

Chapter 1

Weapons Effects and War Wounds

Introduction

Just as with any medical topic, surgeons must understand the pathophysiology of war wounds to best care for the patient. The most important tenet follows:

TREAT THE WOUND, NOT THE WEAPON

Epidemiology of Injuries

- Primary weapons of war can be divided into explosive munitions and small arms.
 - **Explosive munitions:** Artillery, grenades, mortars, bombs, rockets, mines, improvised explosive devices, etc.
 - **Small arms:** Pistols, rifles, and machine guns.
- Three major epidemiological analyses have been conducted to evaluate the cause of battlefield injury, as well as outcome:
 - During the Bougainville campaign of World War II (Table 1-1), a medical team was sent to gather data on the injured, including the cause of injury. This campaign involved primarily infantry soldiers and was conducted on the South Pacific island of Bougainville during 1944.
 - US Army and Marine casualties from the Vietnam War were collected by the Wound Data and Munitions Effectiveness Team (WDMET) in Vietnam (Table 1-2).
 - The Joint Theater Trauma System (JTTS) was developed and implemented in 2004, modeling the success of civilian trauma systems in the United States. The JTTS was developed to support operations in Iraq and Afghanistan to ensure that every military casualty has the optimal chance for survival and maximal potential for functional recovery.

Table 1-1. US Casualties: Bougainville Campaign (World War II), Vietnam, and OEF/OIF

Weapon	Bougainville (%)	Vietnam (%)	OEF/OIF (%)
Bullet	33.3	30	26
Mortar	38.8	19	3
Artillery	10.9	3	<1
Grenade	12.5	11	—
Booby trap/IED	1.9	17	64
RPG	—	12	3
Other	2.6	8	3

IED: improvised explosive device; OEF: Operation Enduring Freedom; OIF: Operation Iraqi Freedom; RPG: rocket-propelled grenade.

Table 1-2. Anatomical Distribution of Primary Penetrating Wounds

Conflict	Head and Neck (%)	Thorax (%)	Abdomen (%)	Extremity (%)	Other (%)
World War I	17	4	2	70	7
World War II	4	8	4	75	9
Korean War	17	7	7	67	2
Vietnam War	14	7	5	74	—
Northern Ireland	20	15	15	50	—
Falkland Islands	16	15	10	59	—
Gulf War (UK)	6	12	11	71	—
Gulf War (US)	11	8	7	56	18
Chechnya	24	9	4	63	—
Somalia	20	8	5	65	2
OEF/OIF	27	5	6	55	7

OEF: Operation Enduring Freedom; OIF: Operation Iraqi Freedom.

The most common battlefield injury pattern is multiple fragment wounds involving multiple anatomical sites.

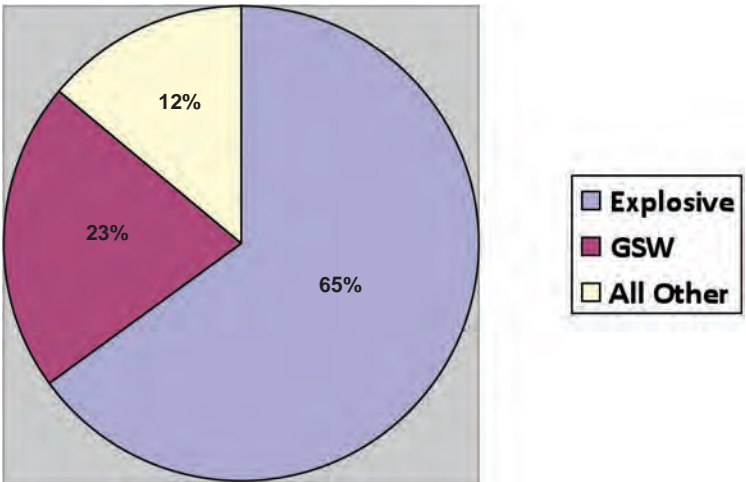


Fig. 1-1. Cause of injury, OEF/OIF. GSW: gunshot wound; OEF: Operation Enduring Freedom; OIF: Operation Iraqi Freedom.

