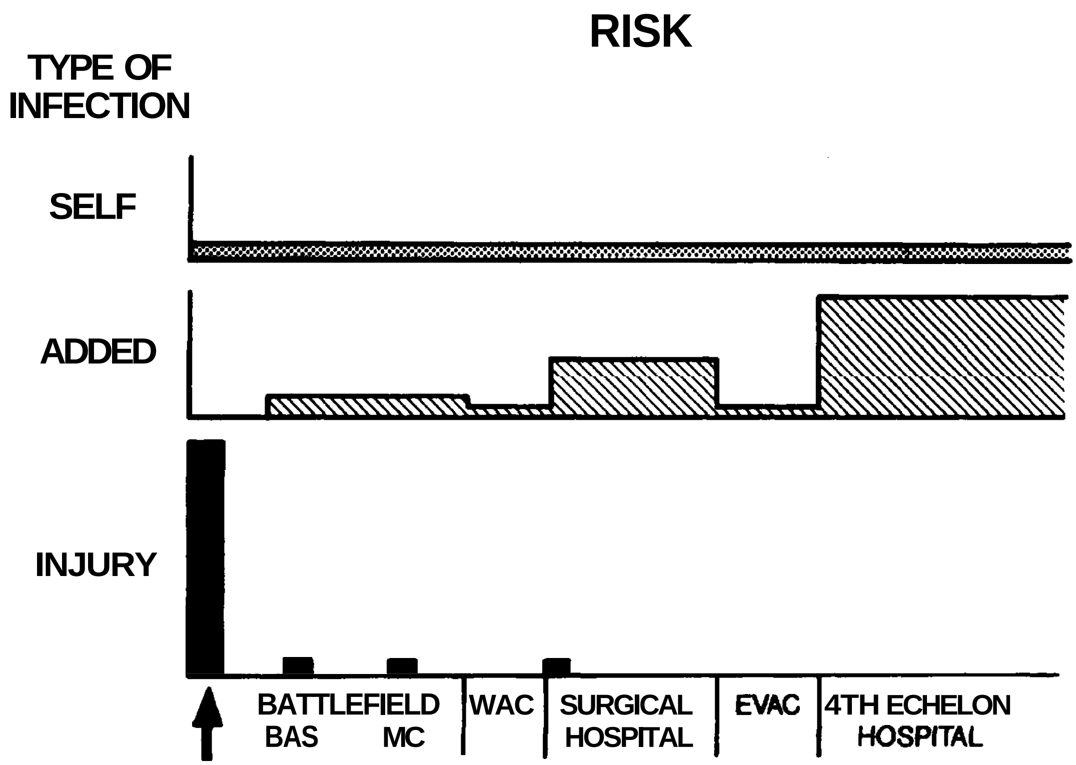


Fig. 5-11. A battlefield wound is subject to three sources of bacterial contamination: from the environment at the time of injury, from the casualty's native flora at any time, and from the medical-treatment environment during wound care.
Source: Redrawn version of Figure 4 in reference 39

Antibiotics

In managing soft-tissue wound suppuration and invasive sepsis, the choice of a therapeutic agent should be predicated upon the surgeon's knowledge of the causative organisms' antibiotic sensitivities. The major conceptual problem with battlefield antibiotic prophylaxis, however, is our inability to decide (because of our lack of knowledge) which casualties really need such therapy. Therefore, doctrine states that all casualties with penetrating injuries will receive antibiotic prophylaxis, which medics and battalion surgeons will administer in the field. Many of the casualties, such as those with en seton gunshot wounds and small, blind, fragment wounds, are probably at small risk for developing wound sepsis. Others, those with huge wounds of exit or external evidence of extensive soft-tissue injury, probably will develop wound sepsis even if they receive prophylactic antibiotics, but administering them may temporarily stave off infection and compensate for delays in evacuation.[60]

Systemic Antibiotics. Although supported by animal experimentation, antibiotic prophylaxis to abort sepsis has not conclusively been proven effective in contaminated battlefield wounds. Combat casualties are exposed to numerous different pathogens, not only when they are wounded, but also when they are evacuated from the battlefield and treated at the next echelons of carc (Figure 5-11). Each stage of treatment exposes the casualty to different organisms:

- During wounding—clostridia and other bacteria of fecal origin from the soil and the casualty's own clothing and skin, and S. *aureus* from the casualty's skin, are likely to be introduced.
- Continuing self-infection—as long as the wound remains open, further contamination from the casualty's own skin (especially with various staphylococcal species) remains possible.
- During treatment—at each echelon where the open wound is manipulated, contamination with a vast spectrum of nosocomial organisms can occur every time the dressing is removed. Beta-hemolytic streptococci are probably added to the flora at this time.

Obviously, the antibiotic must be effective against the organisms likely to contaminate the wound, but choosing the optimal one is difficult because *(a)* the spectrum of organisms likely to be encountered is broad, and *(b)* bacterial contamination is a dynamic process. At a minimum, toxigenic clostridia, coagulase-positive staphylococci, and beta-hemolytic streptococci must be eradicated. Penicillin is quite effective against clostridia and beta-hemolytic streptococci (the sources of the most life-threatening infections) and is alsu both safe and inexpensive. But penicillin, as usually administered, is active for only a short time. For that reason, military surgeons prefer a drug with more favorable pharmacokinetics, like cefazolin. (Physicians should consult the North Atlantic Treaty Organization's handbook *Emergency War Surgery*[61] for appropriate dosing information.)

Experimental studies with animals and a growing body of civilian clinical experience clearly indicate that the appropriate antibiotic, given parenterally during or immediately after wound contamination, will decrease the incidence of sepsis. Initial studies of antibiotic prophylaxis in experimental wounds demonstrated the importance of the time of administration: Penicillin administered to guinea pigs within 2 hours of a wound's contamination with *Staphylococcus aureus* prevented sepsis in YO% of wounds; its administration later than 3 hours produced an infection rate no different than that in control animals.[62] In combat-casualty care, however, a medic or corpsman might not be able to administer the antibiotic in time for the casualty to benefit from its potential effectiveness.

Recent experimental evidence shows that penicillin and possibly other antimicrobial drugs may do more than just impede bacterial growth. Measuring the mass of skeletal muscle that they debrided 12 hours after they shot experimental animals, researchers found that animals given penicillin immediately after they were wounded had only one-third the muscle damage that untreated controls had.[63] The reason for this phenomenon, and whether it might have practical significance in human medicine, remains unknown.

Topical Antimicrobials. Topical antimicrobials such as Sulfamylon have played an important role in preventing and treating sepsis in burned patients; although the concept is attractive, their similar role in managing soft-tissue wounds has not been established. Several convincing studies show that researchers can prolong animal survival by using topical Sulfamylon or penicillin on massive open wounds, where death caused by C. *perfringens* is otherwise certain.[51] But in the only trial in combat casualties of the topical antimicrobials Sulfamylon, Polybactrin, and Neosporin, researchers found no benefit, at least in their ability to control *S. aureus* or *Pseudomonas*.[8]

Unfavorable wound morphology lessens the efficacy of topical antimicrobials. The penetrating wounds that most casualties suffer have narrow wound tracts with small wounds of entrance and exit. In fact, most casualties of modern warfare have small, blind wound tracts. Few have a gaping soft-tissue wound as their major therapeutic problem. How can a surgeon deliver a topical antimicrobial to the walls of a narrow permanent cavity located deep inside an extremity without opening the wound tract?

