique has the advantage of preventing the loss of fluids from the burned area, a factor which may assist in the treatment of shock; the pain is also less severe, and in many cases infection is prevented. On the other hand, the layer of tanned tissues has no elasticity and often breaks away at the junction of the normal skin, so that an infection may be introduced. This is serious, owing to the difficulty referred to above of establishing adequate drainage beneath the coagulum.

I have treated more than 200 cases of burns in factory workers by this method, with results on the whole much better than those obtained by the earlier forms of treatment. Shock and toxemia were noticeably less, and serious infection, though it still occurred, was certainly less frequent. In a good many cases, however, the quality of the scar tissue was poor, and from the ultimate esthetic and functional points of view I thought that the method had no advantage over the use of ambrine.

Saline Baths.—The use of saline packs and baths is now regarded as an effective alternative to coagulation therapy. I cannot do better than quote the following account of its application by one of its chief exponents (McIndoe, 1940):

"Expert nursing is required and the most rigid attention to detail, but the results fully repay the time and labor expended.

"The hands are immersed into small baths containing normal saline at 98° F. The patient is encouraged to move the fingers and wrist joints in the saline solution; two or three baths of one hour each are given during the day. Following the baths the affected parts are gently and carefully covered with tulle gras and then sterile gauze soaked in normal saline is laid upon it, with no pressure, the latter being replaced every two hours without disturbing the underlying tulle gras. It is essential that dressings should not stick to the raw surface and on no account should wet dressings be left to dry and become adherent, as exquisite pain is caused on removal. The hands are then covered with a sterile towel, and supported on light wire splints. The position of the hands and wrists when at rest is important; the wrist should be slightly dorsiflexed and the fingers kept slightly flexed, especially at the metacarpophalangeal joints. The outer dressing, but not the tulle gras, is removed prior to the subsequent baths, the tulle gras floating off in the saline solution. In this way painful dressings are avoided. Although no antiseptic solution is added, sepsis, if it occurs, clears up rapidly within one or two weeks and healthy granulation tissue develops. In some cases epithelial debris separate and form thin white layers over underlying granulations or newly formed epithelium; the debris should be removed by gentle swabbing and occasional addition of soap (pure soap flakes) to the saline, or the hands may be given a thorough but gentle cleansing under a light gas and oxygen anesthetic. This debris appears to be a potent nidus for the development of organisms, and hence is better removed."

In cases of extensive mixed second and third degree burns general baths are provided. The bath is filled with thirty-two gallons of warm water to which is added sufficient salt to form a normal saline solution. The water runs into the bath at the rate of one gallon per minute by means of an automatic device emptying into the head end. A similar amount of water is allowed to run out from the bottom of the bath by means of a specially arranged plug. The temperature of the bath is controlled by a thermostat. The patient is kept in the bath for a half to one hour or longer and then returned to bed and placed on sterile towels under a heated tent.

As can be seen this is a very elaborate procedure which can be adopted only in specialized hospitals working under peacetime conditions. Some obvious limitations are the difficulty of sterilizing the baths and of attending with sufficient care to the large numbers of cases that may require simultaneous treatment in war. Failing the most careful handling of the patients the treatment is painful and secondary contamination of the burned area probable. Elimination of the sloughing debris is rapid, but in most cases from ten to twenty days must elapse before the raw surfaces are ready for skin grafting. The great advantage of the technique is the readiness with which the granulations are cleaned from the small remains of the debris once the great sloughs have been eliminated. It is thus one of the best available after the second or third week of the production of the burn.

Each method, therefore, has its merits, but each too has certain inherent disadvantages. I believe that a really effective method of treatment cannot be established unless we can eliminate all the dead tissue at the beginning. We should regard a burn as a wound and treat it as such. The technique which I now describe is based on this conception. It is not offered as a panacea and it still has some limitations, but it seems to me to make the best provision for the various requirements of burns and to obviate more effectively than other methods the risks which tend to accompany them.

PLASTER TREATMENT OF BURNS

Unfortunately, in the treatment of burns there is as yet no equivalent to the excision of damaged tissues from a wound, and it is therefore still necessary to rely on the natural elimination of dead tissue, with its inevitable risks. Hence plaster is less effective than in the treatment of wounds. Nevertheless, it has been used by Zeno (1938, 1939) in the Argentine and by Löhr (1939) in Germany in many hundreds of cases with satisfactory results. As in the treatment of wounds, the technique comprises several processes.

