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# REPARATIVE SURGERY OF COMPOUND BATTLE FRACTURES IN THE MEDITERRANEAN THEATER OF OPERATIONS

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EXTREMITY SURGERY of the war wounded is divided into three phases[1]:

1. *Initial:* The primary excisional surgery performed in Army Field and Evacuation Hospitals as soon after wounding as possible (usually 8–24 hours) directed at the saving of life and limb and the prevention of infection.

2. *Reparative:* Performed in fixed hospitals at the Base directed at wound healing, anatomic and functional restoration of the extremity and rehabilitation or safe transport to the Zone of Interior in a lag-period of treatment after all that is necessary in the overseas Theater to minimize permanent disability has been achieved.

3. *Reconstructive:* Performed in the hospitals of the Zone of Interior directed at correction of residual defects and deformities resulting from the war wound.

Reparative surgery is largely dependent upon adequate initial surgery,[2] including bold incision, excision of dead and devitalized tissue, good drainage of the wound depths and dead space, an occlusive dressing, and adequate immobilization. It is facilitated by a short line of evacuation which permits transferring of the patient within a few days after wounding to a Base Hospital that is functioning close behind the combat zone. When these conditions are ideally fulfilled, surgical repair of open wounds is a logical and successful procedure in wound management. If the initial surgery has been inadequate, additional excisional surgery anticipating staged repair is usually necessary to prevent or cut short wound sepsis. Successful reparative surgery may make reconstructive surgery unnecessary or may return the patient to the Zone of Interior in a condition that will permit earlier and complete reconstructive surgery with enhanced chances of success.

## CONCEPT OF REPARATIVE SURGERY

Since the early days of this Theater in North Africa, repeated observation has established that wounds with obviously retained devitalized tissue became septic and drained pus profusely. Large hematomata in undrained dead space often decomposed into pus. Systemic or local chemotherapy, or their combination, did not prevent wound sepsis in the presence of dead tissue. Once wound sepsis had developed, there was continuing local

necrosis of living tissue and a vicious circle was established. Large granulating areas exuding plasma were observed to develop and harbor surface infection. These septic wounds, however, seldom manifested the cardinal signs of inflammation. Conversely, wounds which were free of devitalized tissue on their admission to Base Hospitals were clean grossly and free of sepsis. As healing by granulation occurred, many developed surface infection.

Following these observations, reparative surgery began with the successful secondary closure of clinically clean soft-part wounds, even though cultures taken preoperatively demonstrated the presence of an aerobic and anerobic bacterial flora.[1, 3, 4, 5] A wound free of devitalized tissue sutured at its primary dressing, four or five days after initial surgery, without dead space, hematoma in the depths, or excessive tension, and supported by a good pressure dressing and adequate splinting healed regardless of the bacterial flora. Successful suture depended upon a proper clinical appraisal of the wound, atraumatic technic, and surgical limitations imposed by the character of the defect. The clinical observations supported by the bacteriologic studies of Lyons and Rustigian[3] on war wounds which demonstrated that clean wounds and wounds with established sepsis may have comparable bacterial flora, have led to the following concept:

Wound sepsis becomes established as a result of the septic decomposition of devitalized tissue, including hematoma in dead space, rather than from the action of bacteria on living tissue. The devitalized tissue serves as a pabulum[3] for wound pathogens. If the pabulum is not present and is not created by surgery, and if living tissue is protected from invasive infection by an effective antibacterial agent, the bacterial flora of an open wound may be disregarded, wound sepsis need not be feared, and any indicated reparative procedure may be performed under established surgical principles with the anticipation of good wound healing.

Battle-incurred compound fractures demand special considerations when compared with those resulting from traffic and other accidents. Battle fractures are always compounded from "without-in" by missiles which have passed through clothing, often soaked with the grime and mud of the battlefield. The great majority are caused by high explosive shell fragments resulting in extensive muscle and bone damage. Clothing, wood, metallic foreign bodies, cement and mud are frequently buried in the depths of the wound far removed from their point of entry. In spite of excellent field service in this Theater for evacuation of the wounded from the battlefield to a hospital equipped for surgery, the time-interval between wounding and initial surgery usually exceeds 12 and often 24 hours. Accordingly, the wounds are not merely contaminated but are heavily infected with bacteria. The fractures are usually severely comminuted, often with bone loss. These injuries require long incisions, often multiple, for adequate exposure of the devitalized tissue and foreign material and to permit adequate excisional surgery. The large, often irregular, or multiple wounds made by surgeon

and missile must remain unsutured following initial surgery. They, together with muscle and bone loss incident to the injury and the surgery, present a picture and a problem peculiar to military surgery.

Reparative surgery recognizes that complete excision of the devitalized tissue in compound battle fractures is usually impossible or impracticable. At initial surgery, completely detached bone fragments are deemed to be avascular tissue and potential sequestra and, therefore, they are removed together with the devitalized soft tissue. Fragments with complete or partial periosteal attachment are preserved projected towards union of the fracture. Muscle, fascia, tendon, and periosteum attached to the fragments and the denuded cortex of bone constitute questionable devitalized tissue which probably remains in every fracture. Blood clot may form in an undrained area particularly in the dead space of the unreduced fracture or the defect created by the necessary muscle excision. The wounds of these injuries which have had adequate initial surgery have been observed in many instances to be draining profusely on admission to the Base Hospital. Unless wound sepsis became established, the profuse drainage ceased after several days. The discharge has been attributed to the spontaneous sequestration of the residuum of devitalized tissue and has been termed "the products of injury necrosis."[16] However, it is recognized that the residual devitalized soft tissue, partially denuded fragments, or dead space with a contaminated blood clot may be a nidus of infection with wound pathogens,[3] leading to abscess formation with continuing necrosis of living tissue within the wound. These are some of the factors that create specialized problems in the reparative management of compound fractures.

Every method of treating compound fractures seeks to obtain bony union with minimum deformity, a healed wound and maximum function of the extremity. During the year 1943 and early 1944, in the North African Theater of Operations, compound battle fractures were treated by a modified Orr method,[6] consisting of an open wound, infrequent occlusive dressings and traction or plaster immobilization. Wound healing by granulation and the resultant scar formation were accepted as necessary undesirables. In certain instances poor fracture results, malunions, or inevitable nonunions were accepted rather than risk "a stirring-up" of the wound by an open reduction. Wound sepsis with continuing local necrosis of living tissues became established in many cases, particularly in the exposed fracture sites of subcutaneous bones. Wounds with gross retained dead tissue were often managed by a "hands-off" policy which anticipated the spontaneous sequestration of the dead tissue rather than a delayed surgical excision. The unreduced fracture which called for repeated manipulations or adjustments of position in traction was particularly vulnerable to sepsis. A proper appraisal of the problem demonstrated the need for improvement which could be achieved only by a changing approach.

With a background of a year's experience, study and observation in the Theater of Operations, reparative surgery of compound fractures was

visualized and partially planned during the late months of 1943. Following in the wake of successful reparative management of soft-part wounds, it was initiated during the first quarter of 1944, catalyzed by the availability of penicillin therapy.* During the memorable days of Cassino and Anzio, it developed into a plan of management based upon continuing pooled experiences of the Theater surgeons.

In this Theater certain previously planned favorable operations factors obtained:

1. Experienced Forward Hospitals with standardized principles of excisional surgery and transportation splinting.
2. Short chain of evacuation, ambulance and train (Cassino), and air evacuation (Anzio) from Forward to Base Hospital predisposing to safe early transfer of the wounded.
3. Experienced Base Hospitals functioning close behind the combat zone.
4. A bed status in the Base that permitted the patients to be held for reparative surgery and rehabilitation or transfer to the Zone of Interior.
5. An Army blood bank supplying low titer-o blood to and augmenting that drawn in Forward Hospitals and unit banks in each Base Hospital supplying type specific blood.

Such was the prologue for reparative surgery of compound fractures at the "Fall of Rome."

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The reparative surgical program for compound fractures has as its objectives: 1. Minimum wound sepsis. 2. Improved fracture reduction and stabilization. 3. More rapid wound healing, with minimum scar formation. 4. Maximum functional restoration of the extremity.

These objectives are approached by a plan of management based upon: (a) Blood replacement. (b) Chemotherapy. (c) Surgery. Good surgery is the keystone of the program, with blood replacement and chemotherapy as adjuncts.

### BLOOD REPLACEMENT

In spite of what is considered to be an adequate use of blood replacement therapy in the forward area to combat shock, traumatic and operative, patients with compound fractures of the long bones have consistently shown anemia on admission to the Base. Tables I and II show the hematocrit readings obtained in two groups of battle casualties on admission to Orthopedic Sections of two General Hospitals. The tables are separated to allow column 4 of Table I to be presented as evidence of the blood loss sustained by a patient with a battle-incurred fracture of the femur. It will be noted that 50 per cent of this group had hematocrits under 30.

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* The counsel and active participation of Major Champ Lyons, M.C., of the staff of Surgical Consultant, M.A.T.O.U.S.A., was invaluable in the development of the program.

TABLE I(7)

| Hematocrit | No. Cases | Percentage | No. Cases of F.C.C. Femur |
|---|---|---|---|
| Under 30 | 33 | 24% | 19 |
| 31–35 | 24 | 17% | 9 |
| 36–40 | 56 | 40% | 8 |
| Over 40 | 25 | 18% | 2 |
| | 138 | 100% | 38 |

TABLE II(8)

| Hematocrit | No. Cases | Percentage |
|---|---|---|
| Under 30 | 37 | 22% |
| 30–36 | 44 | 26% |
| 37–42 | 54 | 32% |
| Over 42 | 31 | 19% |
| | 166 | 100% |

In order to correct the secondary anemia, type-specific cross-matched whole blood is given preoperatively in an effort to obtain an hematocrit reading of 40, or better, in all compound fractures on which any major reparative procedure is contemplated. Preoperative blood requirements are calculated on the basis of 500 cc. for each three to four points deficit of the hematocrit. There is no proof that this therapy is necessary but it is accepted *a priori* that the wounded man with an hematocrit of 40 is in better condition to withstand a long anesthesia and operative procedure than if his anemia is uncorrected. Additional blood to compensate for operative loss is frequently given during the operation and postoperatively if anemia is reëstablished. Repeated observations by many surgeons that the patients tolerated well and "looked good" after the surgery is sufficient to justify this use of blood replacement therapy. It has not been possible to compile confirmatory evidence, but blood therapy is believed to aid in the prevention of chronic sepsis, and in wound healing.

### CHEMOTHERAPY

Penicillin has been accepted as the most powerful available antibacterial agent to which the bacterial flora, aerobe and anerobe, of war wounds have been proven sensitive. It is recognized that penicillin will protect *living* tissue against invasive infection but it is also recognized that penicillin will not sterilize dead, devitalized or avascular tissue which, inadvisably or of necessity, remains in the wound, nor will it prevent the septic decomposition of a contaminated blood clot which collects in unobliterated or undrained dead space or neutralize locally necrotizing enzymes in undrained pus.[9, 10] Therefore, penicillin is used for the protection of the living tissue from the invasive action of bacteria accepted as present in the residuum of devitalized tissue remaining in compound fractures. The agent will not sterilize that residuum, therefore, surgical measures are necessary for its management. Therapy is continued until wound surgery has been completed, wound healing has been sufficiently obtained and the residuum of devitalized tissue has sequestrated and drained off or has absorbed. Penicillin therapy is used to provide an increased margin of safety in the performance of the indicated surgery.

Penicillin is used routinely and no advantage can be seen in attempting the surgery without it. While there is no proof that it is a necessity, and

although successful reparative procedures on compound fractures without it have been reported, there are two cases on record in which gas gangrene and death followed reparative operations upon compound fractures without the use of the agent. No deaths or serious untoward results from sepsis have been reported in similar cases receiving penicillin therapy as an adjunct to the surgery.

Systemic administration of penicillin, 25,000 units intramuscularly every three hours is the basic therapy. Local instillation into joints, 1,000 units per cc. is supplemental. Otherwise no local therapy is used in extremity surgery.

Patients with compound fractures as a rule are receiving penicillin therapy in the Evacuation or Field Hospital when they are transferred to the Base. Therapy is reinstituted on admission to the Base Hospital and continued until five to ten days after the last traumatizing surgery (which may produce more devitalized tissue) until as outlined above, the wound has sufficiently healed and contaminated devitalized tissue is no longer in evidence.

## SURGERY

The surgery is aggressive rather than passive. Wounds are explored to insure the adequacy of the initial surgery, fractures may be fixed internally and soft-part wounds may be sutured. But the success of the program depends upon the quality of surgical judgment and technic. Every case requires a decision as to the anesthetic; the extent of further excisional surgery; whether to use some form of internal fixation; the extent of closure of the compounding wound possibly aided by relaxing incisions or flaps; whether, where and how to drain; and the postoperative method of obtaining or maintaining reduction.

Five to ten days will have elapsed since initial surgery before the patient with a compound fracture is ready for reparative surgery. With adequate blood replacement, continuing penicillin therapy and good roentgenograms made in the Base Hospital, he is anesthetized in an operating room prepared for any indicated surgery, be it *excisional* or *reparative*. There, the Evacuation Hospital encasement and dressing are removed, the extremity prepared and draped and the wound inspected. A pneumatic tourniquet is frequently used not only to provide a "dry" operative field but to minimize blood loss on the table.

*Wound Revision:* The entire wound including the fracture site is exposed by gentle retraction and explored to insure the adequacy of the initial surgery. Incisions are enlarged if necessary to facilitate exposure. Any remaining foreign material, accessible foreign bodies, totally detached bone fragments or devitalized soft tissue are removed. Old blood clot is cleaned out. Means by which dead space may be obliterated or drained are considered. Further excisional surgery is not infrequently indicated. Failure to perform wound

revision soon after admission to the base is believed to account for many poor results seen in the past. Muscle tissue which appeared viable at initial surgery and, therefore, was not removed may have necrosed in the interim. When the remaining devitalized tissue of dirty wounds was not excised, wound sepsis with continuing local necrosis of living tissues was often established. Late wound exploration in cases of established sepsis has frequently revealed foreign material, or totally detached indriven fragments of cortical bone. Their removal plus proper reparative surgery was followed by subsidence of wound sepsis (Cases 1, 2 and 15). Reduction to the minimum of residual devitalized tissue is the most important step towards the minimizing of sepsis and is the keystone of the plan of management. When sepsis intervenes, reparative measures are doomed to failure, delayed or nonunion may follow, and wound healing will be postponed or prevented.

