Chapter 1

COMBAT TRAUMA OVERVIEW

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INTRODUCTION

For military anesthesiologists to assume responsibilities that transcend their traditional role in field hospitals, they will need a broad understanding of the problems of medical support in the theater of operations. The military anesthesiologist who is aware of what it is that makes military medicine unique and who is well versed in the management of trauma will be able to make important contributions to many of the problems that arise in combat casualty care. This chapter gives an epidemiologically oriented overview of that vast expanse of human misery treated by the specialty of military medicine, with special emphasis on combat trauma sustained in conventional land warfare. The stage will then be set for the ensuing chapters, with their detailed discussions of resuscitation, with special emphasis on emergency lifesaving interventions; the practice of anesthesia in the combat zone; anesthetic management of specific types of combat injuries; and critical-care medicine.

ATTRITION IN WAR

The military anesthesiologist's principal wartime role in the theater of operations will be, of course, to care for casualties with combat trauma, but it needs to be emphasized that such injuries constitute only one of the sources of attrition that can potentially destroy an army. The important sources of personnel attrition in the combat zone are (*a*) enemy action, which by definition includes not only battle injuries but also being captured; (*b*) disease; (*c*) nonbattle injury, which also includes the effect of a hostile environment; (*d*) desertion; and (*e*) administrative action that results in a soldier's being transferred from the unit in question (Figure 1-1). Not all the sources of attrition have medical implications; for the purpose of this chapter, only battle injury, disease, and nonbattle injury will be considered.

It should be noted that the word "casualty" was not used in the preceding paragraph. In the past, in most armies, a casualty was defined as a soldier who had been either physically injured by enemy action or captured. It was therefore inappropriate to refer to "disease casualties" or "psychiatric casualties." The U.S. Army Medical Department (AMEDD) has recently changed the definition of casualty: a combat-zone soldier who is noneffective for any medical reason.[1] This chapter uses the word casualty in its traditional meaning whenever historical data are studied.

Although it is usual to classify battle injury as injury that has resulted from the hostile actions of a military enemy, many battle injuries are actually inflicted by the casualty's own side in the confusion of the fighting. Perhaps because of the pejorative and emotional connotation that surrounds such casualties of so-called "friendly fire," their numerical importance as a source of attrition has been somewhat downplayed in the past. Although unofficial guidance on casualties of friendly fire suggests that

0.5% of battle casualties may fall into this category, more recent studies indicate that the actual prevalence is more like 10% to 20%.[2]

Historical Aspects

When viewed from the perspective of military history, disease and its common companion, a hostile environment, have been far greater threats to soldiers' health than hostile acts of a military en-
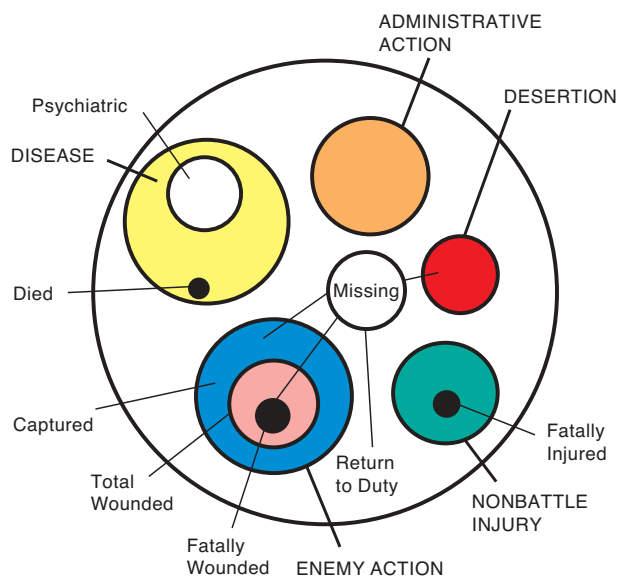
Fig. 1-1. Possible sources of attrition in a military unit. The major categories are enemy action, disease, nonbattle injury, desertion, and administrative action. Psychiatric casualties are placed in the disease category. Soldiers who are missing in action can ultimately be placed in the captured, fatally wounded, or desertion categories, or they can be returned to duty.

TABLE 1-1

ATTRITION IN THE GRANDE ARMÈE IN THE RUSSIA CAMPAIGN OF 1812

Source of Attrition	Number Affected
Died of hunger, exhaustion, cold, or disease	200,000
Killed in battle	100,000
Prisoners of war	100,000
Deserters	50,000
In hospital	50,000

Data source: Bodart G. *Losses of Life in Modern Wars*. Oxford, England: Clarendon Press; 1916: 127.

emy. There is no better example of this than the disaster that befell Napoleon's Grande Armèe in 1812. Napoleon started his invasion of Russia in June with more than 600,000 soldiers and finished in December with about 100,000. One assessment of what happened to the missing 500,000 is given in Table 1-1.[3] Most of these losses were from the group of armies under Napoleon's personal command: of 450,000 soldiers, only 25,000 are believed to have survived.[4] It is part of the mythology surrounding the campaign of 1812 that it was the cold of the Russian winter more than any other factor that destroyed the Grande Armèe, but this explanation was a self-serving fabrication of Napoleon's. More than two thirds of the Grande Armèe had been lost before the end of the summer of 1812 and before the major battle of the campaign, at Borodino on 7 September 1812. Heat and disease (primarily typhus and dysentery) during the summer, not cold and starvation during the autumn, caused the catastrophic attrition.[5] Disease wiped out the Grande Armèe because Napoleon's logistical support was predicated on an unrealistically optimistic appraisal of the campaign's duration (eg, food was available for only 3 wk) and, worse, his medical support was inadequate—even given the primitive nature of military medicine in the early 19th century.

The attrition of the Grande Armèe in Russia was by no means unique in the history of warfare, but lest it be thought that this experience is totally irrelevant to the modern age, the following example of attrition from World War II may be instructive. For brilliance of leadership, the North African campaign of the renowned German general Erwin Rommel is held in the greatest esteem by military authorities. Rommel ultimately lost, but his defeat

is usually attributed to the overwhelming materiel and personnel strength of his adversaries. What is not generally appreciated is that Rommel's manpower problems were much of his own making. Table 1-2 shows the sources of attrition in Rommel's main fighting force—Panzerarmee Afrika—for the 15-month period starting in October 1941.[6]

For every German soldier that Rommel lost to battle injury, almost three were lost to disease. While the destruction of the Grande Armèe was fundamentally due to Napoleon's callous indifference to the needs of his soldiers, the attrition of Panzerarmee Afrika, although partially due to the hostile environment of the North African desert, was primarily the result of Rommel's ignorant indifference to his own and his soldiers' health. He never recognized what disease was doing to the strength of his army, and he clearly never understood that it is the commander and not the military medical service who is ultimately responsible for the health of the soldier.[7] It is not a little ironic that leaders such as Napoleon and Rommel are held in such high regard by the military profession when, in fact, they were a worse threat than the enemy to their own men.

Importance of Attrition due to Battle Injury

The relative importance of losses due to battle injury and from disease and nonbattle injury is determined by a variety of factors, including

- the presence of endemic diseases,
- the climate and the environment,

TABLE 1-2

ATTRITION IN PANZERARMEE AFRIKA[*] OCTOBER 1941–DECEMBER 1942

Source of Attrition	Number Affected
Killed	4,524
Wounded[†]	16,824
Missing[‡]	13,024
Sick[§]	88,320

[*]Average strength 43,000
[†]About 95% required evacuation to Europe
[‡]About 50% were probably captured; the remainder were killed
[§]Required admission to a hospital; at least 28,000 required evacuation to Europe
Data source: Fischer H. *Der deutsche Sanitätsdienst 1921–1945*. Vol 3. Osnabrück, Germany: Biblio Verlag; 1983: 1517, 1535.

- the duration of the deployment, and
- the nature of the tactical mission and the intensity of the fighting.

It is certainly possible for battle injury to be the major source of attrition in short but fiercely fought campaigns. The Battle of Cannae in 216 BC, in which a Roman army of some 86,000 was totally destroyed by Hannibal, with the loss of 50,000 killed and 25,000 captured, is a good example of circumstances in which battle injury is the predominant source of attrition in a campaign.[8] A more recent example of the importance of the intensity of the fighting as a determinant of attrition is the German airborne attack on the Island of Crete. Over a 10-day period in May 1941, a German force of about 22,000 lost no fewer than 6,000 men: 4,000 killed and 2,000 wounded. The first day alone saw 4,000 casualties among the 8,000 airborne troops who had arrived on Crete.[9] Needless to say, losses due to disease during this period were a minor component of the overall attrition.

Thus, given (*a*) intense fighting, (*b*) military leadership that recognizes its responsibility for the health of the men, (*c*) a knowledgeable and efficient medical service, and (*d*) the good fortune to fight in a climate and an environment that are not especially hostile, disease and nonbattle injury may not be the predominant sources of attrition. The British experience in the early weeks of the Normandy invasion in the summer of 1944 may be taken as an example. Figure 1-2 shows the partition of the British army's losses (rounded off to the nearest 500) during the 7 weeks after the landing on D day, 6 June 1944. Battle injury caused approximately 56% of the total British attrition due to medical reasons (missing and prisoner casualties are not considered).[10] Given enlightened leadership and an effective medical service, attrition due to battle injury is likely to be of greater importance than would be suggested from considerations based on the U.S. experience in, for example, the Spanish–American War—in which battle injury caused fewer than 7% of the total deaths.[11]

Magnitude of Attrition

To determine the medical assets (eg, the number of anesthesiologists) required in a war, an estimate of the expected number of battle, nonbattle, and disease casualties is needed. Although the medical threat from disease and the environment can be forecasted if the prevalence of endemic diseases in the theater of operation and its climate are known
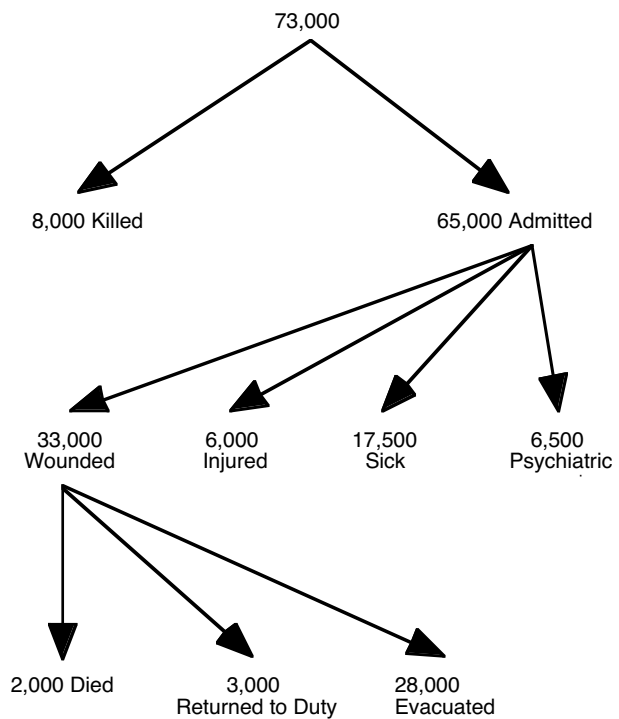

Fig. 1-2. Partition of the medical sources of attrition for the British army in Normandy, 6 June through 31 July 1944. Battle injury was the major source of attrition in the high-intensity campaign. Data source: Crew FAE. *Campaigns. North-West Europe*. Vol 4. London, England: The Army Medical Services, Her Majesty's Stationery Office; 1962: 597, 608, 610.

with some accuracy, the estimation of battle casualty rates is at best an art. Battle casualty rates, like those for disease and nonbattle injury, are usually given as an *incidence* (ie, the number of casualties per 1,000 soldiers per day, or the percentage of a unit of known size per day). The current practice is to use computer models that incorporate historical data to estimate rates for a unit of given size carrying out a specified tactical mission (eg, an airborne battalion assaulting a fortified position, or a division engaged in an opposed river crossing). The major deficiency of this empirical approach is that the data are from unique historical events and may not be applicable to a hypothetical future combat operation. What would have been the result if data gathered during the assault of the Siegfried line (1944–1945) had been used to predict the number of casualties before U.S. forces attacked the Saddam line in Kuwait in February 1991? A prediction based on the historical data would have overestimated by several hundredfold the actual number of casualties

for this simple reason: the defense of the Siegfried line was conducted by well-trained and highly motivated German professionals, while the Saddam line was defended by ineffective Iraqi draftees.
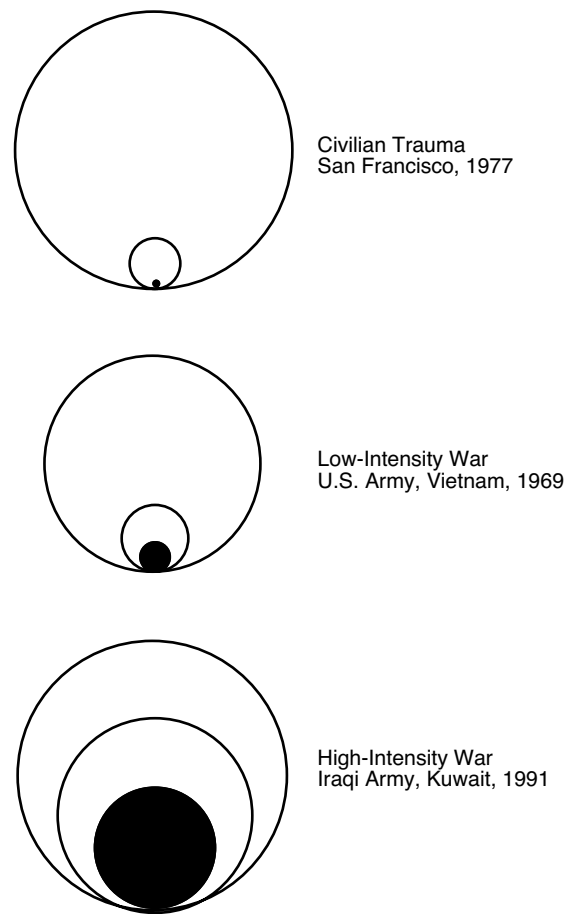
Intensity

Because it is difficult to predict casualty rates for all warfighting scenarios, descriptive terms such as "intensity" have commonly been used as qualitative indicators of expected attrition. Using this approach, it is possible to conceive of a hypothetical spectrum of combat intensities extending from peacekeeping operations to global nuclear war.[12] Between the extremes are various intensities of conventional war. The "low"-intensity end of the spectrum is typified by the Vietnam War, with its multitude of tiny search-and-destroy missions; the 1944 Normandy invasion and the gigantic air-land battle that occurred in the summer of 1943 at Kursk in central Russia are both examples of the "high"-intensity end.

The concept of intensity is meaningful only when viewed as a quasi-statistical term that depends on both the duration of the combat and the size of the population at risk. The term is meaningless when applied to a single soldier or to a short, small-unit combat action. For a soldier who is killed in action, the combat was of maximum intensity regardless of whether his death occurred in a low-intensity peacekeeping operation or a high-intensity global nuclear war. The combat action in Mogadishu, Somalia, on 3 October 1993 (during which 18 U.S. Army Rangers were killed and 70 were wounded during a company-sized operation) was no doubt considered very intense by the participants. However, a single such action during a several-month-long deployment by a brigade- or division-sized unit would qualify the entire operation as one of very low intensity. On the other hand, if the combat action in Mogadishu had been repeated daily over months by hundreds of company-sized units, the level of attrition would have been that of a high-intensity war.

The purpose of the Venn diagrams in Figure 1-3 is to contrast the trauma-generating potential of three very different sources: a modern U.S. city, a low-intensity war, and a high-intensity war. The city is represented by San Francisco in 1977.[13] From a population of about 550,000, the probability of becoming a casualty (defined as either being killed at the scene or sustaining an injury that required admission to a hospital) was about 1 in 78. Of all trauma victims, 6% were fatally injured. The low-intensity war is represented by the U.S. Army in the

Vietnam War for the year 1969.[14–16] The average troop strength was about 326,000 and the overall probability of becoming a battle casualty was slightly more than 1 in 10; for soldiers who were casualties, the probability of dying was about 1 in 5. The Iraqi army (but not the U.S. Army) experienced high-intensity attrition during the Persian Gulf War.[17] Approximately 500,000 Iraqis were deployed in the Kuwaiti theater of operation, of whom about 100,000 were killed and 100,000 were taken prisoner. The Venn diagram that portrays the Iraqi experience makes clear the truth of the famous observation by the noted Russian military surgeon Nikolai Ivanovich Pirogov (1810–1881) that "war is an epidemic of injuries."[18]

Civilian Trauma
San Francisco, 1977

Low-Intensity War
U.S. Army, Vietnam, 1969

High-Intensity War
Iraqi Army, Kuwait, 1991

Fig. 1-3. The largest circle in each Venn diagram is proportional to the population at risk; the inner circle is proportional to the number of casualties, and the black circles are proportional to the number of fatalities. The Iraqi data are provisional. We have assumed that 100,000 have been killed and 100,000 wounded or taken prisoner.

Battle Casualty Rates

Casualty rates can be calculated for the three examples shown in Figure 1-3, but it should be understood that such overall average rates ignore not only day-to-day (ie, stochastic) fluctuations but also unique events (eg, battles) and disasters (eg, earthquakes). They are statistical generalizations and are useful only for illustrative purposes. Calculated casualty rates are about 0.0035% per day for the city, 0.025% per day in the low-intensity war, and 0.7% per day in the high-intensity war. The respective rates for civilian trauma and low-intensity war, and the respective rates for low-intensity and high-intensity wars, each differ by about one order of magnitude. Although the city selected—San Francisco in 1977—had a notably benign milieu given the violence-plagued U.S. cities of the last decade of the 20th century, an increase of the rate much beyond 0.004% or 0.005% per day is unlikely. By way of comparison, the overall attrition rate for Napoleon's Grande Armèe in Russia was from 1% to 3% per day; for Panzerarmee Afrika, attrition due to enemy action averaged about 0.15% per day; and for battle injury in the British army in Normandy, the average rate was about 0.18% per day. A battle casualty rate of 0.17% per day characterized German attrition in the first 100 days of their attack on the Soviet Union in 1941.[9] In actual numbers, this rate meant about 5,500 casualties *per day*—more than 10-fold higher than the *total* U.S. Army losses in the Persian Gulf War. It should be understood that these rates are meaningful only for large populations of soldiers engaged in combat for prolonged periods. They are presented for illustrative purposes and are not equivalent to the official projected rates found in U.S. Army Field Manual 8-55, *Planning for Health Service Support.*[1]

Although there is no completely successful approach to predicting attrition, some well-documented empirical observations on attrition have been made:

- Battle casualty rates are inversely proportional to the size of the unit; for example, a battalion will have a higher rate than a division.[12] There is an obvious explanation for this fact: the smaller the combat unit, the fewer the combat support and combat service support personnel who, by virtue of their duties, are not exposed to direct enemy fire.
- When combat units are actually in contact with the enemy, division battle casualty rates in high-intensity war have usually been about 1% per day, although on rare occasions rates of up to 10% per day have been observed. Corresponding brigade and battalion rates are 3% and 10% per day, respectively. Army rates can be expected to be less than 1% per day.[19]
- Disease and nonbattle injury rates occur at a constant rate, which ranges from 0.1% to 0.3% per day to 0.5% per day when (*a*) combat operations interfere with the provision of effective preventive medicine or (*b*) the environment is especially hostile.[19]

To put the estimation of casualty rates in practical perspective, consider the following example. A brigade-sized force (about 3,000 men) is engaged in day-long, high-intensity combat. Given a battle casualty rate of 3% per day, 100 casualties may be expected. In addition, 15 soldiers can be expected to be lost because of disease. Not all the combat casualties will require anesthetic management, because some of them will have been killed and some will have minor wounds not requiring an anesthetic.