Cliniral and Experimental Therapeutic Trials in Soft-Tissue Wound Management

If randomized, double-blind trials of proposed interventions (that is, antibiotics or no treatment, wound excision en bloc or debridement with antibiotic adjuncts, and so forth) could be performed with humans, the contentious subject of the proper management of projectile wounds sustained on a battlefield could be resolved. But not only have no such trials ever been performed, none is likely ever to be done. We must make do with tantalizing reports such as this from World War 11:

> The author was on the surgical staff of an evacuation hospital during two campaigns in the Southwest Pacific.... The first campaign covered a period of 2 to 2 1/2 months. . . . Casualties did not begin to occur in very large numbers until the campaign was about 3 to 4 weeks old. When they did occur the great majority were seen within 4 to 6 hours of injury by small surgical units very near the scene of action. These units had been directed to debride thoroughly. . . . Following surgery these patients were moved to the rear. . . . On the average they arrived about 48 hours after injury. . . . [C]omparatively few of them showed signs of toxicity. . . . About 10% required a more extensive or a primary debridement. . . . [T]here were 10 cases of gangrene [out of about 1,550 casualties]. . . .
>
> The second campaign lasted only 3 to 4 weeks. The method of treatment of wounds of the extremities in this campaign in the forward area was only the application of sulfanilamide crystals and sterile dressings with adequate immobilization. Any further treatment required in such extremities was to be given in the rear areas. . . . Evacuation in this campaign was from the beachhead medical units . . . to our hospital. . . . The patients arrived on the average about 72 hours after injury. . . . [P]ractically all who had wounds of any extent showed signs of toxicity. . . . Of the 250 patients received during this campaign, 54% required debridement. . . . There

> were 13 cases of gangrene of which 10 were due to bacterial agents. . . . Of the 10 cases of bacterial gangrene 5 . . . had small through-and-through perforating wounds of the extremities without bony injury.
>
> A plea is made for early debridement which at least provides adequate drainage from the wound even if all devitalized tissue is not removed.[64]

Within the historical context of the pre-penicillin era, we cannot challenge the validity of the author's conclusion: Penetrating soft-tissue wounds *must* be debrided. But can his conclusion be extrapolated to the present era, with its powerful antimicrobial drugs? Since the appropriate human studies are neither practicable nor perhaps even possible, a definitive answer cannot be given. We may gain insight from animal experiments that had recovery-or at least the animals' long-term survival—as their end points; however, extrapolating the results of animal studies to the care of human casualties is always dangerous.

Penicillin Prophylaxis* of *Gas Gangrene. Researchers in England sought to determine the prophylactic effects of wound incision, wound excision, and penicillin in sheep that were infected with gas gangrene, with the animals' survival as their end point.[65] They shot sheep through their thigh muscles with bullets that were first passed through a piece of cloth containing a standard dose of toxigenic clostridial spores. The sheep were divided into five groups: *(a)* controls—which were untreated, *(b)* wound incision—in which the entire wound tract was opened, *(c)* wound excision—in which the wound tract was opened and all abnormal-appearing tissue was excised, *(d)* wound incision and penicillin—in which the animals received 600,000 units of penicillin 45 minutes after wounding and another 300,000 units 6 hours after wounding when they had surgery, and *(e)* nonoperative—in which the animals received 600,000 units of penicillin 1–9 hours after being shot. The researchers operated on the sheep 6 hours after wounding them. The animals were considered to have survived if they lived for 200 hours after being wounded. Average survival times (excluding anesthetic deaths and wounds in which muscle was not injured) were: *(a)* among the seven controls, 43 hours: *(b)* among the nine that received incision only, 37 hours; *(c)* among the nine that received excision, 160 hours; *(d)* among the twelve that received both incision and penicillin, 60 hours: and *(e)* among the ten that received only penicillin, 168 hours.

TABLE 5-13

EFFECT OF TOPICAL THERAPY ON GOATS' SURVIVAL FOLLOWING MASSIVE SOFT-TISSUE TRAUMA

(N = 6 in all groups at 0 hours)

Treatment	Percentage of Animals Surviving Over			
	100 hours	200 hours	400 hours	600 hours
Controls	0	0	0	0
Penicillin spray	67	0	0	0
5% Mafenide	67	17	0	0
20% Mafenide	67	50	17	17
5% Mafenide and penicillin	67	67	33	0
20% Mafenide and penicillin	100	100	100	50

Suurce: Reference 51

In this investigation, penicillin alone was clearly as effective as conventional wound excision in preventing death from gas gangrene.

The deleterious effect of wound incision is surprising; these researchers suggest that the incision itself created devitalized tissue that, in turn, assured that the clostridial contamination would progress to gas gangrene. This study confirms the experimental results that were obtained in 1945.[34] It also provides clear-cut evidence that systemic penicillin has an obvious role in preventing gas gangrene, and provides experimental evidence supporting the British World War II clinical finding that prophylactic penicillin reduced the incidence of gas gangrene in Normandy in 1944.[42]

Topical Antimicrobial Treatment* of *Large Soft-Tissue Wounds. After detonating small explosive charges on the thighs of 150 anesthetized goats to create massive open wounds, researchers sought to measure the ability of several topical antimicrobials (alone and in combination) to prolong the animals' survival.[51] They applied the topical preparations immediately after the animals were wounded and twice daily thereafter, but did not surgically manipulate the wounds at all (Table 5-13). Nor did they deliberately contaminate the wounds. They did attempt to prevent the deleterious effects of the animals' prolonged recumbency, however. *C. perfringens* sepsis developed in some of the animals' massive soft-tissue wounds, but the results clearly indicate that topical antimicrobials can prevent the deaths of animals that otherwise would have died.

Studies like this one involve a great amount of custodial care, which are both labor intensive and very costly. But this study's relevance to the management of battlefield casualties is not clear-cut, since casualties usually do not present with a massive soft-tissue injury as their only treatment problem. Furthermore, a battlefield situation in which a treatable casualty did not receive surgical care for weeks on end is hard to imagine. Its questionable relevance illustrates one of the problems medical officers encounter when results of animal experimentation are used to rationalize treatment in human casualties.

Survival Following Untreated Soft-Tissue Ballistic Wounds. Researchers sought to determine spontaneous survival in 147 goats with untreated soft-tissue wounds.[16]

(averaging 406 m/s) or high-velocity (averaging 960 m/s) spheres and fragments, and assessed the animals' survival 3 weeks later. (Animals that died within 1 hour of wounding were excluded from the study.) Of the twenty-seven goats shot with low-velocity spheres, twenty-two survived, and of the twenty-five shot with

five survived. Of the forty-seven goats shot with low-velocity fragments, thirty-one survived, and of the fifteen shot with high-velocity fragments, nine survived.