*Fracture Management:* The thorough wound visualization of reparative surgery affords the advantages of open reduction of fractures. Intervening soft parts are removed. Fragment ends caught in muscle are released. Rotated and twisted fragments are aligned. Complete appraisal of the problem at hand by direct vision as well as by roentgenogram is valuable in determining the means of obtaining and maintaining fracture reduction. The best possible fracture reduction is the objective of fracture management. In addition to the anticipated favorable anatomic result, stabilized fracture reduction eliminates the dead space of an unreduced fracture, and avoids traumatizing multiple manipulations or adjustments of traction in delayed efforts to effect reduction, thereby minimizing the chances of sepsis. In an effort to achieve the maximum fracture reduction, internal fixation is sometimes used under the following principles:

*Internal Fixation:* Internal fixation is by no means an objective of the program, and it is usually neither advisable nor possible because of severe comminution. However, the program permits the use of internal fixation with the limitations outlined below when it is *indicated* to maintain fracture reduction. Eighteen and eight molybdenum steel is relatively inert in the tissues and is not considered *per se* detrimental to wound healing. The fixation may be plating, multiple screws or wire loops.

The rigid stabilization of the fracture in reduction by a plate or multiple screws offers certain advantages (Cases 3, 4, 8, 11, 12):

1. Anatomic opposition and alignment anticipating faster bony union with no deformity.

2. The dead space and traumatizing manipulations outlined above are avoided.

3. Handling of the extremity for necessary subsequent wound care is facilitated.

4. Early joint motion and muscle exercise anticipating a more rapid return to function may be permitted.

5. The management of concurrent injuries which preclude traction and require repeated trips to the operating room is facilitated.

However, the use of internal fixation is limited by three factors other than comminution:

1. The desire to minimize intrawound trauma, *e.g.*, retractor pull, vessel ligatures—which creates additional devitalized tissue.

2. Interference with the covering of all exposed bone cortex with vascular soft parts (to be discussed under closure) (Case 5).

3. The desire to avoid periosteal stripping with its danger of massive sequestration which may be necessary to permit the application of a bone plate (Case 6).

When periosteum is stripped from bone, the outer cortex will die.[11] A basis for this statement is the experimental observation in dogs that the periosteal blood supply nourishes the outer third of the cortex of shafts of long bones.[12] If there is no sepsis, the dying bone is replaced by new bone as one process. But if sepsis is present reattachment of periosteum or other soft parts is prevented and the outer cortex becomes a sequestrum. Therefore periosteal stripping which deprives the outer cortex of bone of its nourishment is an important consideration in surgery in a known "infected" field. Practically, if the wound is appraised clean and the other factors are favorable, especially the availability of vascular soft parts, as in the arm or thigh, there is less hesitancy in stripping sufficient periosteum to permit the indicated surgery but if it is appraised "dirty"* or doubtful, the stripping is restricted or avoided.

Where the factors that might restrict its use are not unfavorable and the fracture permits, rigid internal fixation is frequently employed in order to gain the advantages of a well-reduced and stabilized fracture. Fixation through the compounding wound is at times practical but has the disadvantages of retraumatizing tissue and placing the metal on bone usually devoid of periosteum and at the bottom of dead space created by excision of devitalized muscle. Therefore, for plating, a separate standard approach to the fracture which permits covering of the bone and metal by periosteum and vascular soft parts is advisable (Case 4).

Every refinement in the technic of internal fixation is considered important. There must be intimate contact of the fragments; plate should be sufficiently long (Murray[13] recommends that the length of the plate be five times the diameter of the bone at the fracture); drill holes should be only slightly larger than the shaft of the screw, less the threads, preferably at right angles to the bone and wobbling of the drill or a drill bit at an angle should be avoided to prevent scoring of the drill hole. (Electrically driven drills require extreme caution to prevent burning of the bone); screws

* The term "dirty wound," as a contrast to clean wound is in common usage in this Theater and is herein used to describe the wound which is visualized to contain gross, unexcised devitalized tissue, is discharging pus, often foul-smelling, from the depths of the wound, or is covered by a gray, slimy purulent exudate. Cardinal signs of inflammation are not necessarily present in the dirty wound. When they are present, the wound is said to present "invasive infection."[16]

should be held "true," inserted by a steady hand and be long enough to protrude through the opposite cortex. Oblique screws across the fracture in a plane at or near 90 degrees from that of the plate will increase the rigidity.

In actual practice when internal fixation is deemed indicated multiple screw (two or more) fixation is frequently used (Cases 7, 8 and 11). Many fractures by their obliquity lend themselves to it, little or no additional periosteal stripping is required to permit placement of the screws, and intrawound trauma is not excessive. If the fracture does not permit rigid fixation because of comminution, one or more wire loops may be used to hold major fragments in approximation. These can usually be placed without additional periosteal stripping, a factor of particular importance in a wound with recognized established sepsis. In comminuted fractures with segmental bone loss, wire loops permit approximation of the major fragments (Cases 9 and 10).

Bony union is a prime consideration in any fracture and contact of the fragments greatly enhances the chances of union. Therefore the shortening of an extremity to overcome segmental loss and obtain contact of fragments is often a justifiable indicated procedure that is permitted by reparative fracture surgery. Nerve trunk or muscle group deficits associated with a fracture may indicate the deliberate removal of attached bone fragments and shortening of the extremity, thereby permitting restoration of continuity of all the severed major structures projected towards the maximum functional restoration of the extremity instead of a good fracture result as determined by the roentgenogram.

*Wound Closure and Drainage:* Wound closure is premised upon adequate initial surgery resulting in a clinically clean wound requiring little or no wound revision or traumatizing surgery and upon the feasibility of obliterating or draining dependently the residual dead space. The lag-period between initial and reparative surgery permits drainage of the products of injury necrosis. If initial surgery has been inadequate, resulting in a clinically dirty wound requiring extensive excisional surgery at wound revision, wound closure must be staged until after an additional lag-period for open drainage.

The hazards of an open wound in a compound fracture are the sequestration and sloughing of exposed bone cortex, tendon and fascia, plus reinfection at dressings and slow wound healing by granulation. The advantage of an open wound is continuing drainage from the depths of the wound until healing by granulation has sealed-off the fracture site. The gaping wound forms a natural channel for drainage. However, when it is not dependent and sepsis intervenes, there may be pocketing, puddling or pooling of pus in the fracture site or adjacent fascial planes with continuing local necrosis of the collagenous tissues.

Reparative surgery of compound fractures recognizes and attempts to overcome by wound closure the hazards of the open wound but also recognizes the advisability of a means of egress for the possible septic breakdown of any residual devitalized tissue not yet separated and of a contaminated hematoma

in unobliterated dead space. In the uninfected field, *e.g.,* the simple fracture or following a clean surgical operation, body processes will absorb devitalized tissue and blood clot. In the infected* field the same absorption might occur but the complete closure of wounds of compound fractures is justified only when the pabulum for wound sepsis is *nil.* A deep abscess about the fracture site underneath a sutured or healed epithelial bridge may produce irreparable damage. Therefore, an increased margin of safety can be obtained by providing drainage, dependent if possible, utilizing wounds or counterincisions as indicated. Drains are inserted so as not to cause tissue necrosis and are removed between the third and tenth day depending upon the drainage indications before rigid sinus formation occurs.

The problem of closure of the compounding wound is approached with the major objective of covering exposed bone cortex, tendon and fascia with healthy soft parts and the minor objective of reducing skin defects to a size that is compatible with *adequate* drainage. The sliding or rotation of flaps is often employed to gain these objectives (Cases 11 and 13). The hazard of periosteal stripping finds its antithesis in the value of covering bone exposed by trauma. Soft parts must adhere to the bony cortex to permit its "revascularization," whereby the dying bone may be absorbed and replaced by new living bone. Otherwise sequestration is inevitable (Case 15). Therefore, wound closure is designed to obviate the hazards of exposed bone cortex the salvage of which is probably the most important attainment of reparative surgery of compound fractures (Cases 10, 11, 13 and 14).

When soft-part masses fall over and protect structures that are vulnerable to exposure, *e.g.,* the muscles of the thigh over the femur, the major hazard of the open wound is removed and surgical closure is of less importance. The open wound may be the optimum method for free drainage and is utilized when closure, complete or partial, affords no definite advantages. The closure of a small wound compounding a fracture of the femur is inconsequential as the soft parts will be healed before the bone unites.[2] The open wound is particularly advantageous for drainage following traumatizing surgery, *e.g.,* extensive wound revision for dirty wounds or difficult internal fixations (Cases 3 and 4). In such cases, skin suture is avoided or staged. However, skin defects usually may be reduced and still permit adequate drainage. When the wound is clean and requires no traumatizing surgery, and when dead space is at a minimum, skin may be sutured completely or with a small drain of dry fine-mesh gauze or soft rubber tissue emerging through the most dependent portion of the wound or a counterincision (Cases 8, 9 and 10). When two wounds compound the fracture, one may be closed completely and the other (usually the more dependent) left open or partially closed, with or without drainage material. Surgical limitations, *i.e.,* tension, dead space or difficult dependent drainage as in anterior wounds over fractures of the tibia, may preclude wound suture and

* Infected, herein, denotes only the recognized presence of a bacterial flora capable of establishing wound sepsis in the presence of dead tissue.

the wound may require loose packing anticipating healing from the bottom by granulation (Orr method) (Cases 7, 8 and 14), but in many of these, partial wound closure may be employed to cover exposed cortex of bone. Partial wound closure in reducing the magnitude of compounding wounds facilitates the sealing-off of the fracture site by healing processes rather than attempting the immediate conversion of the compound to a simple fracture and, therefore, it is frequently employed to reduce the size of defects of the compounding wounds. The reduction to a minimum of skin defects minimizes scar, promotes earlier wound healing and leads to improved functional results.

*Postoperative Management:* Immediate adequate reduction and stabilization of the fracture is essential to reduce dead space, prevent the continuing trauma of fragment ends, and provide wound rest to promote wound healing In many cases sheet wadding and plaster encasements for immobilization of the fracture in reduction provide pressure dressings for the control of dead space and wound edema. When skeletal traction is the method of choice for postoperative fracture management, the wounds are supported by bulky dressings and elastic bandages. Variations of, and adjuncts to, skeletal traction methods are frequently employed in obtaining and maintaining fracture reduction, *e.g.,* Army leg splint, "Navy" traction, two-wire traction[14] (Plate 1). Anesthesia is often continued until the completion of the traction set-up on the ward permitting immediate manual reduction verified roentgenologically. By this plan, reduction in traction is quickly obtained, and it is maintained by the skeletal traction. Fractures fixed internally are also immobilized externally by plaster or skeletal traction. In the postoperative management of internally stabilized fractures of the femur, skeletal traction affords added protection and permits adequate wound care, early knee motion and physiotherapy.

The case reports and illustrations which follow are presented to illustrate the details of the principles of reparative surgery as applied to compound fractures. Each case demonstrates the application or omission of one or more of the principles covered in the manuscript. While the majority of the cases in the group illustrate results to be anticipated by reparative surgery, cases illustrating certain pitfalls that occurred during the formative stage of the program are included to emphasize certain conclusions.

Internal fixation has been used in nine cases, herein reported, including two cases of wire approximations of major fragments. The predominance of internal fixation in these reports should not be interpreted to mean that the method is employed in the majority of cases, for such is far from true. The group of cases included illustrate the *indications* for the method and concurrently, other principles. Skeletal traction (Plate 1-a-e) is the usual method of obtaining and maintaining fracture reduction when traction is necessary.

Penicillin therapy, unless otherwise stated, and blood replacement therapy were used in each case according to the plan outlined in the manuscript.

PLATE I

A. Fracture of the femoral shaft in the midthird in balanced suspension skeletal traction utilizing the Army leg splint with the Pierson attachment and a Kirschner wire through the tibial tubercle. The leg splint.—Pierson method is used in the majority of cases.

B. Fracture of the upper third of the femur in balanced skeletal traction, utilizing the "Navy" method. It is an excellent method for upper third fractures, with high thigh or posterior wounds.

C. A ward of fractures of the upper third of the femur treated in balanced skeletal traction, employing the "90-90-90" method (the hip, knee and ankle joint position). After a few weeks in this position during which posterior wound management and fracture reduction is effected, the leg splint—Pierson method is substituted.

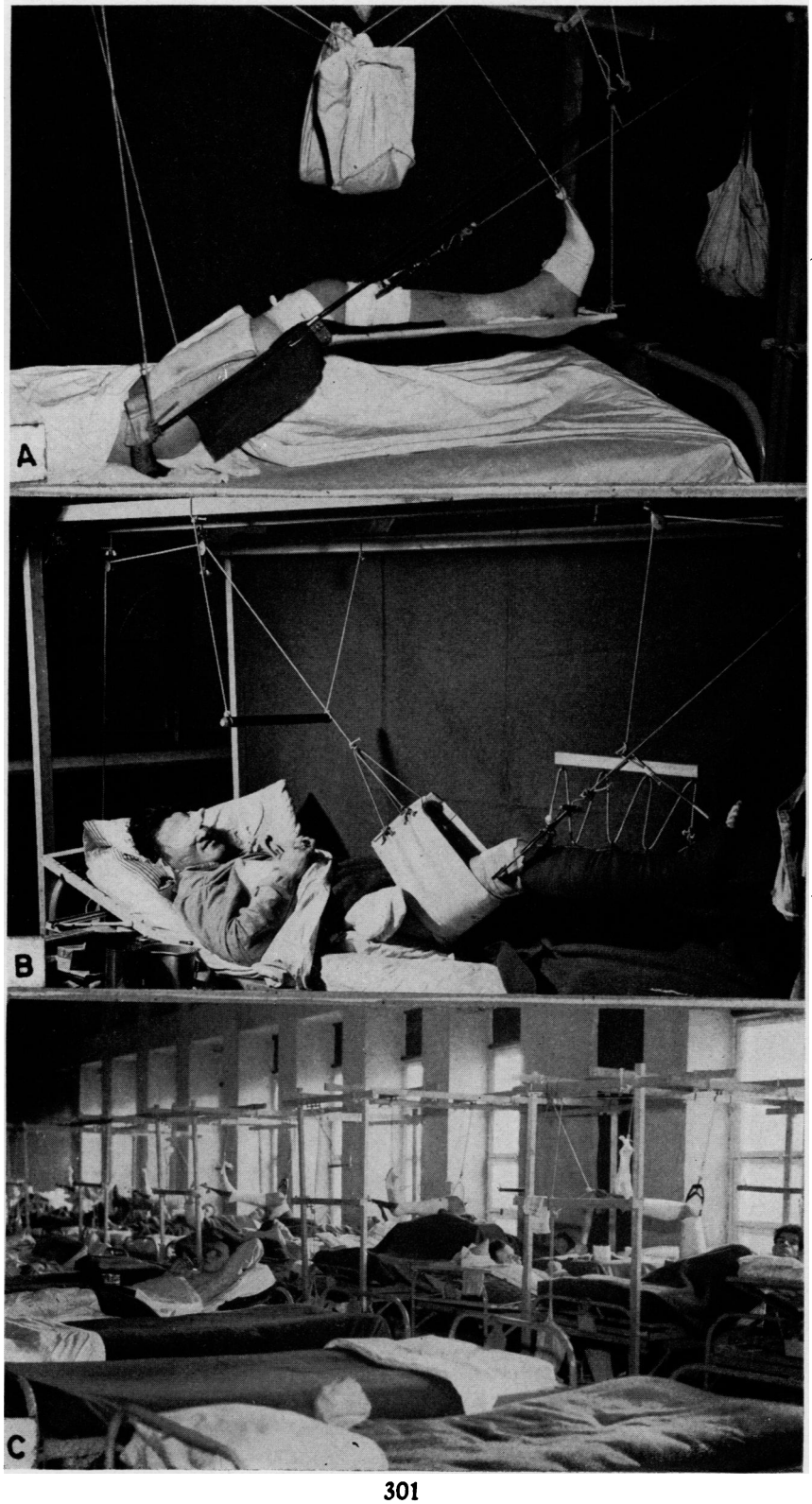

A
B
C

PLATE I (CONTINUED)