THE NATURE OF COMBAT INJURY

Combat injury and civilian trauma differ in significant respects. The nature of combat injury depends on several factors: (*a*) the mechanisms of injury, of which penetrating injury is the predominant; (*b*) the source of penetrating missiles, of which fragments and bullets predominate; (*c*) the distribution of missile wounds on the body surface; and (*d*) the relation between mortality and wound location: specifically, which internal organs have been struck.

Mechanisms of Injury

The mechanisms of injury found in conventional land warfare—penetrating, blast, blunt, and thermal—do not differ from the mechanisms that cause injury in civilian life. What is different is the relative prevalence of the mechanisms. While a blunt mechanism is the most important source of injury for civilians, trauma inflicted during combat is overwhelmingly penetrating in nature (Figure 1-4). Data
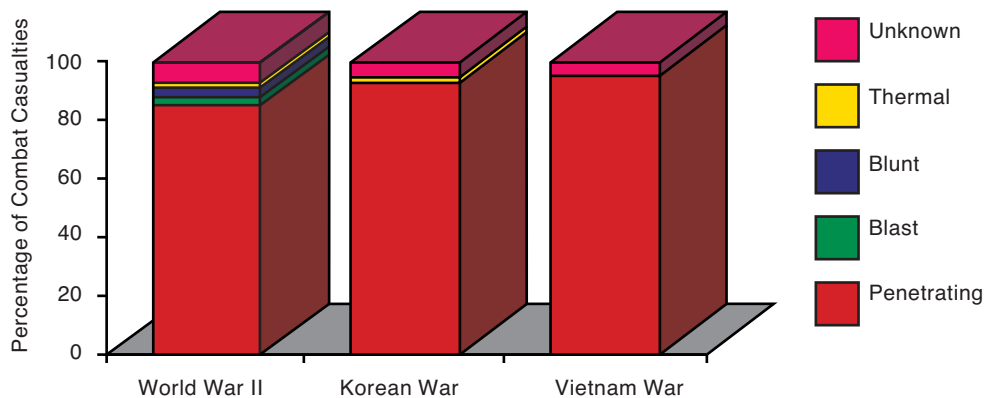
World War II: for 600,000 casualties surviving to receive medical care[1]
Korean War: all combat casualties[2]
Vietnam War: January 1965 to June 1970; for casualties surviving to receive medical care[3]; injuries were either penetrating or other than penetrating

Fig. 1-4. Mechanism of injury in US Army combat casualties. Penetrating missiles were the source of injury in 85% to 95% of casualties. Data sources: (1) Reister FA. *Medical Statistics in World War II*. Washington, DC: Department of the Army, Office of The Surgeon General; 1975: Table 7, p 90 and Table 17, p 202. (2) Reister FA. *Battle Casualties and Medical Statistics: US Army Experience in Korea*. Washington, DC: Department of the Army, The Surgeon General; 1973: 45. (3) Neel S. Medical Support of the US Army in Vietnam 1965–1970. Washington, DC: Department of the Army; 1973: 54.

compiled from the U.S. Army's records for World War II,[20] the Korean War,[21] and the Vietnam War[22] indicate that penetrating missiles are the mechanism of injury in about 90% of all battle casualties (ie, soldiers who are injured as a result of the hostile actions of a military enemy).

It is commonly thought that "blast" is a frequent cause of combat trauma, but this is a misconception. It no doubt springs from popular images of people being blown apart by powerful explosions. Although it is true that soldiers in close proximity to the detonation of a large explosive munition may sustain blast and thermal injuries, penetrating missile wounds constitute the major medical treatment problem. This phenomenon is especially apparent when an extremity is amputated by the detonation of a buried antipersonnel mine. Much of the damage is done by penetrating missiles that arise secondarily from the ground, the soldier's boot, and even his foot. The secondary missiles, in conjunction with the "blast wind" (ie, the mass of air displaced by the explosion) are responsible for the gross mutilation that is characteristic of such injuries. Primary blast injury—due to overpressure from a blast wave—is distinctly uncommon in surviving casualties except in the form of perforated tympanic membranes. It is possible that, in future wars, the development of enhanced blast weapons

such as fuel air explosives will increase the possibility of more-serious blast overpressure injuries involving the lung and solid abdominal viscera.[23]

Blunt trauma, the mechanism of injury responsible for most civilian trauma, is much less common as a cause of battle injury. When combat blunt trauma is found, it is usually in the context of a tactical vehicle detonating an antitank mine.[24] Even in these circumstances, blunt injury is the cause of only a small proportion (8%) of tank-crew casualties.[25]

The infrequent use of flame and incendiary weapons in modern warfare would be expected to make thermal injury uncommon. When soldiers are burned, the thermal injuries are usually caused by secondary explosions and fires arising from the fuel of battle-damaged armored fighting vehicles and aircraft. During World War II, about 40% of tank-crew casualties who survived to receive care were burned.[25] Half of these men had burns as their only injury. The other half had burns in addition to penetrating missile wounds. Most of the remaining 60% of tank-crew casualties had penetrating trauma. The design of the armored vehicles used by the U.S. military, such as the Abrams main battle tank, has minimized the potential for secondary explosions and fires, further decreasing the likelihood for thermal injury.

Unique circumstances, however, may generate large numbers of burned casualties. For example, at least 14% of all British army casualties in the Falklands War sustained burns because of a single combat action: two British troopships were set on fire by enemy action before the soldiers could disembark.[26]

Nonbattle Injury

The preceding treatment of mechanisms deals exclusively with injuries sustained as the result of the hostile actions of a military enemy. There is another category of trauma that may afflict soldiers in the combat zone: nonbattle injury. Nonbattle injuries show some similarity to civilian trauma in that blunt and thermal trauma are common. Vehicular accidents, especially those involving rotor-wing aircraft, are common, but most serious cases of nonbattle injury result from accidents with weapons such as explosive munitions. Thus, penetrating missile wounds are also commonly found in soldiers with nonbattle injuries.

The lethality of nonbattle injuries in the Vietnam War can be calculated: dead at the site of the accident, 5.0%; died in hospital, 1.2%.[27] As will be discussed later in this chapter, the mortality of nonbattle injuries is significantly lower than the mortality of battle injuries.

Service-Specific Aspects of Combat Injury

The mechanisms of injury and the rates of attrition are service-specific. During World War II, the overall U.S. Navy casualty rate was about 0.06% per day.[28] The probability of a fatal outcome following a combat injury on a ship was much higher than that observed in conventional land warfare: 48% of casualties were either killed or missing. Penetrating injuries were found in 39% of surviving naval casualties; this mechanism of action is therefore much less common aboard ship than in land warfare. Burns were the mechanism of injury in 22% of the casualties. Combined penetrating and thermal trauma occurred in 11% of casualties.

As befits the nature of air warfare in the last half of the 20th century, aircrew (air force and navy) casualties are uncommon, and their medical outcome is closely related to the magnitude of the aircraft's battle damage. When the damage is sufficiently severe to cause the loss of the aircraft, about two thirds of the crew can be expected to become casualties. Data indicate that one half of airmen who are injured are killed, and about two thirds of

survivors have orthopedic injuries due to blunt trauma.[29]

Sources of Penetrating Missiles

Bullets from small arms and fragments from explosive munitions are the two sources of penetrating wounds on the modern battlefield. In the major wars of this century, wounds made by explosive munitions have been numerically much more important, being found in more than two thirds of all casualties. Three examples illustrate this statement. One study of British casualties in Normandy found that 69% of the casualties had wounds made by explosive munitions.[9] Similarly, in the Israeli army in the Lebanon War of 1982, explosive munitions caused about 80% of the casualties.[30] The U.S. experience in the Vietnam War was no different: about 76% of all army casualties had penetrating missile wounds caused by fragments from explosive munitions.[16] However, an analysis of the Vietnam data provides this interesting insight: the relative numerical importance of bullet and fragments as the sources of penetrating wounds depends on *how* the war is fought. In the early part of the war, the percentage of soldiers with gunshot wounds was unusually high, sometimes exceeding 50%. The reason is that during the early part of the Vietnam War, U.S. Army units engaged in search-and-destroy operations in which both they and their opponents were usually armed with small arms.[22] A high proportion of casualties with gunshot wounds is one characteristic of low-intensity warfare, unlike what is found in high-intensity warfare involving armored fighting vehicles, artillery, and aircraft.

Explosive Munitions

The explosive munitions that cause fragmentation injuries are shells, rockets, bombs, mortars, mines, hand grenades, and ad hoc devices such as booby traps.[31] The basic design consists of a container, a fuze, and an explosive. Until recently, the container (ie, the shell), being broken apart by the detonation of the explosive, provided the fragments. Because the shell broke into irregular pieces of assorted sizes (some weighing a pound or more) and a range of velocities, it is customary to refer to such weapons as "random"-fragmentation munitions. With explosive munitions of more recent vintage, the container is designed to break up into small pieces of uniform size and shape; therefore, the fragments' initial velocities are constrained to a narrow range. A typical design produces hundreds

to thousands of 50- to 1,000-mg fragments, which are expelled with very high initial velocities (4,000–6,000 fps). In the most modern designs, preformed fragments are placed in the container and are expelled by the detonation of an explosive charge. The Vietnam War–era Claymore mine, with its 700 steel ball bearings (0.75 g each), is a good example of an explosive munitions containing preformed fragments. In the armaments industry, the two latter categories of explosive munitions are referred to as "improved"-fragmentation munitions.

The penetrating wounds produced by random- and improved-fragmentation munitions show characteristic differences. The older explosive munitions, especially the shells, were capable of causing massive mutilating injuries such as decapitation. Improved-fragmentation munitions characteristically produce multiple wounds; frequently, the casualty will be riddled with many small fragments.

Another characteristic of modern explosive munition design is that the individual munitions are frequently clustered (ie, packaged together) in a carrier (a bomb, shell, or rocket) for delivery to the enemy position. The individual submunitions are disseminated from their carrier before being detonated. Such cluster munitions greatly increase the casualty-generating potential of a given weight of munition.

A recently developed cluster munition consists of shaped-charge warheads with easily fragmentable side walls. A shaped-charge warhead is a sophisticated device that was developed during World War II as an antiarmor weapon. The hot, rapidly moving gas produced by the explosion of the shaped-charge warhead is focused in much the same way that a lens focuses light. By combining the antiarmor effect of the shaped-charge warhead with antipersonnel fragmentation effects, a dual-purpose submunition can be made.

Small Arms

The most commonly used military small arms are the assault rifle and the machine gun.[31] Their essential characteristic is that they are fully automatic; that is, they will fire as long as the trigger is pulled and there are rounds in the magazine. This behavior distinguishes military from civilian small arms: the latter class of weapons, although usually but mistakenly referred to as "automatic," are actually "semiautomatic." In a semiautomatic small arm, the trigger must be pulled every time a bullet is fired. What is automatic in a semiautomatic small

arm is the chambering (of rounds) and extraction (of cartridges).

The machine gun was perfected during World War I to the extent that it displaced the single-shot, bolt-action rifle as the dominant military small arm. The machine gun was responsible for some of the most notorious slaughters on the western front, including the killing of some 20,000 British soldiers on the first day of the Battle of the Somme in 1916.[32] The assault rifle was developed during the last years of World War II and may be looked on as an effort to give the individual soldier some of the potential firepower of the machine gun. The two best-known assault rifles today are the M16 series developed in the United States (the M16A2 is not technically fully automatic, as it is designed to fire three-round bursts) and the various designs of Kalashnikov such as the AK47 and the AK74.

The most commonly used machine gun and assault rifle bullets have calibers (in millimeters) of 5.45, 5.56, 7.62, and 12.7. The muzzle velocities range between 2,350 and 3,300 fps. Such velocities are substantially greater than those found in bullets fired by civilian handguns, which typically have muzzle velocities of 800 to 1,200 fps. Because the kinetic energy of a projectile is a function of its velocity squared, bullets fired from military small arms almost always have muzzle kinetic energy substantially greater (3-fold or more) than that of bullets fired by civilian handguns.

The *potential* for massive energy transfer and resultant tissue damage is increased by the high kinetic energy of military bullets. Whether the potential is actually realized, however, depends on aspects of the bullet's construction and the biophysical characteristics of the target tissue. The latter factor is apparent when comparing wounds made in bone and lung. Energy transfer is maximized when a missile strikes bone, but is minimized in lung with its low density and high viscoelasticity. A bullet's construction becomes an important determinant of energy transfer when it potentiates deformation or fragmentation. Bullets fired by military small arms are required by international law to be covered by a metal jacket, which is supposed to minimize deformation. Consequently, deformation of military bullets is less commonly seen than with unjacketed bullets used by civilians. Nevertheless, military bullets can cause extensive tissue damage because they may break up or fragment along their trajectory in the body. The fragmentation occurs because the bullet's metal jacket can easily be disrupted. Fragmentation is commonly seen with the M193 and M855 rounds fired by the

M16 series of assault rifles, but also occurs with 7.62-mm x 51-mm North Atlantic Treaty Organization (NATO) and M1943 Kalashnikov rounds, when manufactured with thinner-than-usual or nonsteel jackets, respectively.

Another factor that tends to increase energy transfer from military small-arm bullets is their propensity to yaw and tumble in tissue. This instability is more common than with bullets designed to be fired from civilian handguns, and is caused by the characteristic long, pointed shape of military bullets, which, by maximizing the separation between the bullet's centers of pressure and mass, predisposes to yaw and tumbling.

Massive energy transfer usually results in massive tissue damage. Nevertheless, it is important to recognize that neither the magnitude of the energy transfer nor the magnitude of tissue damage is necessarily synonymous with the magnitude of the medical treatment problem. A tiny wound of the parietal cortex made by a small fragment with several hundred joules of energy gives rise to a far different medical problem than does a massive above-the-knee amputation caused by the transfer of tens of thousands of joules of energy from an exploding antipersonnel mine.

The lethality of penetrating missile wounds sustained in combat is well defined.[30] The probability of a fatal outcome from a fragment wound made by a random-fragmentation munition is about 1 in 5 for shells and about 1 in 10 for hand grenades. Paradoxically, the lethality of improved-fragmentation munitions is lower: 1 in 7 for shells and as low as 1 in 20 for hand grenades. The probability of a fatal outcome from a single wound made at random by a bullet from a military small arm is about 1 in 3. Due to the fully automatic design of military small arms, multiple wounds can be expected; in fact, data from the Vietnam War show that a soldier killed by military small-arms fire was struck, on average, by 3.2 bullets.[15]

Distribution of Missile Wounds by Body Surface

An understanding of the medical treatment problems caused by bullets and fragments is furthered by understanding the distribution of penetrating missile wounds on the body surface. Unfortunately, data from previous wars giving the distribution of wounds are difficult to interpret for several reasons:

- First, the definitions of body regions lack consistency (eg, where does the shoulder become the thorax?).

- Second, diverse selection criteria are used (eg, some reports deal only with treated casualties, while others include dead as well as living casualties).
- Third, many casualties have wounds that involve multiple regions on the body. How to classify such casualties is a major methodological problem.

It is possible to simplify the analysis of the distribution of penetrating missile wounds by assuming that, to a first approximation, hits on the body are random and thus are distributed as a function of body surface area (eg, a thigh gets more hits than a little toe because it has more surface area). If so, then the observed distribution should be approximated by the "Rule of Nines" (Table 1-3, first column).

Of course, most soldiers are not wounded while standing in the anatomical position, so using the Rule of Nines for estimating regional body surface areas is not likely to make for accurate predictions. During World War II, British analysts attempted to develop a model for the observed distribution of wounds by assuming that the exposed body surface area was very much altered by the position of the soldier at the time of wounding.[33] For example, the regional distribution of the surface area exposed to a frontal attack is very much different for a soldier crouching or in the prone position, compared with one standing in the anatomical position (see Table 1-3, second column).

Although the problem of multiple wounds is not addressed, the most useful treatment of the distribution of penetrating missile wounds is Beebe and DeBakey's analysis of the World War II data of the U.S. Army.[11] The distribution observed in World War II for the total population of casualties for ground warfare (see Table 1-3, third column) shows a major deviation from the predicted distribution in the unexpectedly high proportion of head wounds. Although the observed distribution represents the effect of aimed fire to a limited extent, the increased propensity of missiles to strike the head is primarily due to the head's increased exposure (for tactical reasons) compared with other body parts. The fourth column of Table 1-3 shows the distribution observed for casualties who survived long enough to enter the medical system. It also shows an unexpectedly high number of casualties with head wounds, but the departure from the predicted distribution is less than that seen in the total casualty population. No doubt the decrease in the percentage of casualties with head wounds who survive to

TABLE 1-3

DISTRIBUTION OF MISSILE WOUNDS BY BODY SURFACE AREA (PERCENTAGE)

Body Region	Rule of Nines	Predicted[1]	WWII[2]	
			All	Living
Head, Face, and Neck	9	12	21	15
Chest and Abdomen	37*			
Chest		16	13	10
Abdomen		11	11.5	5
Extremity				
Upper	18	22	23.5	28
Lower	36	39	35	41.5

* The combined surface areas of the torso plus the genitals and the perineum
Definitions:
Rule of Nines: body surface area as used to quantitate the magnitude of a burn
Predicted: the standard anatomical distribution of regional surface areas has been adjusted by assuming that the soldier will be in
  a variety of combat-relevant postures (standing, crouching, and prone), weighted according to an assumed probablity
WWII: All: US Army ground casualties, both living and dead
       Living: US Army ground casualties who survive to enter the medical system
Data sources: (1) Palmer A. Survey of battle casualties, Eighth Air Force, June, July, and August 1944. In: Beyer JC, ed. *Wound Ballistics*. Washington, DC: Department of the Army, Office of The Surgeon General; 1962: 573. (2) Beebe GW, DeBakey ME. *Battle Casualties*. Springfield, Ill: Charles C Thomas; 1952: 92, 186.

receive treatment is indicative of the high immediate lethality of such wounds.

The data in Table 1-3 are consistent with the conclusion that the regional distribution of penetrating missile wounds is an approximate function of the distribution of body surface area except that the head, face, and neck receive about twice as many wounds as expected. The discrepancy is lessened when adjustments are made for the position assumed by the soldier during combat and when only treatable casualties are considered. Either way, about two thirds of all casualties can be expected to have wounds of the extremities.

Wound Depth

The data in Table 1-3 give only the location on the body surface of a penetrating wound and do not tell whether there is an associated internal injury. Both a superficial wound involving only the abdominal wall and a wound made by a missile that perforates through the entire abdomen and injures several intraabdominal viscera are classified as *abdominal*, but only the latter wound is likely to be associated with mortality or significant morbidity. Thus, regional wound distributions need to be interpreted in terms of the depth of the wound tract. A therapeutically useful distinction can be made between penetrating missile wounds that involve only soft tissue (ie, skin, fat, or skeletal muscle) and those

that also involve bone, neurovascular structures, or viscera. The distinction between soft-tissue and visceral wounds can also be applied to resolving the problem of classifying casualties with multiple wounds because many have multiple soft-tissue wounds only, or have, in addition to the soft-tissue wounds, an injury of a solitary internal organ. The classification of penetrating wounds in this chapter uses the distinction between soft-tissue and visceral wounds and utilizes two resources: the Wound Data and Munitions Effectiveness Team (WDMET) study[15] from the Vietnam War and the Abbreviated Injury Scale (AIS)[34] developed by the Association for the Advancement of Automotive Medicine.

The WDMET study consists of detailed descriptions of about 8,000 U.S. Army and U.S. Marine casualties wounded during an 18-month period from 1967 to 1969. Teams of data collectors accompanied company- and battalion-sized units during tactical operations such as search-and-destroy missions. Data were collected on the tactical situation, the weapons that caused the wounds, field first aid and the circumstances of evacuation, the detailed anatomy of wounds (including autopsy reports for those who were fatally wounded), and initial care in hospitals. The WDMET study is uniquely valuable because an effort was made to describe all casualties occurring during a given combat action, including the killed-in-action and carded-for-record-only categories, in addition to casualties who were hospitalized.

