OPERATIVE TREATMENT

Operative treatment is indicated for [most casualties] as soon as possible after the receipt of the injury. Each hour increases materially the damage from infection. . . .

After the arrival of the patient at the hospital, expedition in the surgical treatment must be effected by the help of a well organized routine. The first essential is the careful sorting of cases at the admission tent. Patients presenting a considerable degree of shock should be sent to the shock ward. [Today this is called the resuscitation area. *Authors*] They must first be treated for shock, and operation deferred until reaction is evidenced by a rise in blood pressure. . . . [We know now that immediate surgery is the most effective resuscitation for an exsanguinating casualty. *Authors*] **Walking wounded and slightly wounded [casualties] to the dressing ward or to the service for [the]** slightly wounded. Of the remainder the majority demand X-ray examination and early operation. The dressings are removed and the wounds carefully examined. Those whose condition does not contraindicate it are bathed. Cases with active bleeding, with sucking chest wounds, with penetrating abdominal wounds, with fractures of the femur, with penetrating wounds of the knee, and with multiple wounds receive the first attention. . . . Cases with uncomplicated wounds of the soft parts are, in general, cared for after the more urgent cases.

The success of operation depends largely upon the thoroughness of the roentgenologist's examination and the accuracy of his findings. . . . [Based upon our experience in subsequent wars, Pool's assessment of the value of roentgenography was overenthusiastic. *Authors*]

The patient should always be examined by the surgeon before anesthesia is begun. In wounds of the extremities, the surgeon should determine whether there is a nerve lesion and an arterial pulse. Apparently innocent wounds **of the trunk may, in reality, be very serious. The possibility of intrathoracic or should** always be borne in mind. . . .

The preparation of the patient usually is done in the operating room on an extra table while the preceding operation is being completed. The wound is protected by gauze, the parts shaved thoroughly, and scrubbed with soap and water over a wide area. Application of chemicals may follow. [Pool was referring to an antiseptic such as Dakin's 0.5% sodium hypochlorite solution. Today, we would administer a systemic antibiotic. *Authors*] It is important to prepare a wide field and, in wounds of the extremities, to encircle the limb. The part is draped economically with towels and sheets.

A general anesthetic should be employed except in rare cases. . . . Local anesthesia is rarely used.

Debridement

The general plan or aim of surgical treatment is the prevention or limitation of infection, the early closure of the wound, and the preservation or reestablishment of function. The first indication is to obtain a clean wound. This is accomplished, primarily, by debridement of tissues—that is, by free incision and excision of injured and contaminated tissues, and by removal of foreign material carried by the missile into the wound.

The principle of this procedure may be visualized by considering a typical case of a wound of the soft parts with a tract from the skin to the interior of the muscles, containing a fragment of shell and pieces of clothing along its course, and having for its walls lacerated muscle. Pathogenic organisms are present throughout this tract. The devitalized, pulpified walls of the tract furnish an ideal medium for growth of bacteria. One can readily imagine that immediate wide excision of such a tract as a whole, including removal of the devitalized skin, subcutaneous tissues, aponeurosis, and muscle, together with the shell fragment, clothing, and microorganisms contained within the tract, will leave a healthy aseptic wound, provided the skin adjacent to the wound has been properly prepared and the operator has employed a technique comparable to that used in clean operations. To obtain an aseptic wound is the ideal desired, though it is doubtful whether this is actually achieved in any case. But, however skeptical one may be as to the total eradication of microorganisms under the conditions [that] prevail in these wounds, many wounds after operation undergo repair as if aseptic, and cultures and smears made from them are often sterile.

Even during times of greatest activity, debridement should be properly carried out and the best possible technique observed. The temptation to relax in these respects during periods of stress should be resisted. The time saved by careless work is not sufficient to warrant the additional risk incurred; only rarely is it justifiable to substitute incision and drainage for debridement in recent wounds.

The closure of the wound may be carried out by immediate or primary suture, delayed primary suture, or secondary suture.

Technique. [In the following passage, Pool describes the technique to use in treating a wound like that shown in Figure 5-29. Pool's original illustrations are reproduced as Figures 5-30 through 5-32. *Authors*] The skin incision, when possible, should be made parallel to the long axis of the limb. This permits wide exposure of the underlying tissues and renders subsequent suture less difficult. **A** transverse incision should rarely be employed. In the case of a deep

Fig. 5-29. The perforating soft-tissue wound of the thigh of a casualty who had been shot by an AK47 about 4 hours earlier. The wound of entrance is anterior. Note the extensive ecchymosis and swelling of the thigh—conditions that mandate operative intervention. The wound shown here is like the schematic one shown in Figure 5-22, and also represents the wound whose management Lieutenant Colonel Pool describes in this chapter.
Source: Wound Data and Munitions Effectiveness Team

transverse perforating wound, it **is** better to make two longitudinal incisions and work inward from each rather than make a transverse incision with division or excision of considerable muscle tissue. In the former case, suture is usually readily done at an early date, whereas in the latter, primary suture is often impossible because of the difficulty of uniting the severed muscle. Even when this is accomplished, the sutures frequently tear out and allow retraction of the muscle with resulting dead space and breaking down of the wound. When the transverse wound has not been closed primarily, or has reopened, secondary suture is delayed and is more difficult. The functional result is also less favorable on account of the transverse section of the muscle. [The actual management of the casualty whose thigh is shown in Figure **5-29** involved a transverse incision that divided most of the quadriceps muscle. *Authors*]

Transverse incisions should be employed in the extremities only in superficial wounds involving the subcutaneous tissues or with very superficial involvement of muscle. In the gluteal region and on the trunk the incision, in general, should be in the direction of the fibers of the underlying muscle. Occasionally, as in deep, transverse, through-and-through wounds **of** the calf, a long median incision may be employed advantageously; the tract is exposed in the middle of its course and debridement is carried out from this region in both directions. The skin wounds of entrance and exit are excised by small elliptical excisions and the wound edges approximated. [The midline incision, of course, is left open. *Authors*]

The operation itself consists in the free excision of all tissues with which the foreign body has come into contact and all devitalized tissues, except structures such as nerves, large vessels, and bones, whose removal would interfere with the function of the part and cause permanent disability. Free excision, however, does not mean ruthless, blind butchery of the parts but rather careful, intelligent dissection, with liberal removal of such parts as should be removed, and with equally scrupulous preservation of such parts as may be left with safety.