Mechanism of Injury (Fig. 1-1)

- **Projectile injuries (Table 1-3).**
 - There are two areas of projectile–tissue interaction: permanent cavity and temporary cavity (Fig. 1-2).

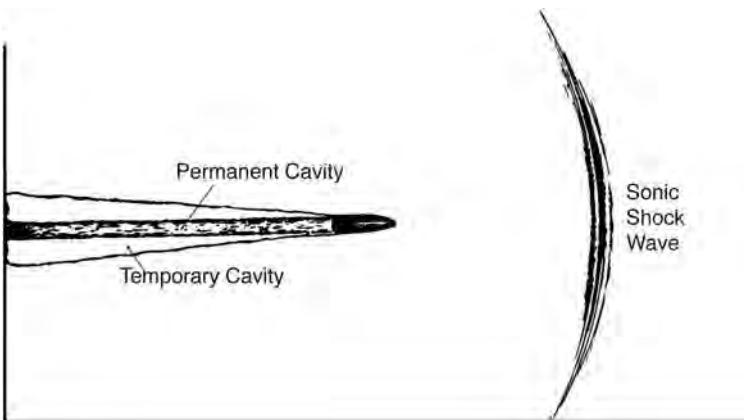


Fig. 1-2. Projectile–tissue interaction, showing components of tissue injury.

- ◆ **Permanent cavity:** Localized area of cell necrosis, proportional to the size of the projectile as it passes through.
- ◆ **Temporary cavity:** Transient lateral displacement of tissue, which occurs after passage of the projectile. Elastic tissue (eg, skeletal muscle, blood vessels, and skin) may be pushed aside after passage of the projectile, but then rebound. Inelastic tissue (eg, bone or liver) may fracture in this area.
- ◆ The shock (or sonic) wave (commonly mistaken for the temporary cavity), though measurable, has not been shown to cause damage in tissue.

Table 1-3. Common Misconceptions About Projectile Wounds

Misconception	Reality
Velocity is the most important determinant of tissue damage.	Velocity is one factor in wounding. An increase in velocity does not increase, per se, the amount of tissue damage. The amount of tissue damage in the first 12 cm of a M-16A1 bullet wound profile has relatively little soft-tissue disruption, similar to that of a .22 long rifle bullet, which has less than half the velocity.
Projectiles yaw in flight, which can create irregular wounds.	Unless a projectile hits an intermediate target, the amount of yaw in flight is insignificant.
Exit wounds are always greater than entrance wounds.	This is untrue and has no bearing on surgical care.
Full metal-jacketed bullets do not fragment, except in unusual circumstances.	The M-193 bullet of the M-16A1 rifle reliably fragments at the level of the cannulure after traversing about 12 cm of tissue in soft-tissue only.
All projectile tracts must be fully excised due to the effects of the temporary cavity.	Wounds should be washed out with necessary debridement of foreign body and necrotic tissue only. Wounds often require subsequent exploration and debridement due to continued devitalization of tissue.

- **Explosive injuries (Table 1-4).**
 - Explosive agents are materials that undergo rapid exothermic reaction when detonated. The degree to which this reaction occurs is dependent on the characteristics of the explosive agent.
 - ◆ Low-order explosives react by rapid burning or conflagration.
 - ◆ High-order explosives produce extreme heat, energy, and a pressure wave known as the “blast wave.” The blast wave is reflected and sustained by fixed structures and confined environments (eg, rooms, vehicles, etc) and may potentiate the effects of blast-related injury. By the same mechanism, water—a noncompressible medium—transfers more blast energy, resulting in greater injuries.
 - Blast injuries are divided into **four categories**:
 - ◆ **Primary blast injuries** are caused by the blast wave. The mechanism of injury is the impartation of blast energy to the body, particularly in air-filled organs. Survival and injury from primary blast are contingent on a number of factors, including energy of the blast, confined versus open space, and distance from the explosive source. Casualties who survive may have tympanic membrane rupture, pulmonary barotrauma, and bowel contusion and perforation. Primary brain injury may also occur.
 - ◆ **Secondary blast injuries** are caused by fragments from the casing and contents of the explosive device and secondary debris (eg, dirt, rocks, body parts, etc).
 - ◆ **Tertiary blast injuries** are caused by physical displacement of the victim, resulting in blunt force trauma (eg, fractures, brain injury, solid organ injuries, etc).
 - ◆ **Quaternary blast injuries** are caused by thermal, chemical, and/or radiation effects (eg, burns, inhalation injuries, etc).
 - Care of explosive-related injury is based on the same principles as standard trauma management paradigms. The basic difference between explosive-related injury and other injury mechanisms is that casualties can have all of the above mechanisms.