Even though the researchers performed extensive anatomical, pathological, and bacteriological studies, they usually could not determine the cause of death. By excluding those deaths that occurred within 1 hour and by performing exacting autopsies on those that died within 72 hours, they ruled out hemorrhage as the cause of death. A small number of animals appeared to have died of gas gangrene, and only about 18% of autopsied animals had evident *C. perfringens* infection. The researchers' most significant observation was that **untreated projectile wounds of soft tissue can be fatal.** One cannot help but wonder how effective surgical and antibiotic interventions would have altered the outcome.

This study raises more questions that it answers. The fact that 41% of the animals died, most without any obvious cause, is mystifying. Something killed these animals and the clear implication for medical officers is that soft-tissue wounds cannot be ignored.

***Nonoperative Treatment @Assault-Rifle* Wounds.** Researchers shot through

rior thighs with solid brass 5.45-mm bullets (replicas of AK74 assault-rifle projectiles, specially made to prevent deformation and fragmentation from contributing to the wounding). The permanent cavities had large wounds of exit. Each animal received 2.5 million units of penicillin intramuscularly 30 minutes after wounding, and 2.5 million additional units twice daily for 5 days. This was the only treatment that five of the swine received. Researchers excised the "severely disrupted and nonviable" muscle from the other five swine. All animals survived and their wounds healed in 20–22 days. The researchers concluded that in well-drained assault-rifle wounds adequately covered with antibiotics, wound excision provides no advantage.[66]

This study has great practical significance, since it suggests that nonoperative treatment is an option even in casualties who have extensive soft-tissue wounds. But several possible limitations need to be considered before medical officers fully accept these results:

- The study gives no information

  type and magnitude of bacterial contamination of the wounds. If contamination were less than 10^6 bacteria per gram of damaged tissue, a similar outcome could be expected regardless of the research protocol. Clearly, debridement alone, antibiotics alone, or no treatment at all would yield similar results in "germ"-free animals shot in a sterile laboratory. Additionally, the real controls for this experiment, animals that received no treatment whatsoever, are missing.

- The experimental protocol design was optimal for nonoperative care. The swine each received a large dose of penicillin soon after being wounded, and the configurations of their wounds allowed for easy drainage. This combination of characteristics is unusual—or at least not predictable—in real combat wounds.
- Although the researchers speculate about the effect that delayed primary closure would have had on this population, in fact they excluded delayed primary closure from their experimental design. The design should have included an additional control group to determine the time necessary for excised wounds to heal after delayed primary closure. Returning wounded soldiers to duty as soon as possible is accomplished both by preventing sepsis and by early closure of sepsis-prone wounds.

No laboratory experimental design can include all the salient aspects of the clinical problems being studied. Does shooting animals in a laboratory replicate the contaminating conditions associated with being shot in Flanders fields, Stalingrad, the Sinai peninsula, or Dak To? Probably not. Medical officers must remember that animal experimentation has limited relevance to combat-casualty care, and must exercise judgment when predicating changes in established policies of wound management based on the results of laboratory investigations. Animal experimentation is useful, but in the absence of clinical trials, most results cannot be extrapolated directly from laboratory animals to human battlefield casualties.

PRACTICAL ASPECTS OF MANAGING SOFT-TISSUE COMBAT WOUNDS

Battlefield surgeons may find that mass-casualty situations are more confusing and difficult than they had supposed. They must make decisions in real time with no more than a few minutes allocated to each casualty, synthesizing all that they have learned about the wounding effects of various weapons, whether and how much to debride, and which wounds are most likely to become infected. Knowledge of theoretical wound ballistics may allow the surgeon to make the necessary decisions more easily.

Management Options

The basic principles of managing soft-tissue combat wounds follow; technical aspects of implementing these surgical options are considered in greater detail at the end of the chapter. Medical officers are also advised to consult the relevant chapters of the Emergency *War Surgery* NATO handbook. The first actions to be taken of chemical contamination and the acute life-threatening conditions considered by the Advanced Trauma Life Support (ATLS) course offered by the American College of Surgeons. The material that follows applies only *(a)* when soft-tissue wounds are the major treatment problem *or (b)* after the more seriously wounded casualties have been treated.

Infected Wounds—Incision and Drainage. The presence or absence of clinical infection when a soft-tissue wound is first seen is the most important determinant of the treatment the casualty will receive. A septic wound should be opened, its pus drained, foreign material removed, and grossly necrotic tissue excised. The surgeon must design the incision so that drainage will be optimal, and make a counterincision if good dependent drainage would otherwise be questionable. A fasciotomy is mandatory if there is any possibility that a compartment syndrome will develop.

Noninfected Wounds—Nonoperative Treatment. Two options are available to the surgeon who is managing a soft-tissue wound that has no signs of infection: *(a)* nonoperative—simply clean the wounds of entrance and exit (if there is one) and give antibiotirs or *(b)* operative—give antibiotics to all casualties and proceed to debridement.

Noninfected Wounds—Minor Debridement. Open the wounds of entrance and exit (if there is one), evacuate blood clots and foreign material, and inspect the lining of the permanent cavity. Open the full extent and depth of the permanent cavity. This frequently requires that fascia must be incised; incision of the fascia is as important as incision of the skin. No further treatment is required if there is little evidence of a zone of extravasation. (In practice, however, most surgeons feel compelled to remove at least a scant amount of tissue.) By degrees, minor debridement passes into major debridement.

Noninfected Wounds—Major Debridement. An extensive zone of extravasation in the wound dictates that the surgeon perform major debridement—excision sufficient to expose normal-looking tissue (that is, the color, consistency, circulation, and contractility appear grossly normal) in the wall of the permanent cavity. Dress the wound so that drainage is not precluded and apply a splint (to minimize pain and swelling in and around the wound) whenever major debridement has been performed on either legs or arms. The wound should *never* be packed.

Wounds of the face or scalp can be closed as part of the initial management, because their sepsis rate is acceptably low. Wounds of the remainder of surface are closed by: *(a)* delayed primary closure, which is performed 4–6 days after the initial care or *(b)* secondary **closure,** which is **usually** performed more than 10 days after the initial care. **(A** more complete distinction between delayed primary and secondary closure will be made later in this chapter.) The dressing applied to the wound after the initial surgery *must not be removed* before delayed primary surgery is attempted unless there are compelling reasons such as *(a)* extensive bleeding, *(b)* pus draining through the dressing, *(c)* evidence of sepsis for which there is no apparent site other than the wound, or *(d)* severe and increasing pain.

Echelons of Care

It is not possible to consider the care of ballistic wounds of soft tissue divorced from the echelons of military medical care. The *first echelon* of care—the battalion aid station—and the *second echelon* of care—the division- or brigade-level medical company—have as their mission providing first aid, initial triage, and if necessary, preparing the casualty for evacuation to a higher echelon. Their essential function is to assure that the casualty with penetrating trauma receives an effective antibiotic upon arrival at a medical treatment facility (MTF). Since the second echelon has a holding capability, it is perfectly feasible to provide nonoperative care there to selected casualties with ballistic wounds of soft tissue. Data from the Vietnam War indicate that one-fourth or more of casualties with soft-tissue wounds need not be evacuated beyond the division-level MTF.