The wound itself, with all contused skin, is excised by removing an elongated ellipse of skin. No healthy skin should be sacrificed on the sides of the ellipse, as it is important to conserve as much skin as possible in the transverse plane of the limb to facilitate suture. This is especially important in the forearm. [During the Vietnam War, surgeons commonly excised a penny- or nickle-sized piece of skin around the wound of entrance of even tiny fragments. This served no useful purpose. *Authors*] There is no advantage in attempting debridement through a short incision. **A** deep debridement demands a long incision. The skin incision must always be vertical to the skin surface; the tendency

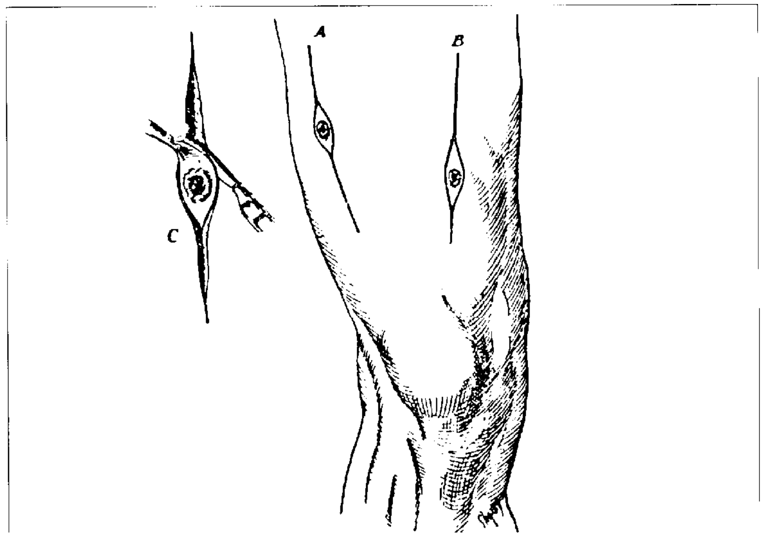

Fig. 5-30. Initial surgery for a wound like the one shown in Figure 29. Two parallel longitudinal skin incisions are made. Little **skin is excised.**
Source: Reference 70

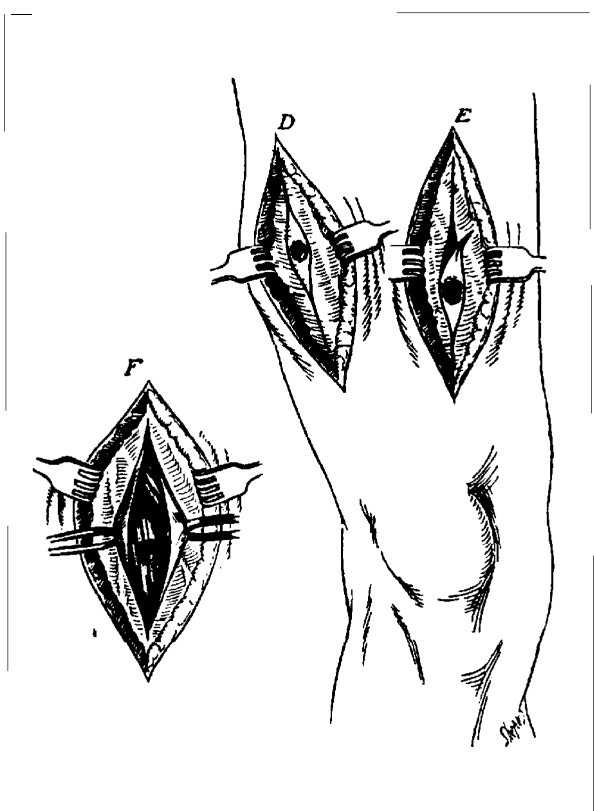

Fig. 5-31. The fascia is incised to further expose the permanent cavity.
Source: Reference 70

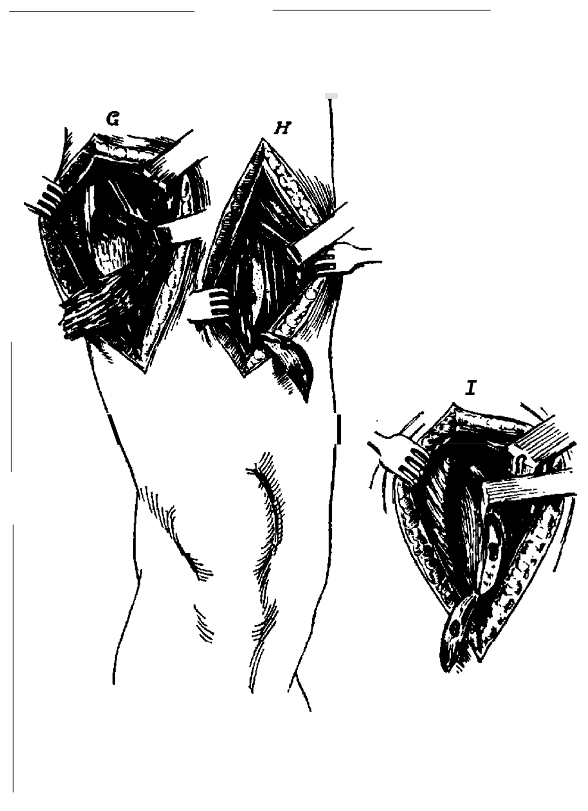

Fig. **5-32.** Debridement of muscle is complete.
Source: Reference 70

to bevel the incision should always be avoided, as this interferes materially with satisfactory suture. . . .