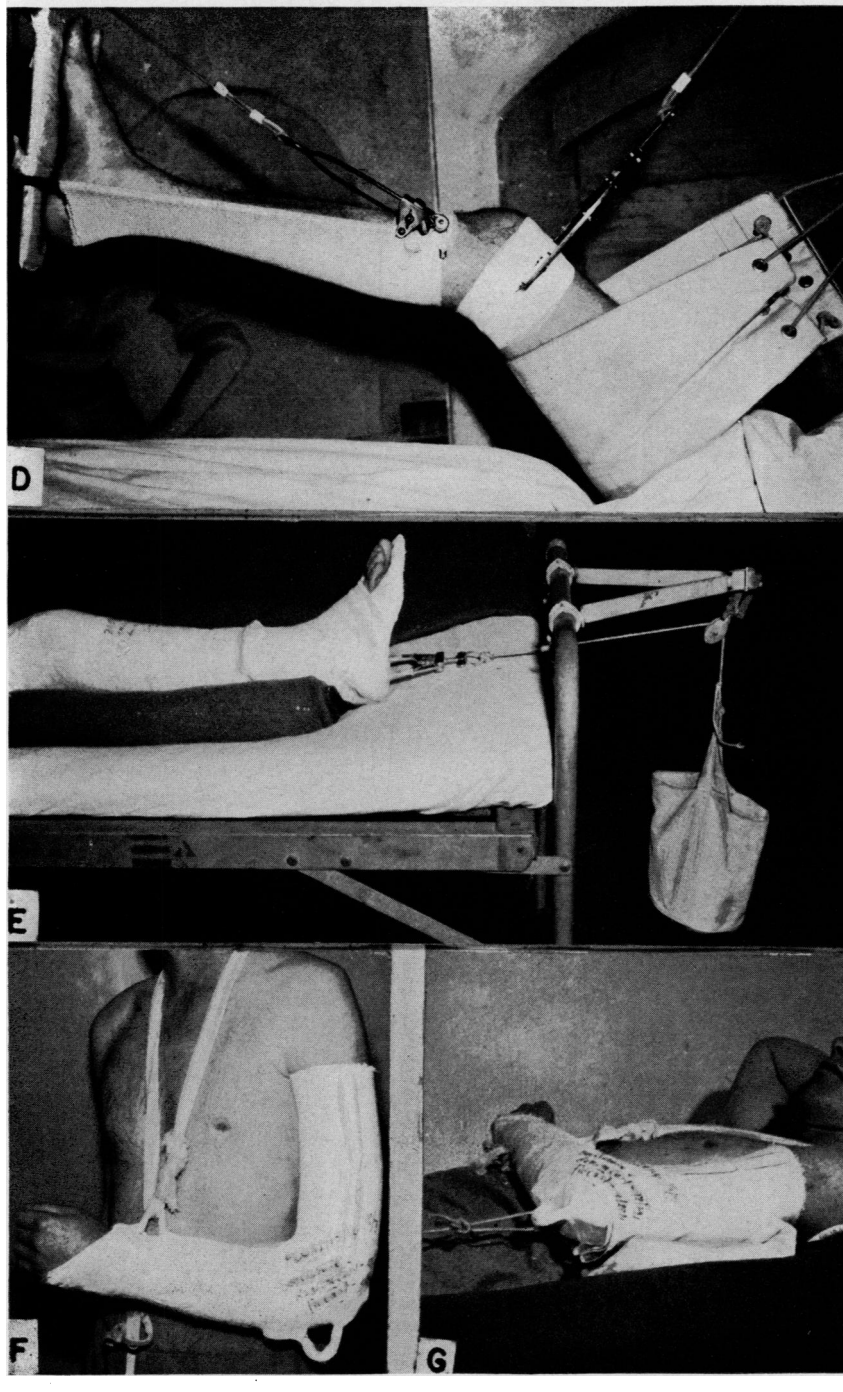


PLATE I (CONTINUED)

D. Two-wire, or double skeletal traction, here used as an adjunct to the "Navy" method for management of a fracture of the lower third of the femur. The two-wire method as illustrated is almost a routine for displaced lower third fractures.

E. "Encasement Traction," a modification of skeletal traction through the os calcis, is a valuable method of maintaining adequate reduction of fractures of both bones of the leg.

F. The "hanging cast"—the most frequently employed method for obtaining and maintaining reduction of fractures of the humerus.

G. A folded towel for support of the arm and traction over a pulley at the foot of the bed permitted by the loop of plaster are employed during temporary recumbency after the reparative surgical procedure.

PLATE II

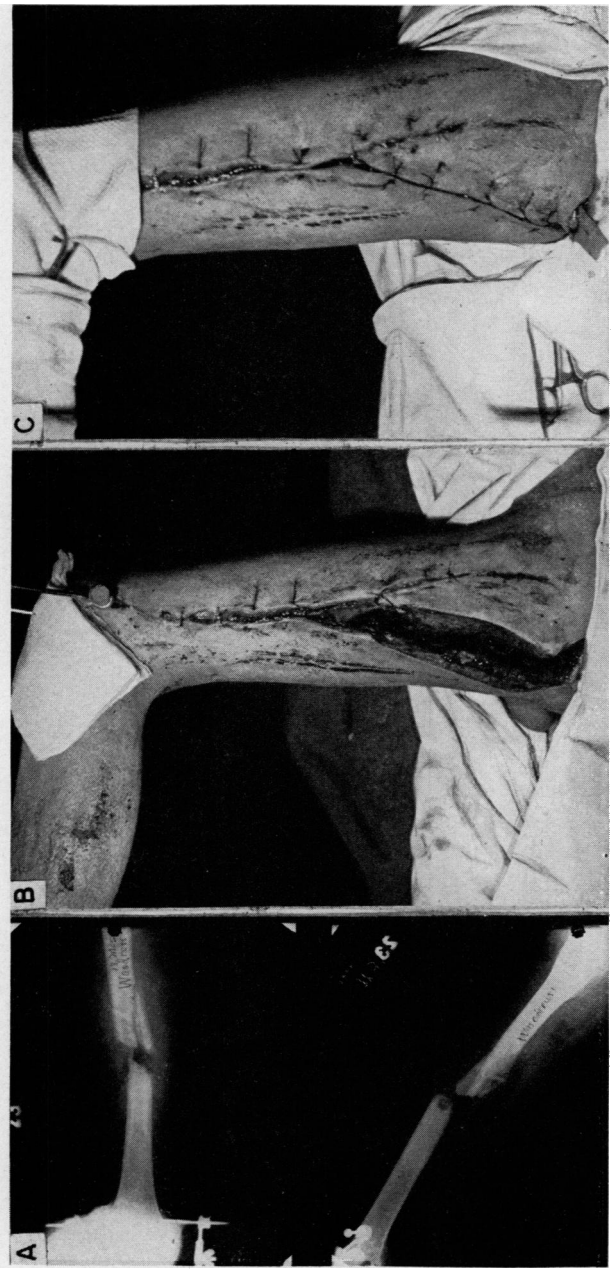
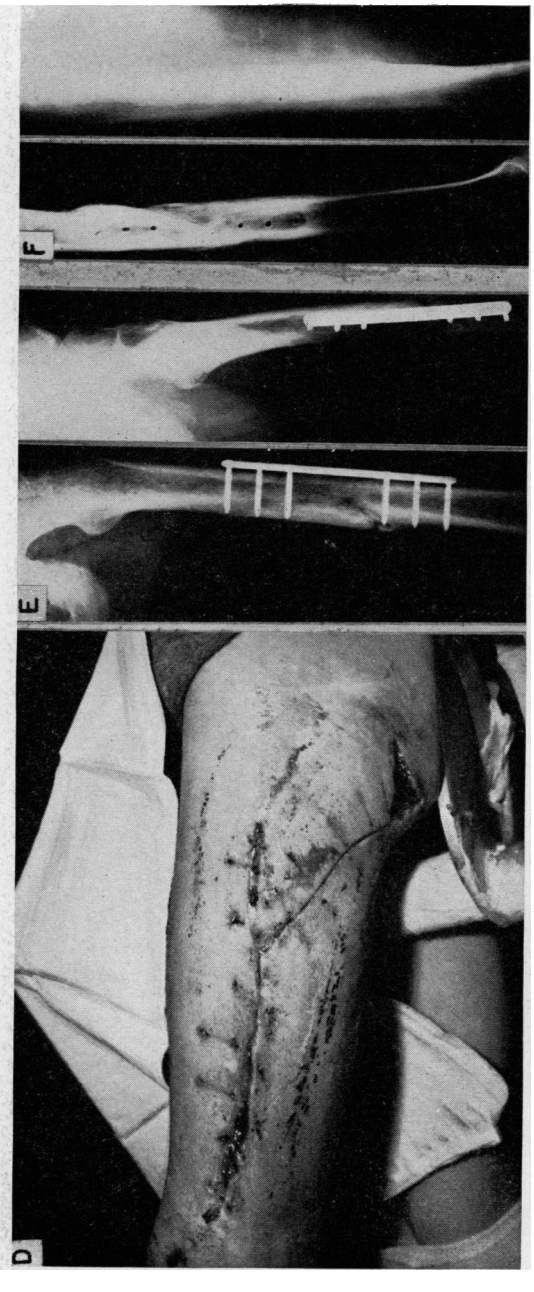



PLATE II.—Case 3: A. Roentgenograms, 13 March, 1944, one month after injury, with the extremity in skeletal traction, revealing distraction and gas abscess formation.

B. Partial wound closure and gaping dependent open wound for drainage at reparative surgery on 15 March, 1944.

C. Staged closure of the remaining portion of posterior wound over a small drain on 21 March, 1944.

PLATE II (CONTINUED)




D. 28 March, 1944. Wound healing has been obtained, except for the small granulating areas in the old compounding wound and at the proximal end of the drainage incision.

E. Roentgenograms showing the internal fixation and suggestion of sequestrum formation. Made in Z of I in July, 1944.

F. Roentgenograms showing end-result.

PLATE III

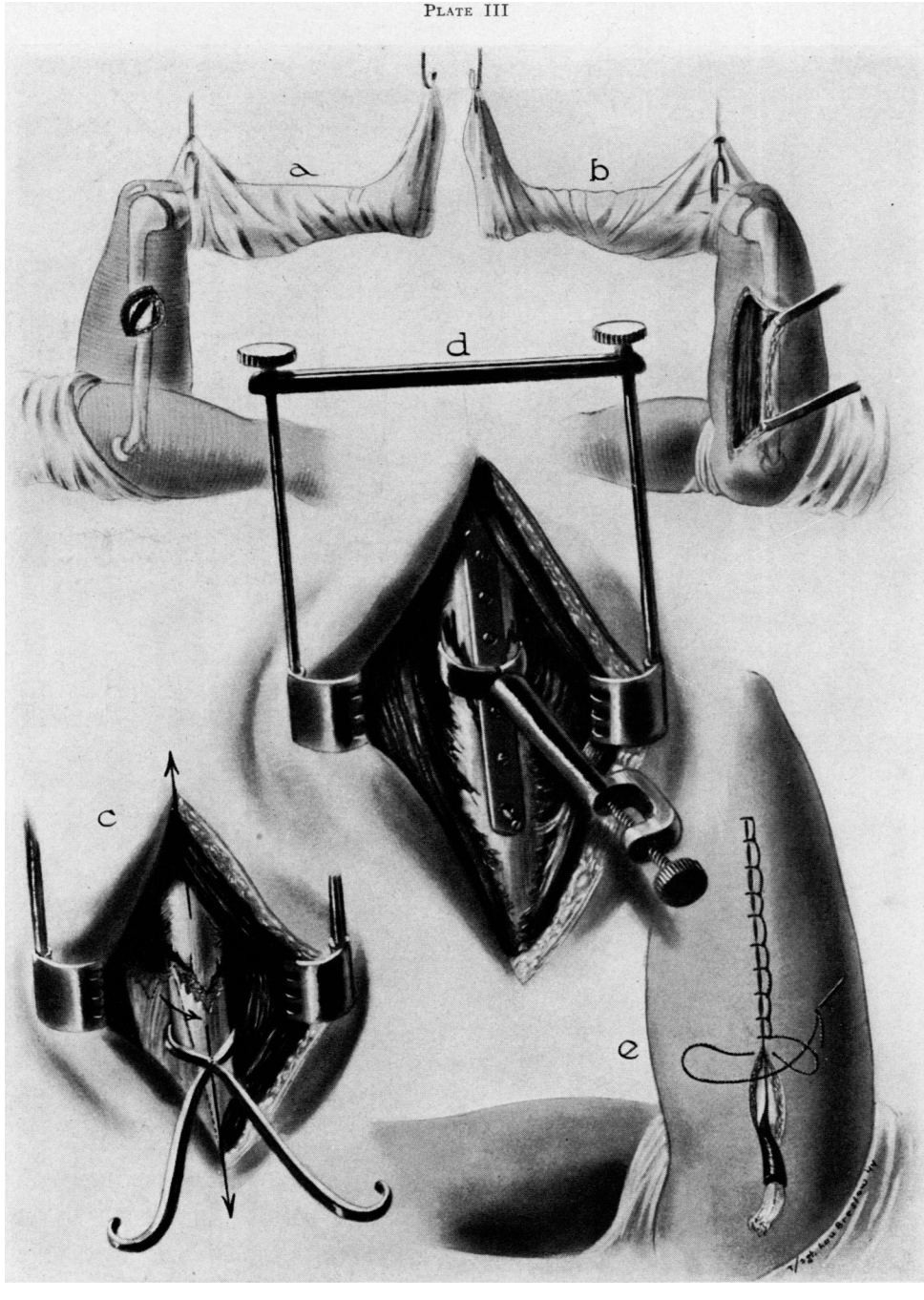



PLATE III.—Case 4: a. Compounding wound.

b. Posterolateral approach.
c. The fracture reduction.
d. Internal fixation.
e. Closure of the operative wound, with drainage. The artist has failed to depict comminution and an obliquity in the fracture.