The AIS was introduced in 1976 for the purpose of standardizing the assessment of trauma resulting from automobile accidents. The potential lethality of a given injury was assigned a numerical rating: 1 (minor), 2 (moderate), 3 (serious), 4 (severe), 5 (critical), and 6 (not survivable). Nine anatomical regions were recognized: head, face, neck, thorax, abdomen, spine, upper extremity, lower extremity including the pelvis, and external. The last region is the skin and superficial soft tissue. Although the AIS initially emphasized blunt trauma, subsequent modifications have included entries for penetrating trauma.

Combat casualties from the WDMET database were classified according to the AIS with these exceptions: following the methodology used by the Injury Severity Score (ISS), the pelvic bones were considered part of the extremities, and the spine was amalgamated into the neck, thorax, and abdomen anatomical regions.[35] The following anatomical definitions were used:

- external, which includes skin, fat, and skeletal muscle anywhere on the body;

- head, which includes the skull and its contents;
- face, which includes the facial bones, eyes, and the oral and nasal cavities;
- neck, which includes the viscera and the cervical spine;
- chest, which includes the rib cage, thoracic spine, and thoracic viscera;
- abdomen, which includes the abdomen, pelvis, and the lumbar spine; and
- extremity, which includes bones and neurovascular structures.

It should be noted that the word "extremity" as used in this analysis does not have the same meaning that it has in Table 1-3; in those data, not only fractures and neurovascular injuries but also wounds of the soft tissues are included in the term "extremity."

A casualty with two or more wounds was assigned to a specific body region rather than the multiple category only if the AIS value for an injury in one region exceeded the AIS values for all injuries in the other regions. Only casualties who had two or more injuries of equal AIS value in different body
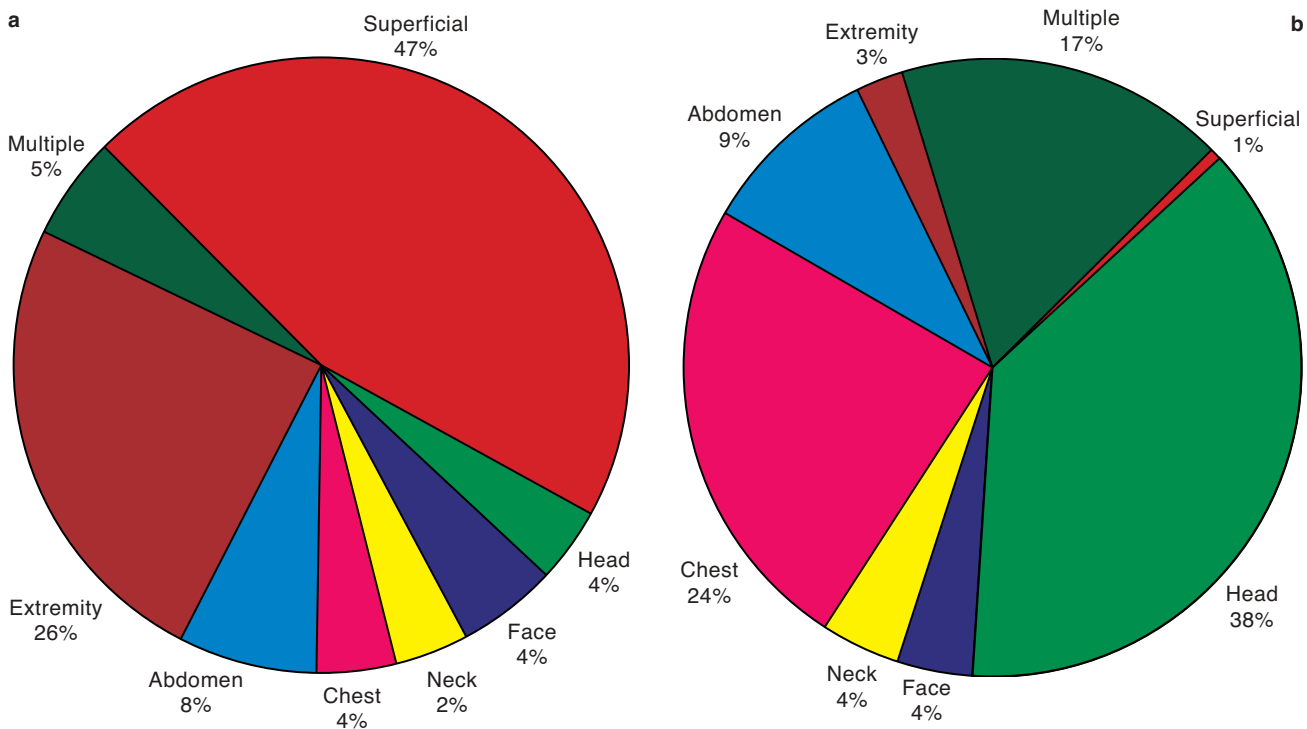
Fig. 1-5. Distribution of nonfatal (**a**) and fatal (**b**) wounds by body region. Superficial wounds (involving the skin, fat, and skeletal muscle) and injuries to the bones of the extremities are the most common sites of nonfatal wounds. The head and chest are the most common sites of fatal injuries. The multiple wounds category is restricted to casualties whose injuries were (1) of equal value according to the Abbreviated Injury Scale and (2) to at least two different body regions. Data source: Wound Data and Munitions Effectiveness Team database.

regions were classified as multiple. Thus, a casualty with AIS injuries of 5 for both the brain and the lung was classified as multiple, while a casualty with an AIS injury of 4 in the liver and 3 for the extremity was placed in the abdominal category. The analysis of the WDMET data in terms of the AIS for casualties who were fatally wounded and for those who survived is shown in Figure 1-5. About two thirds of fatally wounded casualties had wounds of either the head or the chest. Wounds of the soft tissues and the extremity skeleton were found in about three fourths of living casualties. This last finding is consistent with the military surgery experience of the 20th century, which is that at least two thirds of operations performed on combat casualties involved the management of soft-tissue wounds and fractures.

MEDICAL OUTCOME OF COMBAT INJURY

The medical outcome of combat trauma is usually discussed in terms of *mortality* and *morbidity*. Mortality is easily measured because it is not difficult to recognize when someone is dead. Much more difficult is arriving at an all-embracing definition of morbidity. When is an injury present, and how severe must it be to for the soldier to be classified as a casualty? These are not idle questions. One of the major problems of interpreting combat casualty data from the Vietnam War is that in addition to such casualty categories as killed in action, died of wounds, and wounded in action, there is a fourth category: carded for record only. Casualties who are carded for record only have very minor wounds that require either no treatment or treatment that does not require admission to a medical treatment facility. Should these soldiers be included in any assessment of medical outcome? Inclusion of casualties who are carded for record only has a marked effect on mortality and morbidity data because the population is not numerically insignificant: they constituted the largest single group of the U.S. Army's combat casualties in the Vietnam War. Such casualties have been excluded from the following analysis because their conditions do not constitute medical problems.

Combat mortality is quantitated in terms of two indicators: killed in action and died of wounds.[1] They differ not only in terms of *time* of death but, more importantly, in *where* death occurred. The locations of death for fatally wounded U.S. soldiers in World War II, the Korean War, and the Vietnam War, combined, are shown in Figure 1-6.[11,20,21] About 90% of fatally wounded U.S. soldiers expired on the battlefield; only about 10% expired after having entered the medical system. Expiring before entering the medical system is tantamount to dying before receiving effective medical care; in AMEDD, this means dying before reaching the battalion aid station, the lowest level at which a medical treatment facility is found. Thus, casualties who are killed in action expire *before* reaching any medical treatment facility, while casualties who die of wounds expire *after* reaching a medical treatment facility.

Mortality outcome data are given not only as the gross number of casualties who are classified as killed in action or died of wounds but also as nor-
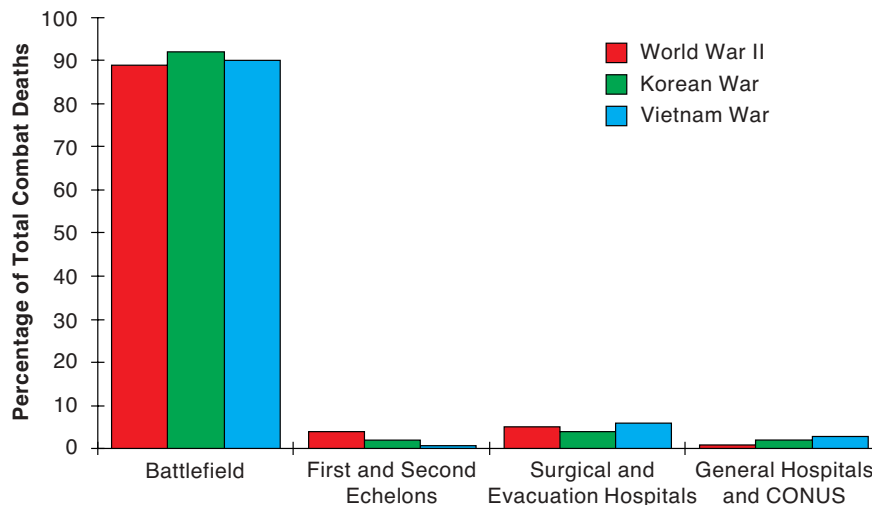
Fig. 1-6. The site of death for 90% of fatally wounded combat casualties is the battlefield. CONUS: continental United States. Data sources: (1) Beebe GW, DeBakey ME. *Battle Casualties*. Springfield, Ill: Charles C Thomas; 1952: 21, 92, 125, 186. (2) Reister FA. *Medical Statistics in World War II*. Washington, DC: Department of the Army, Office of The Surgeon General; 1975: 13; 90, Table 7; 202, Table 17. (3) Reister FA. *Battle Casualties and Medical Statistics: US Army Experience in Korea*. Washington, DC: Department of the Army, The Surgeon General; 1973: 12, 17, 45.

malized statistics: as the percentage of the total casualty population, or the percentage of the *admitted/ hospitalized* population (ie, casualties who were admitted to a medical treatment facility, the vast majority of whom were then hospitalized), respectively.

Killed in Action

The formula for calculating the percentage of casualties classified as killed in action is

$$\frac{\text{total number classified as killed in action}}{\text{total number of casualties}} \cdot 100$$

The magnitude of the percentage of the population who are killed in action depends on at least three factors:

1. The lethality of the weapons. A war fought with assault rifles is likely to have a greater percentage of casualties who are killed in action than a war fought with BB guns.
2. The feasibility and effectiveness of first aid.
3. The length of time required for evacuation from the battlefield to a medical treatment facility. The longer a casualty remains on the battlefield, he is not only more likely to die from his original wound but he is also more likely to receive a new and possibly more-lethal wound.

Exhibit 1-1 shows sample calculations of percentages of killed in action for the U.S. Army in the Vietnam War.[16] Depending on which data and definitions are used, the percentages range between 14.6% and 24.2%. The higher figure is probably a better indicator of the probability of a fatal outcome when wounded by enemy action, because it excludes the casualties who are carded for record only and includes all killed and missing soldiers.

Data from 604 soldiers recorded in the WDMET study as having been killed in action suggest that most fatally wounded casualties die very rapidly, with perhaps 70% being apparently dead within 5 minutes of wounding (Figure 1-7). This observation has important implications for interpreting the relation between mortality and the time for evacuation. One of the major criteria for judging the effectiveness of the medical service in the field is the time taken to evacuate casualties. During the Vietnam War, the time from wounding until a U.S. Army casualty left the battlefield was unprecedentedly short (median time 29 min).[15(T4-1-7)] Because most casualty evacuation in Vietnam was by

helicopter and most evacuation flights lasted less than half an hour (usually 5–20 min), it seems quite likely that most casualties were received by hospitals within 1 hour of wounding. Nevertheless, this evacuation time, which is so much faster than that of any previous war (eg, in Italy in 1944, the average time was 11.4 h from wounding to operation[36]), is still not swift enough, when considered in the context of Figure 1-7, to save more than a tiny fraction of fatally wounded casualties.

Died of Wounds

The formula for calculating the percentage of casualties classified as died of wounds is

$$\frac{\text{total number classified as died of wounds}}{\text{total number of admitted or hospitalized casualties}} \cdot 100$$

The magnitude of the percentage of the population who die of wounds depends on at least two factors:

1. Adequacy of surgical care. For example, if no neurosurgical care can be given, the number of casualties with head wounds who die will increase.
2. Casualty load and triage considerations. For example, during a mass casualty situation, it may be necessary to place certain casualties in the expectant category, resulting in a greater number of casualties who will die of wounds.

Exhibit 1-1 also shows sample calculations of percentages of casualties who died of wounds for the U.S. Army in the Vietnam War. Depending on which data and definitions are used, the percentage who died of wounds can be calculated to be 2.2%, 3.1%, or 3.4%. The first figure included the casualties who were carded for record only in the denominator and is invalid, since FM 8-55 states that the died-of-wounds population is part of the wounded-in-action population, but the carded-for-record-only population is not.[1] The population base for the 3.1% figure includes only admitted/hospitalized casualties and is, therefore, a more valid indicator of mortality in casualties who need medical treatment. Hospital mortality (ie, excluding the casualties who died while at the first or second echelons) was 3.4%.

The time of death for casualties who died of wounds as found in the WDMET data is shown in Figure 1-7. These data are similar to those of the British experience in the Normandy campaign, in which 50% of deaths occurred in the first 24 hours,

EXHIBIT 1-1

KILLED IN ACTION AND DIED OF WOUNDS DURING THE VIETNAM WAR, 1961–1979

Dead:

1. Killed in action	27,129[*]
2. Died of wounds	3,529[†]
3. Died while missing in action	5,998[‡]

Wounded in Action (WIA) but Survived:

4. WIA, admitted to hospital	96,924
5. WIA, admitted to nonhospital medical treatment facility, or quarters	13,716
6. Carded for record only	44,858

[*]Records of the Office of The Adjutant General (OTAG) state that there were 30,562 casualties classified as killed in action.
[†]104 casualties died at the first or second echelons (ie, before reaching a hospital).
[‡]Records of OTAG state that 5,998 soldiers were classified as died while missing; these casualties are in addition to those killed in action. Most were probably killed in helicopters that were destroyed in combat actions.
Data source: The Office of The Surgeon General as collated in: US Army Patient Administration Systems and Biostatistics Activity. Battle Injury Dispositions by Causative Agent—Active Duty Army Personnel with Initial Admission in Vietnam. Fort Sam Houston, Tex: Academy of Health Sciences, Department of the Army: 2 June 1981. Unpublished data.

Sample Calculations
(The numerals on the left side of the equation refer to the categories shown above)

Percentage Killed in Action:

14.6: Defined as number classified as killed in action divided by the total number of casualties exclusive of the missing: categories $1 \div (1+2+4+5+6) = (27{,}129 \div 186{,}156) \bullet 100$

17.2: Defined as number classified as killed in action plus died while missing divided by total number of casualties: categories $(1+3) \div (1+2+3+4+5+6) = (33{,}127 \div 192{,}154) \bullet 100$

18.6: Defined as number classified as killed in action according to OTAG plus died while missing divided by total number of casualties: categories $(1+3) \div (1+2+3+4+5+6) = (36{,}460 \div 195{,}587) \bullet 100$

24.2: Defined as number classified as killed in action according to OTAG plus died while missing divided by total number of casualties minus the carded for record only: categories $(1+3) \div (1+2+3+4+5) = (36{,}460 \div 150{,}729) \bullet 100$

Percentage Died of Wounds:

2.2: Defined as number classified as died of wounds divided by total number of casualties minus killed and missing: categories $2 \div (2+4+5+6) = (3{,}529 \div 159{,}027) \bullet 100$

3.1: Defined as number classified as died of wounds divided by total number of casualties admitted to hospital, nonhospital medical treatment facility, and placed on quarters: categories $2 \div (2+4+5) = 3{,}529 \div 114{,}169 \bullet 100$

3.4: Defined as number classified as died of wounds minus 104 (number dead at first or second echelons) divided by the total number of casualties admitted to hospital: categories $2 \div (2+4) = (3{,}529 - 104) \div (100{,}453 - 104) \bullet 100$

80% within 3 days, and all but 5% by the end of the first week.[10] Because medical care can play an important role in determining the outcome in casualties who are at risk of dying of wounds, the lethality associated with wounds of specific body regions has changed during wars in which the U.S. Army has been involved. During World War I, casualties with wounds of the extremities who developed anaerobic infection were the largest component of the died-of-wounds category.[11] During World War
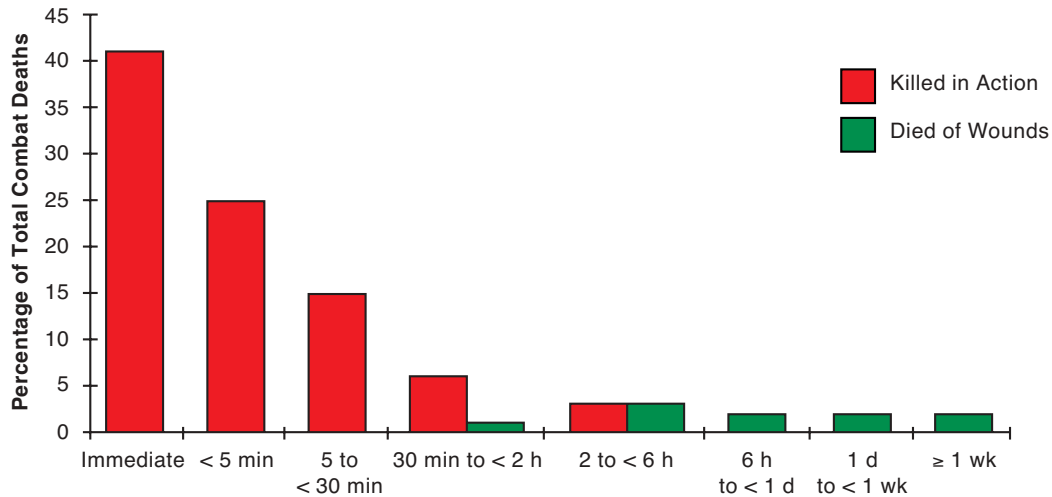
Fig. 1-7. When the time to death after wounding is plotted for battlefield casualties who are killed in action and who die of wounds, most are seen to die in less than 10 minutes, demonstrating that the "Golden Hour" seen in civilian casualties does not apply. Data source: Wound Data and Munitions Effectiveness Team database.

II, the major cause of death in soldiers who died of their wounds was intraabdominal injury.[37] During the Vietnam War, soldiers who died from wounds of the head constituted the largest component of the died-of-wounds category.[38]

This last fact has important implications for understanding the reciprocal relation between the killed-in-action and died-of-wounds categories. It is likely that rapid evacuation of gravely wounded casualties from the Vietnam battlefield brought casualties to the hospital level who, in prior wars, would have expired on the battlefield (and thus would have been classified as killed in action). Thus, the percentage of casualties who were killed in action would be reduced, while the percentage of casualties who died of their wounds would be elevated. The converse will be true given prolonged evacuation from the battlefield: the great majority of the gravely wounded will die on the battlefield (and will thus be classified as killed in action). Relatively few will reach the hospital level, so the percentage of casualties who died of wounds will be strikingly low. This situation—a high percentage of casualties who were killed in action (31%) and a low percentage of casualties who died of wounds (1.1%)—characterized the British army's Falklands War experience, a war in which evacuation time may have been unusually long.[26]

In the past, the quality of medical care has all too often been assessed in terms of the died-of-wounds rate. However, this assessment may give very misleading results. The reciprocal relation between the number of soldiers who are killed in action and the number who die of wounds is shown schematically in Figure 1-8, in which two hypothetical scenarios with identical casualty populations are contrasted: one in which evacuation is sluggish and hospital care is mediocre, and one in which evacuation is quite prompt and hospital care is optimal. Because the died-of-wounds rate is higher in the second scenario, it is possible to conclude that the quality of care is worse. The correct conclusion becomes apparent only if the overall mortality is considered. Then it is obvious that the care given in the first scenario is inferior. The effectiveness of the entire field medical system is measured when overall mortality is studied.