When there are two wounds, one or two incisions may be employed as already described. Similarly, when a foreign body has taken a transverse or oblique course, penetrated a considerable distance, and lodged in the tissue, two incisions may at times be used to advantage, one over the foreign body and one to excise the wound of entrance, both being used for excision of the tract.

After excision of the skin edges, the instruments should be discarded or washed in alcohol. The skin edges are widely retracted and the subcutaneous tissues removed as far as there is evidence of laceration or contamination [Figure 5-30]. It is not necessary, however, to remove all blood-infiltrated subcutaneous tissue. In general, the fingers are kept out of the wound and dissection is made with instruments. Good exposure of every plane by retraction is essential, the edges being rolled outward and tooth retractors or some other form of clamp, such as the Allis forceps [used].

The aponeurosis is treated in the same manner as the skin—that is, by a long, straight incision with removal of the wound [that is, the permanent cavity] by a relatively narrow ellipse [Figure 5-31]. The aponeurosis is of great value in secondary sutures in the lower extremity and shoulder, and, therefore, should not be ruthlessly sacrificed. It must be emphasized that liberal excision of aponeurosis or skin is not necessary because it is not in these tissues that infection ordinarily originates or develops. The aponeurosis should be widely retracted and muscle planes exposed. It is this tissue [muscle] that favors infections. All traumatized and devitalized muscle must be removed. This demands excision for a distance of 0.5–1.0 cm on all sides of the tract. [This is the zone of extravasation. Note that the excision is not to extend for inches into the muscle; there is no need for radical excision of muscle. *Authors*] The dissection is made parallel to the fibers of the muscle; a long, relatively narrow ellipse is removed so that the sides tend to fall together after the excision. The dissection should be made by planes, muscles should be identified, and the situation of nerves and large vessels should always be borne in mind. The tract should be followed by sight, not by probing; for this purpose a reflecting headlight is indispensable. [Headlights were not **issued** to surgeons in Vietnam; army surgeons in the Panama campaign took their own. *Authors*] If the tract is lost between muscle planes, often slight flexion or extension of the limb will bring it into view. Careful hemostasis is necessary at all stages. Sponging of blood should be done by pressure and not by rubbing, because the latter method may carry organisms from an infected to a clean part of the wound and may **cause** a small tract to be lost to view. The foreign body should not be extracted until reached in the dissection, otherwise the parts fall together and the tissues immediately beyond the [foreign] body, which often contain clothing, may not be adequately excised [Figure 5-32]. When the excision is complete all exposed muscle must look healthy, contract when pinched with forceps, and ooze when snipped with scissors; otherwise its vitality has been diminished to such a degree as to favor gas bacillus infection. [Note Pool's criteria for deciding which muscle is devitalized: the four Cs; "look healthy" includes both consistency and color. *Authors*] At times the [surgeon's] finger must be introduced to search for the foreign body, but, as a rule, in cases where the tract is lost or where for other reasons difficulty arises in locating the foreign body, fluoroscopy should be employed. If this fails, the tissues should not be blindly torn up, but after a careful search one should desist, leaving the wound open and removing the foreign body subsequently, after more careful X-ray localization or under the [fluoroscope] screen. [Current practice de-emphasizes finding the foreign body. *Authors*] When the deep tissues are so markedly infiltrated with blood **as** to suggest the possibility of constriction of the muscle under the overlying fascia, this fascia must be incised so as to free the muscles from internal pressure.

When the fragment or tract is in proximity to a large vessel, **as,** for instance, the brachial vein, the vessel should be inspected. . . . [Pool goes on to describe the management of vascular injury. Not surprisingly, much World War I–doctrine pertaining to neurovascular repair is no longer valid. *Authors*] Though sudden and unexpected hemorrhage will occasionally confront the surgeon, the absence of an arterial pulse below the lesion and the widespread [bloody] infiltration of the soft tissues about the wound usually warn the operator in advance of the presence of a vascular lesion.

Care should be taken to avoid injury to nerves by careless dissection. A severed nerve should be united. . . . [Modern practice does not support nerve-repair during initial wound surgery. *Authors*]

When the excision has been completed all hemorrhage should be controlled. As little catgut as possible should be buried. [The same can be said **of** the synthetic absorbable sutures now available. *Authors*] The wound should be irrigated with saline. . . .

If the wound is left open, vasolined gauze is placed over the exposed skin edges and subcutaneous tissues in order to prevent the dressing from adhering and to lessen oozing and pain when the dressing is removed. . . . [Modern practice would cover the wound with fine-mesh gauze. The important point is **to** not pack the wound. *Authors*] Dry gauze is applied over this and the dressing kept in place with a bandage. . . .

Primary and Secondary Suture

There are two conditions under which war surgery is performed at the front: first, [during] relatively quiet periods; second, times when military activities are acute. . . .

The ultimate aim of treatment is to restore the soldier to full activity, with complete restoration of function, in as short a time as possible. Obviously, one of the conditions of such restoration is the repair of the wound. During quiet times, early closure of the wound may be undertaken successfully in a large proportion of cases. Great benefit thereby accrues both to the patient and to the service. . . .