● **Ballistic.**

- Fragments from explosive munitions cause ballistic injuries.
- Fragments are most commonly produced by mortars, artillery, grenades, and improvised explosive devices (IEDs).
- Fragments produced by these weapons vary in size, shape, composition, and initial velocity. They may vary from a few milligrams to kilograms.
- Fragments from exploding munitions have greater variability in size and shape when compared with bullets from small arms.
- Although initial fragment velocities of 5,900 ft/s (1,800 m/s) have been reported for some of these devices, the wounds observed in survivors indicate that striking velocities were less than 1,900 ft/s (600 m/s). Unlike small arms, explosive munitions cause multiple wounds.

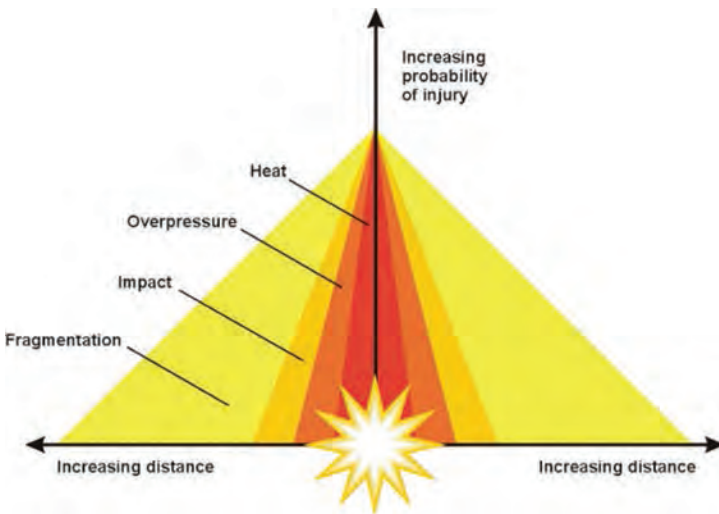


Fig. 1-3. The probability of sustaining a given trauma is related to the distance from the epicenter of the detonation.

● **Blast.**

- The blast wave effects rapidly dissipate as distance from the epicenter increases (Fig. 1-3).

Table 1-4. Classification of Explosive Injury

Category	Characteristics	Body Part	Types of Injuries
Primary	Unique to high-order explosives; results from the impact of the blast wave	Gas-filled structures most susceptible: lungs, GI tract, middle ear	Blast lung (pulmonary <u>barotrauma</u>) (uncommon) Tympanic membrane rupture and middle-ear damage (common) Abdominal hollow viscus perforation and hemorrhage (rare) Globe (eye) rupture (rare)
Secondary	Results from flying debris and weapon casing and content fragments	Any body part	Penetrating fragments or blunt injuries Eye penetration (can be occult)
Tertiary	Results when bodies are thrown by blast wind	Any body part	Fracture and traumatic amputation Closed and open brain injury
Quaternary	All explosion-related injuries, illnesses, or diseases not due to primary, secondary, or tertiary mechanisms; includes exacerbation or complications of existing conditions	Any body part	Burns (flash, partial thickness, and full thickness) Crush injuries (building collapse) Asthma, COPD, or other breathing problems from dust, smoke, or toxic fumes Angina Hyperglycemia, hypertension

COPD: chronic obstructive pulmonary disease; GI: gastrointestinal.