Absence of a "Golden Hour" in Combat Trauma

Since D. D. Trunkey's report[39] on civilian trauma was published in 1983, it has become customary to assume that the times at which fatally injured trauma victims die fall into three distinct periods: *immediate* (within the first hour), *early* (2–3 h after injury), and *late* (several days to several weeks after injury). Trunkey's study showed that about half of all deaths occur in the immediate period, 30% in the early, and the remainder in the late. Based on this distribution, there is reason to believe that, given rapid evacuation to a trauma center and excellent care there, many of the deaths that occur in the early period can be prevented. The first hour after injury has been called the "Golden Hour," since care insti-
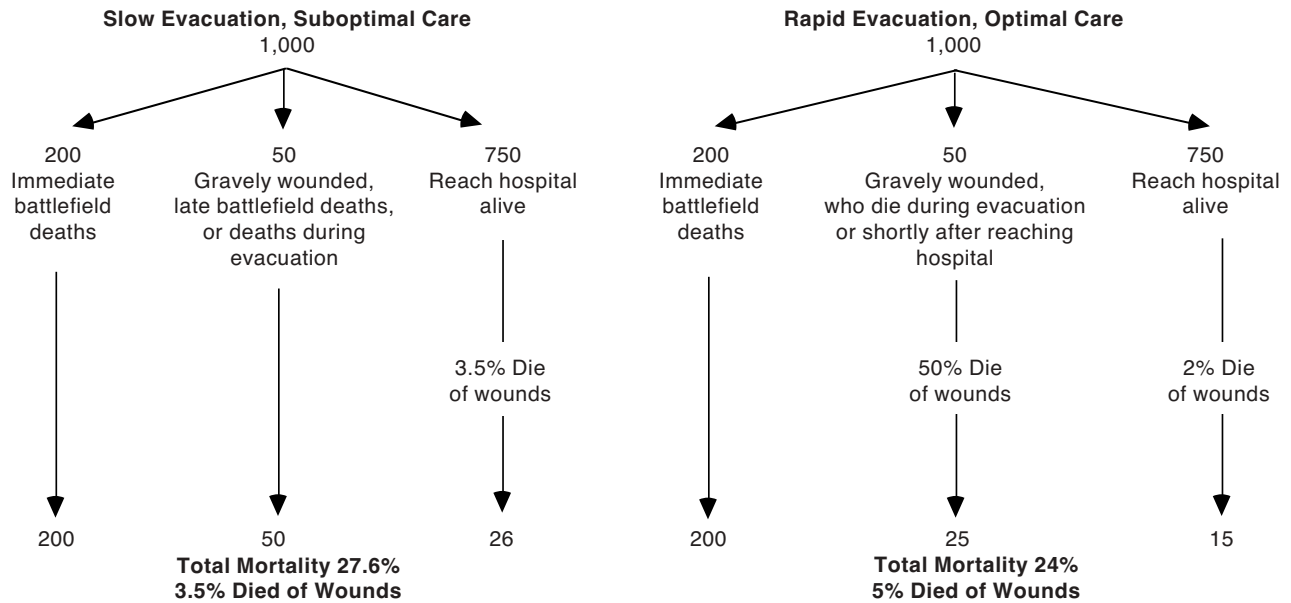
Fig. 1-8. These two hypothetical populations of combat casualties with identical Injury Severity Scores are evacuated at different speeds and receive different medical care. The difference in medical outcome appears paradoxical: the number of casualties who die of wounds is much higher in the rapidly evacuated group, although the total mortality is lower.

tuted within this interval is likely to be lifesaving for trauma victims who might otherwise die in the early period. Care started after the first hour is more likely to be futile. A similar, albeit less well-substantiated and -defined concept, is found in combat casualty care: the medical service has an hour to institute lifesaving first aid in the critically wounded soldier; otherwise, survival becomes increasingly unlikely.

The clinical evidence that was used to establish the trimodal distribution of trauma deaths is of civilian origin and, therefore, blunt trauma was the usual mechanism of injury. However, Figure 1-7 shows no evidence of a trimodal distribution of combat deaths: 80% to 90% of all deaths occur during what, by analogy, would be Trunkey's immediate period, with perhaps 70% occurring in the first 5 minutes. Although there are late deaths, it is difficult to recognize a distinct cluster of deaths after the initial peak. It is likely that this difference between the military and civilian experiences arises from the great predominance of penetrating trauma in the former, with penetrating injury's potential for rapid exsanguinating hemorrhage. Support for this view comes from a 1993 study[40] of a civilian trauma population who had a much higher percentage of penetrating trauma than the population in Trunkey's study. Most deaths in the 1993 study occurred during what would be Trunkey's immedi-

ate period, following which deaths became progressively less common until the onset of sepsis and multiple organ failure days afterward. The implication for combat casualty care, based on the observed distribution of deaths found in the WDMET data, is obvious: if there is a "golden" period, it is a golden 5 minutes.

Historical Trends in Combat Mortality

Historical trends in combat mortality and their supporting data are shown in Figure 1-9. The wars have been selected for illustrative purposes and do not constitute a systemic appraisal of combat mortality. As a general rule, at present, given optimal combat casualty care, 20% to 25% of battle casualties can be expected to be killed in action and 3% to 5% of survivors reaching the hospital level alive will die of their wounds. This conclusion depends on two important qualifications: (1) medical care must be state of the art and science and (2) the tactical situation must allow for application of the available medical resources. The latter qualification means that the army in question must not be losing badly. Losers may have terrible combat mortality. Two 20th-century battles illustrate this point: at the battle of Stalingrad, about 75% of German casualties were in the killed and died categories after mid-December 1942[41]; at the battle of
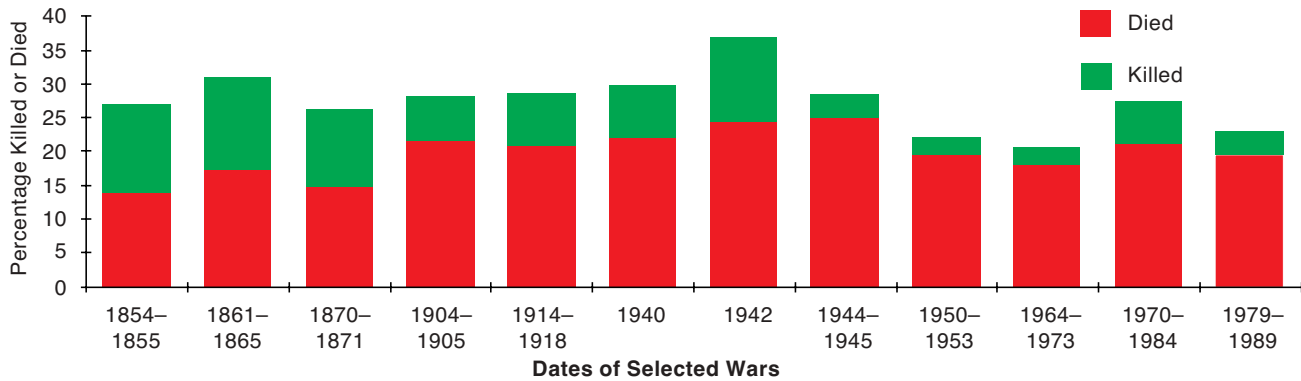
Fig. 1-9. *See legend on page 19.*

Okinawa, Japanese mortality was about 95% of all soldiers.[42] If there is one lesson that military history teaches, it is that the essential prerequisite for low combat mortality is to win!

Outcome of Specific Body-Region Injuries

The mortality of combat injuries can be understood best when wounds of separate body regions are studied. The following outcome data are from the WDMET study for soldiers wounded in the head, chest, abdomen, and extremities.[15] Casualties were placed in the *head* category when a projectile (bullet or fragment) reached the periosteum of the skull or deeper; in the *chest* category when a projectile reached the rib cage or deeper; in the *abdominal* category when a projectile perforated the peritoneum; and in the *extremity* category when a projectile injured the skeleton or a neurovascular structure in the upper or lower extremity. Injuries were classified as *primary* (ie, one body region had an AIS score greater than any other body region) or *multiple* (ie, two or more body regions had injuries of equal potential lethality according to the AIS). Casualty outcomes were defined as follows:

- killed: succumbed on the battlefield,
- died: succumbed while receiving care at a medical facility,
- hospitalized: admitted to a medical treatment facility, and
- survived: either returned to duty or was alive when evacuated from Vietnam.

Head

- Total mortality: $^{373}/_{477} = 78\%$
- Hospital mortality: $^{37}/_{141} = 26\%$
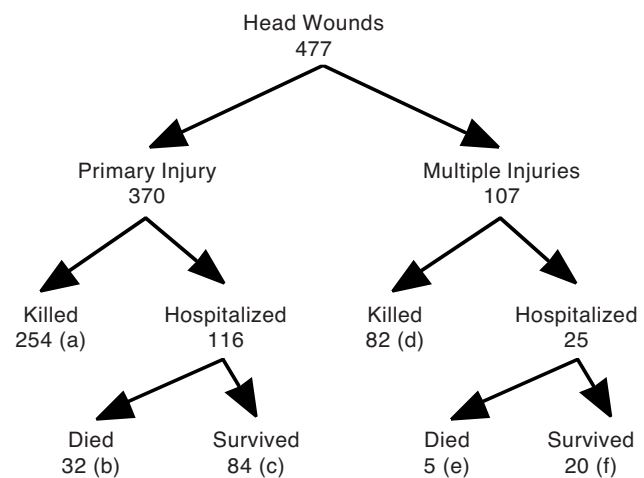
Primary Injury. Of the 254 casualties whose head wounds were their primary injury and who were killed (point *a* on the diagram), 184 (72.4%) sustained massive brain destruction (eg, injury to three or more lobes, avulsion of the brain, decapitation, crushing of the head), and 43 (17%) had isolated injury to the midbrain or brainstem. The remainder had an injury involving one or two lobes or a depressed skull fracture.

Of the 32 who died after being hospitalized (point *b* on the diagram), slightly fewer than one half were treated expectantly.

Of the 84 casualties who survived (point *c* on the diagram), 44 had an injury that involved only one cerebral lobe, 15 had injuries involving two lobes, and 12 had depressed skull fractures caused by tangential gunshot wounds.

Multiple Injuries. Of the 82 casualties with multiple injuries who were killed (point *d* on the diagram), 27 (33%) had massive brain destruction in addition to grossly mutilating injuries to other parts of the body. Most of the remainder had injuries to one or two lobes.

Fig. 1-9. Percentages of casualties who died or were killed in selected wars. The figure is based on the following supporting data:

1854–1855: British battle casualties in the Crimean War. Killed: 1,933; died: 1,599[1]; wounded: 12,100.[2] The high hospital mortality is characteristic of the preantisepsis era of military surgery. An additional 11,477 died of disease.

1861–1865: Union battle casualties in the American Civil War. Killed: 67,058; died: 43,012; wounded: 318,187.[3] An additional 233,789 died of disease. The killed figure does not include the missing in action, a significant proportion of which probably were also killed.

1870–1871: German battle casualties in the Franco–Prussian War. Killed: 17,300; died: 11,000; wounded: 96,200.[4]

1904–1905: Japanese battle casualties in the Russo–Japanese War. Killed: 47,500; died: 11,500; wounded: 173,400.[4] The first "modern" war in several senses: machine guns and high-explosive shells dominated the battlefield, and some military surgeons used antiseptic and aseptic techniques.

1914–1918: British battle casualties in France and Flanders. Killed: 381,261; died: 151,356; surviving wounded: 1,837,613; missing and assumed killed: 144,890.[5]

1940: German battle casualties during the conquest of France, May–June 1940. Killed: 21.9%; died: 7.8%.[6] Actual numerical data are not given, but according to Fischer[7] there were approximately 48,000 battle fatalities. The Germans ascribed the high mortality to the delayed evacuation of casualties from rapidly moving armored units.

1942: German battle casualties on the Russian front, January 1942. Killed: 24.4%; died: 12.3%.[6] Actual numerical data are not given, but the same source indicates that there were about 55,000 battle fatalities.[6] The high mortality is the result of the extraordinary difficulty of providing effective combat casualty care in the extreme cold during the massive Soviet counterattack that followed the collapse of the German attack on Moscow.

1944–1945: American battle casualties in Italy, January 1944–May 1945. Killed: 25,183; died: 2,770; total admissions (carded for record only category excluded): 76,351.[8] Reister's data are somewhat different from those given by Snyder and Culbertson[9]: killed: 16,648; hospitalized/died: 1,631; hospitalized/survived: 61,393; killed: 20.9%; died: 2.6%. The latter data do not include casualties who died of wounds prior to hospitalization nor some 9,000 additional soldiers who were killed but were presumably still classified as missing when the data were collated in 1945.

1950–1953: American battle casualties during the Korean War.[10]

1964–1973: US Marine Corps battle casualties during the Vietnam War. Killed: 11,490; died: 1,454; nonfatal wounds/hospital care required: 51,399.[11] The Marine Corps' mortality data appear to be more favorable than are the corresponding US Army data.

1970–1984: British army casualties from Northern Ireland, for soldiers killed or wounded by explosive devices. Killed: 174; died: 42; total injured: 828.[12] These data are useful for understanding mortality in "peacekeeping" operations (now officially known as operations other than war [OOTW]). Evacuation time from the site of wounding to surgical care was almost certainly shorter than that in any of the wars described. It is also probable that the wounds were, on average, more severe.

1979–1989: Russian battle casualties during the Afghanistan War. Two sources are available. The first[13] gives normalized statistics for killed (19.5%) and died (3.5%), but actual data are given for what may be different casualty categories: fatally wounded, 13,833, and wounded, 49,985. The second[14] has the following entries: killed: 9,511; died: 2,386; surviving wounded: 51,367. Using these data, killed in action would be 15.0% and died of wounds 4.4%. Which source is correct is not known. Both sources indicate that there were more than 400,000 admissions for disease.

Data sources: (1) Palmer A. *The Crimean War*. New York, NY: Dorset Press; 1987: 244. (2) Beebe GW, DeBakey ME. *Battle Casualties*. Springfield, Ill: Charles C Thomas; 1952: 77. (3) Livermore TL. *Number & Losses in the Civil War in America: 1861–65*. New York, NY: Kraus Reprint Co; 1969: 8. (4) La Garde LA. *Gunshot Injuries*. New York, NY: Wm Wood and Co; 1916: 413. (5) Mitchell TJ, Smith GM. *Casualties and Medical Statistics of the Great War*. London, England: The Army Medical Services. His Majesty's Stationery Office; 1931: 108. (6) Mueller-Hillebrand B. Statistics System. US Army Historical Division Study PC 011 Koenigstein Ts. 1949: 121, 136. Unpublished. Available at the National Archives, Washington, DC. (7) Fischer H. *Der Deutsche Sanitätsdienst 1921–1945*. Vol 2. Osnabrück, Germany: Biblio Verlag; 1983: 343. (8) Reister FA. *Medical Statistics in World War II*. Washington, DC: Department of the Army, Office of The Surgeon General; 1975: 76–79. (9) Snyder HE, Culbertson JW. Studies of Fifth US Army hospitalized casualty deaths. In: Beyer JC, ed. *Wound Ballistics*. Washington, DC: Department of the Army, Medical Department, Office of The Surgeon General; 1962: 473. (10) Reister FA. *Battle Casualties and Medical Statistics: US Army Experience in Korea*. Washington, DC: Department of the Army, The Surgeon General; 1973: 45. (11) Directorate for Information Operation and Control. Number of casualties incurred by US military personnel in connection with the conflict in Vietnam. Washington, DC: Department of Defense (OASD Comptroller), January 15, 1976: Table 1051. Unpublished. (12) Mellor SG, Cooper GJ. Analysis of 828 servicemen killed or injured by explosion in Northern Ireland 1970–1984: The Hostile Action Casualty System. *Br J Surg*. 1989;76:1006–1011. (13) Nechaev E. Soviet military experience in providing health care during Afghanistan War: Problems of further military medicine development. *Military Medical Journal* (Moscow). 1992;2:5–14. (14) Krivosheyev GF, ed. *Losses to the Armed Forces of the USSR in Battles, Combat Operations, and Military Conflicts: Statistical Investigations*. Moscow, Russia: Military Press; 1993: 402–404.

Of the 5 hospitalized casualties with multiple injuries who died (point *e* on the diagram), 2 were treated expectantly. Of the 20 hospitalized casualties who survived (point *f* on the diagram), 7 had single-lobe and 6 had double-lobe injuries.

In addition, the fatal head wounds of 7 casualties who were killed in action were insufficiently described to justify inclusion in the diagram. An additional 27 casualties, also not included, sustained systemic mutilation that almost certainly included a fatal brain injury. Eight casualties with gunshot wounds and 4 with fragment wounds of the scalp did not have evidence of skull or central nervous system (CNS) injury. They are not included, but one casualty with a gunshot wound of the scalp and a cerebral concussion is included.

Type of Penetrating Missile. The partition by outcome of casualties whose primary injury was in the head by type of penetrating missile is as follows: 53% of those who were fatally wounded and 5% of those who survived were injured by bullets; 28% of those who were fatally wounded and 14% of those who survived were injured by explosive munitions. These data indicate that the probability of being fatally wounded if struck in the head by a bullet approached 9 in 10. In fact, of the casualties who survived to be evacuated from Vietnam, only 3 in the entire population (477) had penetrating head wounds caused by a bullet in which the brain parenchyma was directly injured (as distinct from a depressed fracture of the skull with associated brain injury caused by a tangential bullet wound). Casualties with multiple injuries of which one component was in the head were likely to be victims of explosive munitions rather than small arms.

Chest
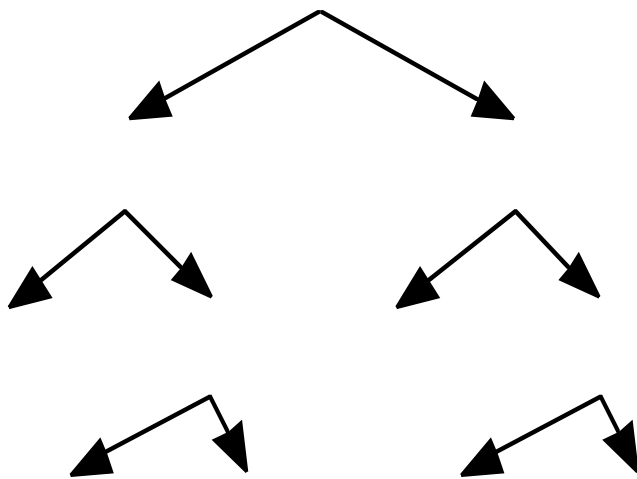
- Total mortality: $^{435}/_{613} = 71\%$
- Hospital mortality: $^{30}/_{208} = 14\%$

Primary Injury. Of 613 casualties who were classified as having chest wounds, the chest wound was the primary injury in 415. Of these, 260 were killed (point *a* on the diagram). The sites of fatal injury were heart or great vessels or both, 43%; lung, including trachea, 30%; and heart, great vessels, and lung, 27%.

Of the 155 casualties who were hospitalized with primary injury, 17 died (point *b* on the diagram): 8 deaths occurred intraoperatively, 7 died preoperatively, and 2 died postoperatively. Nine of these casualties had wounds of the lung only, 4 had wounds of the heart or great vessels, and 4 had wounds of the heart or great vessels and lung.

Of the 138 casualties who survived their primary injury (point *c* on the diagram), 61% had wounds of the lung, 34% had a significant chest-wall injury in addition to a lung injury, and 5% had a wound of the mediastinum, which, in two cases, involved a partial-thickness laceration of the myocardium.