It must be recognized, therefore, that local conditions such as the degree of battle activity alter materially the indications for suture, particularly for primary suture, in the advanced area.

[T]he general principles and [techniques] of the three varieties of suture of war wounds, namely, [*(a)*] primary suture, [*(b)*] delayed primary suture, and [*(c)*] secondary suture in wounds of the soft parts [follow:]

Primary Suture. Debridement having been completed, the choice of treatment lies between primary suture and leaving the wound open. If ideal conditions, that is, early and thorough debridement, have been approximated and the [casualties] can be watched for some days, primary suture may be made. In active periods, as in an offensive, when there are many wounded, the exigencies of a service demand haste in the primary operation, and the patient must be evacuated, passing from the operator's control soon after the operation. Under these conditions, primary suture should not be considered.

The advantages of primary suture are obvious; the disadvantages consist chiefly in the danger of closing within a wound, especially within a wound imperfectly debrided . . . anaerobes of the types [that] produce gas gangrene. A resulting gas bacillus infection, or a pyogenic infection in a few cases, will counterbalance many successful closures. . . . [Military doctrine during World War I did not absolutely prohibit primary closure. Pool discusses in detail the technical and administrative requirements for primary suture of war wounds and concludes that, as a general rule, only wounds of the face and scalp can be considered for primary closure with any frequency. *Authors*]

Technique. Thoruugh debridement is essential, and aseptic technique must be observed throughout the opcrotion. Hcmostasis must bc complctc. Thc wound should bc to remove blood clots and loose fragments of tissue.. . . The muscles and aponeuroses are approximated with interrupted catgut. As little and as fine catgut should be introduced as will approximate the tissues and obliterate dead spaces. The skin and subcutaneous tissues are closed with interrupted silkworm gut. [Modern practice employs synthetic absorbable sutures rather than catgut for the subcutaneous tissues and fine wire or nonfilamentous sutures for the skin. *Authors*] Urainage should be avoided. If employed, the drain should be removed as soon as possible, in general, within **24** hours. . . . After the dressing has been applied, the part should be immobilized.

A wound [that] has been closed by primary suture should be examined within **24** hours. . . . These precautions can not be too strongly urged. [These precautions were taken to avoid the development of gas gangrene, which Pool discusses at length. *Authors*]

Delayed Primary and Secondary Suture. The distinction between delayed primary suture and secondary suture is one of tissue repair rather than of time. Delayed primary suturc is onc in which thc cdgcs can bc approximotcd and will unite without excision of tissue. Secondary suture is one in which the epidermis has grown inward and must be excised for proper union [to occur]. This is, in general, about one week. In late secondary suture, dense granulation tissue must also be excised. . . . [Pool goes on to discuss the need for bacterial cultures of the wound as a determinant of when it may be closed. His primary concern was finding hemolytic cocci; their presence precluded wound closure. Of course today the hemolytic cocci would be eradicated with an antibiotic and the wound would be closed with antibiotic coverage. *Authors*]

Delayed primary suture is usually made within 6 days after the primary operation. The advantages of this method are the practical elimination of the danger of gas bacillus infection and the marked lessening of the danger of pyogenic infection. The disadvantages are the possibility of post-operative contamination of the open wound and the subjection of the patient to a second operation. . . . [Thus the modern prohibition of changing dressings. *Authors*]

Technique. The details of [delayed primary closure] are the same as for primary suture. . . . [There are] two varieties of secondary suture:

Secondary suture of the skin. The incision surrounds the new epidermis along the wound edges. A healthy normal skin edge must be present for successful suture. The skin is freed by undermining in all directions as far as necessary in order to approximate the edges with minimum tension. The separation is made in the plane immediately superficial to the deep fascia. Only dense scar tissues or projections of granulation tissue are removed from the wound. The deep fascia are then approximated with interrupted catgut when possible; usually this may be done in the thigh and shoulder, but rarely in the leg, arm, and forearm. The skin and subcutaneous tissues are closed with silkworm gut. . . . [Modern practice would use wire. In primary and delayed primary closure (but uncommonly in secondary closure) the skin edges can sometimes be approximated with tape, which is less traumatic than suturing and therefore desirable. *Authors*] The results of suture are directly proportionate to the degree of tension. If there is extreme tension, infection may be expected. . . .

Secondary suture reconstruction. The granulation tissue and scar tissue are removed from the entire wound and all layers are reconstructed by suture.[70]

ANAEROBIC INFECTIONS OF MILITARY IMPORTANCE

Gas Gangrene

Gas gangrene is the generic name for three discrete clinical syndromes that manifest severe and frequently fatal infections. They are especially interesting to military surgeons because in civilian medicine. Clostridial infections were especially common during World War I, perhaps because of the unique (that is, the heavily manured) battlefield conditions in Europe.

The three syndromes are known by a variety of names:

- *Necrotizing fasciitis,* also called *anaerobic cellulitis* and *clostridial cellulitis.* This infection involves subcutaneous and connective tissues and spreads along fascial planes without destroying either the overlying skin or the underlying muscle. The pathology is primarily due to the growth of toxigenic clostridia such as C. *perfringens* or *C. septicum,* but the usual presence of a polymicrobial flora—including streptococci and staphylococci—suggests that the fully developed syndrome requires the synergistic interaction of several bacterial species.
- Gua *gangrene,* also called *clostridial myonecrosis* and *clostridial myositis.* This clostridial infection invades and destroys living muscle. *C. perfringens* is present in most cases, but depending upon the locale, other toxigenic clostridia such as C. *novii* and *C. septicurn* may also be present.
- *Anaerobic streptococcal myonecrosis,* also called *streptococcal myositis.* This infection, also characterized by necrosis of living muscle, is caused by anaerobic streptococci of the tribe Peptostreptococceae. Like the other anaerobic infections, this usually indicates a mixed bacterial flora including aerobic streptococci and staphylococci.