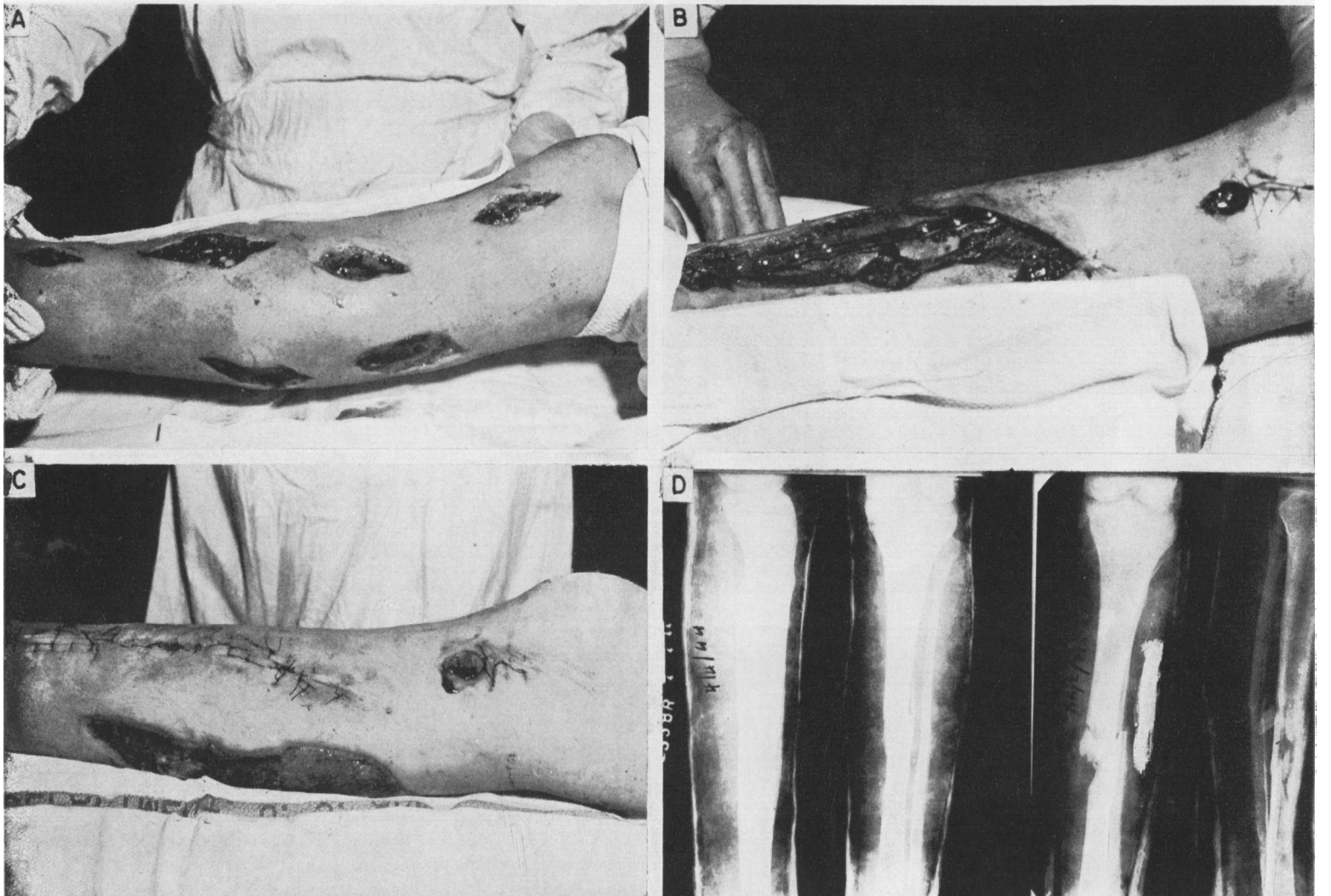
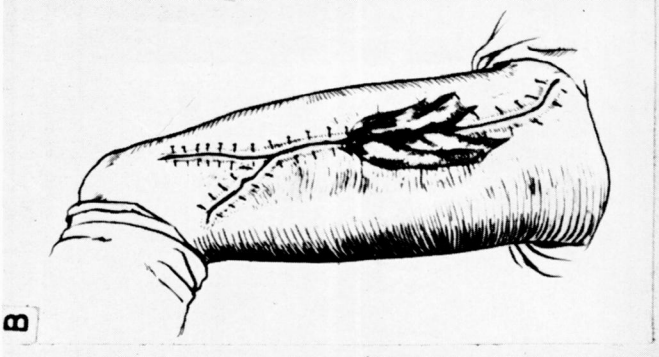


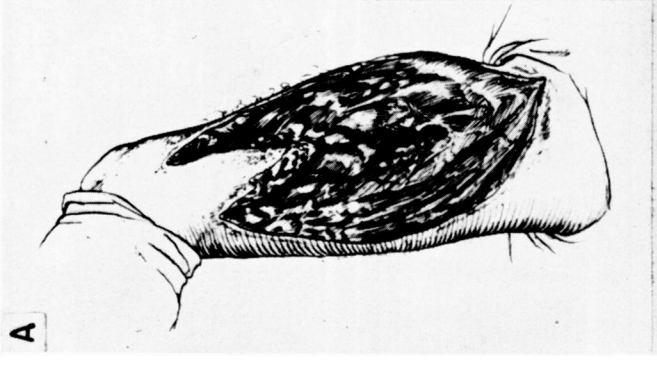

PLATE IV.—Case 5: A. The wounded extremity prepared for reparative surgery on 3 April, 1944.
B. The fracture stabilized by the plate passing over a large fragment.
C. The closed operative wound and the converted relaxing incision through which drainage was planned.
D. Roentgenograms made pre- and postoperative. Note the hair line reduction of the fibula in the postoperative films (on left). Conversely, plating of the fibula will produce adequate reduction of a severely comminuted tibia.

PLATE V

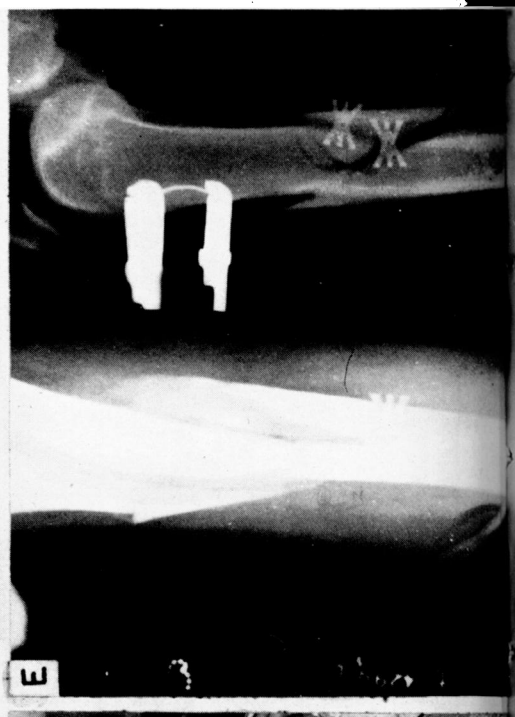
C



B



A



E

D

PLATE V.—Case 6: A. Drawing of the huge wound as it presented itself at operation.

B. Drawing of the partial closure with fine-mesh gauze drainage to residual dead space.

C. In two-wire skeletal traction on the Ward 26, October, 1944. Wound healing is progressing satisfactorily.

D. 17 November, 1944, one month postoperative, complete wound healing has been obtained.

E. Roentgenograms, 24 October, 1944, showing adequate apposition and good alignment. This reduction was maintained until bony union occurred. Note the "lifting" of the distal fragment into apposition in the lateral view.

PLATE VI

A

B

PLATE VI.—Case 7: A. 15 July, 1944. The former defect which has filled with granulations, without sinus to bone.

B. 15 July, 1944. The healed operative incision for the plating of the fibula.

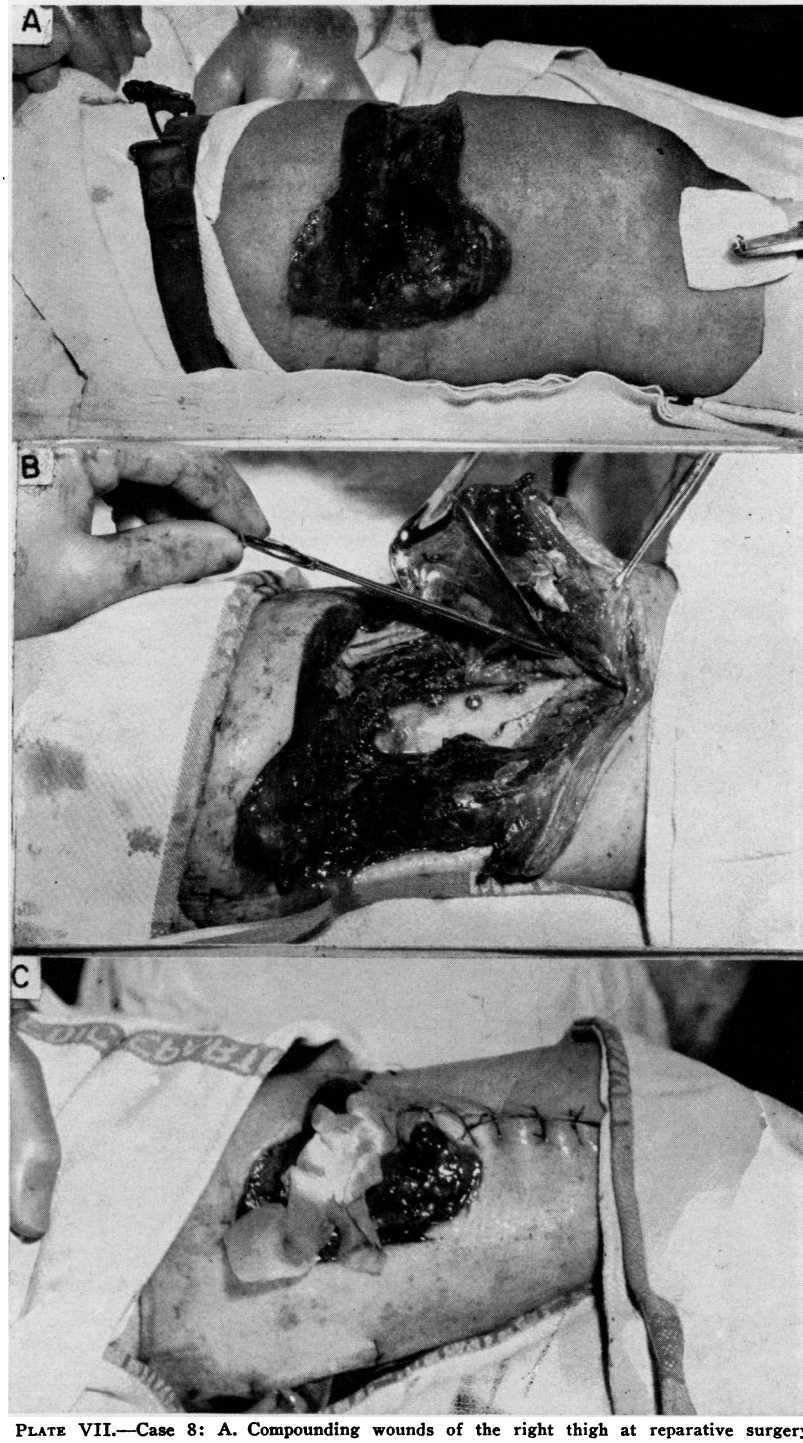



PLATE VII.—Case 8: A. Compounding wounds of the right thigh at reparative surgery, 9 April, 1944.

B. The internal fixation by four screws. Minimal periosteal stripping was required.

C. Partial closure and loose packing of the dead space, with dependent drainage through a separate incision in the posterolateral fascial plane.