The third *echelon* of care—the corps-level evacuation and combat support hospitals—has as its mission providing initial wound surgery. Most soft-tissue wound debridement will be performed in third-echelon facilities. Mobile Army Surgical Hospitals (MASHs)—which are also third-echelon units, but which are usually located further forward with the division-level medical assets—have as their mission performing emergency or resuscitative surgery. Since soft-tissue wounds **do** not usually constitute immediate life-threatening problems, they would not **usually** be seen at a MASH, unless they were debrided there in conjunction with the management of severe visceral or extremity wounds. Although wound closure can be done at third-echelon facilities, their limited holding capacity and the need to maintain adequate resources for the care of incoming casualties make such surgery there undesirable.

The *fourth* and *CONUS echelons* of care—from general hospitals to medical centers—perform definitive and reconstructive surgery. Most wound closures are performed at fourth-echelon facilities. However, in mass-casualty situations and when third-echelon facilities are not fully **operational,** casualties with less-severe soft-tissue wounds may be evacuated from the first and second echelons to the fourth echelon (and even CONUS) for wound debridement.

Matching Injuries and Options

In **the** broadest sense, whether or not a penetrating wound becomes septic will be determined by the interaction of

- the magnitude of tissue damage
- the magnitude of bacterial contamination
- the timeliness and appropriateness of care

The interaction of these three factors can be visualized in highly simplified form (Figure 5-12). These individual factors may be thought of as one-dimensional vectors, which differ from war to war (Table 5-14). The one-dimensional vectors define a vector in three dimensions; the length of this vector will, in some general sense, determine the probability that sepsis will develop in a wound. Figure **5 13** was drawn using the same coordinates that were developed in Figure 5-**12** and data from Table 5-14, and demonstrates that soft-tissue wounds sustained during the Vietnam War were less likely to become septic than wounds sustained during World War I. Therefore, the minimal therapy required to prevent sepsis from developing might also have been different in the two wars, and nonoperative therapy—or no therapy at all—rather than debridement might have been feasible in some Vietnam War–casualties. Still using the same three coordinates that were used in Figures 5-12 and 5-13, Figure 5-14 generalizes this concept with two hypothetical casualty populations. The inner region indicates a population with clean wounds and slight tissue damage who receive prompt care. Nonoperative treatment suffices for this population. Beyond the inner region lies a population with dirty wounds and more massive tissue damage who receive delayed care. Nonoperative care will not be sufficient for this population; debridement offers the only hope to abort

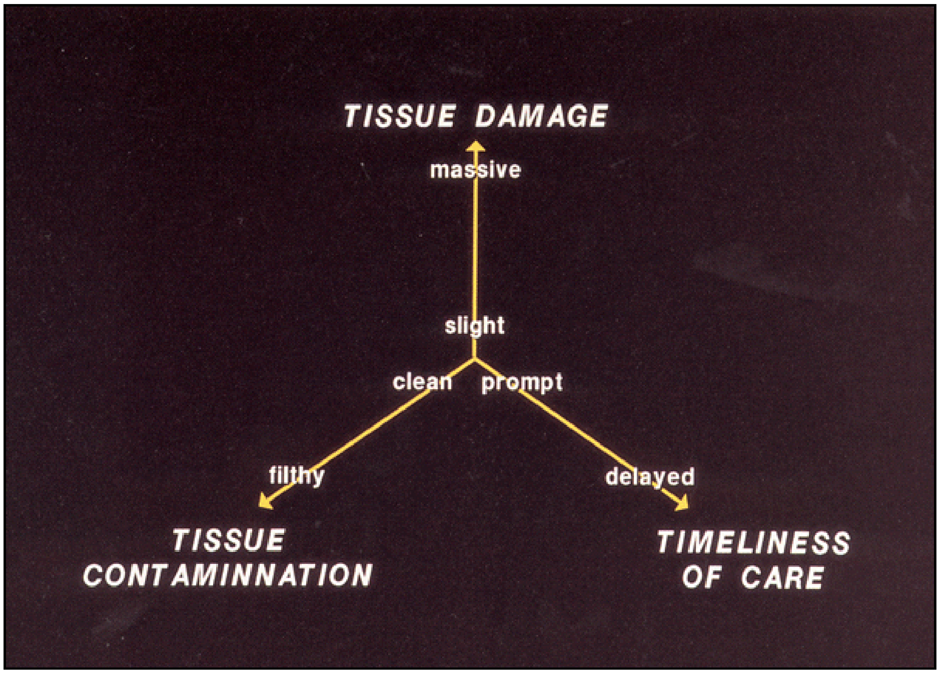


Fig. 5-12. The vertical axis shows the magnitude of tissue damage, the left horizontal axis the magnitude of tissue contamination, and the right horizontal axis the timeliness of care.

TABLE **5-14**

DETERMINANTS OF WOUND SEPSIS IN VERY DIFFERENT WARS

Determinants	World War I	Vietnam War
Tissue damage (typical injury)	massive: several-gram fragments from random-fragmentation munitions	small: 200-mg fragments from improved-fragmentation munitions
Tissue contamination	dirty	clean (1/3 were sterile)
Timeliness and appropriateness of care	8–24 hours, no effective antimicrobials	1 hour, antibiotics

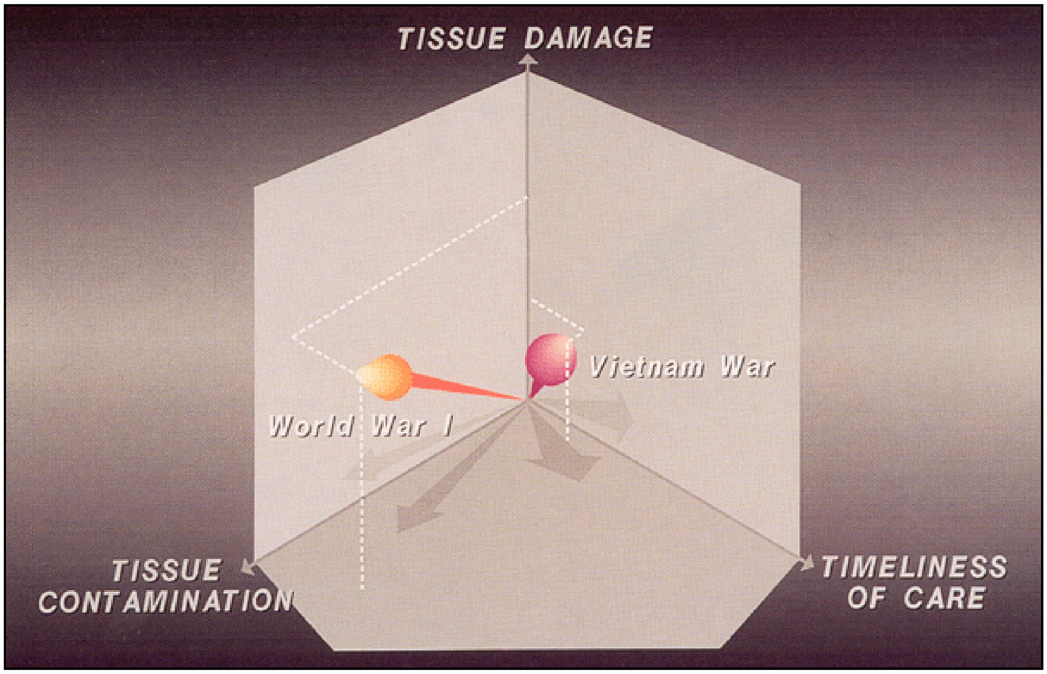


Fig. 5-13. The same coordinate system that was described in Figure 5-12 is used here. The World War I vector indicates the greater potential for wound sepsis in that war.