The effects of all the forms of gas gangrene are devastating, but because their prognoses and therapies are very different, medical officers must learn to distinguish among these syndromes (Table 5-15). While a patient with any of the three fully developed syndromes will be gravely ill, the "explosive" onset of clostridial myonecrosis is a distinguishing feature that helps make the diagnosis. The actual kind of gas that is produced is not known, but its presence can bc detected on a roentgenogram. The tissue and pus contain gas bubbles that are not only visible but also can be palpated under the skin. However, gas production is not necessary to establish the diagnosis, and the presence of gas, which may have been aspirated into the permanent cavity during temporary cavitation, does not necessarily indicate an anaerobic infection. Although wounds in the buttocks and legs are most likely to become the sites of anaerobic infections, all other wounds should be considered at risk.

Prevention is more important with these anaerobic infections than with any other diseases. Traditional prophylaxis has emphasized that tissue at risk for anaerobic infections be surgically removed. In fact, preventing gas gangrene has been the raison d'etre for much of the military surgeon's soft-tissue wound management. Today, however, perhaps less emphasis should be placed on prophylaxis by radical excision. Experimental and, to a lesser extent, clinical evidence suggest that early administration of antibiotics may be as beneficial to the casualty—and far less disfiguring.

Medical officers must not forget that gas gangrene is most commonly accompanied by a major vascular injury that causes extensive muscle ischemia. No systemic antibiotic—including penicillin—is likely to be effective in this circumstance. And there should be no doubt that surgery is the therapeutic intervention of choice when confronted with established clostridial myonccrosis.

Surgical intervention is required in all cases of anaerobic infection if for no other reason than to establish the extent of the infection. However, specific aspects of the surgery and the antibiotics employed depend upon the syndrome being treated.

Anaerobic Fasciitis. Make incisions that expose the underlying fascia without devitalizing the overlying skin. Since a polymicrobial flora is likely, antibiotic therapy should involve using more than just penicillin, although it remains the agent of choice when clostridia and beta-hemolytic streptococci are present. Additional drugs that have been proposed are *(a)* an aminoglycoside, *(b)* clindamycin or metronidazole, and *(c)* ampicillin. Optimal post-operative wound care usually includes continuous wound irrigation. Note that skeletal-muscle debridement is not emphasized. This is usually unnecessary, although neglected anaerobic fasciitis associated with clostridia may progress to myonecrosis.

Clostridial Myonecrosis. Radically excise in-

TABLE **5-15**

DIAGNOSTIC FEATURES OF ANAEROBIC SOFT-TISSUE INFECTIONS

Syndrome	Necrotizing Fasciitis	Clostridial Myonecrosis	Streptococcal Myositis
Typical Wound	dirty, old, subcutaneous contamination	large muscle group containing dead muscle	not defined
Incubation	>3 days	<1 day	**3 4** days
Onset	gradual	acute	insidious
Toxicity	slight	very severe	slight, then severe
Pain	absent	very severe	variable
Swelling	slight	marked	marked
Skin	normal	pale, then tense, bronzen, bullae	tense
Discharge	slight	variable	profuse
Gas	abundant, not in muscle	rarely pronounced in muscle	little
Smell	foul	sweet to foul	slight
Muscle	no change	necrosis	early edema, then necrosis

Source: Based on Table 20 **in reference 41**

fected—not just necrotic—muscle. (Some surgeons use Gram stains of excised muscle as a guide to the extent of the resection.) Amputating an extremity may be necessary and can be life-saving when the patient **manifests severe systemic toxicity. Give Penicillin G** intravenously at the rate of 1–2 million units every 2–**3** hours (a total dose of 20 million units per day). Because most infections are polymicrobial, most authorities recommend using a second antibiotic—such as chloramphenicol—as well.

Serum therapy with an antitoxin directed against the principal toxins elaborated by the clostridia was successfully used during World War 11, but for unknown reasons has since fallen into disuse. The vaccine is designed to **inactivate the alpha toxin, a lecithin**ase, and the omega toxin, a protease. However, these antitoxins are no longer available through military supply channels.

Hyperoxia inhibits the growth of clostridia and **decreases their** production **of toxins. Civilian sur**geons have used hyperbaric oxygen therapy as an adjunct to surgery and antibiotics. The U.S. Air Force is presently attempting to solve the logistic and administrative problems that impede fielding hyperbaric oxygen in third-echelon surgical facilities.

Clostridial myonecrosis, although increasingly rare (only **22** instances out of a population of 132,000 Vietnam War casualties), remains one of the bona fide horrors of war (Figure 5-33).