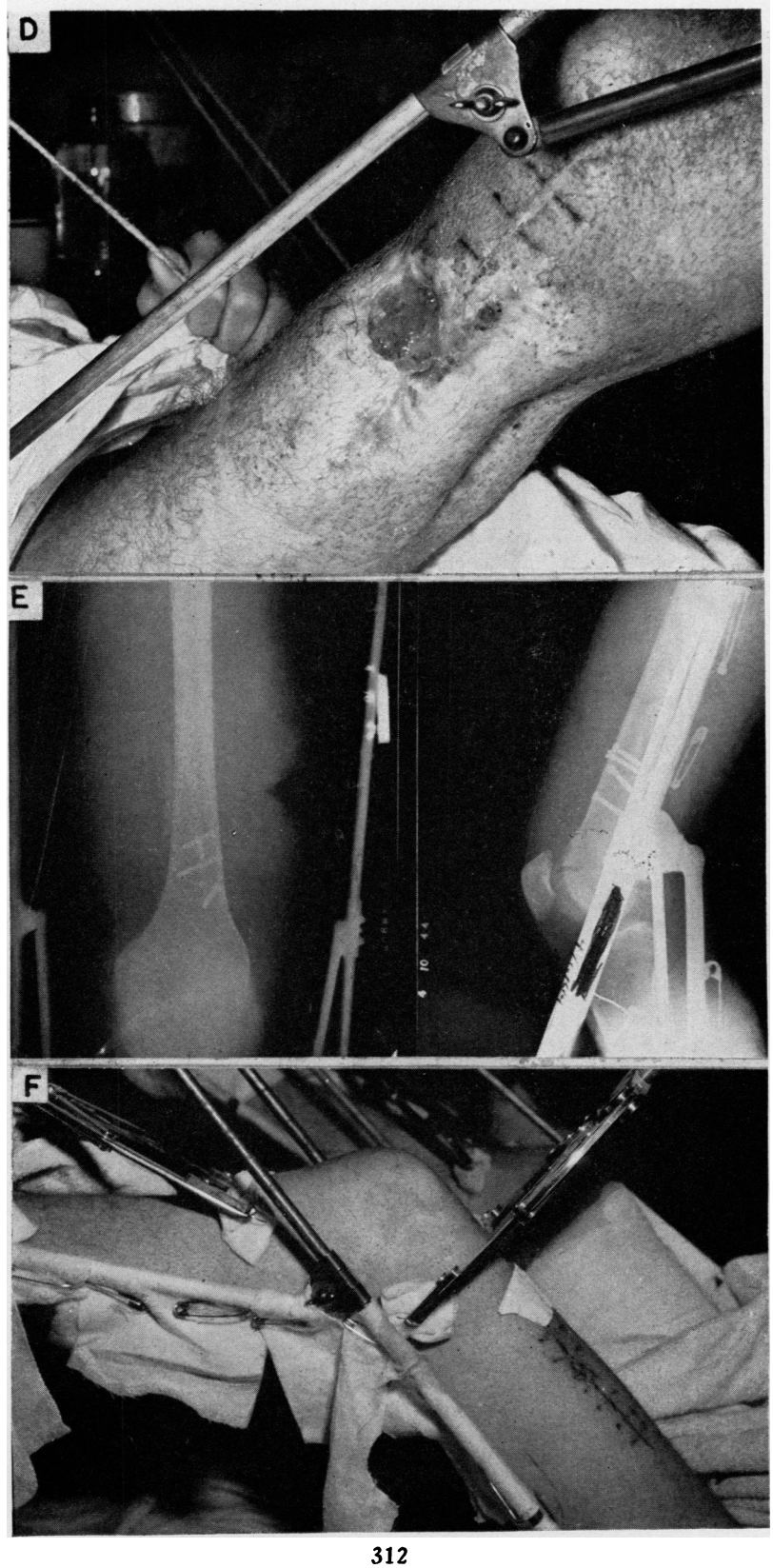
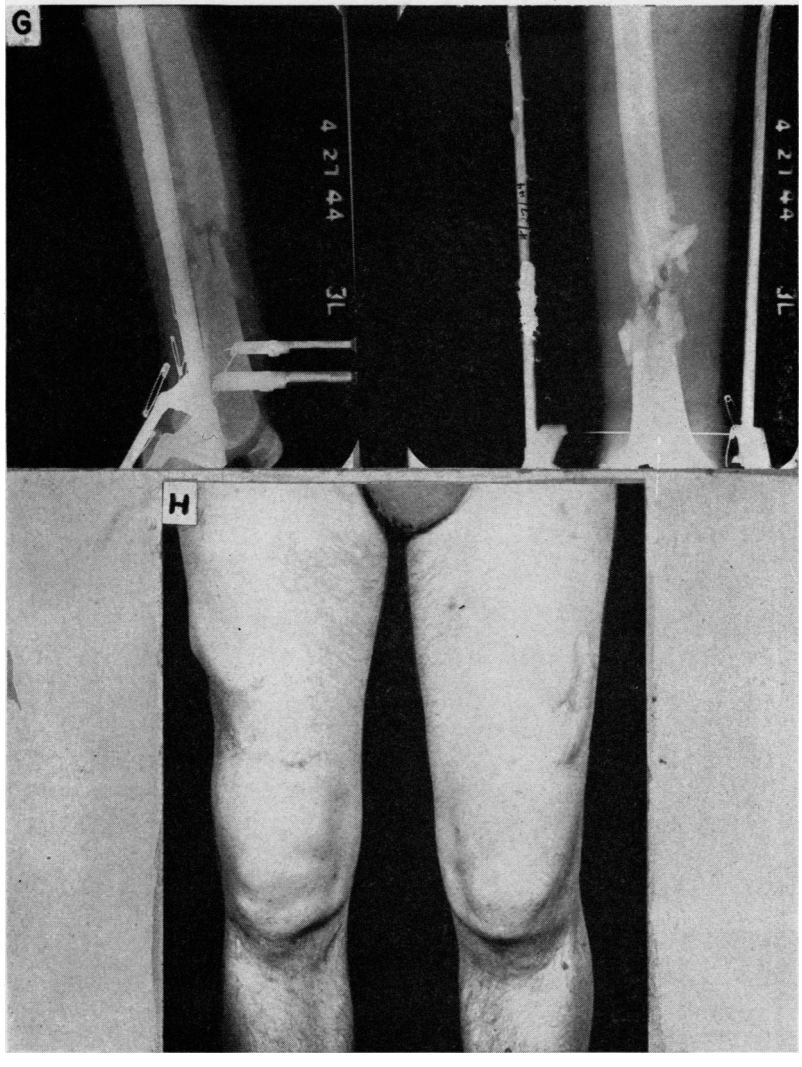

D
E
F

PLATE VII (CONCLUDED)




D. Sutured and drainage wounds are firmly healed and the dead space has filled with granulations, without sinus to bone. 6 July, 1944.

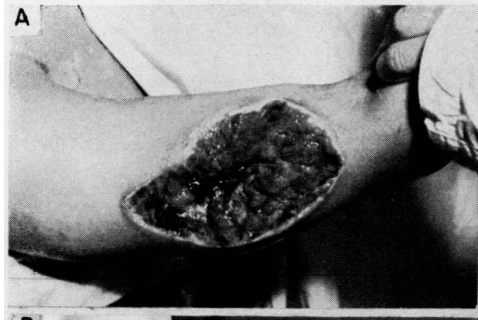
E. Roentgenograms of right femur made postoperative.

F. Left lower extremity in two-wire traction showing the healed anterior thigh wound. The posterior wound was also healed. 6 July, 1944.

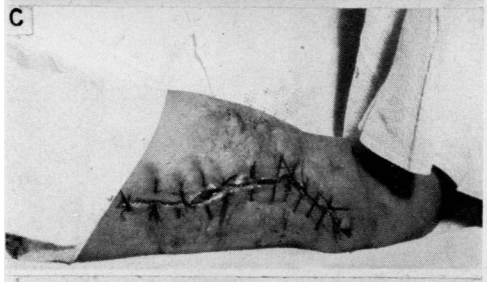
G. Roentgenograms of left femur in two-wire traction.

H. The patient fully ambulatory with all wounds healed and 90 degrees knee flexion (excellent for lower third battle fractures) in early 1945.

PLATE VIII









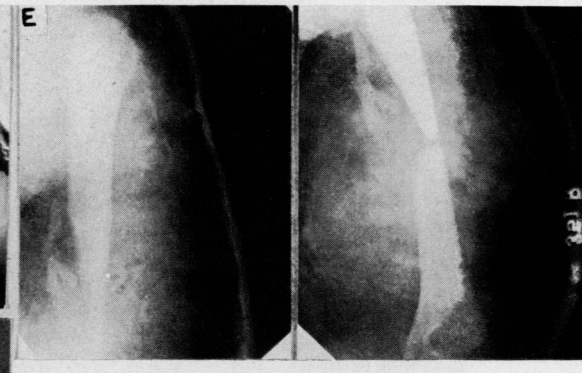



PLATE VIII.—Case 9: A. Lateral wound in operating room 30 October, 1944.

B. Medial wound in operating room 30 October, 1944. Note large blood clots in the wound.

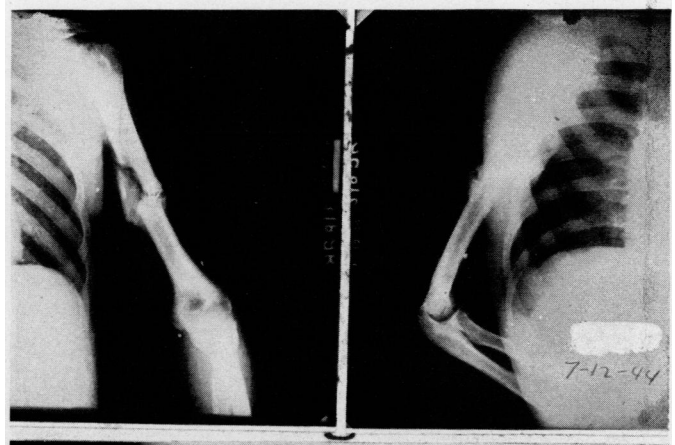
C. Sutured lateral wound at reparative surgery 30 October, 1944.

D. Grafted medial wound 30 October, 1944.

E. A. P. and lateral views of fracture in plaster. Approximately one-inch bone deficit has been overcome by the wire loop fixation.

PLATE IX

A




B

PLATE IX.—Case 10: A. The united fracture of the humerus in July as shown roentgenologically. The humerus was shortened about one and one-half inches at reparative surgery to obtain contact of fragments.

B. The healed grafted area over the humerus. The graft had been performed through a large window in the spica, hence, the raw area on the chest had not been grafted.

PLATE X

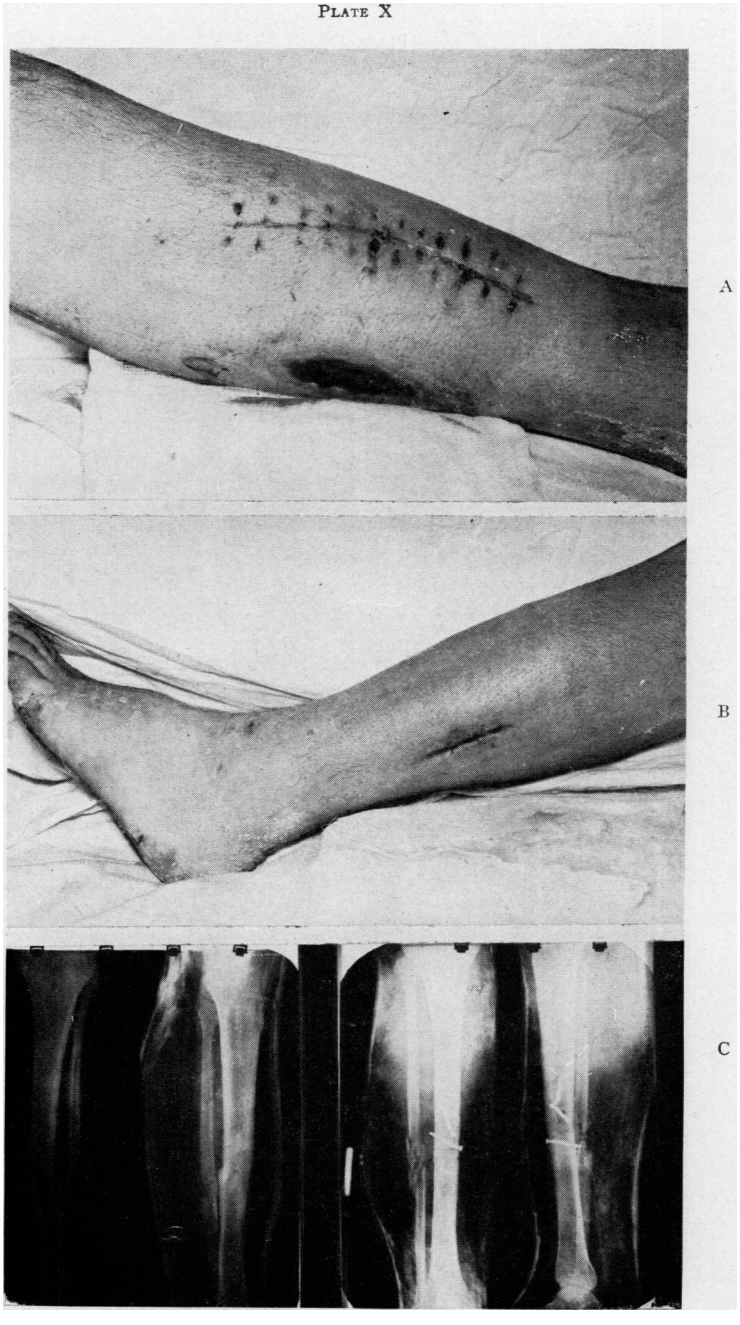
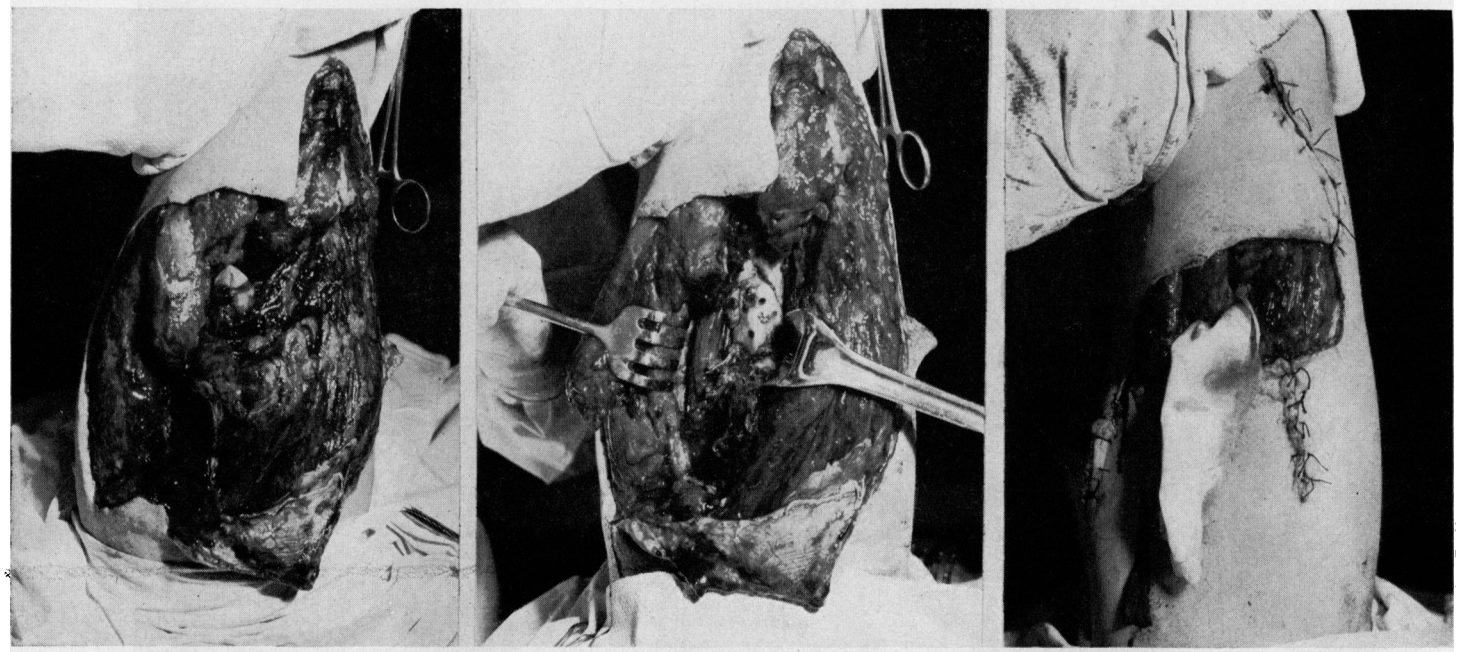



PLATE X.—Case 11: A. 15 July, 1944, four weeks after reparative surgery. Healed sutured wound over the tibia and the granulating relaxing incision. The latter might have been split-skin grafted.

B. The healed lateral wound through which drainage was established for a few days.

C. Roentgenograms made pre- and postoperative. The upper screw missed the drill hole in the distal cortex.

PLATE XI



A B C

PLATE XI.—Case 12: A. Exposure of massive wound, with thigh in the "90-90-90" operative position. Note the projecting bone in wound.

B. Fracture stabilized by multiple screw fixation, with no additional periosteal stripping.

C. Partial wound closure and drainage of residual dead space with dry fine-mesh gauze. The sutured areas possibly represent surgical extensions of the wound for adequate exposure. The remaining raw area probably represents the skin loss at the time of wounding.