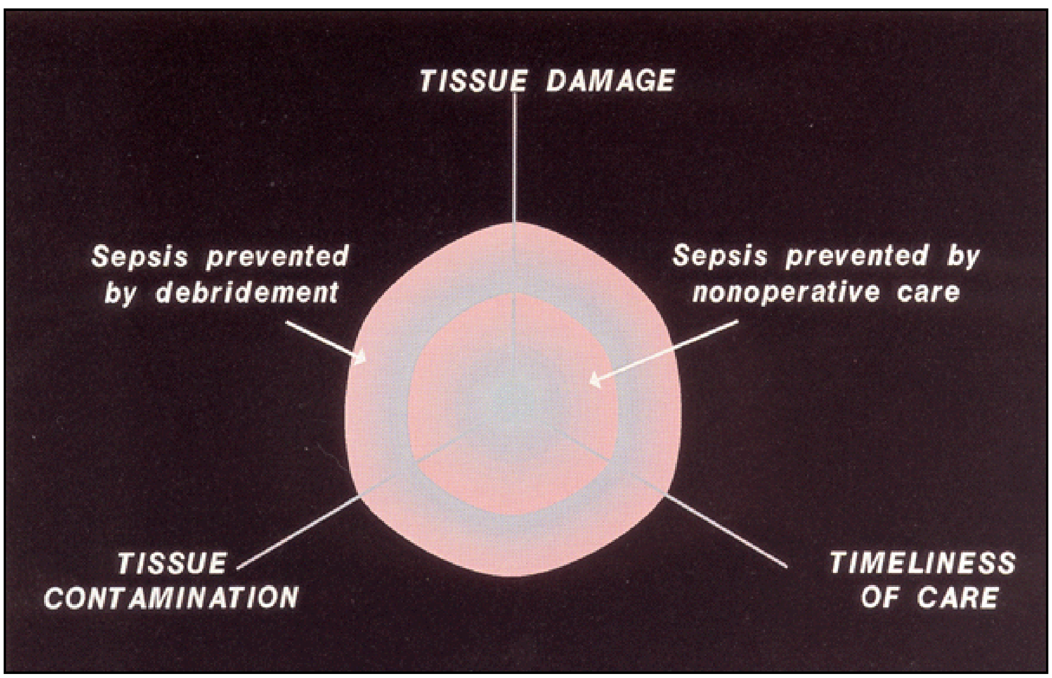


Fig. **5-14.** Still using the same three coordinates that were used 5-13, the inner region represents a population of combat casualties with wounds that will do well with nonoperative management. Moving out from the center is a region where debridement is required to prevent sepsis. The outermost region represents a population whose severe wounds are already septic when first seen for surgical treatment.

Fig. 5-15. This casualty has a small grenade-fragment wound of the left groin. Operative management is indicated, not so much because of the magnitude of either tissue damage or wound contamination, but to determine that the underlying neurovascular bundle is intact.
Source: Wound Data and Munitions Effectiveness Team

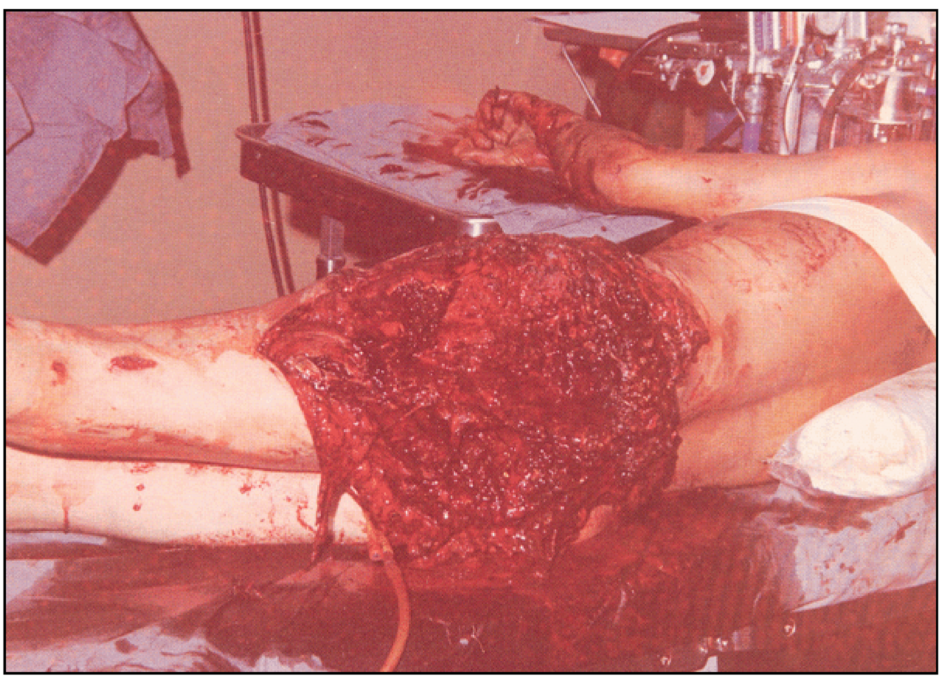


Fig. 5-16. **A** massive avulsion of soft tissue caused by an explosive munition. The management of this wound is beyond the scope of this chapter, but the wound must be freed of contamination and dead or injured tissue. Closure will be done in stages and will probably involve a combination of skin flaps and grafts. This wound would be an ideal one to treat initially with topical antimicrobials.
Source: Wound Data and Munitions Effectiveness Team

sepsis. All wounds lying in the outermost region are (or will become) septic due to the extent of the tissue damage, the magnitude of bacterial contamination, and delayed casualty care. What Figure 5-14 suggests should be obvious to medical officers: that possible treatment options should be matched to individual injuries. During wartime, however, mass casualties and echelon-based care may make this ideal difficult to achieve. Doctrine dictates that the treatment most likely to succeed be the treatment rendered first. In combat surgery, there is nu time fur a
on a given casualty; thus, medical officers have a propensity to overtreat.