- The ears are most often affected by the blast wave, followed by the lungs and the gastrointestinal (GI) tract hollow organs. GI injuries may present 24 hours later.
- Injury from blast is a pressure and time-dependent function. By increasing the pressure or its duration, the severity of injury will also increase.
- **Thermobaric.**
 - Thermobaric devices (eg, fuel-air explosions) work by increasing the duration of a blast wave. The device initially explodes and puts a volatile substance into the air (fuel vapor). A second explosion then ignites the aerosolized material producing an explosion of long duration. The effects from this weapon are magnified when detonated in an enclosed space.
 - Air displaced after the explosion creates a blast wind that can cause tertiary blast injuries.
- **Thermal.**
 - Thermal effects occur as the product of combustion when the device explodes.
 - Patients wounded near exploding munitions may have burns in addition to open wounds, which may complicate the management of soft-tissue injuries.
- **Antipersonnel landmines.**
 - There are three types of conventional antipersonnel landmines common throughout the world: static, bounding, and horizontal spray.
 - ◆ **Static** landmines are small, planted landmines (100–200 g of explosive) that are detonated when stepped on, resulting in two major areas of injury (Fig. 1-4).
 - ◇ Partial or complete traumatic amputation, most commonly at the midfoot or distal tibia.
 - ◇ Debris and other tissue are driven up along fascial planes with tissue stripped from the bone.
 - ◇ Factors influencing the degree of injury include size and shape of the explosive, point of contact with the foot, amount of debris overlying the mine, and the type of footwear.
 - ◆ **Bounding** mines propel a small explosive device to about 1–2 meters of height and then explode, causing multiple

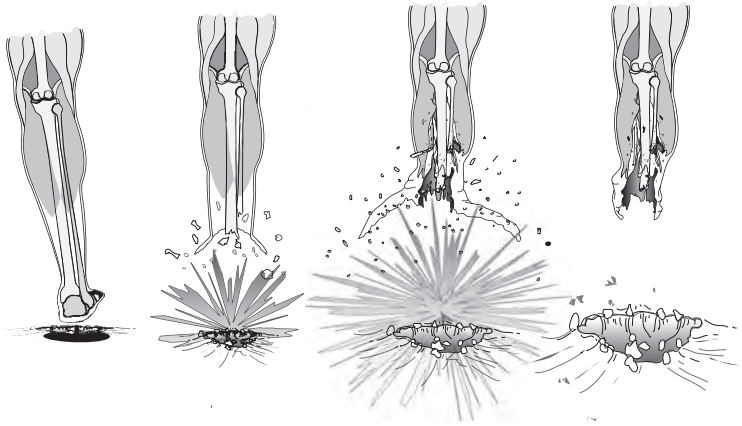


Fig. 1-4. Mechanisms of injuries caused by antipersonnel landmines.

small fragment wounds to those standing nearby. These landmine casualties have the highest reported mortality.

- ◆ **Horizontal spray** mines propel fragments in one direction. This landmine can be command-detonated or detonated by tripwire. As an example, the US Claymore mine fires about 700 steel spheres of $\frac{3}{4}$ gram each over a 60° arc. Horizontal spray mines produce multiple small-fragment wounds to those nearby.
- The **IED** is an unconventional weapon. Typically, another piece of ordnance is used, such as a grenade or a mortar shell, or the device is completely fabricated out of locally available materials.
- **Small arms.**
 - Pistols, rifles, and machine guns.
 - ◆ Trends for small arms since World War II include rifles that have increased magazine capacity, lighter bullets, and increased muzzle velocity.
 - ◆ On the following pages are some examples of the characteristics of commonly encountered firearms. The illustrations show the path of missiles fired from 5 to 10 meters into ordnance gelatin blocks. Variations of range, intermediate targets (eg, body armor), and body tissue will alter the wounds seen.

- ◆ The AK-47 rifle is one of the most common weapons seen throughout the world. For this particular bullet (full metal jacketed or ball), there is a 25-cm path of relatively minimal tissue disruption before the projectile begins to yaw. This explains why relatively minimal tissue disruption may be seen with some wounds (Fig. 1-5).