PLATE XII

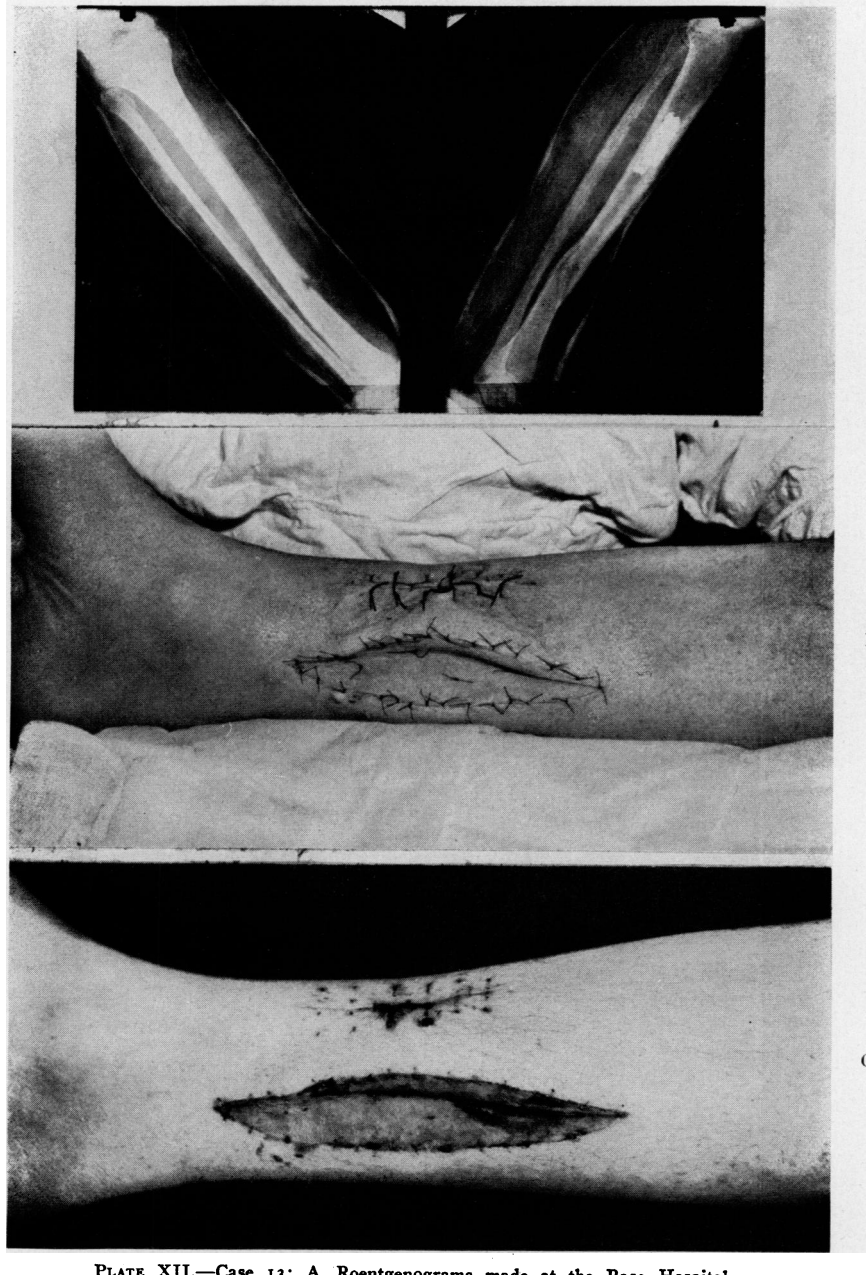



PLATE XII.—Case 13: A. Roentgenograms made at the Base Hospital.
B. Sutured compounding wound and skin-grafted relaxing incision of reparative surgery.
C. The healed wound and 95% take on skin graft, two weeks after reparative surgery. Sound wound healing followed shortly. The patient returned to duty in this Theater.

PLATE XIII

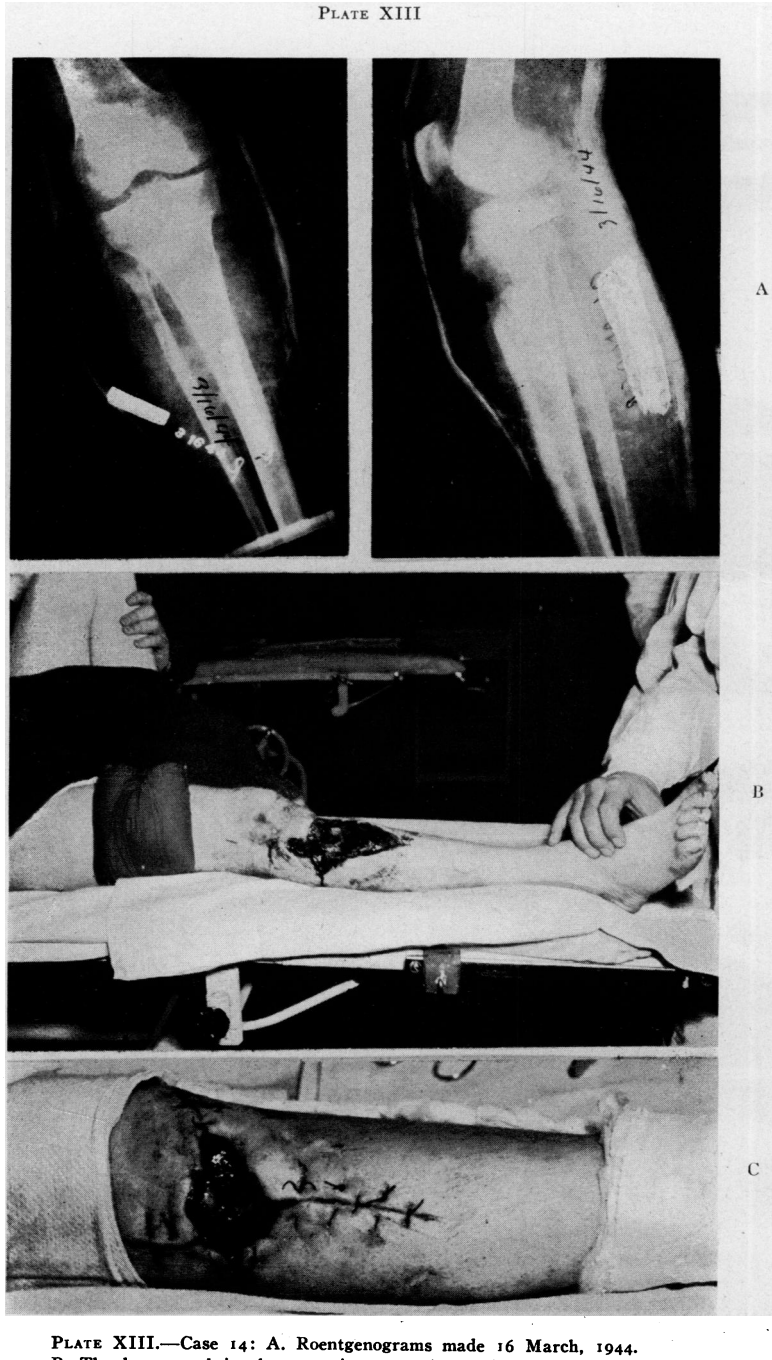


PLATE XIII.—Case 14: A. Roentgenograms made 16 March, 1944.

B. The leg wound in the operating room just prior to reparative surgery. Note the pneumatic tourniquet. Blood loss from upper tibial fractures is usually severe.

C. The healed sutured projections of the wound and the clean fracture cavity on 23 March, 1944. Sutures were removed, the cavity loosely filled with dry fine-mesh gauze and a plaster encasement applied, anticipating no wound disturbance for several weeks.

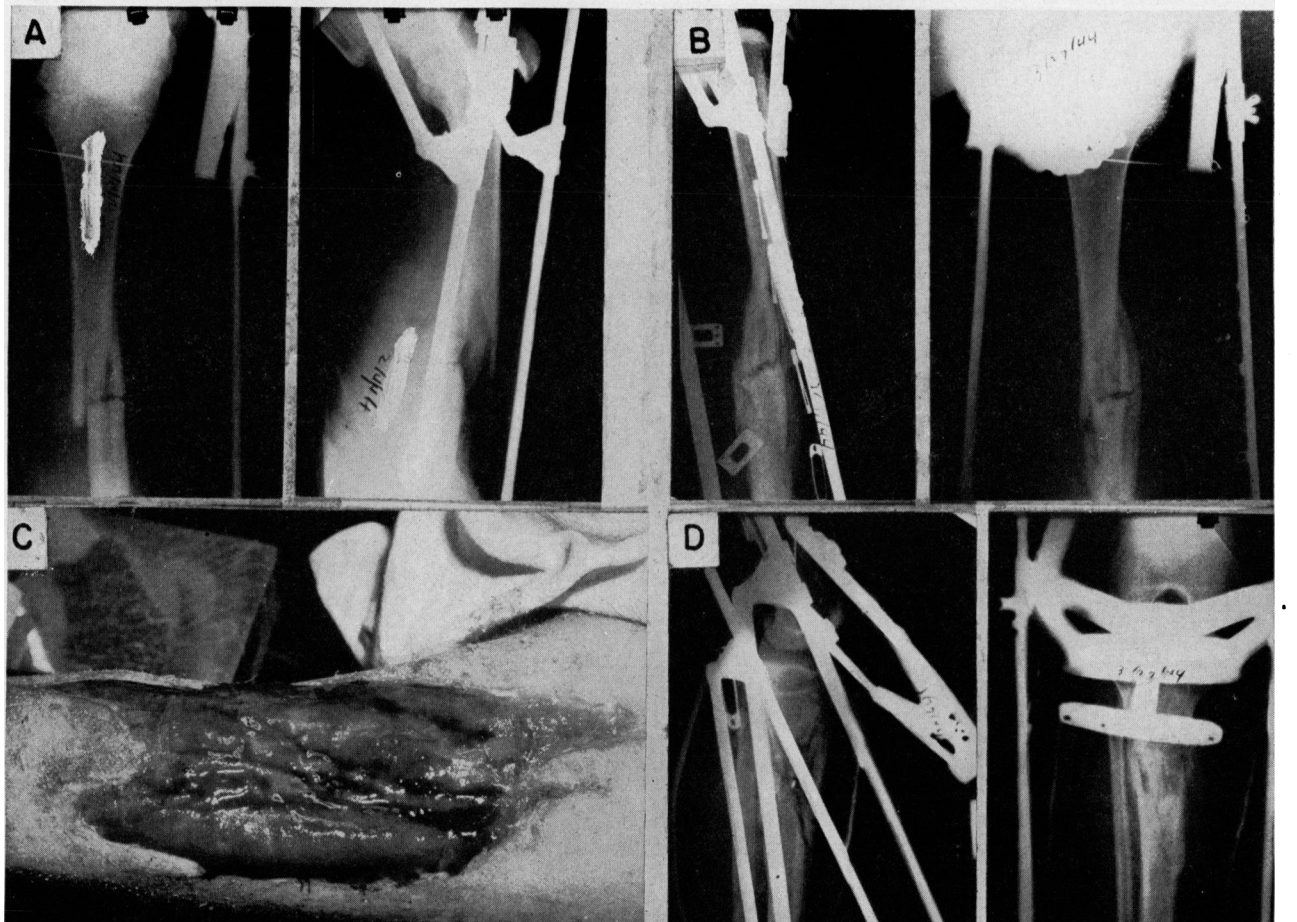



PLATE XIV.—Case 15: A. A. P. and lateral views of the femoral fracture in skeletal traction on 4 February, 1944. Improved reduction was obtained later.
B. A. P. and lateral views 27 March, 1944, showing the partially united fracture with massive sequestrum formation.
C. The large raw anterior thigh wound on 6 April, 1944. The fracture site was open and pus puddled in the depths of the wound.
D. A. P. and lateral views of fracture of the tibia.





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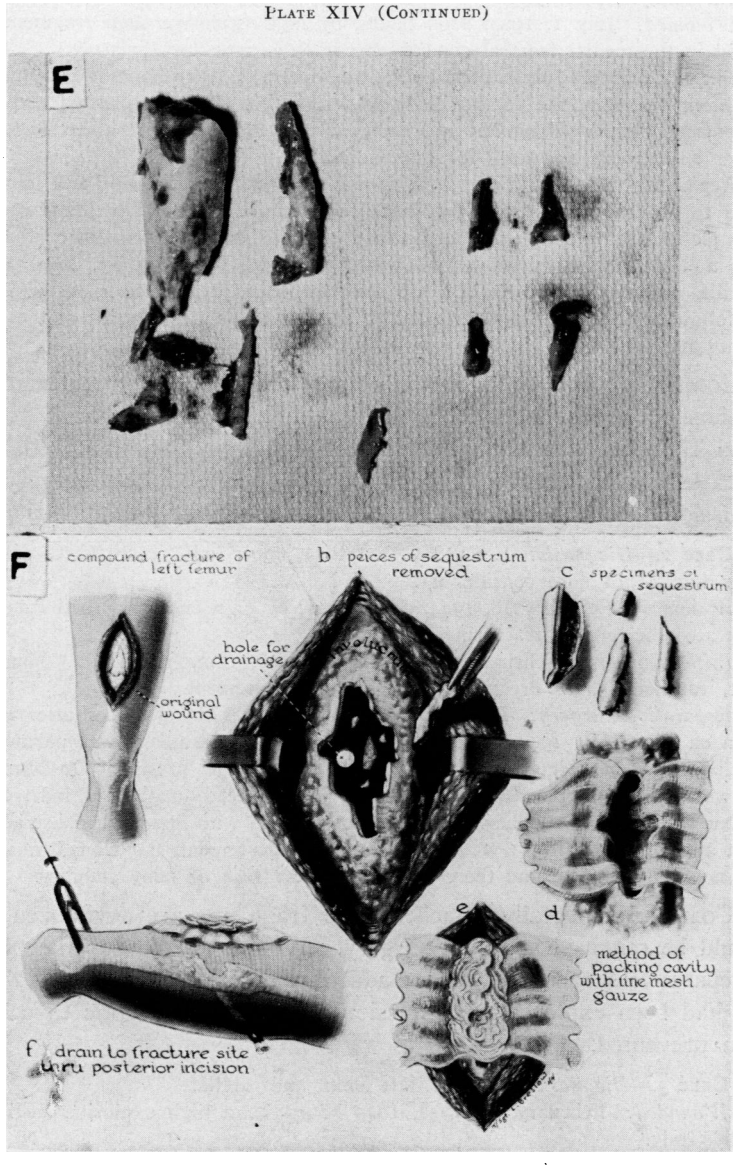
PLATE XIV (CONTINUED)




**E. Sequestra removed from the femur (left) and tibia (right), at operation on 6 April, 1944.**

**F. Drawings of the reparative surgery on the femur.**

ILLUSTRATIVE CASE REPORTS*

**Case 1.**—*Diagnosis:* Penetrating wound of left knee joint, with fracture of medial femoral condyle, incomplete.

*Wounded:* July 1, 1944, 2100 hours, by high explosive shell fragment which embedded in the medial femoral condyle through the articular surface.