1. In early cases the first object is to remove the dirt from the skin round the burned area. The skin is cleansed with a 5 per cent solution of soap (preferably one with a sodium coconut or sodium ricinoleate base) or with 1 per cent C.T.A.B. detergent, in hot water. The burned area itself need not always be cleansed, especially if the burn is not more than four hours old. It must, however, be isolated, and handled very gently so that the blisters which remain intact should not be broken.

2. Intact blisters should be slightly incised in the most dependent part to allow serous fluid to drain off; broken blisters must be excised with scissors.

3. The whole area is then very thoroughly dried (a piece of sterile cotton material is best for this purpose) and a layer of gauze soaked in a 10 per cent solution of tannic acid is laid over the burn for fifteen minutes. At the end of this time a thin coagulum will have been formed over the whole area, being more a clot of the fluids than of the tissues. This "partial" tanning of the burned region suffices to prevent undue loss of fluids from those layers of the skin which have lost their epidermal protection, while at the same time it does not give rise to the constriction, or to the other difficulties associated with the formation of scar tissue, that commonly occur if the coagulum is thick and hard. The thin layer provides a useful protection against secondary infection; although, of

course, without the plaster-of-Paris cast, which is applied immediately after the tanning, it would not in itself be a sufficient covering for the burn.

In those parts of the body where plaster of Paris cannot be used, such as the face, abdomen, and genital and perineal regions, Bettmann's practice of using a combination of 5 per cent tannic acid and 10 per cent silver nitrate provides a stronger coagulum and obviates the need for dressings and bandages, which are always a source of pain and misery for the burned patient. In severe burns of the face, and particularly round the eyes and mouth, it is preferable to use ambrine or a liniment of equal parts of calcium and some vegetable oil (to which sulfanilamide or pencillin may be added); for in these areas the coagulation of the tissues tends to increase the depth of the damage and leads to secondary contractions which have subsequently to be corrected by plastic operation. In deep burns or in cases treated after four hours, it is better to avoid superficial tanning: instead the burned area is covered with bandage gauze soaked in vegetable oil with 10 per cent of calcium.

4. After the main tanning process a piece of gauze soaked in a 5 per cent solution of tannic acid is placed over the burned area and a plaster-of-Paris cast is applied. This cast must immobilize not only the nearest joint on either side of the burn, but also the whole of the next segment beyond the joint. This is a point of great importance, for any movement in this more distant region will tend to displace the skin at the site of the burn and lead to friction against the plaster and consequent ulceration. The limb must be immobilized in complete relaxation, i.e., the arm in 30° of abduction and the leg in 45° of flexion.

Position of the Fingers

The position of the fingers of a burned hand is of special importance. The classical deformity that follows a severe burn of the hand which has not received preventive treatment is only too well known—the first phalanges in complete extension, or even hyperextension, and the second and third phalanges in marked flexion. This deformity is due in the first place to a muscular spasm, which is followed later by a retraction of the muscles and, in some instances, of the scar tissues also. The importance of the muscles in this whole problem is not generally recognized. Many surgeons, for instance, advocate immediate exercise of the fingers as the best method of preventing deformity. I believe this to be a great mistake and even the actual cause of many deformed hands, for it is based on a false conception of the anatomical and functional causes of the deformity, which is attributed almost exclusively to retraction of the scar and to articular alterations (see Fig. 140). Apart from cases in which there is an initial lesion of the capsule, which inevitably involves

an injury to the extensor tendons also, articular stiffness and ankylosis are nearly always due to lack of muscular relaxation and edematous infiltration.

Fig. 140.—Crippled hand fixed in a position of spasm. Septic tenosynovitis of the fifth finger subsequently extending to the thumb. The hand was never immobilized in position of muscular relaxation. In spite of lack of participation of the flexors of the second, third, and fourth fingers in the septic process, and of any of the extensors, the permanent disability is similar to one produced by deep burns of the dorsum of the hand in patients who have not been properly immobilized.

To understand how muscular spasm and contraction produce this well-known deformity, we must look closely at the anatomical arrangement of the flexor and extensor muscles of the fingers and consider their relative strength. The strongest flexors of the fingers, the flexor sublimis and flexor profundus, bend the second and third phalanges respectively, while the flexion of the first phalanx is produced mainly by combined action of the interossei and lumbrical muscles, which are short and comparatively weak. The strongest extensor muscle, on the other hand, the long extensor communis, operates chiefly on the first phalanx, the second and third phalanges being extended mainly by another action of the interossei and lumbricals. Thus the powerful flexor and extensor muscles do not counterbalance each other, since they work on different segments of the fingers. On the contrary, the strong extensor and flexor muscles are each opposed by comparatively weak flexors and extensors. Consequently, a hand in which the muscles are activated continuously, as in spasm, inevitably shows a systematic deformity in the position of the fingers, with marked extension of the first phalanx and extreme flexion of the second and third phalanges.