Multiple Injuries. Of the 198 casualties with multiple injuries (but whose chest wounds were predominant), 145 were killed (point *d* on the diagram). Of these, 53% had wounds involving the lungs, 37% had mutilating wounds of the entire trunk, and 10% had wounds of the lung and/or the heart and the great vessels.

Of the 53 casualties with multiple injuries who were hospitalized, 13 died (point *e* on the diagram). Of these, 6 died before operation, 4 died intraoperatively, and 3 died postoperatively.

All of the 40 casualties who were hospitalized and survived had wounds of the lung or chest wall or both (point *f* on the diagram).

In addition, but not included in the diagram, 37 casualties had thoracic injuries in which the chest component was of lesser severity when compared to an injury in another body part. Of these casualties, 24 were killed, 4 died, and 9 survived. The thoracic injury was limited to the lungs in 82% of these casualties. An additional 18 casualties had nonpenetrating injuries, but they also are not included here.

Of the 155 casualties who were evacuated alive from the battlefield with primary thoracic injuries, 24 (15%) had a formal thoracotomy. Mortality in this group was 10 of 24 (42%). Three casualties with multiple injuries had a thoracotomy; all died.

Type of Penetrating Missile. The partition by outcome of casualties whose primary injury was in

the chest by type of penetrating missile is as follows: 44% of those who were fatally wounded and 11% of those who survived were injured by bullets; 30% of those who were fatally wounded and 15% of those who survived were injured by explosive munitions. These data indicate that the probability of being fatally wounded if struck in the chest by a bullet is about 4 in 5. Most of the casualties in the multiple category who had thoracic wounds were injured by explosive munitions.

Abdomen

Abdominal Wounds
476

Primary Injury
318

Multiple Injuries
158

Killed
53 (a)

Hospitalized
265

Killed
85 (d)

Hospitalized
73

Died
25 (b)

Survived
240 (c)

Died
14 (e)

Survived
59 (f)
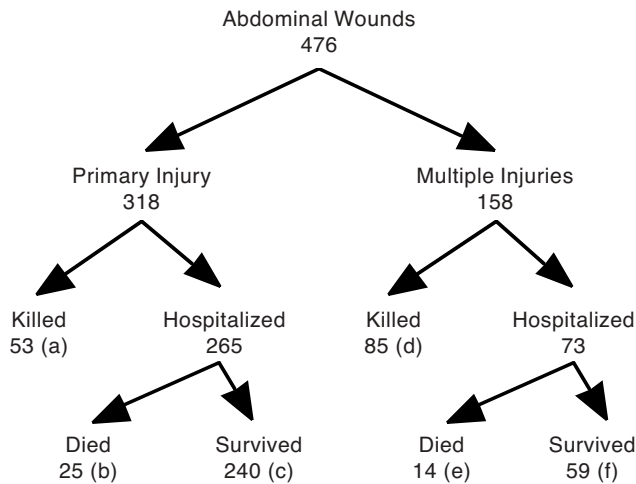
- Total mortality: $^{177}/_{476}$ = 37% (42% when casualties with negative laparotomies are excluded)
- Hospital mortality: $^{39}/_{338}$ = 11.5% (13.3% when casualties with negative laparotomies are excluded)
- Total mortality of casualties whose primary injury involves the abdomen: $^{78}/_{318}$ = 24.5% (28% when casualties with negative laparotomies are excluded)
- Hospital mortality of casualties whose primary injury involves the abdomen: $^{25}/_{265}$ = 9.4% (11% when casualties with negative laparotomies are excluded)

Primary Injury. Of the 318 casualties whose abdominal wounds were their primary injury, 53 were killed (point *a* on the diagram). In all casualties, death was due to hemorrhage: 42% exsanguinated from an intraabdominal vascular injury (45%, iliac vessels; 40%, aorta or inferior vena cava; 15%, miscellaneous); 25% had a mutilating abdominal injury; 18% had involvement of multiple intraabdominal organs exclusive of the named vessels; 11% had a liver injury; and 4% had an involve-

ment of a single intraabdominal organ other than the liver.

Of the 265 casualties who were hospitalized with primary abdominal wounds, 25 died (point *b* on the diagram). Death was due to hemorrhage in 60% of casualties, intraabdominal sepsis in 25%, and pulmonary insufficiency in 15%. The sites of abdominal injury were as follows: multiple sites, exclusive of vessels, 38% (average number of injured organs was 4.4); intraabdominal vessels, 30% (the iliac vessels accounted for two thirds of these); liver, 21%; single organ exclusive of the liver, 12%.

Two hundred forty casualties survived their primary abdominal wounds (point *c* on the diagram). On average, survivors had 1.8 injured intraabdominal organs; one half of the survivors had an injury to only one organ. The most commonly injured organs were the colon including the rectum, 23%; the small bowel including the duodenum, 23%; and the liver, 14%. Only 1% of survivors in the primary category had a vascular injury.

Multiple Injuries. Of the casualties with abdominal wounds, 158 had multiple injuries. In this category, 85 casualties were killed (point *d* on the diagram). Of these, 71% had injuries to the chest; about one half had true thoracoabdominal wounds (ie, a single missile traversed both thorax and abdomen). The remaining casualties had various combinations of abdominal injuries in addition to wounds of the head or extremities.

Of the 73 casualties with multiple injuries who were hospitalized, 14 died (point *e* on the diagram). All casualties in this category had wounds of the lung in addition to their intraabdominal injuries.

Of the 59 hospitalized casualties who survived (point *f* on the diagram), 65% had extremity wounds in addition to their abdominal wounds; 25% had head wounds, all but one of which were treated by craniotomy; and 10% had chest wounds, one of which required a thoracotomy.

There were an additional 7 casualties in whom the abdominal component was of lesser severity than a wound to some other body part. All 7 were fatally wounded, and in all casualties the more serious wound was to the head. An unknown number of casualties had an injury that was subsequently shown to involve only the abdominal wall. The number of such casualties approximates but is greater than the number of casualties who had negative laparotomies (39 casualties in the primary category and 11 in the multiple categories, 15% of all laparotomies). Casualties who had a negative laparotomy were classified in the abdominal cat-

egory even though no intraabdominal injury was present.

Type of Penetrating Missile. The partition by outcome of casualties whose primary injury was in the abdomen by the type of penetrating missile is as follows: 24% of those who were fatally wounded and 10% of those who survived were injured by bullets; 19% of those who were fatally wounded and 47% of those who survived were injured by explosive munitions. These data indicate that the probability of being fatally wounded if struck in the abdomen by a bullet was about 2 in 3. Most of the casualties in the multiple category who had abdominal wounds were injured by explosive munitions.

Extremities

Extremity Wounds
832

Primary Injury
777

Multiple Injuries
55

Killed
56 (a)

Hospitalized
721

Killed
17 (d)

Hospitalized
38

Died
4 (b)

Survived
717 (c)

Died
5 (e)

Survived
33 (f)
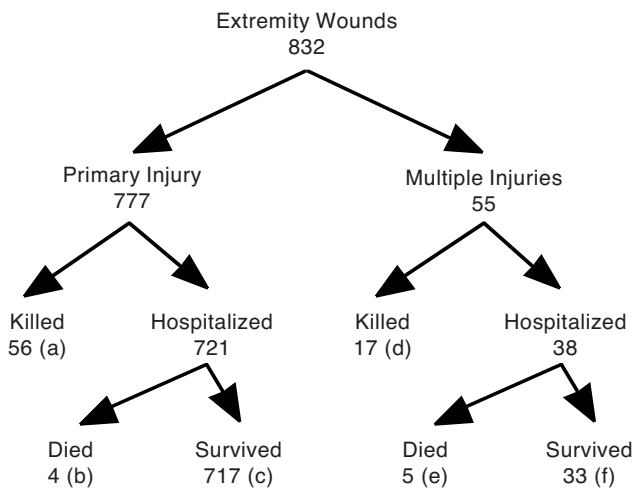
- Total mortality: $82/832 = 9.9\%$
- Hospital mortality: $9/759 = 1.2\%$

Primary Injury. Of 832 casualties classified with extremity wounds, 777 had these wounds as their primary injury. Of these casualties, 56 were killed (point *a* on the diagram) and in all, the cause of death was exsanguination. Thirty-five deaths were caused by amputations of an arm or leg, 17 exsanguinated from an isolated arterial wound (the femoral artery was the most common site), and 4 died who had sustained multiple extremity fractures.

Of the 777 casualties whose extremity wounds were the primary injury, 721 were hospitalized. Of these, 4 died (point *b* on the diagram). Two casualties died while being treated for femoral artery lacerations, one died of gas gangrene following a failed axillary artery repair, and one died in what was reported as "mysterious circumstances" following treatment for a forearm amputation.

Of the 721 hospitalized casualties, 717 survived (point *c* on the diagram). About 50% of the survivors had fractures of extremity long bones, and 20% had fractures involving the hands or feet. Major extremity amputations and isolated vascular injuries were each found in 8% of the casualties in this category.

Multiple Injuries. Of the 832 casualties with extremity wounds, 55 were classified as having multiple injuries; of these, 17 were killed (point *d* on the diagram). Most casualties with multiple injuries exsanguinated from major extremity amputations or femoral artery lacerations, in addition to hemorrhage from injured intraabdominal viscera. The remainder had injuries to the head or thorax in addition to the extremity wound.

Of the 55 multiply injured casualties in the extremity wound category, 38 were hospitalized, and of these, 5 died (point *e* on the diagram). Casualties in this category exsanguinated from femoral artery injuries in conjunction with bleeding from within the chest or abdomen.

Of the 38 hospitalized casualties with multiple injuries, 33 survived (point *f* on the diagram). In these casualties, the extremity injury coexisted with injuries to the head (including the face), chest, and abdomen, in that order.

Excluded from the extremity analysis were approximately 300 casualties in whom the extremity injury was of secondary severity. Most of these casualties fell into one of two categories: (1) grossly mutilating injuries in which the extremity injury coexisted with major disruption of the head or trunk, and (2) a long-bone fracture in addition to a severe and frequently fatal injury of the head, chest, or abdomen.

Type of Penetrating Missile. The partition by outcome of casualties whose primary injury was in the extremity as a function of the type of penetrating missile is as follows: 4% of those who were fatally wounded and 30% of those who survived were injured by bullets; 11% of those who were fatally wounded and 55% of those who survived were injured by explosive munitions. These data indicate that the probability of being fatally wounded if struck in an extremity by a bullet that injured bone or neurovascular structures was about 1 in 11. Explosive munitions were actually more deadly than bullets: the probability of a fatal outcome was about 1 in 6. The reason for the higher lethality of explosive munitions is no doubt related to the propensity of antipersonnel mines to cause amputations.

Morbidity

The ability of the medical service to perform its mission, which is summarized in such statements as "conserve fighting strength" and "maintain the fighting power of the command," depends on how effectively combat morbidity is reduced. Morbidity is more difficult to measure than mortality because the latter has a clear endpoint. Indices of morbidity that have been used are (1) the percentage of surviving wounded who return to duty, or alternatively, the percentage of surviving wounded who are separated from the army, and (2) the length of time a soldier who ultimately does return to duty remains noneffective following a combat injury (Table 1-4).[20–22,43] The morbidity data for the U.S. Army have not changed appreciably in the wars of this century. The explanation is probably to be found in two facts:

- The rate of healing of bone and soft tissue has not changed very much.
- The organization of the army in the theater of operations, as well as other administrative factors, does not allow rapid return to duty.

The latter observation may seem strange given the official emphasis placed on conserving fighting

TABLE 1-4

INDICES OF MORBIDITY

War	Days Noneffective	Disability Separation (% of Wounded)
World War I[1]	96	11
World War II[2]	118	18
Korea[3]	93	9
Vietnam[4]	86*	11*

*No final figures appear to have been published for indices of morbidity. Neel gives data that are specific for Vietnam, but how long the soldiers who had been evacuated from there remained noneffective is unclear. The figures given in this table were obtained by extrapolation using factors derived from the World War II and Korean War data given by Neel.
Data sources: (1) Love AG. *Statistics*. In: *Medical and Casualty Statistics*. In: *Medical Department of the United States Army in the World War*. Vol 15, Part 2. Washington, DC: Government Printing Office; 1925: 1181, 1183. (2) Reister FA. *Medical Statistics in World War II*. Washington, DC: Department of the Army, The Surgeon General; 1975: 13. (3) Reister FA. *Battle Casualties and Medical Statistics: US Army Experience in Korea*. Washington, DC: Department of the Army, Office of The Surgeon General; 1973: 712, 717. (4) Neel S. *Medical Support of the US Army in Vietnam 1965–1970*. Washington, DC: Department of the Army; 1973: 52–53.

strength but was a well-known fact during both the Vietnam War and the Persian Gulf War. During the latter, there were many anecdotal reports that field medical facilities were told to evacuate all casualties regardless of how soon they were expected to return to duty. The reason for this decision is simply that extensive casualty-holding facilities within the combat zone constitute a considerable logistical burden. In a short conflict such as the Persian Gulf War, in which there may be little need for replacements, it is neither necessary nor cost-effective to hold wounded and sick soldiers in the combat zone.

What happened in Vietnam has a different explanation. Because there was a congressionally mandated limit on the number of troops within the combat zone, senior commanders were faced with the choice of either allowing the wounded to recover in country (and thereby reducing the number of effective soldiers in combat units) or evacuating the casualties from Vietnam and bringing in replacements, thereby maintaining the fighting strength. The latter course was usually chosen, although commanders recognized that evacuated soldiers usually were not returned to duty in Vietnam.

An army's commitment to return to duty is implicit in its evacuation policy (ie, the maximum number of days a casualty can be allowed to remain in the theater of operation before he must be evacuated).[1(p4-1–4-3)] For example, if the evacuation policy is set at 30 days, a casualty judged by the medical service to require more than 30 days to return to duty would be evacuated as soon as possible. The longer the evacuation policy, the greater the return to duty from the theater of operation but, conversely, the greater the medical deployment. Evacuation policies have ranged from as long as 180 days in the European Theater of Operations in 1944 to as short as 7 days during one phase of the Persian Gulf War.
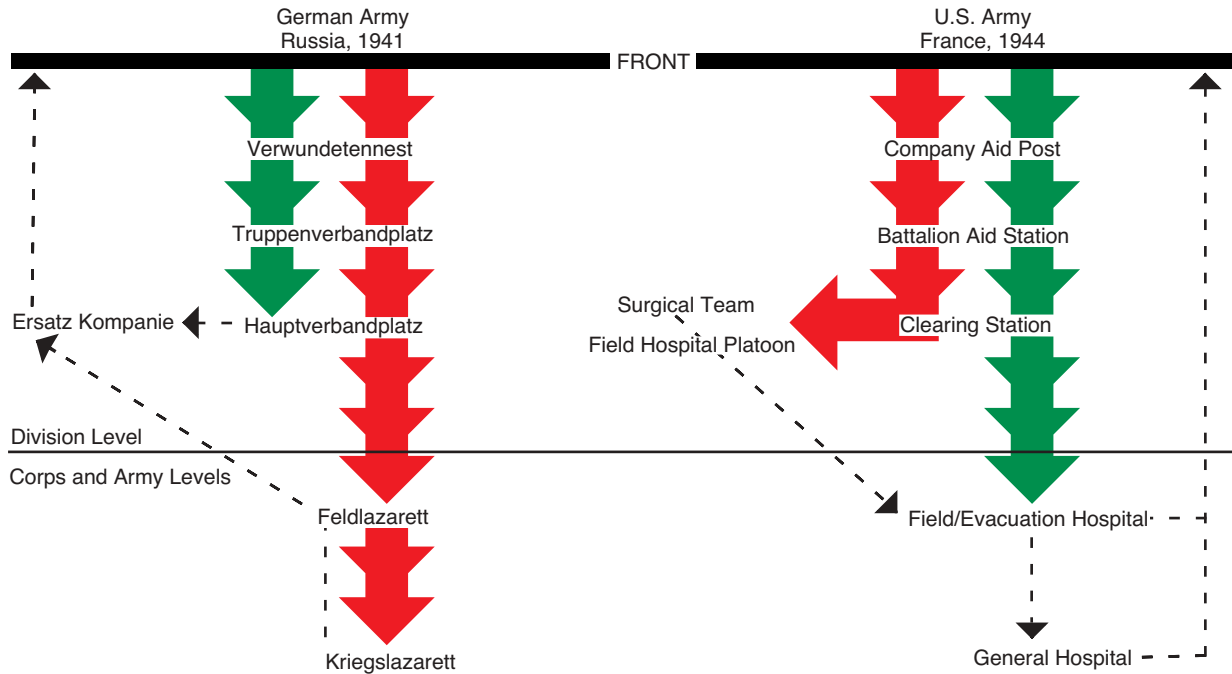
Soldiers with soft-tissue wounds and fractures together constitute about three fourths of surviving casualties (see Figure 1-5). Because soft-tissue wounds heal much more quickly, on average, than do fractures or complicated wounds of the trunk or head, the population of casualties with soft-tissue wounds makes a disproportionately small contribution to the total number of man-days lost. As a general rule, about one third of the total man-days lost are due to soft-tissue wounds, one third are due to fractures, and one third are due to all other wounds (but especially to complicated abdominal or facial injuries).