Streptococcal Myositis. vention in-

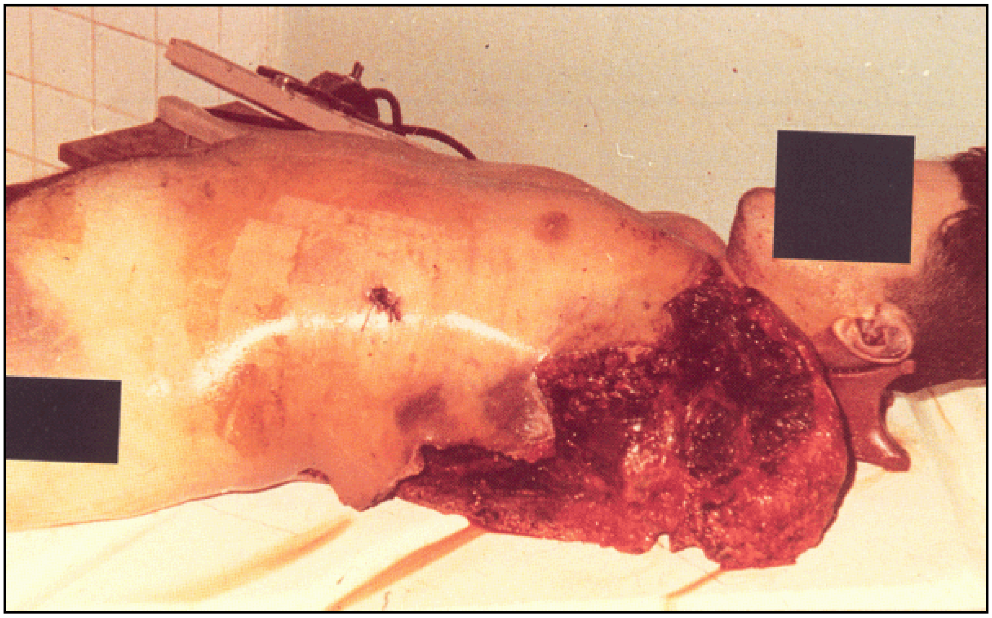

Fig. ***5-33.*** This casualty sustained a perforating gunshot wound of his left shoulder. The bullet severed the axillary artery, which surgeons repaired during initial wound surgery. Signs and symptoms of clostridial myonecrosis were present within 8 hours after the casualty was wounded. Surgeons re-explored the wound, found that their arterial reconstruction had failed, and because gas gangrene was developing rapidly, performed a forequarter amputation. The casualty died 22 hours later. His bronzen, edematous chest wall is characteristic of this terrible disease.
Source: Wound Data and Munitions Effectiveness Team

volves excising the necrotic muscle, but because penicillin therapy will limit the spread of this disease, the extent of excision need not approach that practiced with clostridial myonecrosis. Extensive fasciotomies may be required to *(a)* alleviate vascular compromise and *(b)* allow antibiotics to reach the septic area. Administer Penicillin G intravenously at the rate of 1–2 million units every 2–3 hours until sepsis has abated.

Tetanus

Tetanus should not occur among American military combat casualties. **All** soldiers receive mandatory active immunization with tetanus toxoid when they are inducted, and all casualties, regardless of their injuries, receive a tetanus toxoid booster. Military medicine does not make the civilian distinction between minor, clean wounds and tetanus-prone wounds. Prophylactic administration of human tetanus immune globulin has not been necessary in past wars, no doubt because *(a)* the policy of universal active immunization Is effective, and *(b)* military surgeons take excellent care of tetanus-prone wounds.

But remember that the successful tetanus prophylaxis **of** past wars partly depended on the fact that most soldiers were draftees who were discharged within ***2*** years—when their antibody levels would have been far above the minimum protective level. Members of today's professional army may serve many years after their initial immunizations; if they have not received a recent booster, they are at risk of developing tetanus if they are wounded. Data from World War I and World War II indicate that **1%–3%** of nonimmunized casualties can be expected to develop tetanus.[71] In addition to the tetanus toxoid boosters that all casualties routinely receive, those at risk also require tetanus immune globulin (at least 250 units).[72]

Using antibiotics prophylactically will also decrease the occurrence of tetanus, since antibiotics such as penicillin, erythromycin, and tetracycline inhibit the reproduction of the vegetative phase of *Clostridium tefani.*

ANCILLARY ASPECTS OF WOUND BALLISTICS

Retained Projectiles

Most projectiles are nonperforating and are not removed at initial wound surgery, remaining lodged within the casualty's body. The indications for their subsequent removal include the following:

- proximity to an internal viscus, such as a bronchus or intestine, with the attendant possibility of subsequent erosion into the viscus
- ongoing infection or episodes of hemorrhage from the wound tract
- persistent pain or impairment of function
- psychological distress

These requirements are infrequently met; the overwhelming number of retained projectiles, especially those in soft tissue, cause no problems and need not be removed. Exceptions are projectiles in the central nervous system, the eyes, and the heart. Size is the main criterion for removing retained projectiles from less-sensitive areas such as the lungs and abdomen: In **general, projectiles with diameters greater than 1.5 cm** should be removed. No criterion has been established for removing projectiles retained in soft tissues except for the obvious indication of persistent local sepsis. But removing even large projectiles may be difficult. The foreign bodies are frequently hard to find, and the surgical exploration may cause even more tissue-damage than the projectile did. The history of military surgery contains many examples of "metal detectors," but none seem to have stood the test of time. Beyond two-view radiography, intraoperative fluoroscopy, and computed axial tomography—which are not likely to be available in combat-zone hospitals—the only additional diagnostic modality that has been suggested for use in the intraoperative localization of retained projectiles is high-frequency B-mode ultrasound.[73] Two aspects of retained projectiles require additional discussion: vascular migration and lead poisoning.

Migrating Projectiles. Rarely, a projectile may gain access to the casualty's vascular system and not cause life-threatening hemorrhage. Of course, most projectiles that penetrate into vessels that are large enough to have anatomical names cause massive exsanguination. The **projectile may remain dormant at its original site** for varying lengths of time, but eventually it will migrate to another part of the body where it may cause vascular obstruction. The WDMET database contains one example of this phenomenon: **A** casualty sustained a solitary wound in the left anterior superior chest (Figure 5-34). Surprisingly, although the roentgenogram showed a hemothorax, it showed no evidence of the projectile that caused it (Figure 5-35). Later the same day, the casualty complained of pain in his left leg, which was cool, pale, and pulseless. A roentgenogram of his left knee showed a fragment located in the area of the popliteal artery (Figure 5-36). The surgeon removed the fragment from the artery, and the patient had a benign post-operative course. The fragment must have entered a pulmonary vein and then migrated through the left atrium, the left ventricle, the aorta, the left common iliac artery, the left external iliac artery, the left femoral artery, and into the popliteal artery, where it lodged and cut off the circulation to the leg.