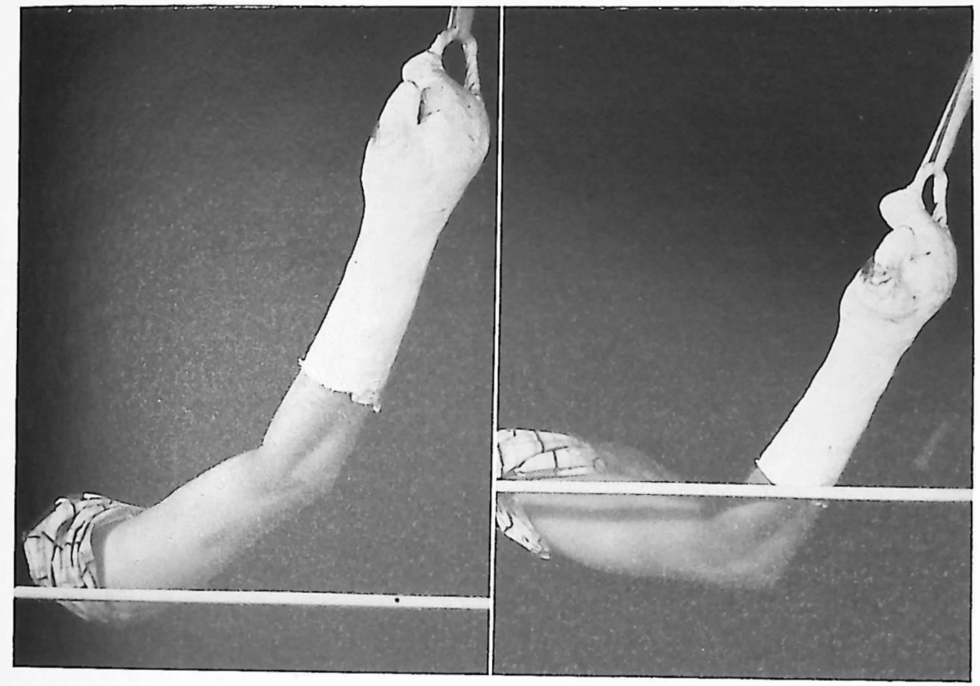
A. *B.*

Fig. 141.—Hyperextension of first phalanx in a hand burned at the dorsum. This hand was never immobilized in flexion. (Photographs by courtesy of Dr. J. Marquis Converse.)

If further proof were needed that the tragic "claw hand" is generally due to muscular spasm, it could be found in the absence of this deformity in cases where spasm has been prevented by immobilization of the muscles in relaxation, i.e., with the fingers in semiflexion and the wrist in slight dorsiflexion. After being completely immobilized in plaster in this position for three weeks, the fingers will regain full mobility a few minutes after removal of the plaster. When treated in this way the only hands likely to show deformity are those in which the burn has damaged the articulations, for in these the overlying extensor tendons have also inevitably been damaged. In these cases the joints have a tendency to

ankylosis, but the position of the fingers is quite different, and the complete rest afforded by immobilization encourages quick healing of the burn, prevents articular inflammation, and thus leads to a better ultimate functional result.

Last, but not least, immobilization of the hands and fingers in the correct position makes it possible, even in the worst cases, to secure a result in which, even if the joints are ankylosed, the position of the fingers is nevertheless of some functional use and never that of the "claw hand" due to muscular contraction. When the dorsal surface of the



A. *B.*

Fig. 142.—Burned hand immobilized with plaster of Paris. The elevated position of the hand is absolutely necessary to prevent swelling and thus compression by the plaster.

A. Patient lying in bed; note level of elbow.
B. Patient sitting up in bed; elbow is not below the shoulders.

hand has been severely burned, the damage caused to the tendons and the scar adhesions and retraction often results in reduced function and some deformity. If, however, such cases are properly treated and the hand is immobilized in a good position, hopeless deformity will very rarely be seen, and the disability will for the most part be confined to a limited power of flexion in the fingers, which can be substantially increased by massage and exercises. (See Fig. 141.)