Soft-Tissue Trauma—An Overview of Typical Combat Wounds

The spectrum of penetrating injury to the soft tissues extends from minor wounds (Figure 5-15) to massive mutilating trauma (Figure 5-16). The necessity for surgery in managing the casualty shown in Figure 5-16 is obvious. But it may not be so obvious that surgery also has a role in managing the casualty shown in Figure 5-15. The management question that must be answered is: Where did the projectile go? This wound requires surgery, not because the surgeon expects to encounter either massive tissue damage or contamination, but because the wound is near important anatomical structures—in this case the vessels and nerves of the femoral triangle. Thus in many instances the indication for surgery is not simply one of soft-tissue wound management. (Of course, once the wound has been opened, soft-tissue wound management may be indicated.)

Some of the range of typical soft-tissue combat wounds are shown schematically in Figures 5-17 through 5-26. Consider the thigh to be the target. The permanent cavity is shown as a void, while the surrounding dotted region shows the zone of extravasation. The projectiles, not shown, enter from the left.

Figure 5-17 shows a wound that a small, low-velocity grenade fragment might make. The wound tract is blind. The small amount of tissue that may have been injured by temporary cavitation is found immediately adjacent to the wound of entrance. There is little or no swelling or tenderness deep to the wound of entrance. Many combat wounds in Vietnam were of this type, and with the advent of improved-fragmentation munitions that produce tiny projectiles, this type of wound is likely to be the one most commonly encountered in living casualties on the modern battleheld.

Figure 5 18shows a wound that cithcr a largc, low velocity fragment or a small, high-velocity fragment might make. There is a large wound of entrance but no wound of exit. The tissue around the wound of entrance is swollen and bruised, and the substantial injury extends inwards like an inverted cone. Many combat wounds in World War I were of this type.

Figure 5-19 shows a wound that a stable flechette might make. This projectile easily perforates tissue, leaving a tiny permanent cavity with little if any zone of extravasation. The en seton wounds of entrance and exit are needle-like holes.

Figures 5-17 through 5-19 show solitary wounds, **but** medical officers will commonly encounter casualties with multiple wounds like these from fragmentation munitions and fléchettes. If the casualty is struck by projectiles in close proximity to one another, the potential exists for a synergistic interaction, producing greater tissue damage than might have been expected from the simple summation of the individual wound tracts.

Figure 5-20 shows a wound that a large-caliber, low-velocity, stable, nondeforming pistol bullet might make. The wounds of entrance and exit ore small. Most of the tissue damage resulted from the bullet's cutting action. The size of the zone of extravasation is trivial. Many civilian gunshot wounds are like this.

Figure 5-21 shows a wound that a small-caliber, high-velocity, stable, nondeforming rifle bullet might make. The wounds of entrance and exit are small. The bullet's cutting of the tissue caused most of the damage. The size of the zone of extravasation is trivial. Note that the only real difference between this and the wound shown in Figure 5-20 is that the permanent cavity made by the low-velocity, but larger-caliber, bullet is larger. This is an example of an en seton bullet wound.

Figure 5-22 shows a wound that the same bullet described in Figure 5-21 might have made, except that this bullet developed significant yaw midway along its trajectory through the tissue. Consequently, both the permanent cavity and the zone of extravasation are greatly enlarged. A wound like this in an extremity produces noticeable tenderness, swelling, and skin ecchymosis. Note that the wound of exit is not different from the wound of entrance; therefore, the bullet must have displayed a small angle of yaw when it exited. Note also that the initial portion of the trajectory is identical to the one shown in Figure **5-21.** Thus, because a projectile must travel a characteristic minimum distance within a target before it becomes unstable, the target's thickness is an important determinant of the nature of the wound.

Figure 5-23 shows a wound that might have been

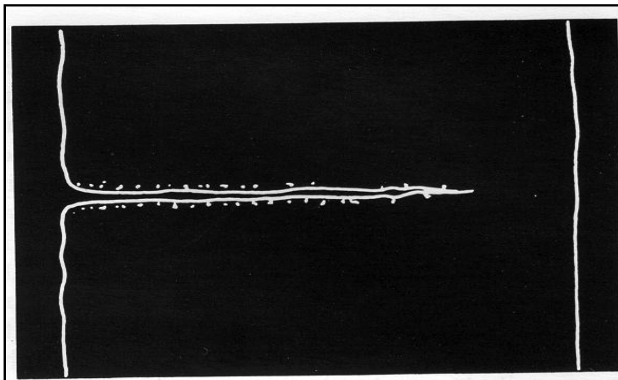


Fig. 5-17. Schematic representation of a blind wound made by a small, low-velocity fragment. The wound of entrance measures a few millimeters across. In this and all Figures 5-18 through 5-26, the permanent cavity is shown as a void and the zone of extravasation is shown as dots.

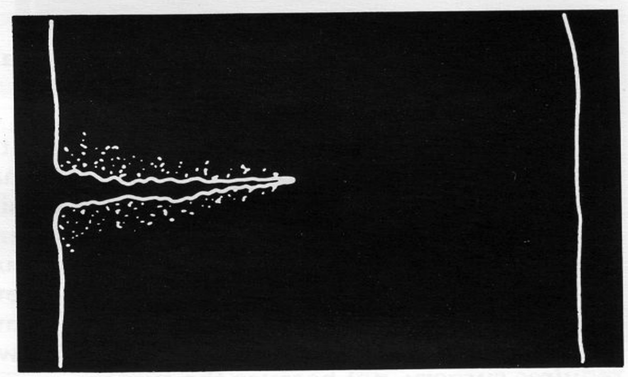


Fig. 5-18. Schematic representation of a blind wound made by a large fragment. The wound of entrance measures 1 cm across. The permanent cavity and the zone of extravasation are large.

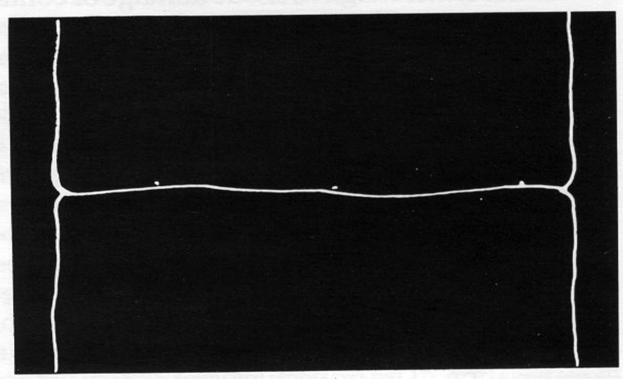


Fig. 5-19. Schematic representation of a perforating wound made by a stable fléchette. The wound of entrance is a needle-like hole and there is essentially no zone of extravasation.

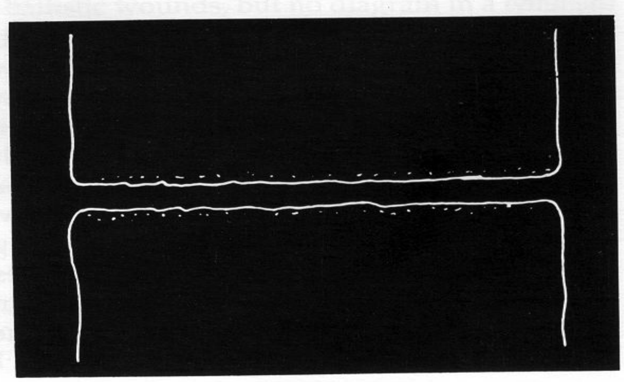


Fig. 5-20. Schematic representation of a perforating wound that a stable, nondeforming, large-caliber pistol bullet might make.