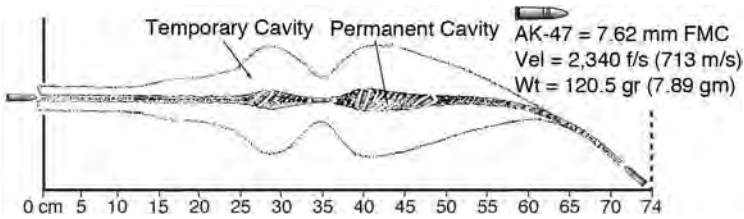


Fig. 1-5. Idealized path of tissue disruption caused by an AK-47 projectile (10% gelatin as a simulation). FMC: full metal case; Vel: velocity; Wt: weight.

- ◆ The AK-74 rifle was an attempt to create a smaller caliber assault rifle. The standard bullet does not deform in the tissue simulant, but does yaw relatively early (at about 7 cm of penetration).

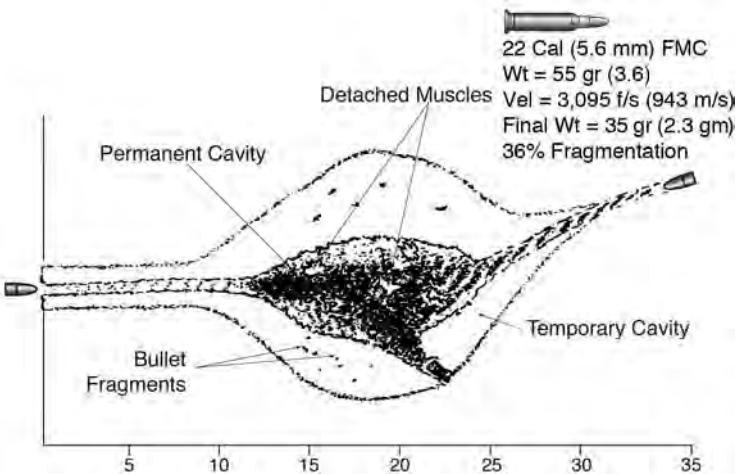


Fig. 1-6. Idealized path of tissue disruption caused by an M-16A1 bullet fired from the M-16A1 rifle (10% gelatin as a simulation). Cal: caliber; FMC: full metal case; Vel: velocity; Wt: weight.

- ◆ The M-16A1 rifle fires a 55-grain full metal-jacketed bullet (M-193) at approximately 950 m/s. The average point forward distance in tissue is about 12 cm, after which it yaws to about 90°, flattens, and then breaks at the cannulure (a groove placed around the midsection of the bullet). The slightly heavier M-855 bullet used with the M-16A2 rifle shows a similar pattern to the M-193 bullet (Fig. 1-6).
- ◆ The 7.62-mm NATO (North Atlantic Treaty Organization) rifle cartridge is still used in sniper rifles and machine guns. After about 16 cm of penetration, this bullet yaws through 90° and then travels base forward. A large temporary cavity is formed and occurs at the point of maximum yaw (Fig. 1-7).

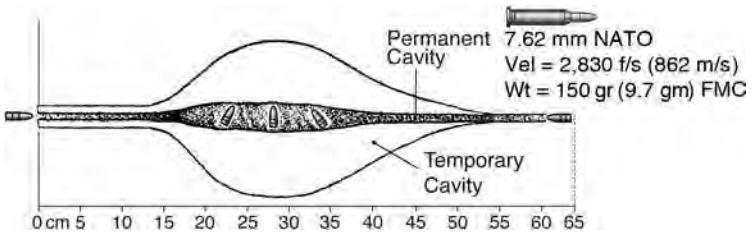


Fig. 1-7. Idealized path of tissue disruption caused by the 7.62-mm projectile (10% gelatin as a simulation). FMC: full metal case; NATO: North Atlantic Treaty Organization; Vel: velocity; Wt: weight.

● **Armored vehicle crew casualties.**

- Since the first large-scale use of tanks during World War I, injuries to those associated with armored vehicles in battle have been a distinct subset of combat casualties.
- Examples include tanks, infantry fighting vehicles, armored personnel carriers, armored support vehicles, and "light-armored vehicles."
- There are three main types of antiarmor weapons: shaped charge, kinetic energy round, and antitank landmines.