The organization of the medical service in the field can have an important impact on the magni-

Fig. 1-10. A highly simplified and idealized diagram of evacuation patterns used by the German Army in Russia in July 1941 and by the US Army in France in summer and fall, 1944. The red lines indicate the flow of casualties with potentially fatal injuries; the green lines, the flow of casualties with nonlethal injuries. The German organization was designed to evacuate to the corps and army levels all casualties whose injuries made return to duty within a few weeks unlikely. Casualties with lesser injuries were retained within the division, where they were segregated to facilitate rapid return to duty. The American organization was designed to evacuate the great majority of casualties, including those with minor injuries, to the corps and army levels. Casualties with life-threatening injuries, however, received resuscitative surgery before leaving the division. Thus, the American organization emphasized the saving of lives; the German, the return to duty of the lightly wounded. Adapted with permission from Bellamy RF. Contrasts in combat casualty care. *Milit Med*. 1985;150:406.

tude and duration of noneffectiveness of combat casualties. Mortality can also be affected by the way the medical services are organized. These conclusions are illustrated by comparing the U.S. and German field medical organizations as they existed during two discrete periods of World War II: the German Army in Russia, summer 1941; and the U.S. Army in France, summer 1944 (Figure 1-10).[44]
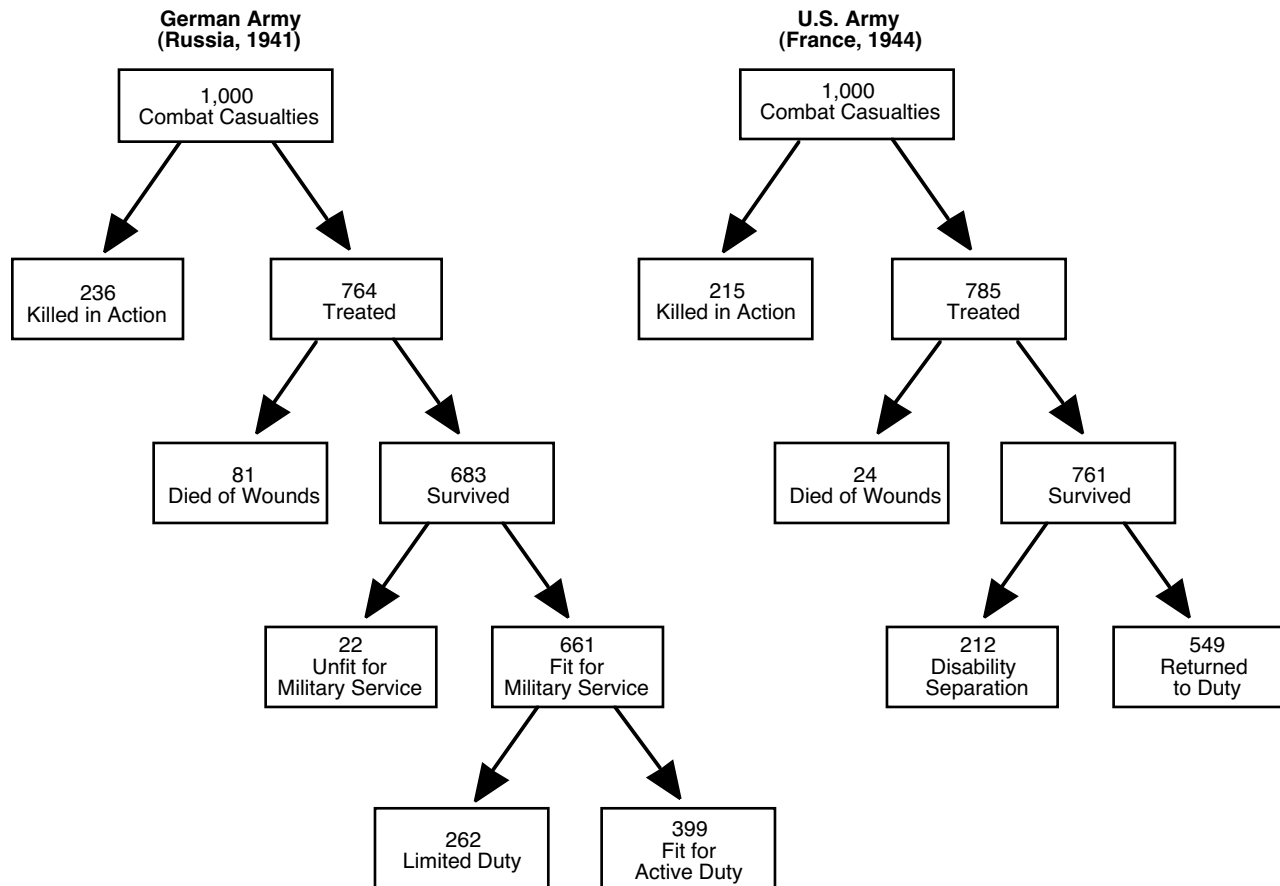
The German organization emphasized early return to duty by treating the less-seriously wounded in the division area. To achieve this goal, a replacement company (Ersatz Kompanie) was attached to the main medical unit *organic to* (ie, an intrinsic part of) the division. Seriously wounded soldiers were evacuated from the division to corps- and army-level hospitals far to the rear.

The U.S. Army's medical system was almost the opposite in both casualty flow and goal. When needed, a small surgical hospital derived from corps assets was attached to the main medical unit or-

ganic to the division for the purpose of providing resuscitative surgical care for the most-gravely wounded soldiers. All other casualties, but especially those with less-severe injuries, were sent to hospitals in the corps or army area, from where it was difficult to effect a rapid return to duty.

As expected, the outcomes in terms of mortality and return to duty for these contrary ways of organizing the medical system were very different (Figure 1-11). The German system sacrificed the seriously wounded (German died of wounds, 10.6%) at the expense of soldiers who might be expected to return to duty (German return to duty, 87%), while the U.S. system strove to save lives (U.S. died of wounds, 3.1%) but somewhat ignored the organizational aspects that would accelerate the return to duty of the less severely injured (U.S. return to duty, 70%). It should be understood that the twin goals of saving lives and conserving fighting strength are not necessarily incompatible.

German Army
(Russia, 1941)

U.S. Army
(France, 1944)

[Figure: Two flowchart diagrams comparing casualty outcomes.]

German Army (Russia, 1941):
- 1,000 Combat Casualties → 236 Killed in Action; 764 Treated
- 764 Treated → 81 Died of Wounds; 683 Survived
- 683 Survived → 22 Unfit for Military Service; 661 Fit for Military Service
- 661 Fit for Military Service → 262 Limited Duty; 399 Fit for Active Duty

U.S. Army (France, 1944):
- 1,000 Combat Casualties → 215 Killed in Action; 785 Treated
- 785 Treated → 24 Died of Wounds; 761 Survived
- 761 Survived → 212 Disability Separation; 549 Returned to Duty

Fig. 1-11. The numerical counterpart of the functional differences shown in Fig. 1-10. The German system returned to duty a higher percentage of the surviving wounded than did the US Army but at the expense of a fatal outcome in almost one third of the casualties. Adapted with permission from Bellamy RF. Contrasts in combat casualty care. *Milit Med*. 1985;150:408.

Injury Severity Assessment

Approaches to injury severity assessment modeling fall into two categories: (1) those that measure physiological parameters and (2) those that quantitate the anatomical damage. The best known and most extensively used of the physiological injury severity scoring systems is the Trauma Score, which is calculated from measurements of respiratory rate, respiratory effort, systolic blood pressure, capillary refill, and the Glasgow coma scale.[45] The range of the Trauma Score is from 1 (dead) to 16 (normal). The probability of survival is a function of the Trauma Score; the ensuing curve has a sigmoid shape, with scores of 8 or 9 predicting a 50% probability of survival. The desirable feature of the Trauma Score, as with other physiologically based injury severity systems, is that it is simple to apply and, therefore, being readily repeatable, can easily demonstrate changes in the casualty's condition over time.

The purpose of the Trauma Score is to predict the probability of death and, thereby, the desirability of sending an injury victim to a trauma hospital. It does this well when assessed in terms of predictive power.[46] However, the questions that need to be asked in combat casualty care are not only "How likely is the casualty to die?" but also "Is the casualty noneffective?" and "Does the casualty therefore need to be evacuated?" A casualty with a penetrating missile wound of the abdomen, regardless of the actual Trauma Score, will require evacuation and laparotomy. A casualty with an open, comminuted fracture of the femur may be physiologically intact but will certainly need to be evacuated from the battlefield. A physiological injury severity index will not be helpful in making the determination. Accordingly, the actual use of such indicators of injury severity has been uncommon in combat casualty care. Military anesthesiologists interested in the important subject of the desirable

features of a militarily useful triage methodology are referred elsewhere[47] in the literature.

Anatomical injury severity models differ from the physiological indices in this important respect: physiological indices are battlefield useable, but the anatomical indices are utterly useless for real-time application. The reason for this deficiency is the near impossibility of obtaining the needed detailed description of the anatomical injury at the time that triage and treatment decisions are made. Nevertheless, the anatomical models, applied retrospectively, may permit useful insight into *why* observed mortality and morbidity occurred.

The best known anatomical model is the Injury Severity Score,[48] which is, in essence, an algorithm for combining Abbreviated Injury Scale entries for different body regions. The major deficiencies of this approach are well known: first, the Abbreviated Injury Scale was developed to assess, and is most applicable to, blunt trauma; and second, the Injury Severity Score ignores the cumulative effect of multiple injuries within a given body region. Nevertheless, the application of injury severity scoring to combat casualties should have some heuristic value, in that the shape of the frequency distribution of injury severity may suggest how feasible it really is to reduce combat mortality.

Theoretical Distribution

Many frequency distribution curves are theoretically possible. One possible curve is the standard normal distribution (ie, the Gaussian curve) (Figure 1-12). With this distribution, most trauma victims
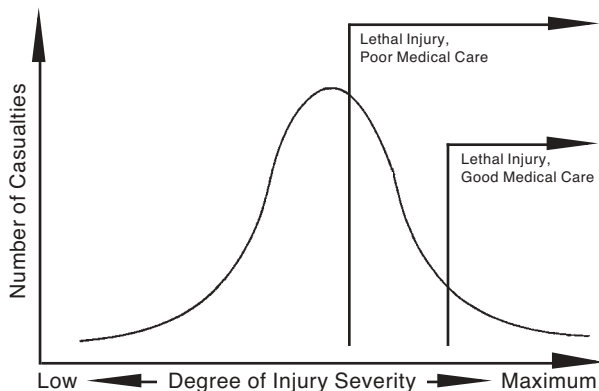
Fig. 1-12. Normal distribution of injury severity. In this hypothetical population, the degree of injury severity at which casualties would die if they receive poor medical care falls higher on the curve than it does if the medical care they receive is good.
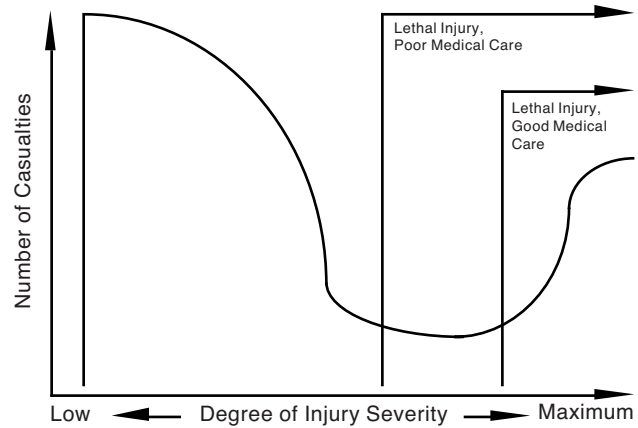

Fig. 1-13. If the distribution of injury severity is bimodal, then the quality of medical care has less effect on mortality than it would if distribution were normal.

will have injuries of intermediate severity; there are few minor or very severe injuries. A second possible curve has two peaks: this is known as a bimodal distribution (Figure 1-13). With this distribution, most trauma victims will have either minor or severe injuries; a few will have injuries of intermediate severity.

The bimodal distribution, because of its peculiar shape, seems intuitively unlikely; yet, some well-defined types of trauma have injury severity distributions of this shape. Figure 1-14 shows the distribution of injury severity found for domestic airplane crashes in which at least one life was lost.[49] The indices of injury severity used here are very simple: none, minimal, serious, fatal. A bimodal distribution is clearly apparent. Figure 1-15 shows the injury severity distribution, quantitated in terms of the Injury Severity Score, for a 1989 airplane crash on the M1 motorway in England.[50] Again, a bimodal distribution of injury severity is seen. Data published in 1994[51] indicate that the distributions of both the Trauma Score and the Glasgow coma scale in typical populations of trauma victims are also bimodal.

For didactic purposes, distributions shown in both Figures 1-12 and 1-13 are assumed to have a score above which all casualties will die even when they receive medical care. However, the score associated with death will be higher with good care and lower with poor. Figure 1-12 shows that improving medical care will markedly increase the number of survivors if the distribution is normal. By way of contrast, Figure 1-13 shows that a similar improvement in the quality of medical care will be associated with much less salvage if the distribution is
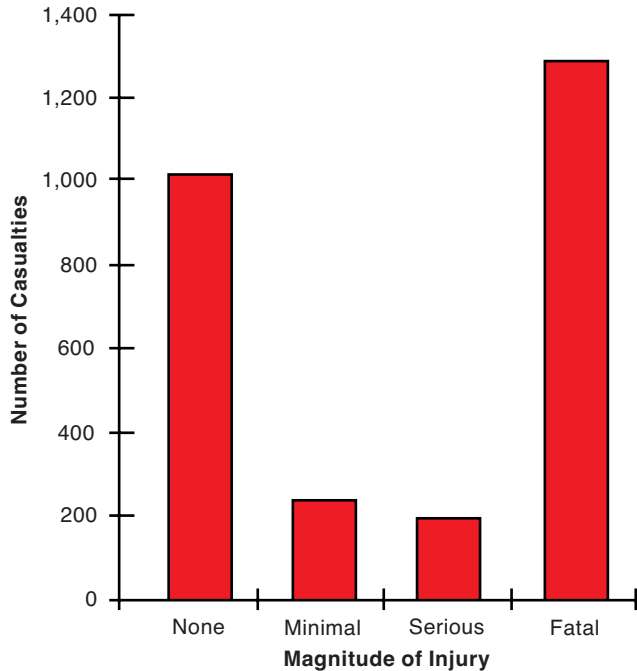
Fig. 1-14. Distribution of the magnitude of injury in all domestic airplane crashes during the period 1979 through 1984 in which one or more passengers were fatally injured. A bimodal distribution is apparent. Data source: National Transportation Safety Board.

bimodal. In terms of military medicine, care of poor quality might be thought of as military surgery as practiced in the early part of the 20th century, and good care might be military surgery as it is practiced at the end of the 20th century. Clearly, a major reduction in mortality would be expected if injury severity of combat casualties has a normal distribution, but a much smaller reduction would be expected if the real distribution has a bimodal shape.

Actual Distribution

Figure 1-16 shows the distribution of injury severity found for combat casualties in a sample taken from the WDMET database.[35] The distribution is clearly not normal in shape but it is also less obviously bimodal than is the distribution shown in Figure 1-15, primarily because of the peak in deaths in the Injury Severity Score interval 20–29. Most of the dead casualties who appear in this interval are soldiers who had sustained penetrating head wounds, the lethality of which is grossly underestimated by the Abbreviated Injury Scale. They are assigned an Abbreviated Injury Scale score of 5, but a more realistic assessment would be to assign them a score of 6 (Injury Severity Score = 75). Most of the dead casualties in the Injury Severity Score interval 20–29 should, therefore, be in the Injury Severity Score interval > 60.

Given this needed change, there is no doubt that the casualty population found in the WDMET study is best described by a bimodal injury severity distri-
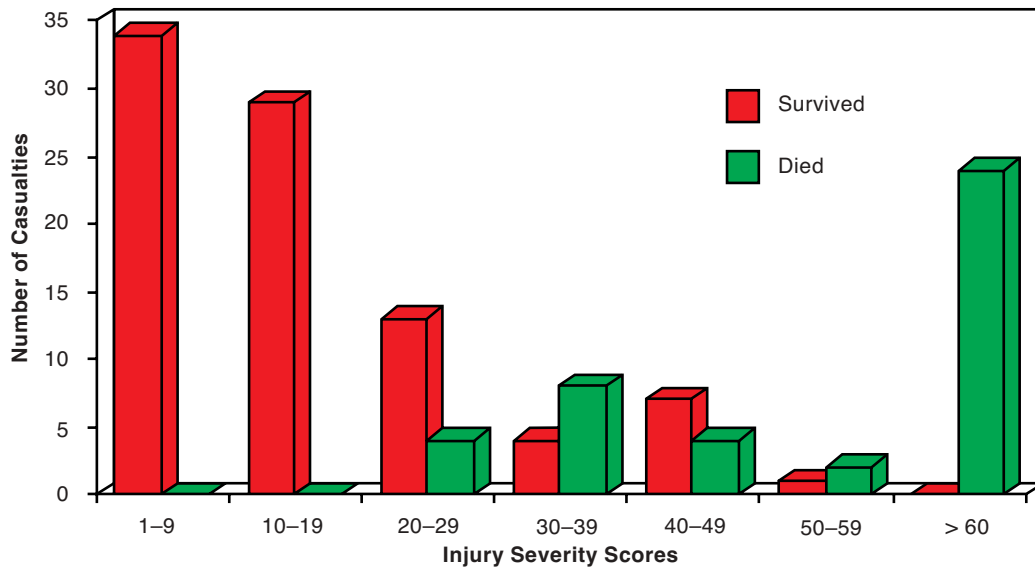
Fig. 1-15. Injury Severity Scores for the victims of the crash of a Boeing 737-400 onto the M1 Kegworth motorway in England, 1989. The bimodal distribution of injury severity is apparent. Data source: Rowles JM, Kirsh G, Macey AC, Colton CL. The use of injury scoring in the evaluation of the Kegworth M1 aircrash. *J Trauma*. 1992;32:441–447.
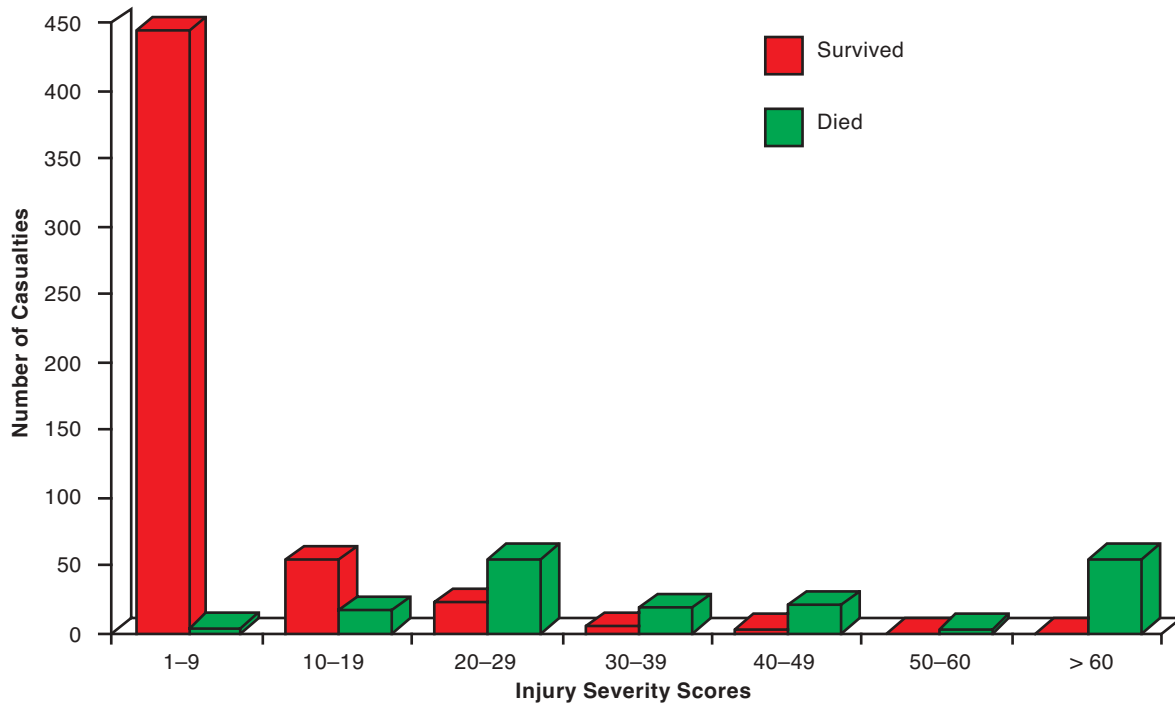
Fig. 1-16. Distribution of Injury Severity Scores in a population of casualties from the Vietnam War. A bimodal distribution is apparent, with most casualties falling into one of two populations: those with minor to moderately severe injuries, and those with nonsurvivable injuries. Data source: Wound Data and Munitions Effectiveness Team database.

bution. In simple terms, there are two major subpopulations: the larger one containing casualties with minor or moderate injuries, and the smaller containing those with critical and unsurvivable injuries. Only a small minority (perhaps 10%), those with serious or severe injuries who fall between the two major subpopulations at either end of the injury severity distribution, are likely to be helped by trauma care of the highest quality and sophistication. Survival of the casualties at either end of the injury severity distribution is not appreciably influenced by the quality of care. Those with minor or moderate injuries do not die if given even a modicum of care, and those with critical or unsurvivable injuries are beyond any conceivable help. What this means for military medicine is that it will not be easy to achieve a substantial decrease in combat mortality because of the small size of the population that is helped by surgical care of the highest quality. These considerations are consistent with the relatively small decrease in combat mortality observed in U.S. wars of this century.[52] It must be emphasized that this conclusion applies only to mortality and not to the morbidity of combat injuries. Modern military surgery has unquestionably reduced the

morbidity of battle injuries—especially through the decrease in wound sepsis.

Pathophysiological Causes of Death

Medical interventions designed to reduce combat mortality must be predicated on a thorough understanding of the pathophysiological derangements that cause the death of injured soldiers. Figure 1-17, which is based on the WDMET study[15] and Arnold and Cutting's paper[38] on the causes of death in medical treatment facilities in Vietnam, provides the needed information. Mortality is classified as killed in action due to exsanguination (44%), CNS injury (31%), and combined injuries (13%); and died of wounds due to CNS injury (5%), multiple organ failure/sepsis (4%), and shock (3%).