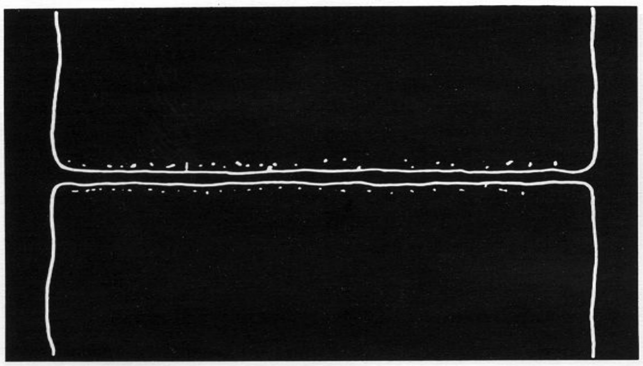


Fig. 5-21. Schematic representation of a perforating wound made by a stable, nondeforming, small-caliber rifle bullet. The zone of extravasation is small.

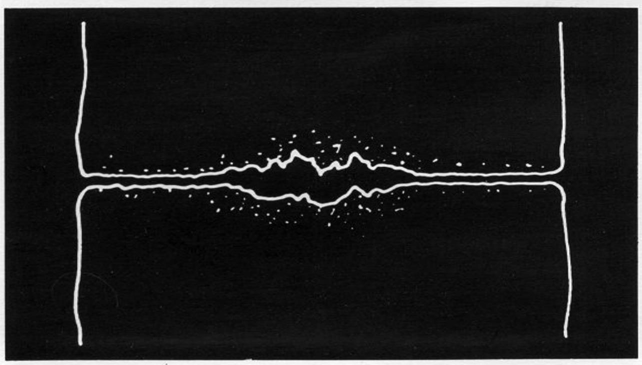


Fig. 5-22. Schematic representation of the wound that might result if the same bullet described in Figure 5-20 had developed substantial yaw midway along its trajectory through the thigh. The wound contains a large permanent cavity and zone of extravasation.

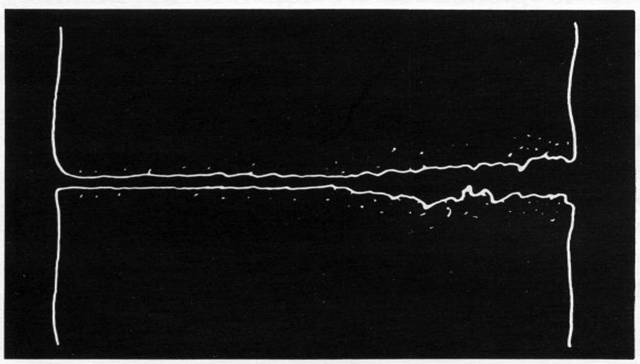


Fig. 5-23. Schematic presentation of the tissue-damage that might result if the bullet that made the wounds shown in Figures 5-21 and 5-22 had yawed near the wound of exit. Note the large zone of extravasation near the large wound of exit.

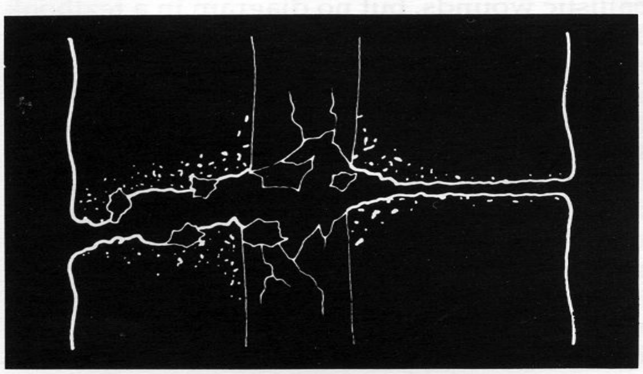


Fig. 5-24. Schematic representation showing the very large permanent cavity and zone of extravasation that might occur if the bullet represented in Figure 5-21 struck a large bone.

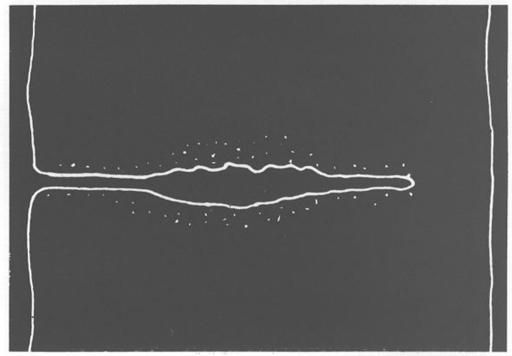


Fig. 5-25. Schematic representation of the large permanent cavity and zone of extravasation that might result from a deforming bullet.

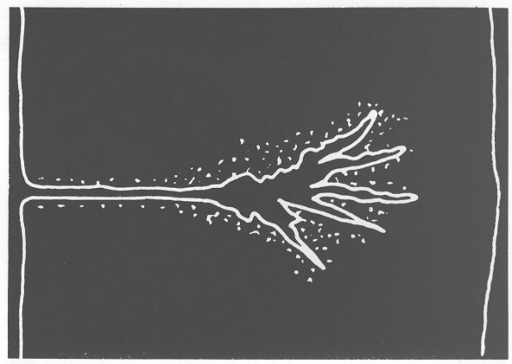


Fig. 5-26. Schematic representation of the tissue damage that might result when a bullet fragments within tissue.

made by the same bullet described in Figures 5-21 and 5-22, except that this bullet became unstable as it exited and produced an explosive wound of exit. Although this type of wound is possible, it occurs uncommonly.

Compare Figure 5-24 with Figure 5-21. A small-caliber, high-velocity, stable, nondeforming bullet perforated the target, but before it exited, it collided with the femur. Both bone and bullet shattered and formed multiple secondary missiles, creating an explosive wound of exit and an extensive zone of extravasation. This is a distinctly common type of combat wound. An extremity with this kind of wound will show obvious external evidence of significant injury such as deformity, tenderness, swelling, and skin ecchymosis.