Burns on the neck may also be treated by immobilization of the head, neck and upper part of the thorax, the plaster being carefully moulded over the jaw and neck, but some friction will still be present due to insufficient immobilization. In cases in which the burn involves the axilla or thorax, a thoracobrachial plaster should be applied. Plaster is less efficient in these areas than in the hands and legs.

5. Once the plaster has been applied, the next step is to provide a satisfactory position for the injured part in the patient's bed. The best position is one which will prevent edema of the extremity and thus facilitate the circulation, with all the advantages which this entails, e.g., improved bactericidal action and better healing. In general the affected limb should be kept raised and suspended by a handle (made of a plaster bandage) fixed at the most distal part of the plaster cast (see Fig. 142). If this precaution is not taken, any edema which may already be present will be increased by the compression of the plaster and will cause intense discomfort, making it necessary to remove the cast. When, however, the limb is kept raised, the transudation, already reduced by the compression, is further decreased by the fall in the hydrostatic pressure of the blood and less plasma passes through the capillary walls. Such fluid as does escape from the capillaries in spite of the elevated position of the limb is readily drained from the tissues by the lymphatic system, with the result that edema quickly disappears. Finally, by keeping the limb raised the amount of discharge is reduced, and, just as in the case of wounded limbs, the plaster can be retained for a longer period without smelling.

Duration of Treatment

In cases in which the first plaster has been applied before edema and infection have made their appearance, and in which the extremity has been kept raised from the beginning, the plaster can generally be retained for ten days. At the end of this period it is advisable to change the plaster, as in most cases it will now be too big for the limb and will no longer provide effective immobilization, with the result that the skin may be chafed and develop ulcers. This is particularly important in the hands, and, as soon as a patient finds he is able to move his fingers freely inside the plaster, a change of plaster is due. At this stage the patient is ready for a skin graft if this is needed. Otherwise the granulating area is covered with vaseline or with oil gauze of close mesh or with elastoplast. The second plaster, if needed, can be kept in position for ten to fifteen days, or if necessary for longer. The hands should not preferably be immobilized for longer than four weeks, but, apart from the most severe burns of the hand, there are few cases in which the burned area has not healed in a month (see Figs. 143 and 144). If at this time, in spite of the treatment, a raw area still remains, this should be dressed with elastoplast or, better still, grafted, and the hand and fingers placed on a palmar splint made of plaster. After five days the

splint and dressings should be removed each day for a short while and the fingers actively exercised to prevent stiffening of the joints. In many cases only a part of the hand or one finger will require immobilization at this stage, and this makes the re-acquisition of movement in the remaining part much easier.

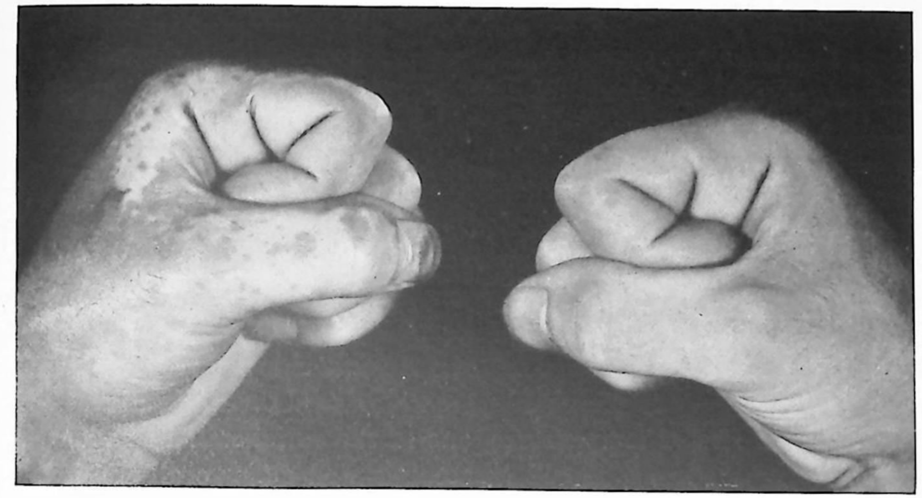


Fig. 143.—Burn of the left hand immobilized by plaster. Free flexion when the plaster was removed after twenty-one days of continuous immobilization in relaxation.