*Initial Surgery:* July 2, 0400 hours, time-interval, seven hours. Through a two-inch arthrotomy incision, the foreign body was removed, the joint cleaned and the synovia and capsule closed. Penicillin was instilled into the joint and given systemically. A plaster encasement was used for immobilization.

*Reparative Surgery:* Soon after admission to the Base, wound and joint sepsis was found to be established. Maggots crawled from the joint. The joint was reëxplored and a piece of khaki cloth was found buried in the defect in the femoral condyle. Removal of it and devitalized cartilage followed by lavage, joint closure, local and systemic penicillin and immobilization in a hip spica, produced a subsidence of the infection. A late follow-up, April 5, 1945, revealed 90 degrees of painless motion at the knee and all wounds healed.

COMMENT: Incomplete initial surgery allowed foreign material to remain. Established sepsis indicated a surgical approach. At wound revision, the khaki cloth and remaining devitalized cartilage were removed, permitting indicated reparative surgery. The completion of excisional surgery soon after admission to the Base Hospital is the keystone of the plan of management.

**Case 2.**—*Diagnosis:* 1. F. C. C. left tibia, upper half. 2. F. C. C. of right femur, upper third (not here considered).

*Wounded:* February 18, 1944, 0800 hours, by high explosive shell fragments which penetrated the left leg fracturing the tibia.

*Initial Surgery:* February 18, 1944, 1030 hours. Time-interval, 2.5 hours. Débridement, vaselined gauze dressing and a plaster encasement.

*Reparative Surgery:* The primary encasement was changed soon after admission and again on March 13, 1944, when it was noted that the drainage was purulent and foul-smelling. An incipient osteomyelitis was thought to be present. On March 30, 1944, the wound and fracture were explored. Several dead unattached indriven fragments of bone were removed. The wound was loosely filled with fine-mesh gauze and an encasement applied. On May 1, 1944, at change of encasement, the wound was clean, there was no foul drainage, and there was clinical evidence of bony stability.

COMMENT: Totally detached bone fragments are devitalized tissue that should be removed at initial surgery. Wound revision as the primary step in reparative surgery insures the adequacy of initial surgery. If this fracture site had been explored on admission to the Base, a septic tibia might have been prevented.

**Case 3.**—*Diagnosis:* F. C. C. left femur and patella.

*Wounded:* February 16, 1944, 1045 hours, by a high explosive shell fragment at Anzio, Italy.

*Initial Surgery:* February 16, 1944, 2320 hours. Time-interval, 1235 hours. All wounds débrided and metallic foreign body removed from the left knee, 1.5 hip spica applied. He was evacuated to the Base on February 19, 1944, by L. S. T.

* The reported cases were managed by the staffs of Forward and Base Hospitals of the Mediterranean Theater of Operations. It is regretted that because of insufficient information adequate acknowledgment cannot be given to the surgeons who produced the splendid results. The photographs and artist's drawings were produced by detachments of the Museum and Medical Arts Service.

*Reparative Surgery:* On February 22, two days after admission to the Base Hospital, exposure of the wound revealed incomplete initial surgery, requiring further excisional surgery. The wound was left open. Skeletal traction was instituted.

On March 14, 21 days after wound revision, he appeared sick and washed-out, and had a continuous low grade fever. The fracture site was visible through a gaping lateral wound. Skeletal traction had failed to obtain fracture reduction. Roentgenograms showed the fracture in distraction, and the seat of a gas abscess. Three thousand cubic centimeters of blood had been administered in the Base Hospital. Operation March 15, 1944: An abscess in the posterolateral plane of thigh, pocketing in the proximal portion, was incised and drained. Totally loose bone fragments were removed, and the fracture was fixed in reduction by a bone plate. After excision of the old wound edge and granulation tissue, the exposed bone, including the fracture site, was covered by partial wound closure. The fracture site and fascial plane were adequately drained by the remaining gaping incision. Two thousand cubic centimeters of blood were given on the day of surgery and penicillin therapy in adequate dosage was instituted. On March 21, 1944, six days later, the wound was found to be clean and was sutured over a Penrose drain emerging at its proximal most dependent portion.

Postoperative course was not eventful. The drain was removed on the seventh postoperative day. A minimal amount of purulent drainage continued intermittently for several weeks. On May 2, 1944, there was no drainage site. A small sequestrum was suggested by late roentgenograms. The patient was evacuated to the Zone of Interior in a plaster encasement in mid-May.

In the Z. of I., solid bony union in anatomic alignment and wound healing followed. There was some absorption about one screw, therefore, the metal was removed. The wound of this procedure healed *per primam.*

COMMENT: This septic fracture developed following inadequate initial surgery. The fracture site was the seat of dead space and gas abscess formation. Drainage of the septic process by a lateral wound had been inadequate and a pocket of pus had formed in the posterior proximal thigh. At reparative surgery, sequestra were removed and the dead space of an unreduced fracture was obliterated. The fracture was stabilized in reduction and sufficient wound closure was done to cover all exposed bone. The wide-open posterior wound provided dependent drainage for the residual dead space which was further reduced by the staged closure six days later.

By reparative surgery, sepsis was controlled, the unreduced fracture was stabilized, and bone and wound healing were obtained.

**Case 4.**—*Diagnosis:* F. C. C. of femur.

*Wounded:* March 10, 1944, 1500 hours, by a high explosive shell fragment which penetrated the left thigh medially, fracturing the femur in the midthird.

*Initial Surgery:* March 10, 1944, 1900 hours. Time-interval, four hours. Débridement and removal of foreign bodies, loose fine-mesh gauze drain and dressing and plaster encasement.

*Reparative Surgery:* On the 19th of March, nine days after wounding, and two days after admission to the Base Hospital, the fracture was approached through a posterolateral incision, passing between the vastus lateralis and the biceps femoris, and stabilized in reduction by a bone plate. An additional screw was inserted through the compounding medial wound. The compounding wound was closed without drainage. The operative approach was closed over a soft Penrose drain. The extremity was placed in skeletal traction in a Thomas splint and Pierson attachment. The drain and sutures were removed on the tenth postoperative day. Healing was excellent, and the drainage area was dry on April 13, 1944. Beginning about April 1, 1944, active and passive knee

motion were permitted and quadriceps exercises were encouraged. In mid-April a 1.5 hip spica was applied for transportation to the Zone of Interior. The fracture went on to union and the wound remained healed. The range of knee motion by early 1945 was practically normal. In March, 1945, he returned to duty in a motor pool at a large General Hospital.

COMMENT: A standard anatomic plane approach was used, which permitted the bone exposed by surgery to be covered by healthy soft parts and also permitted dependent drainage. The fracture was anatomically reduced and stabilized, which permitted the necessary handling of the extremity for the removal of drain and sutures. The procedure permitted early knee joint motion and quadriceps exercises. The patient was evacuated to the Zone of Interior approximately one month after wounding. Treatment of the fracture by skeletal traction would probably have given adequate reduction but joint exercises would have been delayed and approximately three months hospitalization would have been required in a busy Theater of Operations.

**Case 5.**—*Diagnosis:* F. C. C. right tibia and fibula.

*Wounded:* March 27, 1944, 0500 hours, by high explosive shell fragments penetrating right leg (also injuries of other extremities) fracturing the tibia and fibula in the midthird.

*Initial Surgery:* March 27, 1944, 0900 hours. Time-interval, four hours. All wounds débrided, foreign bodies removed, sulfa crystals, vaselined gauze dressing and plaster encasement.

*Reparative Surgery:* On admission, March 31, 1944, his hematocrit was 22. Twenty-four hundred cubic centimeters of blood were given over a three-day period. At operation, April 3, 1944, anterior wounds over a fracture were connected. An unsuccessful effort was made to fix the fracture by multiple screws. Then periosteum over a long middle fragment was stripped and a long plate was applied anteromedially, stabilizing the fracture. Two posteromedial wounds were connected to form a relaxing incision, allowing closure of the operative wound. However, the latter failed to heal completely. The center of the incision opened exposing one inch of plate. There was no evidence of wound sepsis but simply failure of healing due to mechanical factors. At his last plaster change in this Theater in mid-May, the wound was clean but about .75-inch of plate was exposed. Following removal of the metal and several sequestra, in the Zone of Interior, at which time the fracture was firmly united, the wound healed and function of the extremity was resumed.

COMMENT: In retrospect, the fractured tibia might have been adequately stabilized by plating the fibula or treated by encasement traction, thereby avoiding periosteal stripping and the placing of metal at a point where it interfered with closure of soft parts over bone. The anteromedial surface of the tibia is not a good location for the plate if there is any question of wound healing. The wounds in this case determined that the location of the incision was over the site of the metal.

**Case 6.**—*Diagnosis:* F. C. C. femur, junction M/3 and L/3.

*Wounded:* September 28, 1944, by small arms fire.

*Initial Surgery:* October 1, 1944. Time-interval, 60 hours. Extensive excision of devitalized muscle with established sepsis was necessary in the posterolateral thigh through a huge, jagged wound. Vaselined gauze dressing and 1.5 hip spica.

*Reparative Surgery:* On October 17, 1944 (delayed for tactical reasons), the encasement was removed, a K-wire was inserted in the tibial tubercle and the extremity placed

in the 90–90–90 operative position. The contour and location of the fracture plus the delay in definitive fracture management might have been considered an indication for rigid internal fixation. However, wound exploration revealed *no exposed bone* and extensive periosteal stripping would have been necessary for fixation. Therefore, skeletal traction was selected, using the tibial wire for traction and a supracondylar wire for lift. The huge wound was partially closed with good drainage. A snug pressure dressing was applied.

COMMENT: The disadvantages of internal fixation in compound fractures outweighed the advantages, therefore, it was not employed. To have extensively stripped periosteum would have recompounded the fracture, risking bone sequestration. The result justified the judgment.

**Case 7.**—*Diagnosis:* F. C. C. of tibia and fibula, left.

*Wounded:* May 24, 1944, by high explosive shell fragment which penetrated the medial surface of the left leg midthird fracturing both bones.

*Initial Surgery:* Not recorded but apparently routine.

*Reparative Surgery:* At reparative surgery, May 26, 1944, several totally loose fragments of a badly comminuted tibia were removed through the compounding wound. The transverse fracture of the fibula was plated through a separate operative approach, thereby stabilizing the fractured tibia in adequate reduction. The operative wound was sutured but muscle and skin loss precluded suture of the compounding wound. It was filled with fine-mesh gauze and an encasement applied for Orr treatment. The sutured wound healed and the medial wound granulated to complete healing before evacuation to the Zone of Interior in mid-July.

The wound remained healed but union of the fracture was delayed (bone loss). Because wound healing had been achieved early, reinforcing bone grafting was carried out as soon as the indication could be determined. The fracture is now solidly united in full length and alignment.

COMMENT: Wound revision as the primary step of reparative surgery of compound fractures revealed totally loose bone fragments. Fibula plating converted for practical purposes the fracture of both bones of the leg into a fracture of only the tibia. The character of the defect of the wound of injury precluded closure. Therefore, the Orr method was employed with good results. The excellent reparative surgery permitted early and complete reconstructive surgery.

**Case 8.**—*Diagnosis:* F. C. C. of the femur, bilateral.

*Wounded:* March 26, 1944, 0300 hours, by machine gun bullets perforating each thigh, fracturing each femur about the junction of the middle and lower thirds.

*Initial Surgery:* March 26, 0930 hours. Time-interval, 6.5 hours. The wounds of entry and exit were incised and the bullet tracks débrided of the devitalized tissue. The wounds of the left thigh were not extensive, but there was severe muscle damage of the right thigh which created a loss of continuity of the vastus lateralis muscle. Considerable muscle was necessarily excised.

*Reparative Surgery:* On April 9, 1944, three days after admission to the Base Hospital, and after 1,500 cc. of blood replacement, reparative surgery was carried out on both femurs. The right femur was reduced and stabilized by multiple screw fixation, through the compounding wound, enlarged by an incision distally. The size of the defect was reduced by as much closure as possible, which placed soft parts over the metal and most of the exposed bone. The remaining cavity was loosely filled with fine-mesh gauze. In addition, dependent drainage was established through the postero-

lateral plane. The compounding wounds on the left were sutured and dependent drainage was established. Both drains were removed on the eighth postoperative day.

Both extremities were placed in skeletal traction—that on the right to protect the internal fixation, permit early joint motion and provide access to the wounds for necessary dressings—that on the left, for definitive fracture reduction. The sutured portion of the right thigh wound healed and the defect slowly filled with granulations. It was necessary to use two-wire skeletal traction on the left femur but union in excellent reduction was obtained and the wounds healed. A late follow-up observation on March 23, 1945, reveals the fracture firmly united, all wounds healed and about 90 degrees of motion in each knee.

COMMENT: Multiple screw fixation of the right femur produced anatomic reduction and alignment with minimal periosteal stripping. The partial closure covered practically all exposed bone, but it was necessary to resort to a method of loose packing and infrequent dressings to permit granulations to fill the defect. The dependent drainage established on the right was considered important, but that on the left might have been omitted. In fact, the surgeon performing the operation stated that his drain did not reach the fracture site.

**Case 9.**—*Diagnosis:* F. C. C. humerus with bone loss.

*Wounded:* October 21, 1944, 1200 hours, by high explosive shell fragment perforating arm and fracturing the humerus.

*Initial Surgery:* October 21, 1944. Excision of devitalized tissue. Four centimeters of humerus were missing; the brachial artery, median and ulnar nerves were exposed and found intact; the radial nerve was severed. Because of danger of injury to the artery by the sharp fragment ends, a wire loop was used to overcome the 4 cm. gap and hold the fragments in approximation. The wounds were dressed and a Velpeau plaster utilized as transportation splinting.

*Reparative Surgery:* On October 30, 1944, the fracture site was inspected, the wounds cleaned of blood clots and a few tags of muscle excised. The lateral wound was closed. The medial wound was grafted. A slip of fine-mesh gauze extended through the grafted medial wound to dead space about fracture site. A pressure dressing was applied and a shoulder spica used for immobilization. On November 17, 1944, at change of plaster, the lateral wound was solidly healed, a 75 per cent take of the graft was seen. The fracture site appeared to have sealed-off, and there was no opening to bone.

COMMENT: This case illustrates an excellent use of internal fixation at initial surgery and justifies a policy of permitting the procedure in Forward Hospitals on definite indications usually to protect vessels or nerves. If the wire loop had not been used in the Evacuation Hospital, it would have been placed in the Base to overcome the bone deficit. By closure and graft, plus a partial open wound with fine-mesh gauze for drainage the skin defects were minimized and the compound fracture soon became sealed-off.