Among the 7,500 casualties listed in the Vietnam Vascular Registry, a team of vascular surgeons found migrating projectiles in only **22** of them.[74] Since the major clinical manifestation of projectile migration is vascular, this survey probably counted most of the **cases that occurred during** **War. Assuming** about **150,000** nonfatally wounded American casualties, the prevalence of migrating projectiles among combat casualties is probably less than 0.02%. About 80% of the migrating projectiles were found in the arterial circulation, which suggests that they entered through a pulmonary vein. The remaining 20% of projectiles were found in the venous systemic circulation. Although the usual pattern of migration is *antegrade* (that is, from the extremities to the lungs), retrograde venous migration has been described.[75] Fragments accounted for 90% of the migrating projectiles observed in Vietnam.

While migration can occur anytime after wounding, it most commonly occurs within **3** weeks. Removing a projectile that appears to lodged in a large central vessel before it migrates is clearly desirable, and longstanding doctrine recommends prophylactic removal of projectiles embedded in the heart.

Lead Poisoning. Most retained projectiles are fragments made of iron. But given the large number of people who have retained projectiles that are partially or completely made of lead, the number of reported **cases** of **lead poisoning caused by retained projectiles** is surprisingly low.[76] Nevertheless, lead poisoning does occur. Its clinical presentation can be quite pleomorphic and includes encephalopathy, anemia, nephropathy, and abdominal pain. Absorption of lead

Fig. **5-34.** This casualty was wounded by a fragment that entered his body through the left anterior superior chest wall. There was no wound of exit.
Source: Wound Data and Munitions Effectiveness Team

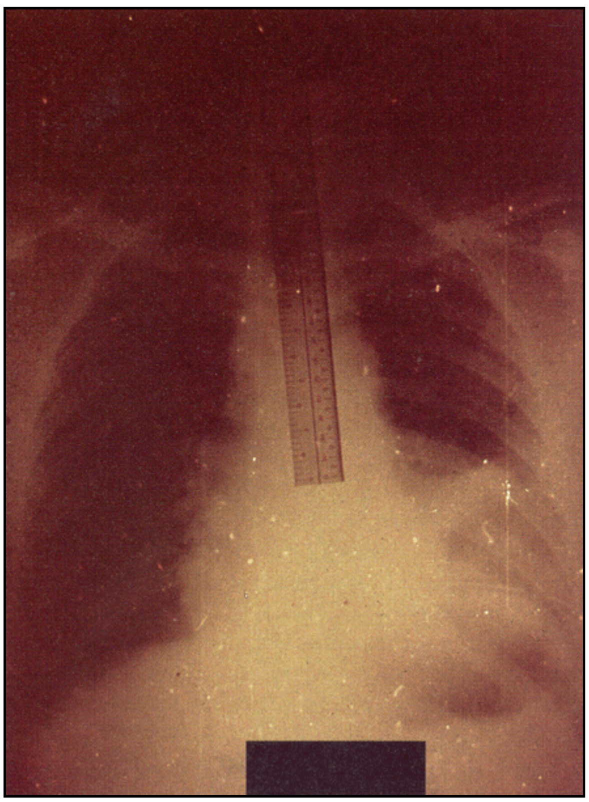

Fig. **5-35.** This roentgenogram of the chest of the casualty shown in Figure **5-34** shows a hemothorax but no sign of the projectile.
Source: Wound Data and Munitions Effectiveness Team

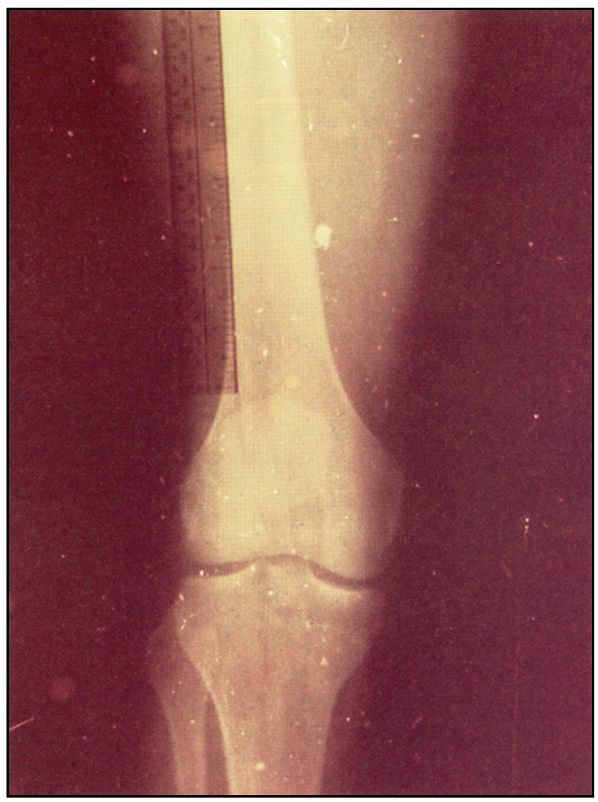

Fig. **5-36.** This roentgenogram shows the missing projectile, a fragment located near the left knee of the casualty shown in Figure **5-34.** The surgeon found the fragment in the popliteal artery. After it lacerated the casualty's lung, the fragment probably entered a pulmonary vein and embolized to his leg.
Source: Wound Data and Munitions Effectiveness Team

seems to be accelerated if the projectile is retained within a synovial space. Experimental studies indicate that lead concentration in the blood peaks within 4–6 months.[77]

Blunt Trauma That Results from Ballistic Projectiles

Blunt trauma may be the major injury that a ballistic projectile causes when *(a)* body armor defeats a projectile and *(b)* a projectile such as a rubber bullet is used. In both circumstances, the mechanism of injury is localized, rapid, inward deformation of the body. The more rapidly the deforming force is applied, the greater the potential for injury; the longer the duration of the impact, the greater the energy transfer. Usually a projectile's mass, not its velocity, determines the energy transfer necessary to produce blunt trauma. Both stress and shear waves may be generated at impact, although shear waves cause most of the injury. Contusion of the underlying soft tissues is the major clinical finding.