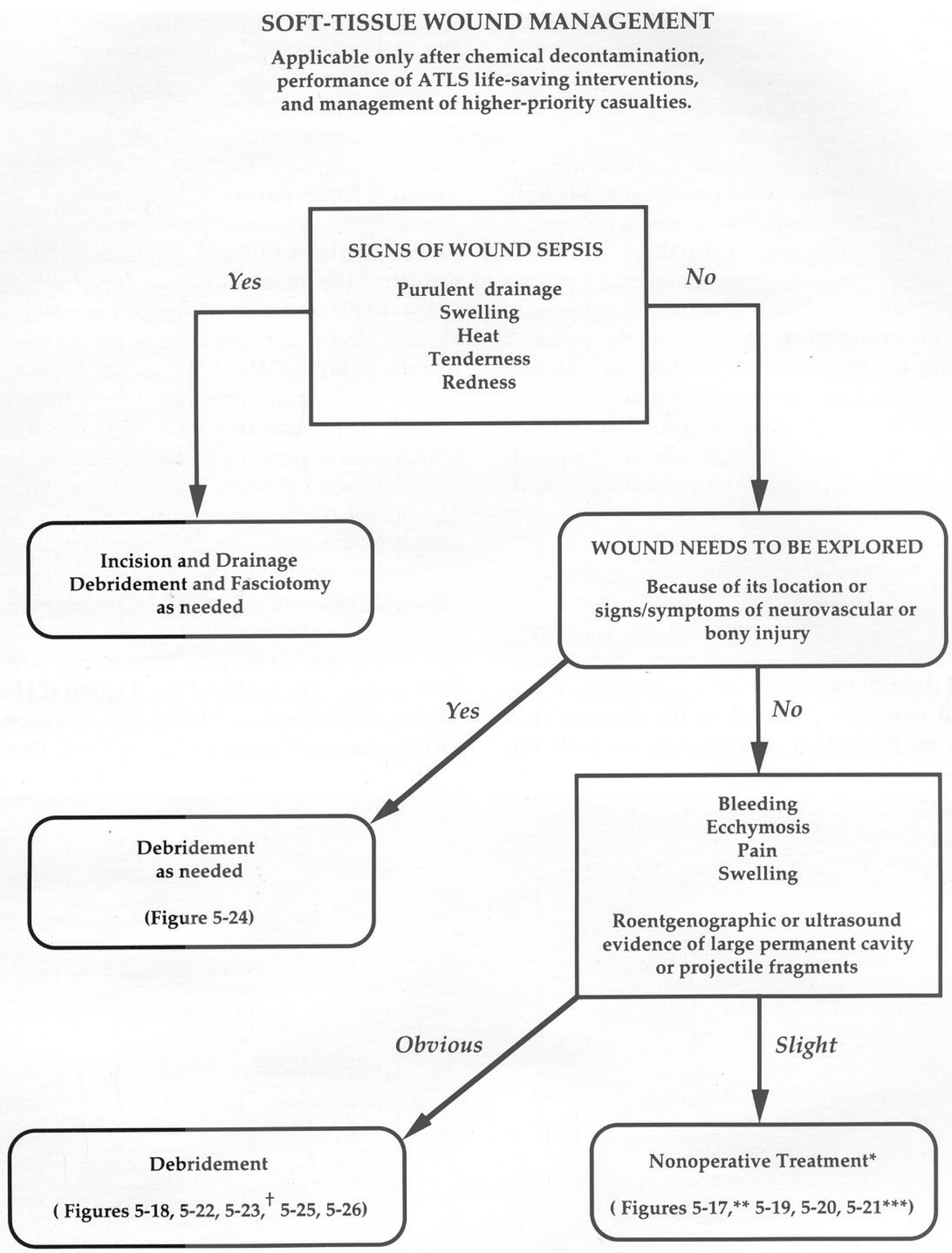
Figure 5-25 shows a wound that a deforming soft-point or hollow-tip bullet might make. The large permanent cavity begins just distal to the wound of entrance and is surrounded by a large zone of extravasation. An extremity containing such a wound will show obvious external evidence of a significant injury such as tenderness, swelling, and skin ecchymosis.

Figure 5-26 shows a wound that a fragmenting bullet might make. The best-known current examples are the M193 or M855 bullets fired by the M16 assault rifles. After traveling 10–15 cm in tissue, the bullet destabilizes; the stresses arising from the resulting yaw cause the bullet to break up. The fragments become multiple secondary missiles that cut the tissue, which is then ripped apart by explosive temporary cavitation. A very large zone of extravasation surrounds the extensive permanent cavity. An extremity containing such a wound will show obvious external evidence of a significant injury such as tenderness, swelling, and skin ecchymosis.

Management Decisions

An algorithm can provide a theoretical framework for making management decisions in treating soft-tissue ballistic wounds, but no diagram in a textbook can reflect the actual conditions—confusion, danger, fatigue—on a battlefield (Figure 5-27). While algorithms may seem to be logical and carefully thought out, their real value will be known only when medical officers test them in the field.

The various components of the decision tree are defined by the typical schematic wounds shown in Figures 5-17 through 5-26. The drawings all show single wounds, but real combat wounds are not only frequently multiple, they may also have blast and burn components. Multiple confluent wounds in a small area (Figure 5-28) and polytraumas all speak for more



*Predicated upon the presence of effective antibiotic coverage, otherwise invalid.
**Including multiple minor superficial wounds, but multiple confluent wounds are an indication for debridement.
***At least sixty references (including English, German, and Russian sources) state that the treatment of en seton wounds need not be surgical.[67]
† Animal research has demonstrated that such wounds can be successfully treated with a nonoperative approach.[66]

Fig. 5-27. Algorithm for managing soft-tissue wounds invasive surgical management. Furthermore, most experienced military surgeons are aware of instances, especially if the wounding projectile is a fragment, in which a seemingly benign wound of entrance conceals serious underlying soft-tissue damage.

The presence of multiple wounds in different body parts in the same casualty and the presence of multiple casualties with individual soft-tissue wounds requires that treatment be prioritized. Casualties with soft-tissue injuries only are usually assigned triage priorities of *delayed*. But those with destructive soft-tissue wounds of the buttocks or thighs may be given a higher priority for care because of their heightened Amnng multiple casualties with soft-tissue wounds only, those with wounds of the buttocks and thighs should be given first priority for care, followed by casualties with wounds of the calves, and finally, casualties with soft-tissue wounds of the arms.[68]

Destructive soft-tissue and orthopedic wounds resulting from buried antipersonnel mines or surface-detonations of explosive munitions of any type have the potential to massively contaminate the wound. Only radical debridement will suffice to prevent potentially fatal wound sepsis. Since the weapon that was used is an important determinant of both the degree of wound contamination and of tissue damage, military surgeons must know the wounding characteristics of commonly encountered weapons.[69]

Surgical Interventions

For clarity of thought and expression, the description that Lieutenant Colonel Eugene H. Pool, M.D. (1874–1949) wrote of debridement, delayed primary closure, and secondary closure for the official surgical history of World War I is notable. From the broadest concepts tn seemingly minnr terhniral details, his treatise on soft-tissue wound management, excerpts of which follow, remains as valid today as it was when it was published in 1927. The original volume is largely unavailable today, except in libraries with historical collections.

During World War I, Dr. Pool served in France as Chief Surgeon of an evacuation hospital, was promoted to Consulting Surgeon to the Fifth Army Corps, and at the war's end was Consulting Surgeon to the First Army. He received the Legion d'Honneur, the Distinguished Service Medal, and a citation for "meritorious services" from General John J. Pershing.

Fig. 5-28. **An** example of multiple, confluent, soft-tissue wounds. **A nonoperative approach is contraindicated** in this situation.
Source: Wound Data and Munitions Effectiveness Team