◆ **Shaped charge.**

See Fig. 1-8a.

- ◇ The shaped charge or high explosive antitank (HEAT) round consists of explosives packed around a reverse

cone of metal called a melt sheet or a liner. This is the principle behind the warhead of the rocket-propelled grenade (RPG).

- ◇ Shaped charges range in diameter from the 85 mm RPG-7 to the 6-inch diameter tube-launched, optically tracked, wire-guided (TOW) missile.
- ◇ Injury effect of shaped charge munitions:
 - First, there is the jet of the shaped charge itself. This may cause catastrophic wounds to casualties who are hit, or it may ignite fuel, ammunition, or hydraulic fluid.
 - Second, there is a debris injury factor called spall, which is material knocked off from the inside face of the armored plate. This produces a spray of small, irregularly shaped fragments inside the compartment (Fig. 1-8b).

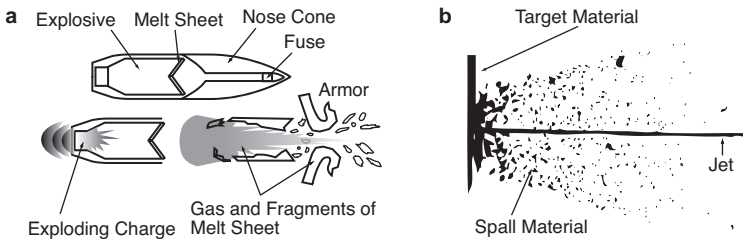


Fig. 1-8. (a) Disruptive mechanisms of the shaped charge warhead. (b) Diagram taken from photograph of an actual detonation of a shaped charge warhead against an armor plate caused by antitank land mines.

◆ Kinetic energy round.

- ◇ The kinetic energy round contains an aerodynamic piece of hard metal (eg, depleted uranium or tungsten) shaped like a dart. The metal is usually encased in a carrier or sabot that falls away from the projectile after it leaves the barrel. Fragments of depleted uranium should be treated during initial wound surgery as any retained metal foreign body. There is a potential risk, over the years, that casualties with retained depleted uranium fragments may

develop heavy metal poisoning. This concern by itself does not justify extensive operations to remove such fragments during initial wound debridement.

- ◇ Injuries to those inside a vehicle are due, in part, to the direct effects of the penetrator or from fragments knocked off the inside face of the armored plate. The range of fragment masses may be from a few milligrams to over a kilogram.

◆ **Antitank landmines.**

- ◇ Blast mines are those with a large explosive filler of 4–5 kg. Injuries are often from blunt trauma due to crewmembers being thrown around inside the vehicle after it detonates the mine.
- ◇ Closed-head injuries and fractures of the extremities and spine are common.
- ◇ Mechanisms of injury (Fig. 1-9).
 - Multiple injuries take place as the result of defeated armor (as described previously).
 - **Thermal:** Burns occur because of ignited fuel, ammunition, hydraulic fluid, or as the direct result of the antiarmor device.
 - Two large studies, one from British World War II tank crewmen and one from Israeli casualties in Lebanon, showed that about one-third of living, wounded casualties have burns.
 - The severity of burns range from superficial to full thickness. Most burns are superficial to exposed skin, most often of the face, neck, forearms, and hands. These are often combined with multiple fragment wounds.
 - **Blast overpressure** can occur from the munition breaching a vehicle's armor and then an explosion occurring inside a confined space. During explosions outside of a vehicle, the blast wave has been shown to be dissipated by the armor.
 - **Toxic fumes** secondary to phosgene-like combustion byproducts cause a chemical inhalation injury (Teflon-coated antisplatter liners of armored vehicles).