**Case 10.**—*Diagnosis:* F. C. C. right humerus.

*Summary:* The patient was wounded on April 8, 1944, by a high explosive shell fragment which produced a massive soft-tissue injury of the right arm and a comminuted fracture of the humerus. A radial palsy was present. Initial surgery was the routine. At reparative surgery in the Base, several totally loose bone fragments were removed, producing a one-inch segmental bone defect, which was overcome by the use of a wire loop to hold the major fragments in contact. The radial nerve was visualized intact. The muscles of the arm were sutured over the exposed bone with

fine-mesh gauze drainage from the fracture site and a shoulder spica applied. After a granulating bed had formed, the skin defect was covered by a split-skin graft on May 20, 1944. Complete healing of the compounding wound was obtained and the fracture united prior to evacuation to the Zone of Interior in July. There was partial recovery of radial power.

COMMENT: At reparative surgery, potential sequestra were removed and bony contact predisposing to union was obtained by wire loop internal fixation. Muscle closure over bone obtained the major objective of wound closure. Fine-mesh gauze drainage was used for a few days. Delayed skin grafting completed the reparative surgery.

**Case 11.**—*Diagnosis:* F. C. C. of tibia and fibula.

*Wounded:* June 8, 1944, by high explosive shell fragments penetrating the left leg, fracturing the tibia and fibula.

*Initial Surgery:* Not recorded but presumably routine.

*Reparative Surgery:* June 17, 1944, four days after admission to Base Hospital, exposure revealed two clean wounds, one anteromedial exposing the fracture site, the other posterolateral. The tibia was stabilized in reduction by multiple screw fixation through the anteromedial incision, which was then sutured after a posteromedial relaxing incision. Drainage was established through the posterolateral injury wound. The sutured wound healed and the two posterior wounds were almost healed, with no sinus formation, when he was evacuated to the Zone of Interior in mid-July.

In the Zone of Interior the fracture united in anatomic alignment and the wounds remained healed. He is now on duty in a General Hospital.

COMMENT: Multiple screw fixation permitted stabilization of the fracture in anatomic reduction without additional periosteal stripping and without excessive intrawound trauma. The relaxing incision permitted the sliding of a skin flap and closure of the anterior wound without tension over the exposed bone, thereby attaining a major objective of reparative surgery of compound fractures.

**Case 12.**—*Diagnosis:* F. C. C. femur.

*Wounded:* October 26, 1944, 1200 hours, by high explosive shell fragment, which fractured the left femur in its midthird and produced an extensive soft-tissue wound.

*Initial Surgery:* October 26, 2200 hours. Time-interval, 10 hours. Excision of devitalized tissue; vaselined gauze dressing and Tobruk splint.

*Reparative Surgery:* November 1, 1944, six days after wounding, and three days after admission to the Base Hospital, during which time 1,500 cc. of whole blood were given, the femur was stabilized by multiple screw fixation, and the large gaping wound was partially closed. The wound was dressed with fine-mesh gauze and the extremity placed in skeletal traction. November 15, 1944, the sutured wounds were healed. The fracture site had sealed-off so the remaining defect was skin grafted.

COMMENT: Multiple screw fixation stabilized the fracture in anatomic reduction and permitted handling of extremity for subsequent management of the extensive soft-part wound. Partial skin closure reduced the size of the defect. This is an excellent example of reparative surgery of a severe battle compound fracture. Reduction in skeletal traction is difficult to maintain when the surrounding soft tissue loss is extensive.

**Case 13.**—*Diagnosis:* F. C. C. right tibia lower third.

*Summary:* The patient was wounded by a fragment following a land-mine explosion which penetrated the anteromedial surface of the right leg, fracturing the tibia. At

initial surgery, the wound of entry was débrided and a foreign body removed. At reparative surgery in the Base Hospital a long posteromedial relaxing incision permitted closure of the compounding wound covering the exposed fracture site. The defect created by the relaxing incision was covered by split-skin graft. Complete wound healing was obtained.

COMMENT: The exposed fracture site was covered with soft-parts facilitating their revascularization, preventing contamination at changes of plaster and providing healthy skin over the bone.

**Case 14.**—*Diagnosis:* F. C. C. tibia, upper third, right.

*Wounded:* March 8, 1944, 1745 hours, by high explosive shell fragment which perforated the proximal leg, comminuting the tibia.

*Initial surgery:* March 8, 1944, 2130 hours. Time-interval, 3.75 hours. The wounds of entry and exit were connected to provide exposure for débridement and arrest of severe hemorrhage from the cancellous bone which required tight packing.

*Reparative Surgery:* March 16, 1944, the day after admission to the Base Hospital, the fracture site was cleansed, the irregular wound was sutured so as to cover, as best as possible, the exposed bony cortex, tips of denuded fragments remaining exposed were ronguered away, the wound was dressed with fine-mesh gauze and an encasement applied. The patient remained on his side, facilitating dependent drainage. At change of encasement a week later the wound was clean and "dry" and healing of the closed wounds permitted removal of the sutures. The cavity remaining was loosely filled with fine-mesh gauze and an encasement applied. The latter was changed in late April, at which time the wound was clean and partially filled by healthy granulations. No bony cortex was exposed. He was then evacuated to the Zone of Interior.

COMMENT: The partial wound closure covered, protected and aided in preserving the exposed cortical bone and reduced the size of the wound defect. Initial surgery was excellent, so no further excisional surgery was necessary. The character of the defect including the loss of tissue and residual dead space dictated the Orr method of treatment.

**Case 15.**—*Diagnosis:* (1) F. C. C. left femur, midthird. (2) F. C. C. left tibia, upper third.

*Wounded:* January 18, 1944, 1500 hours, by high explosive shell fragments penetrating left leg and thigh anteriorly, fracturing the tibia and femur.

*Initial Surgery:* January 18, 1944: Débridement of all wounds, removal of foreign bodies, application of a 1.5 hip spica.

*Early Base Care:* January 30, 1944, 12 days after wounding, the wounds were dressed, and femoral skeletal traction instituted, with a boot encasement on the leg and foot. The anterolateral wound compounding the femur was extensive, with muscle loss exposing the femoral fragments for several inches. The fracture of the femur united in good position but there was massive sequestration of portions of the major fragments as well as minor comminuted pieces. The thigh and leg wounds continued to drain with no signs of healing but the patient was not toxemic.

*Reparative Surgery:* April 6, 1944, 2.5 months after injury, at operation, the sequestra of the femur were removed, and dependent drainage was established in addition to the open anterior wound. At exploration of the tibia, sequestra of indriven cortical bone in the marrow cavity were removed. Both compounding wounds were loosely filled with dry fine-mesh gauze, and a plaster encasement applied. Twelve days later, at a change of encasement, both wounds appeared clean. The patient remained afebrile, and was evacuated to the Zone of Interior about May 1, 1944.

In the Zone of Interior all wounds were healed by September, 1944. Both fractures were sufficiently solid by December to permit weight-bearing.

COMMENT: There was massive sequestration of bone not covered by soft parts, including part of the major fragments. Wound sepsis of both the thigh and leg wounds persisted because of sequestra. Early reparative surgery by wound closure over exposed bone might have prevented the sequestration of the femoral fragments and by adequate wound revision might have prevented the septic tibial wound. Following delayed reparative surgery, the processes were controlled, and wound and fracture healing were achieved.

DISCUSSION.—The plan of management provides indicated surgery in an effort to achieve the best possible anatomic and functional result in the least practicable period of time. The old concept that surgery in a known infected field would result in failure and possible serious complications is ignored. The success attained varies with the accuracy of surgical judgment and the skill of operative technic. Wound revision is conceived as a meticulous completion of excisional surgery to remove tissue that may harbor infection rather than a meddlesome and traumatizing procedure. Clean, well-drained wounds require little or no revision. Fracture management permits the surgeon to "know" the fracture. The adjustment of fragments under direct vision may be an important step towards obtaining maximum fracture reduction.

Internal fixation of battle fractures is admittedly a controversial subject. It is utilized when its advantages outweigh the disadvantages and is employed frequently at the primary operation of reparative surgery in fractures about joints to permit anatomic replacement of articular surfaces, *e.g.*, condyles of femur or humerus; in fractures of long bones deep in muscle tissue, a situation which favors early reattachment of soft parts, *e.g.*, the femoral shaft and upper radius; in those fractures which experience teaches are difficult to hold in reduction by other means, *e.g.*, olecranon, associated massive soft tissue loss (Case 12), and in fractures with segmental bone loss to achieve contact of fragments in an effort to prevent nonunion. It is to be avoided when the disadvantages predominate, *e.g.*, the tibia, where periosteal stripping is hazardous because the overlying skin is not a sufficiently vascular soft part and where metal may interfere with even skin closure. The surgeon who finds many indications for internal fixation in the management of simple fractures will find many indications in battle fractures, but he must ever be mindful of the hazards of the method. He who uses it as a last resort in simple fractures will use it sparingly in battle fractures. An accurate appraisal of the possibilities of stabilizing the fracture by plating or multiple screws is essential. If the fracture remains unfixed after the metal is placed, the procedure is doomed, as motion at the fracture site will produce absorption about the screws. Experience verifies this conception.

When the indications and advantages are not clear-cut, it is preferable to perform wound closure and attempt fracture reduction by manipulation or traction. If these are unsuccessful, a planned open reduction and internal fixation may be carried out later, perhaps after wound healing. The important point is that poor anatomic results are no longer accepted for fear of

lighting-up infection if they can be prevented by surgical measures performed under good principles.

Reparative surgery has established *delayed* closure over fractures as a logical and surgically sound procedure. Wound closure is conceived primarily to salvage the denuded bone, *protect* the exposed fracture site and *prevent* sepsis; secondarily, it attempts to speed wound healing by the surgical approximation of tissues, thereby minimizing the resultant scar. It does so under the conception that a wide open wound is not essential for adequate drainage if excisional surgery is complete and dead space held to a minimum; that drainage is preferably dependent and that it may be adequately provided in many instances by fine-mesh gauze or rubber wicks emerging through sutured wounds or counterincisions. The theoretic objection that drains to fracture sites are conducive to sinus formation has not been substantiated in this experience. Wound healing, while affected by several factors, is a natural cellular growth[15] provided the wound does not contain dead tissue, strangulating ligatures, dead space, *etc.* Wound closure, in an effort to achieve rapid wound healing, is practiced to the extent to which these qualifying factors may be surgically obviated.

Clinically clean cases on admission to the Base Hospital lend themselves to the full program, with anticipated good results. Of even greater importance, a surgical approach is established for the clinically dirty wounds and for wounds with established sepsis, groups which always were the major problems in war surgery. By judicious application of the surgical principles of reparative surgery, *i.e.,* excision of dead tissue, obliteration or dependent drainage of dead space, pressure dressings, adequate reduction and immobilization of fractures and staged closures, these problem cases may be converted into clean cases, reparative procedures instituted and the objectives of the program achieved.

A thesis of this treatise is the restoration (or preservation) of the periosteal blood supply of the cortex of bone to prevent its sequestration. Indeed, the major problem of the management of battle fractures is the denuded cortex of bone which will surely sequestrate unless it is rapidly revascularized. In the presence of sequestrating bone, wound healing and fracture union are retarded or prevented. If all denuded bone in a battle fracture could be excised, wound healing would come easy, but the price in deformity is prohibitive. Therefore, the problem is the restoration of vitality to denuded bone while at the same time obtaining and maintaining fracture reduction projected towards bony union and the functional restoration of the extremity. The principles of reparative surgery of compound fractures are designed to solve that problem.

## APPRAISAL OF RESULTS

In a Theater of Operations, statistical results on compound fractures cannot be compiled. End-results are not seen as many cases are evacuated to the Zone of Interior before wound or fracture healing is complete. Multiple

observers in many hospitals compiling tables of results would only confuse the issues. Therefore, conclusions of experienced overseas War Surgeons based upon continuing study and observation must serve to evaluate the over-all program. The consensus of opinion on the reparative program for compound fractures is summarized as follows:

1. Septic patients are few. No deaths, amputations or serious sequelae *resulting from* overzealous reparative surgery have been reported. This refutes the old impression that surgery in an infected field would establish a generalized sepsis.

2. Wound sepsis has been minimized. When it is established following reparative surgery, wound revision is again employed excising or draining the pabulum anticipating staged closure if surgically feasible, rather than await sequestration of the devitalized tissue and risk further local necrosis of living tissues.

3. Fracture reductions are greatly improved as inadequate reduction is not tolerated if it can be improved by nonoperative or operative procedures. Segmental bone deficits forecasting nonunion are rarely accepted.

4. Internal fixation of fractures particularly around joints has restored joint congruity and permitted early joint motion and muscle exercise pointing towards improved functional results.

5. Complete wound healing following suture has been obtained in many cases. In others, the fracture site was rapidly closed-off resulting in, for practical purposes, a simple fracture with skin defects to heal by granulation aided by split-skin grafting. In many cases prolonged drainage from the depths of the wound has been inevitable with any form of treatment, *e.g.*, badly comminuted fractures with many partially detached fragments and with associated dead space. Drainage will persist until the denuded bone has been revitalized or becomes a sequestrum and removed. As sequestration occurs, sinus formation develops and persists. If there is free egress for the drainage, continuing local necrosis is *nil* or at a minimum. Where the sinus is to sequestra that could not be prevented surgically, they must be accepted as a result of the injury. Here, again, the failure of wound healing results from retained dead tissue, the sequestrum, rather than from the invasive action of bacteria *per se*. When the degree of wound healing obtained has not been that anticipated, the result has been attributed to errors in judgment as to what was surgically feasible or to errors in technic. Under the plan of management scar formation, with its effects on future function, has been minimized.

It is regretted that figures are not available on the end-results of fracture and wound healing obtained when metallic internal fixation was used. It is stressed that reduction of the fracture, not the use of internal fixation is the objective. Observation within the Theater and reports from the Zone of Interior indicate that, in a substantial majority, the fractures have united and the wounds have healed. Persistent sinus formation, possibly to metal, possibly to sequestra, is anticipated in a certain percentage of cases. If

union of the fracture in good position occurs and the wound heals after removal of the metal and sequestra in the Zone of Interior, as is anticipated in this group, the result will be considered satisfactory. Any nonunions should be evaluated against the probabilities of nonunion had internal fixation not been used. The over-all results must be evaluated in the light of the problem at hand for which the surgeon chooses internal fixation as a part of reparative surgery. Through arrangements approved by the Surgeon-General and the Surgeon, Mediterranean Theater of Operations, a detailed follow-up study on this group of cases is under way, and will be the subject of a later report.

A comparative appraisal of the reparative program with methods of management previously employed is deemed unessential. It is sufficient that veteran war surgeons who have observed and studied the development and results (as seen in this Theater) of reparative surgery of compound fractures are satisfied that the objectives of the program have been "surrounded and isolated" if not "taken." Further experience with continuing reëvaluation of results will undoubtedly produce modifications in the surgical management of these war wounded. Blood and penicillin, the surgical adjuncts, have contributed greatly, possibly their maximum, to the success of the program. However, improved results may be anticipated with perfection of surgery for which there is no substitute in the management of the wounds of war.

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