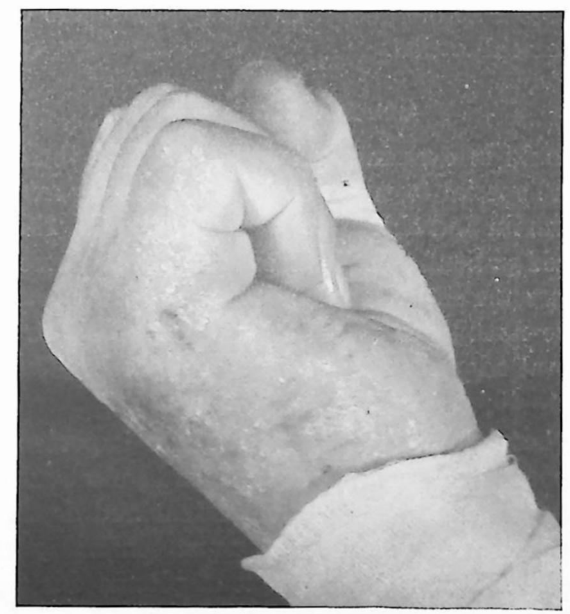


Fig. 144.—Range of flexion of a hand which suffered second and third degree burns, three days after removing the plaster which had immobilized the hand thirty-one days.

In severe burns, particularly those of the third degree affecting the dorsal part of the hand, the surgeon has to decide when the first plaster is changed whether or not a skin graft should be made, since by about this stage, i.e., 10 to 15 days after the burn, the slough will probably have been eliminated. In very extensive burns treated only by plaster, excepting those of the hands, the cast may with advantage be left in position for a further five or six days after epithelization is complete, thus allowing time for the newly formed surface to grow stronger. In some cases where there has been a copious discharge, a thorough cleansing with soap and water will be required. If a skin graft is applied it should be of the Thiersch-Ollier type.

Complications

The only complication is infection. When all proper precautions have been taken, this is rare and is due to one of two causes: inadequate protection of the affected area, or incomplete immobilization. I have already stressed the importance of immobilizing not only the adjacent joints on both sides of the burn but also the segments beyond these joints, in order to prevent friction. If, in spite of good immobilization, a patient shows a rise of temperature, one of the sulfonamide compounds, preferably sulfathiazole, should be administered either orally or by injection. If after this the temperature still persists, the plaster should be removed and applications of sulfanilamide made directly on the burn. Meanwhile a plaster splint placed on the opposite side of the limb will provide some immobilization.

General Treatment

The urine should be examined from the first day, the total output being recorded and special features, such as the density and the content of urea, sugar, albumin and chlorides, being observed. The general treatment of a burned patient must be based largely on these findings. For the first 24 hours the diet should be restricted to water, which is then replaced for the next three to six days by a milk diet. Acidosis may be treated by oral administration of sodium bicarbonate or intravenous injection of 20 to 40 c.c. of a 20 per cent solution.

Red-cell and hemoglobin estimations are also important (see p. 160). These factors, combined with temperature and pulse and the local characteristics of the burn (i.e., the region, extent and depth), provide the basis for prognosis, and the treatment must conform with the relative importance of these signs. Transfusion of plasma during the first few hours and intravenous injection of sodium chloride in the next day or two are of great value to patients suffering from shock. We must, however, be more careful in giving plasma to the burned than to the wounded patient, because from the first day the kidneys and liver are subjected to the heavy strain of eliminating the products from the burned area,

and the introduction of large amounts of proteins increases the risk of failure of these organs. The function of the liver may be stimulated by a daily injection of insulin, in a dose of 5 units if the patient's urine is sugar-free, and in a larger dose varying with the amount of sugar, if this is present. Transfusion of blood may be very useful in later stages for combating the anemia which develops in seriously burned patients who have been treated with large amounts of plasma. The amount of blood given depends on the hemoglobin content.

All persons suffering from burns are very sensitive to external temperature and need to be treated in a warm room, i.e., 70° to 75° F. The patient should be made to sit up in bed to help the pulmonary circulation, but burned hands must still be kept raised. Care should be taken to place the elbows above the level of the shoulders (see Fig. 142).

In some cases, and particularly where the face has been burned, secondary plastic treatment may be required to correct deformities.

Even the most careful technique will not always dispense with the need for plastic surgery, particularly round the corners of the eyes and mouth, which cannot be immobilized. Here secondary infections tend to develop, the granulation tissue is apt to be very prolific, and the scars are often contractile. Hence, in all serious burns of these areas, the help of the plastic surgeon is required.

If complications should develop, not in the burn itself, but as a consequence of it, such as pneumonia, acidosis or nephritis, the treatment must be regulated by the condition. Fortunately, with the plaster method these complications are seldom seen. Nephritis, in particular, rarely occurs, a fact which I believe to be due to the diminution in the absorption of toxic products through the lymphatics which results from immobilization in plaster.

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