Body Armor. The nature of the injury seen when blunt trauma occurs behind body armor, especially armor worn over the trunk, depends upon the protective equipment's design. Hard, inflexible substances such as steel or ceramic plates may themselves be broken up as they defeat a projectile. The armor's breakup diffuses the projectile's impact over a wide area, and soft-tissue contusion can be extensive. When flexible armor defeats a projectile, both the impact and the underlying injury are more localized and, in that area, more intense, because the protective material protrudes into the body. Blunt trauma occurring behind body armor can be markedly decreased if its design includes a foam-rubber-like pad between the armor and the soldier's body.[78]

Rubber and Plastic Bullets. Rubber or plastic bullets, such as those used in civilian crowd control or to control rioters, are soft, broad, blunt, nonmetallic projectiles that have a muzzle velocity of about 200 fps and kinetic energy of about 370 J. When fired at the recommended range of 30 m or more, they are unlikely to penetrate the skin and usually cause only a painful bruise. When the range is 20 m or less, they can cause more serious soft-tissue injuries, fractures of small bones, and serious injuries to the eyes, brain, and lungs.[79] The original rubber bullets were notably unstable in flight, and consequently were inaccurate when aimed at a body part like the legs. Plastic bullets—designed to be more stable than rubber ones—appear to have lessened the numbers of facial and skull injuries that inadvertently occurred, with a corresponding increase in hits to the aiming point.[80]

Since soft-tissue contusion is the most common injury caused by these bullets, their introduction has not created any new management problems. In rare instances, slough of tissue has occurred, necessitating a skin graft.

SUMMARY

Infection and sepsis are the complications of soft-tissue wounds most likely to prevent a casualty's early return to his unit. Most penetrating wounds sustained on the battlefield are contaminated with a variety of bacteria, but contamination does not necessarily lead to infection. Most wounds will probably heal without infection or with only a well-localized wound abscess of little consequence. The likelihood that a wound will become infected depends upon many factors including the season, the nature of the soil, the biophysical aspects of the wound, and the casualty's physical resistance to infection.

In the past, the pyogenic cocci were the most likely sources of wound sepsis; a few casualties (certainly less than 20% and probably less than 5%) were at risk of developing life-threatening sepsis from organisms like the clostridia and (to a lesser extent) *Streptococcus pyogenes.* This group of casualties probably sustained wounds that contained more than a trivial amount of devitalized muscle.

Bacterial contamination is not constant from war to war. It depends on the battlefield environment, the local climate, the season of the year, the weapons used and the kinds of wounds they create, and probably other factors as well. Thus the medical response may need to be tailored to the conditions of the current war, not be a simple repetition of the procedures that were followed in the post.

The outcome of ballistic wounds depends upon four factors, of which the first is by far the most important:

- the body part that is hit
- the physical aspects of the projectile and the biophysical aspects of the projectile-target interaction
- the environment in which the wounding occurs
- the quality and timeliness of surgical care

Obviously, if a projectile hits one casualty in the brain stem and an identical projectile hits another casualty in a toe, their wounds will have different outcomes. With wounds of only soft tissues, the body part that is hit is less important. After all, a projectile can do only *so* much damage to the soft tissue at the periphery of the body before visceral or bony injuries occur.

The physical aspects of the projectile and the biophysical aspects of its interaction with the target receive disproportionate emphasis in any ballistic analysis. Certainly, high-velocity projectiles such as assault-rifle bullets have greater potential than low-velocity bullets have to cause severe soft-tissue damage, but it is unusual for this potential to be fully realized without a far more serious visceral or bony injury also occurring. Increasingly, modern munitions are being designed to cause multiple wounds. This multiplicity of wounds made by small, frequently low-velocity fragments and their possible synergy characterize many coinbat-related ballistic wounds.

The physical environment in which the wounding occurred is a critically important determinant of the magnitude and type of wound contamination. Identical bullet wounds sustained in a desert or a muddy farm field may represent radically different threats to the casualty. It follows that if the threats differ from one combat environment to the next, then the optimal treatments may also differ.

Treatment is the only variable over which the medical officer has any control. If there has been a dominant trend in American management of battlefield soft-tissue wounds, it has probably been in the direction of too much, rather than too little, surgical intervention. One well-respected authority[81] estimated that, among American troops in Vietnam, nonoperative treatment would have resulted in rapid and satisfactory healing in about 80% of all the casualties who had soft-tissue wounds only. Furthcrmorc, a nonopcrativc approach would have returned many of those casualties to duty far sooner. The trade-off would have been the potential for serious and occasionally fatal wound sepsis in the remaining 20%. Contrast this potential outcome with the actual 5% rate of sepsis and low death rates that were obtained — with indiscriminate debridement applied to almost all casualties. The hidden costs *for* this achievement are *(a)* prolonged noneffectiveness (some of it iatrogenic) for many casualties and *(b)* the huge logistic burden of providing the required surgical care.

Whether or not a more selective approach, with nonoperative treatment a real option — allowing maximum return to duty and minimal septic complications — could work in a future war is difficult to say. Some would say yes; many would say no. Wound ballistics is *not* a simple subject.

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