Exsanguination was the most common cause of death for U.S. ground forces in Vietnam, accounting for about one half of the combat mortality in the WDMET study. The most common sites of injury were the heart, thoracic aorta, pulmonary artery, and intraparenchymal pulmonary vessels. However, in about 20% of the casualties who exsanguinated on the battlefield, the site of bleeding was
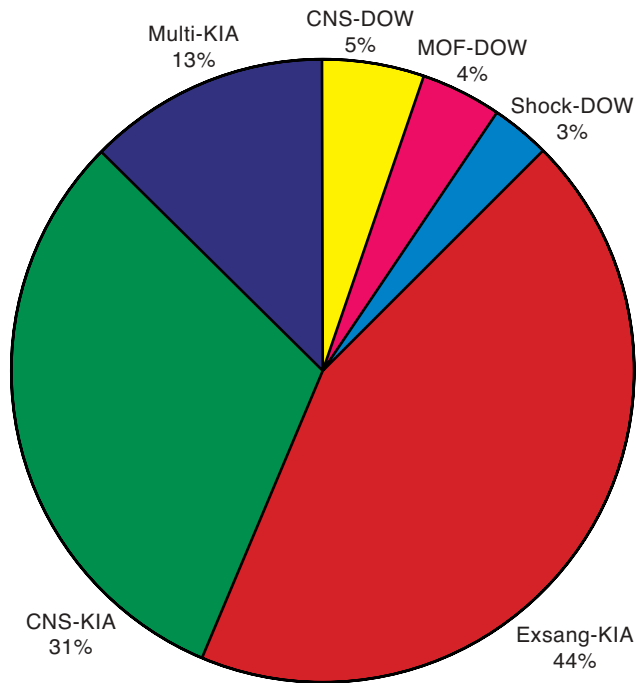
Fig. 1-17. The pathophysiological causes of death in the Vietnam War. Data from the Wound Data and Munitions Effectiveness Team database show that exsanguination and injury to the central nervous system were the most common causes of death. Key: CNS: central nervous system; DOW: died of wounds; Exsang: exsanguination; KIA: killed in action; MOF: multiple organ failure; Multi: multiple injuries. Data sources: (1) Wound Data and Munitions Effectiveness Team. *The WDMET Study*. 1970. (2) Arnold K, Cutting RT. Causes of death in United States military personnel hospitalized in Vietnam. *Milit Med*. 1978;143:161–164.

an artery in an extremity (femoral and brachial were the most common), in which first aid could, in theory, have been lifesaving.[53] Death from shock at the hospital level was uncommon, even though some 10% of all WDMET hospital admissions were judged by their surgeons as being in circulatory shock.[15(T4-7-9)] Of the hospitalized casualties who died of shock, roughly equal numbers were categorized as dying of continued bleeding (the sites were most commonly the liver or pelvis), uncontrollable coagulopathy, and "irreversible shock." Given that about 50% of the killed die by exsanguination, it would appear from the WDMET data that about 18% of all casualties are at risk of dying from exsanguination or shock, with the overall mortality in this group being 60%.

The difficulty of affecting the outcome in the remaining 80% of the casualties who die of

exsanguination is suggested by the data given in Exhibit 1-2, which describe the clinical and anatomical features in 10 consecutive casualties in the WDMET study who were killed in action but who survived for 10 or more minutes after being fatally wounded. It should be apparent that stabilization by conventional first aid has little to offer to these gravely wounded soldiers even though (*a*) they lived long enough to receive battlefield first aid and (*b*) had injuries that are much more surgically treatable than are wounds of the heart or aorta. Only an intervention designed, in essence, to slow the process of dying until surgery can be carried out has any possibility of preventing death in this group. What is needed is a radically new approach to battlefield stabilization, perhaps based on yet-to-be-discovered biochemical and biophysiological interventions, which will make possible metabolic down-regulation with consequent temporary suspension of cardiopulmonary function without causing permanent tissue injury. Finding successful solutions to the combat casualty problems listed in Exhibit 1-2 should be considered a challenge by all military anesthesiologists.

Injury to the CNS was the second-most-common cause of death in combat casualties studied by WDMET. These injuries were almost always so devastating (eg, three or more lobes injured, avulsion of the brain, decapitation, or injury to the brainstem) that they offered little potential for better surgical management to improve outcome. Surprisingly, the most common cause of death at the hospital level was CNS injury. The extent to which better care might be able to decrease this cause of mortality is unclear: one half of these casualties had been triaged into the expectant category because they were considered brain dead. The famous Bougainville study[54] of World War II reached the same conclusion regarding the relative importance of the pathophysiological causes of death: hemorrhage accounted for the largest number of combat fatalities (55%), while those who succumbed to injuries to the CNS composed the second-largest group (26%).

Most of the WDMET casualties in the multiple category had the misfortune to sustain potentially lethal injuries to the head, chest, or abdomen. The most common combinations were head and chest, and chest and abdomen. Some of these casualties sustained what was described as mutilating blast injury, in which the body was essentially disintegrated, but others had combined injuries as a consequence of the propensity of assault rifles and machine guns to cause multiple wounds.

EXHIBIT 1-2

CLINICAL AND ANATOMICAL DIAGNOSES OF 10 CASUALTIES WHO DIED 10 OR MORE MINUTES AFTER BEING WOUNDED

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1. Casualty lived 15 minutes; perforating gunshot wound of chest; bullet entered at right anterior axillary line and exited to the left of the spine above the iliac crest; pulmonary laceration, fracture of T12; severed spinal cord; 2,000 mL of blood in right hemithorax.

2. Casualty lived about 10 minutes; through-and-through gunshot wound of abdomen; bullet entered right flank and exited under left costal margin; celiac axis and superior mesenteric vein transected; 1,750 mL of blood in abdominal cavity.

3. Casualty lived less than 1 hour; perforating gunshot wound entered right shoulder and exited lower abdomen; lacerations of right lung, diaphragm, liver, and kidney; a total of 1,600 mL of blood in chest and abdomen.

4. Casualty died 10 to 15 minutes after being wounded: bullet entered laterally on the right side of the abdomen and passed out of the left hip; autopsy showed transection of right internal iliac artery, sigmoid colon, and left femoral artery, multiple perforation of small bowel; 1,750 mL of blood in abdominal cavity.

5. Casualty lived 50 minutes; gunshot wound of chest with fractures of ribs 7, 8, and 9; small hemothorax (250 mL); massive "traumatic atelectasis" of lung [pulmonary contusion?—*RFB*]; casualty became unresponsive 2 minutes after being wounded and after he stated "I think I've got a punctured lung."

6. Casualty lived 15 minutes; 2 gunshot wounds of the upper chest; one bullet, after fracturing T 4-5, lacerated the trachea, esophagus, and one lung; second bullet passed through chest into abdomen, where it injured the liver, kidney, and pancreas; 250 mL of blood in abdomen.

7. Casualty lived for 15 minutes; four gunshot wounds of left lateral hip and lower abdomen; extensive fracture of pelvis; perforation of right common iliac artery; 1,000 mL of blood in abdomen.

8. Casualty may have lived for 15 to 20 minutes; two perforating gunshot wounds of left side of body; one passed through the arm and entered the chest, where it fractured four ribs; no description of hemo- or pneumothorax; second bullet fractured T10 and severed the spinal cord at that location.

9. Casualty lived for 20 to 25 minutes; bullet entered right flank and passed through liver, diaphragm, and all lobes of right lung; several severely fractured ribs at wound of exit; 650 mL of blood in chest and abdomen.

10. Casualty lived 10 to 15 minutes; perforating gunshot wound of abdomen with lacerations of liver, duodenum, and kidney; 1,300 mL of blood in abdomen.

Data source: Wound Data and Munitions Effectiveness Team. *The WDMET Study*. 1970. Original data are in the possession of the Uniformed Services University of the Health Sciences, Bethesda, Maryland 20814-4799. Three summary volumes contain extensive abstracts of the statistical data and can be obtained from Defense Documentation Center, Cameron Station, Alexandria, Virginia 22304-6145.

A minority of the casualties in the multiple category did not have true multiple injuries but had respiratory tract wounds as the cause of death. It is not unusual to find chest X-ray films of WDMET dead that show the presence of a massive tension pneumothorax. In casualties seen alive at the hospital level, about 3.2% were said to be in respiratory distress: about one half had tension pneumothorax and one half had an open chest wound. The importance of injury to the upper airway (face and neck) as a cause of death on the battlefield is unclear; no doubt it is much less important than exsanguination or CNS injury. The WDMET study indicates that of casualties who were alive when they reached a medical treatment facility, about 1.3% required immediate upper airway control.[15(T4-7-9)] However, slightly more than one half of these casualties required airway control because of massive CNS injury; a minority only had direct injury to the upper airway.

About 4% of the fatally wounded soldiers died from what would now be called the systemic in-

flammatory response syndrome apparent as multiple organ failure and sepsis. The most common manifestations were septic shock (usually caused by severe peritonitis), adult respiratory distress syndrome, and acute renal failure. To put the magnitude of these problems in perspective, about 1 casualty in 1,000 died of renal failure. Assuming that the condition has a mortality of 50%, there would have been about 2 cases of renal failure per 1,000 casualties.

THE ANESTHESIOLOGIST AND COMBAT CASUALTY CARE

Some civilian trauma anesthesiologists, most prominently C. M. Grande,[55] believe that trauma anesthesiologists must go beyond their familiar role in the operating room and become life-support physicians in the broadest sense, involved in all aspects of the casualty's care. In combat casualty care, however, the potential for lifesaving, nonsurgical intervention in the operating room is somewhat limited. In lieu of data from a more recent war, the data contained in Table 1-5 may be taken as evidence for this contention.[37] The table stratifies by phase of treatment the deaths of 1,450 combat casualties, which occurred in hospitals in the Fifth U.S. Army in Italy between January 1944 and May 1945.

Although these data are nearly 50 years old, they suggest that it would be difficult to do much better, because only 6.3% of the total hospital mortality occurred during the anesthetic induction and the operation itself. Where there is room for improvement is in the preoperative, and especially in the postoperative, phases. It is for this reason that the focus of this book goes beyond anesthesia per se and puts strong emphasis on perioperative care. Unfortunately, as has been shown, the battlefield is the site of the great majority (90%) of combat fatalities. For the concept of the trauma anesthesiologist as life-support physician to find its full realization, military anesthesiologists must look beyond the hospital level to the battlefield. The military trauma anesthesiologist must be prepared to assume a leadership role in providing resuscitation at the first and second echelons of care. Because the Advanced Trauma Life Support course (ATLS)[56] of the American College of Surgeons provides the scientific and doctrinal basis for AMEDD's initial care of combat casualties, it is necessary for military trauma anesthesiologists to take a critical look at ATLS as it is presently practiced.

Advanced Trauma Life Support Course

The ATLS course is a systematic approach to the initial diagnosis and management of trauma victims. It emphasizes the recognition of immediately life-threatening injuries and provides instruction in the first-aid skills that are necessary to optimize patient survival in the early postinjury period. In the broadest sense, ATLS should be applicable to all trauma victims. However, because it was developed by civilian physicians for managing civilian trauma in a civilian setting, the military anesthesiologist should not be surprised to find that specific aspects of ATLS are not entirely appropriate to combat casualty care. There are significant differences in the epidemiologies of civilian and battlefield trauma. They arise not only from dissimilarities in the mechanisms of injury (eg, blunt trauma is much more common in civilian life than in war), but they also reflect the following characteristics of military medicine:

- Military trauma management is echelon (now also called *level*) based. Each echelon either returns the soldier to duty or evacuates the casualty safely to the next echelon.
- Medical personnel are in much greater physical danger when providing combat casualty care than they are when providing civilian trauma care (about 10% of the soldiers in the WDMET study were wounded while attempting to help a casualty).

TABLE 1-5

PARTITION OF HOSPITAL DEATHS BY PHASE OF MEDICAL MANAGEMENT

Phase of Management	Deaths (%)
Dead on admission or died shortly after admission	7.8
Died before anesthesia began	23.2
Died during anesthetic induction	1.1
Died during initial surgery	5.2
Died after initial surgery	62.7

Adapted from Snyder HE, Culbertson JW. Studies of Fifth US Army hospitalized casualty deaths. In: Beyer JC, ed. *Wound Ballistics*. Washington, DC: Department of the Army, Medical Department, Office of The Surgeon General; 1962: 473.

- Military trauma care is performed in an austere and resource-limited environment.

It is in the areas of organization and in what can be called the conditions of practice that ATLS in its usual civilian guise may need to be modified when used to care for combat casualties in conventional land warfare.

Military Organization for the Provision of Care

Both civilian and military trauma care depend on an organized system of prehospital treatment. While the civilian prehospital care organization typically consists of ambulances and paramedics, the military prehospital system consists of two levels of deployable medical facilities, ground or air ambulances, and attendant personnel numbering as many as 600 for one division. The extensive nature of the military prehospital system reflects the cost of providing a mobile and self-contained healthcare system for a large number of personnel who are subject to a variety of infectious diseases and environmental hazards and, worse, exposed to a risk of violence that exceeds anything in civilian experience by 1 or 2 orders of magnitude.

The military trauma care organization differs from the civilian model by providing care by echelons, wherein military casualties are either returned to duty or evacuated through successive echelons that are capable of increasingly sophisticated care. Table 1-6 describes the echelons of care and their function. Resuscitative surgery—surgery performed to control bleeding and to eliminate contamination—is carried out at the third echelon (or at lower echelons by a third-echelon forward surgical team [FST]), while restorative surgery—surgery performed to heal wounds and to restore function—is carried out at the fourth echelon or in the continental United States (CONUS). In the civilian system, the emergency department (the site of ATLS) is in the same building as the operating room (the site of resuscitative surgery). In the military system, ATLS is performed at the first and second echelons (where it must be done if acute life-threatening processes are to be reversed), many kilometers (or hours, depending on the mode of evacuation) from the site of resuscitative surgery.

The contents of the preceding paragraph describe the organization as prescribed by army doctrine,[1] but exceptions do exist. During much of the Vietnam War, the first and second echelons of care were frequently so atropic that third-echelon hospitals had a function not too dissimilar from that of a civilian trauma center. Casualties frequently arrived directly from the battlefield without having received any care, which meant that first-aid interventions that ideally should have been performed in the field were commonplace at the hospital level. Still, the analogy with the civilian system was not

TABLE 1-6

LEVELS OF MILITARY MEDICAL CARE AND THEIR USUAL FUNCTION

Echelon/Level	Medical Unit	Trauma Management
First/Unit	Medical platoon, BAS	ATLS
Second/Division	Medical company	ATLS
	Medical battalion	Minor surgery
	FST*	Resuscitative surgery
Third/Corps	MASH†	ATLS
	CSH	Resuscitative surgery
Fourth/COMMZ	Field hospital	Reconstructive surgery
	General hospital	Reconstructive surgery
Fifth/CONUS	Medical center	Reconstructive surgery

*Surgical squads are organic to airborne and air-assault divisions and, in the form of forward surgical teams, may be attached when needed to medical companies of other divisions.
†The MASH is to be deleted; its function will be assumed by the FSTs.
ATLS: Advanced Trauma Life Support; BAS: battalion aid station; COMMZ: communications zone; CONUS: continental United States; CSH: combat support hospital; FST: forward surgical team; MASH: mobile army surgical hospital

total because only resuscitative surgery, and not reconstructive surgery, was normally carried out. In recent years, the U.S. Army's involvement in peacekeeping operations, under the doctrinal guise of operations other than war (OOTW),[1(p1-1)] has raised the possibility that military anesthesiologists will practice in a situation in which the functions of the first three echelons of care are telescoped together into one medical treatment facility. Military anesthesiologists may also have the opportunity to serve in hospitals of the International Committee of the Red Cross. Although typical military wounds are treated in these circumstances, there are no echelons of care and the primitive economic infrastructure, the lack of medical resources, the underlying social chaos, and a perhaps fatalistic acceptance of death by the population being served create conditions that are likely to be new to most medical officers in the U.S. military.[57]

Battlefield Conditions

Four factors—danger, austerity, casualty density, and goals—distinguish the military use of ATLS from its use in the civilian sector.

Danger. Field medical units, especially those of the first and second echelons, are subject to enemy attack. Even necessary defensive measures, such as entrenchment and construction of bunkers, may prevent an optimal flow of casualties. Furthermore, when the possibility of unconventional warfare (chemical or biological) exists, even the individual casualty must be considered a threat to the medical troops, and appropriate steps must be taken to reduce the risk of exposure. These dangerous possibilities may interfere with, or prevent the full application of, ATLS as it is practiced in civilian emergency care.

Austerity. Field medical units lack the pleasant ambience of civilian hospitals. Tents, mud floors, cots, and battery-operated lights are not insurmountable obstacles to the proper application of ATLS, but they can reduce the efficiency of all but the most ardent and most experienced practitioners. The need to employ noise and light discipline complicates battlefield ATLS. The lack of many diagnostic modalities, even such basic ones as X-ray units, seriously impairs the ability of military physicians to apply ATLS as practiced in the civilian sector, especially in first- and second-echelon facilities. Finally, medical supplies such as syringes, intravenous catheters, and even gloves are available in limited amounts; they cannot be expended unless there is good reason to believe that their use will benefit the casualty. Furthermore, the wearing of protective devices against communicable disease (ie, the universal precautions) is not feasible in the field echelons of care.

Casualty Density. Mass casualty situations are not unique to the military, but mass casualty situations among civilians are usually considered atypical, while they are a constant threat in the military. As has been described previously in this chapter, the casualty-generating potential of the modern battlefield is 10- to 100-fold greater than it is in even the most violent urban setting. Although the ATLS primary survey may take only a few seconds to perform, the complete examination is not suited to situations in which only a few minutes per casualty are available for diagnosis and presurgical resuscitation.

Goals. ATLS is designed to assist the physician in recognizing acute, life-threatening, pathophysiological disturbances. The focus is on lethality and the prevention of gross morbidity. The military anesthesiologist cannot forget that the missions of the medical services—conserve fighting strength and maintain the fighting power of the command—can be carried out only if each casualty is assessed in terms of his ability to return rapidly to duty. This is not to say that the demands of military medicine require that the seriously injured be ignored. Rather, the slightly wounded should be accorded higher priority for care than they would be if the military medical treatment system were driven solely by ATLS considerations of lethality.

Specific Aspects of Advanced Trauma Life Support

The following is not to be construed as an attempt to replace ATLS with an alternative approach to managing trauma. Instead, its purpose is to indicate areas in which ATLS should be modified when used in combat casualty care. Perhaps the most important point is that ATLS must be tailored to the echelon of care and to the prevailing tactical posture. For example, in a quiet, third-echelon surgical facility, the military practice of ATLS may not deviate from the civilian standard, but this will certainly not be true at a first-echelon facility that is being shelled while it is receiving several dozen casualties. In general, the more theoretically relevant ATLS may seem to be, the *further forward on the battlefield it must be implemented* to be effective. The realities of the battlefield are, however, that the *further forward the care is needed, the less practical it is to provide*.

Most medical officers, and certainly all military anesthesiologists, will be ATLS trained, so only a brief summary need be given here of the sequence of events and their purposes:

- primary survey (with simultaneous correction of any life-threatening conditions):
  - airway patency with cervical spine control,
  - breathing and ventilation,
  - circulation and hemorrhage control,
  - disability, as determined by neurological status, and
  - exposure;
- triage determination, which may be made as part of the primary survey;
- secondary survey (a detailed examination of the casualty); and
- definitive care.