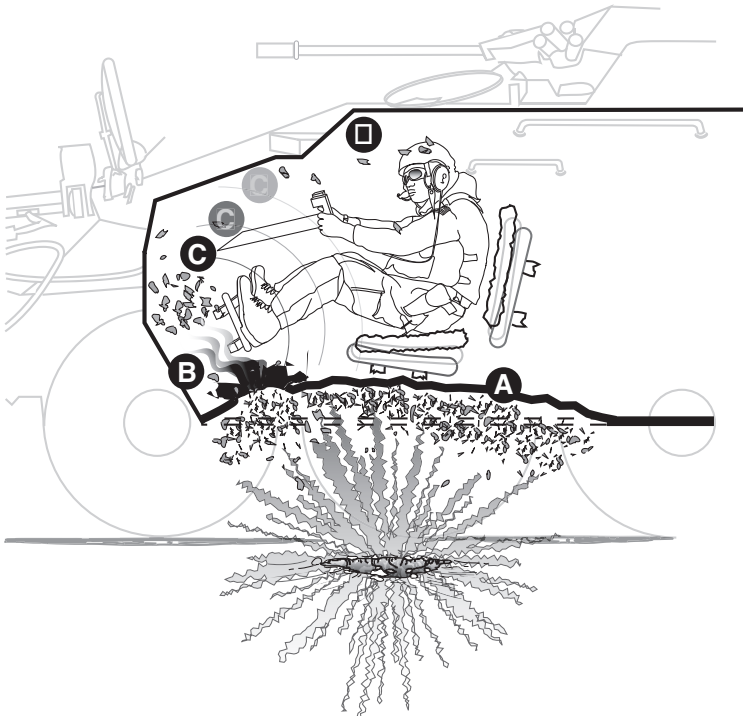


Fig. 1-9. Injuries sustained as a result of defeated armor, (A) translational blast injury, (B) toxic gases, (C) blast overpressure, and (D) penetrating missile wounds.

- Treatment is supportive and may require IV steroids (1,000 mg methylprednisolone, single dose).
- Surgical triage considerations: Emergent if pulmonary edema, expectant if hypotensive and cyanotic. Reevaluate nonemergent patients every 2 hours.

● **Inhalation injury.**

- Injury exacerbated by retained soot and chemicals.
- **REMEMBER:** Inhalation injury is primarily a chemical injury that will benefit from removing the chemical. Supportive treatment.

- **Unexploded ordnance.**
 - Unexploded ordnances (UXOs) are embedded in the casualty without exploding.
 - Rockets, grenades, mortar rounds.
 - Some UXOs must travel a specific distance (50–70 meters) or number of rotations in order to arm.
 - Fuses are triggered by different stimuli (impact, electromagnetic, laser).
 - **Notify explosive ordnance disposal team immediately!**
 - Thirty-one of 31 victims and treating teams survived removal (historical review of US casualties).
 - The casualty should be triaged as **nonemergent**, placed far from others, and **operated on last**.
 - Preplan for how to handle both transport and operation.
 - Transport.
 - ◆ If by helicopter, ground the casualty to the aircraft (there is a large electrostatic charge from rotors).
 - Move into a **safe area**.
 - ◆ Revetment, parking lot, or back of building.
 - **Operate in a safe area, not in the main OR area.**
 - Operative management.
 - ◆ Precautions for surgeon and staff.
 - ◆ Sandbag operative area, use flak vests and eye protection.
 - ◆ Avoid triggering stimuli.
 - ◆ Electromagnetic (avoid use of defibrillator, monitors, Bovie cauterizer, blood warmers, or ultrasound or CT machines).
 - ◆ Plain radiography is safe. It helps identify the type of munition.
 - Anesthesia.
 - ◆ Regional/spinal/local preferred.
 - ◆ Keep **oxygen** out of the OR.
 - ◆ Have anesthesiologist leave after induction.
 - Operation: The surgeon should be alone with the patient.
 - ◆ Employ gentle technique.
 - ◆ Avoid excessive manipulation.
 - ◆ Consider amputation if other methods fail.
 - ◆ Remove en bloc if possible.

The decision to remove a chemical/biological UXO is a command decision. Immediately after removal, hand the munition to explosive ordnance disposal (EOD) personnel for disposal.

For Clinical Practice Guidelines, go to
http://usaisr.amedd.army.mil/clinical_practice_guidelines.html