Casualty

```
        ┌─────────────┐
        │ Is the casualty
        │  a threat?  │
        └─────────────┘
       Yes          No
┌────────────┐
│  Disarm    │
│Decontaminate│
└────────────┘
        ┌─────────────┐
        │ Does the casualty
        │ require lifesaving
        │  first aid? │
        └─────────────┘
     Yes            No
┌────────────┐
│Give first aid│
└────────────┘
              ┌─────────────┐
              │ Can the casualty
              │ be returned to
              │ duty from this
              │   echelon?  │
              └─────────────┘
           No            Yes
┌────────────┐        ┌────────┐
│ Evacuate   │        │ Treat  │
└────────────┘        └────────┘
                      ┌──────────────┐
                      │ Return to Duty│
                      └──────────────┘
```
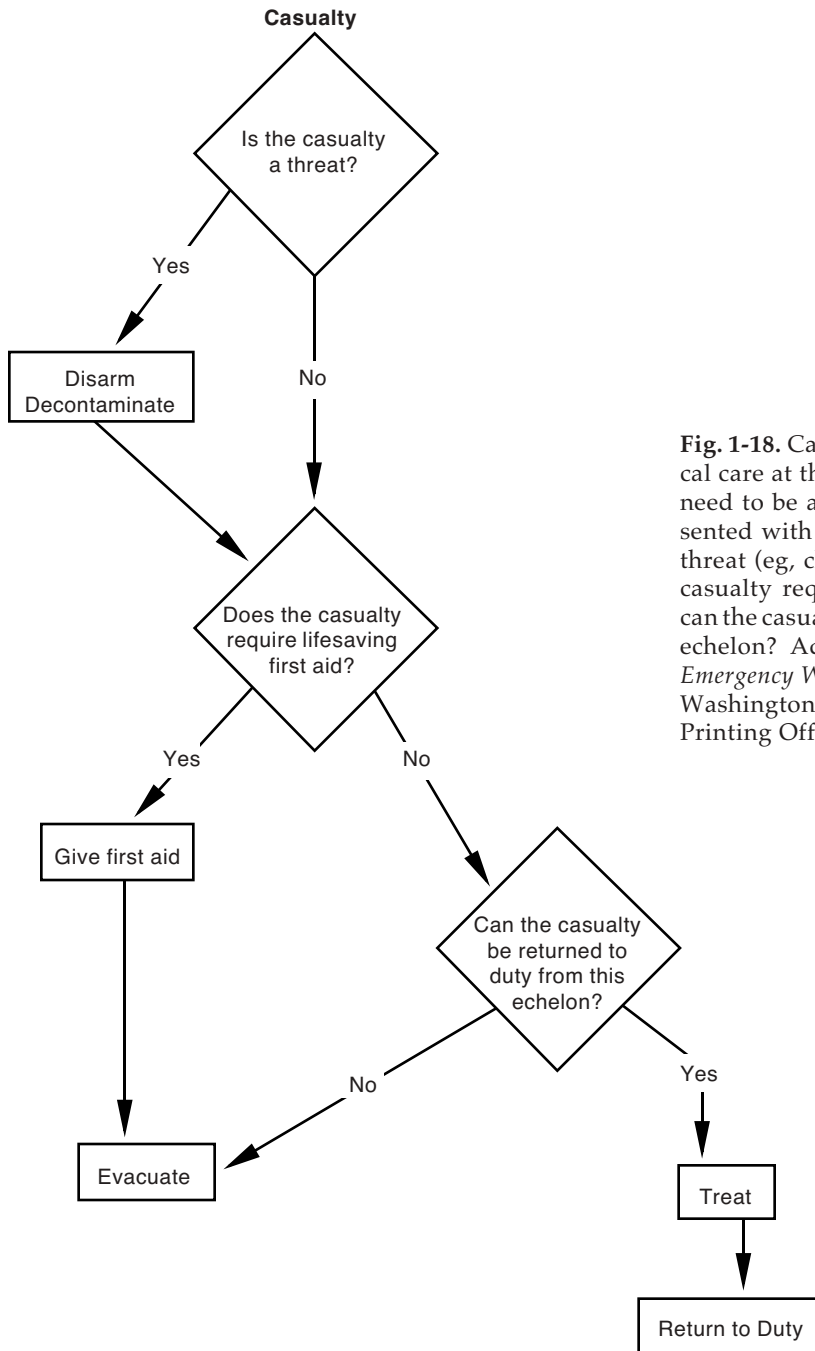
Fig. 1-18. Casualty care decision tree applicable to medical care at the field-echelon level. Three basic questions need to be asked when a field medical provider is presented with a casualty. First, is the casualty a potential threat (eg, chemically contaminated)? Second, does the casualty require immediate lifesaving first aid? Third, can the casualty be treated and returned to duty from this echelon? Adapted from Bowen TE, Bellamy RF, eds. *Emergency War Surgery NATO Handbook*. 2nd rev US ed. Washington, DC: Department of Defense, Government Printing Office; 1988: 204.

The following is a chapter-by-chapter critique of the ATLS manual as it applies to combat casualty care.

Initial Assessment and Management

The triage algorithm from the *Emergency War Surgery NATO Handbook* (Figure 1-18)[58] is applicable to the first and second echelons of care, but it may also be appropriate at facilities that provide surgical care as well.

Medical officers must ask themselves three questions:

1. Is the casualty a threat? The threat comes from casualties who have been contaminated by exposure to chemical or biological agents. Intelligence sources (S-2, G-2) will usually know if the enemy has the capability and the intent to employ unconventional weapons.

2. Does the casualty require emergency lifesaving resuscitation? Medical officers should require no more than a few seconds to determine whether interventions utilizing the ATLS lifesaving skills are needed. As has been indicated previously, the Vietnam War experience showed that about 15% of combat casualties benefited from ATLS airway (1.3%), breathing (3.2%), and shock (10%) interventions.

3. Can the casualty be returned to duty from this echelon? A problem-oriented approach is required: Where is the wound and what is its nature? The medical officer must not waste time preparing a comprehensive list of all the possible diagnoses and *certainly* should not spend time and effort ruling out a large collection of diagnoses that are likely to be important only in the context of ATLS as it is practiced in a civilian emergency department. If the wound will prevent the casualty from performing his duty, and if the treatment capabilities of the echelon cannot reverse the pathophysiology of the injury, then the casualty must safely and expeditiously be evacuated to the next echelon.

Many aspects of the complete ATLS program are not applicable to combat casualty care. For example, it is a mistake to cut off all the casualty's clothing to perform the complete ATLS examination. Not only can climatic conditions make this unwise, but a fresh uniform will not be available as a replacement. Performance of the secondary survey should be left to medical officers at higher echelons. This is especially true because the necessary diagnostic modalities are absent in the battalion aid station, medical company, and even some third-echelon hospitals.

Airway and Ventilatory Management

Combat casualties (exclusive of those with a severe brain injury) who require airway management almost always have such destructive wounds that a surgical airway (tracheostomy or cricothyroidotomy) will be required. The possibility that a casualty whose upper airway problem is the result of a penetrating wound will also have a subtle, unrecognized, coexisting injury to the cervical spine is so remote that it may be ignored. Airway control in combat casualties with facial or neck wounds is a necessary but not a sufficient therapeutic intervention; safe evacuation to the third echelon of care will be impossible unless hemorrhage into the oral cavity can be stopped, or at least free egress of blood from the mouth can be achieved.

Shock

Hemorrhage is the major cause of death in combat casualties. In about 20% of those casualties at risk of exsanguination,[53] bleeding can be controlled by first-aid techniques such as applying pressure at the site of hemorrhage or applying a tourniquet. The latter intervention is especially useful when the site of bleeding is from an amputation stump. There can be little doubt that of the ATLS lifesaving interventions, those associated with the control of bleeding are most important. Nevertheless, the associated intervention—starting two large-bore intravenous lines and infusing 2 L of Ringer's lactate—although having the status of established dogma, has recently been called into question by numerous laboratory studies on experimental animals and human clinical trials.[59,60] It seems well established that infusion of a crystalloid fluid will elevate the systemic blood pressure and thereby potentially increase the rate of hemorrhage from injured vessels. The rationale for administering intravenous fluids in a casualty with ongoing, uncontrolled hemorrhage can only be that a net increase in intravascular volume will take place, and this will occur only if the fluid is infused faster than it can leave the vascular bed. There is an obvious

limit to this approach: as was demonstrated during the Vietnam War, massive administration of crystalloid fluid without concomitant rapid control of bleeding may very well result in a degree of hemodilution incompatible with life (ie, the "white blood syndrome").

The value of ATLS in the management of combat casualties in shock will depend on the echelon of care. Clearly, when surgical care is immediately available, the ATLS shock module should be entirely appropriate. Its value at the first and second echelons, where resuscitative surgery is usually not available, is less obvious. It would indeed be ironic if it were to be shown that the importance placed on asanguineous fluid resuscitation in the field of casualties in shock from uncontrolled bleeding did more harm than good. It becomes even more ironic when we are reminded of the World War II experience with fluid resuscitation and combat casualty care:

> When internal hemorrhage persisted…there could be no resuscitation without surgery, and it was wasteful of both time and blood to attempt to raise the patient's blood pressure to normal before operation. The blood or plasma which was administered merely leaked into the traumatized regions and was wasted….[36(p6)]

It is uncertain at this time what should be done about fluid resuscitation in casualties with ongoing hemorrhage, in circumstances in which surgical control of bleeding is not immediately possible. An experimental study published in 1993[61] showed that although infusion of crystalloid fluid during uncontrolled hemorrhage did increase the magnitude of the blood loss, infused animals lived longer than controls that received no fluid. The magnitude of the volume infused is important because both the 1993 study and another one published in 1992[62] found that survival was better when the volume infused did not exceed 40 mL/kg. Some intravenous fluid may be better than none at all, as was appreciated in World War II:

> [Plasma] superbly fulfilled the role of supporting life until transportation could be accomplished to an installation at which whole-blood transfusion was feasible.… By temporarily sustaining a seriously falling blood pressure and increasing the cardiac output, it kept the patient alive long enough for more effective measures to be taken.[36(p22)]

Nevertheless, there are limits to how long such stabilization will be effective. Until asanguineous oxygen-carrying blood substitutes are developed,

there is no substitute for immediate surgery in the rapidly exsanguinating casualty; nonsurgical stabilization is an act of futility.

There is an additional area in which the realities of battlefield medicine intrude on the performance of ATLS. Invasive monitoring techniques will not be available in the first three echelons of care; thus, clinical signs will need to be followed during volume replacement. In this regard, the World War II and Vietnam War experiences showed that tachycardia was an unreliable and inappropriate indicator of the degree of shock.[63]

Thoracic Trauma

Casualties with thoracic wounds who survive to be evacuated from the battlefield should be treated following the ATLS algorithm; however, a penetrating chest wound is itself an indication for inserting a chest tube. Reinfusion of shed blood may be possible because autotransfusion devices are being added to the table of organization and equipment (TOE) of third-echelon facilities. Thus, ATLS principles are appropriate, but sepsis remains the main potential source of morbidity. Cardiac tamponade is seen very uncommonly. The decision to perform a pericardiocentesis is usually predicated on the presence of shock that is unresponsive to fluid administration in a casualty who has a wound of the anterior chest wall.

Abdominal Trauma

Casualties with abdominal wounds should be treated by the ATLS algorithm, but the following facts need emphasis:

- Among casualties who have abdominal wounds and who survive to be evacuated from the battlefield, the major threat to life is sepsis from peritoneal contamination rather than shock from hemorrhage. Thus, antibiotic coverage needs to be emphasized.
- Indications for operation are simpler than suggested by ATLS; the presence of a penetrating wound is sufficient justification. Peritoneal lavage as mandated by ATLS has no role in the management of combat casualties with penetrating wounds.

Head Trauma

Casualties with penetrating head wounds who survive to reach a medical treatment facility fall

into two main categories: (1) those with tangential gunshot wounds of the skull, with laceration of the brain caused by bony fragments that are driven into the brain parenchyma; and (2) those with penetrating wounds of the brain made by one or two small fragments. Most surviving casualties will be conscious at the time of admission and will have high Glasgow coma scale scores. Thus, the ATLS mini-neurological examination is needed to establish evacuation and treatment priorities. If these casualties fail to receive neurosurgical care within 24 hours, they are at risk of developing potentially fatal cerebral sepsis. A combat casualty who is comatose secondary to penetrating head wounds has a very poor prognosis. In the absence of neurosurgical intervention, the best that can be done is to assure an open airway by inserting an endotracheal tube.

Spine and Spinal Cord Trauma

ATLS and the reality of combat casualty care have their greatest potential conflict with spine and spinal cord trauma. Penetrating missiles that wound the cervical, thoracic, or lumbar spine have a high lethality because the missile has a propensity to also strike contiguous structures (eg, the carotid artery or thoracic aorta). Wounds of the cervical spine may or may not involve the cervical cord, but when they do, the outcome is almost always fatal (98%).[15] There is no evidence that a penetrating missile wound that involves only the cervical spine will predispose the patient to a subsequent cervical *spinal cord* injury when the neck is manipulated. Essentially no combat casualties with *penetrating* neck wounds will benefit from immobilization of the cervical spine, except the rare living casualty who has an existing neurological defect that is thought to be caused by a spinal injury.[64] Given the well-established danger of carrying out care on the battlefield, battlefield immobilization of the neck of a casualty with a penetrating neck wound is therefore unwarranted. However, ATLS principles do apply to casualties with *blunt* trauma to the head and neck.

Extremity Trauma

During the pre-ATLS era, much of field medical training consisted of practicing the application of dressings and splints to casualties with fractures or soft-tissue wounds of the extremities. In fact, these remain the essential skills required to give effective combat casualty care at the first and second ech-

elons. For the military ATLS trainer, the chapter in the ATLS manual on extremity trauma is *the important* chapter. Emphasis should also be placed on the prehospital administration of antibiotics that will decrease the potential for clostridial and strepto-coccal wound infections.

Third-echelon extremity care will differ from ATLS practice because the radiographic equipment necessary to rule out vascular injury will probably not be available. Although Doppler probes may be available to assist in making the diagnosis of a vascular injury, the diagnosis will usually have to be made by exposing the vessel at the time of soft-tissue wound management.

Burns

Inhalation injury is a major source of mortality and morbidity during naval warfare and will probably become more important in future land warfare because of the prevalence of armored fighting vehicles. Medical officers at field medical facilities should predicate their therapies on the burned casualty's ability to clear the tracheobronchial tree. If secretions cannot be raised, the medical officer will have to decide whether scarce resources should be used for intubation and ventilation. Bronchospasm must be broken and pneumonitis must be prevented or treated. Antibiotic treatment may have to be initiated without the physician's knowing the specific bacterial flora that is growing in the lung, undesirable as this may be. In an important departure from ATLS, topical antimicrobial therapy such as with Sulfamylon (manufactured by Don B. Hickon, Inc., Sugar Land, Tex.) or Silvadene (manufactured by Marion Merrell Dow, Inc., Kansas City, Mo.) burn cream should be started before the casualty is evacuated from the field echelons. The appropriate escharotomies should be performed early when treating a casualty with deep, third-degree extremity burns whose evacuation to a higher echelon is likely to be delayed.

Stabilization and Evacuation

Stabilization and evacuation of casualties are aspects of ATLS that are difficult to implement fully. There is no 911 number to call on the battlefield nor will the referring physician be able to contact the receiving physician. In these respects, the military and civilian trauma-care systems are markedly dissimilar. At the unit and division levels, medical officers will need to know how to contact the supporting ambulance unit for either

air or ground evacuation. At the third echelon, the evacuation, which will usually be done by the U.S. Air Force, will be organized by the medical regulating officer.

Regardless of the echelon, the medical officer will be responsible for establishing priorities for evacuation and treatment. ATLS concepts can usefully be combined with existing military criteria for triage at first- and second-echelon medical facilities:

- Priority I—URGENT and Priority IA—URGENT-SURG: the casualty fails to respond or responds transiently to ATLS airway, breathing, and circulation (ABC) skills;
- Priority II—PRIORITY: the casualty responds to ATLS ABC skills and remains stable; and
- Priority III—ROUTINE: ATLS ABC skills are not needed to stabilize the casualty.

Note: casualties with massive injuries to large muscle masses (such as the thigh or the pelvis) and casualties with open comminuted fractures of the femur or the hip should be triaged into the priority category because of the propensity of such wounds to develop anaerobic sepsis.

ATLS concepts can also be used to establish treatment priorities not only at first- and second-echelon facilities but also for third-echelon war surgery:

- Urgent: this triage category includes the uncommon casualty who is at risk of rapid death after an injury that causes airway compromise, respiratory derangement, or shock that is not responsive to ATLS stabilization. Emergency surgery must be performed within minutes for there to be any hope that the casualty will survive.
- Immediate: this triage category includes most casualties with abdominal or chest wounds who responded to ATLS emergency

lifesaving skills and those with extensive soft-tissue and bony injuries, especially when a major vascular injury is present. Surgery is needed within 6 hours.
- Delayed: this triage category includes most casualties with fractures or soft-tissue wounds. ATLS ABC skills are not needed, but surgical care must be provided within 12 to 24 hours.
- Minimal or ambulatory: this triage category includes casualties who are carded for record only. These soldiers require outpatient treatment and should not be evacuated to higher echelons.
- Expectant: this triage category includes casualties whose injuries are so severe that they cannot reasonably be expected to survive given the available medical care. Those who are brain dead or who have deep burns over much of their bodies are in this category. These casualties are not evacuated from the echelon that assigns this priority.

The assignment of treatment or evacuation priorities is a dynamic process. The medical officer must continually update priorities. For example, a casualty who is in the delayed category may become immediate. Similarly, a casualty's category will be influenced by the prevailing tactical situation and the availability of medical resources. Given an unfavorable tactical situation, a casualty who might otherwise be classified in the urgent or the immediate category may have to be classified in the expectant. The converse is occasionally true: a casualty who has been classified as expectant may be retriaged into the urgent category because more medical resources have suddenly become available. Furthermore, priorities need to be reassessed for treatment and subsequent evacuation on arrival at the receiving echelon. Triage is ongoing, and no decision should be considered final.

SUMMARY

Although catastrophic attrition from disease or a hostile environment is an ever-present threat in military operations, battle injury is likely to assume an increasing proportion of attrition compared with the historical norm. The magnitude of the attrition depends on the size of the units engaged, their tactical posture, and the intensity of the warfare. Typical battle casualty rates in war are 10- to 100-fold greater than the rate found for civilian trauma.

In contrast to civilian trauma, where blunt trauma predominates, combat injuries are overwhelmingly (> 90%) penetrating in origin. Explosive munitions are the most common sources of penetrating missiles in modern warfare. The location of penetrating injuries is, to a first approximation, a function of the size of the body surface over the body regions, except that the head sustains about twice as many injuries as would be expected on the basis of its

surface area alone. Surviving casualties usually have injuries to bones or skeletal muscle, while those who are killed most commonly have wounds to the head or trunk.

The mortality of combat trauma is commonly measured by two normalized statistics: the percentage who are killed in action, and the percentage who died of wounds. The former category includes soldiers who expire on the battlefield, while the latter category includes those who expire while receiving treatment at a medical facility. Typical historical data from recent wars indicate that about 20% to 25% of casualties are killed in action and about 3% to 5% die of wounds. Penetrating missile wounds of certain organs have a very high probability of death: wounds of the brain (about 4 of 5); wounds of the chest (about 3 of 4).

Morbidity in combat casualties results in noneffectiveness following a combat injury, which can be measured as man-days lost. The distribution of injury severity in combat casualties has a bimodal appearance with two major subpopulations: the larger consists of soldiers with minor or not–life-threatening (albeit frequently incapacitating) injuries; the smaller subpopulation consists of soldiers with critical and nonsurvivable injuries.

The ATLS course of the American College of Surgeons is the basis for initial assessment and resuscitation of combat casualties. However, modifications in ATLS are necessary to make it compatible with the realities of combat casualty care in three areas: the nature of the injuries, the organization of the military medical system, and the conditions of practice on the battlefield.

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