

Chapter 1

Weapons Effects and War Wounds

Introduction

An understanding of the pathophysiology of war wounds will allow the surgeon to best care for the patient. The most important tenet is:

TREAT THE WOUND, NOT THE WEAPON

Epidemiology of Injuries

- The 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.
 - 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.

- Combat injury causes in recent and historic conflicts are compared in Table 1-1. Anatomic distribution of penetrating wounds are compared in Table 1-2.

Table 1-1. Causes of Battle Injury in US Casualties: Bougainville Campaign (World War II), Vietnam, and Military Operations 2007–2017

Weapon	Bougainville (%)	Vietnam (%)	Military Operations 2007–2017 (%)
Bullet	33	30	19.2
Mortar/Rocket/Artillery	50	22	7.8
Grenade	12	11	4.6
RPG	—	12	4.5
Booby trap/IED	2	17	60.4
Other	3	8	3.5

RPG: rocket-propelled grenade; IED: improvised explosive device.

Data source for recent military operations: Department of Defense Trauma Registry.

- DoDTR data illustrates mechanisms of injury (Fig. 1-1) and anatomic distribution of penetrating injury (Fig. 1-2) for military operations 2007–2016.

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

- There are two areas of projectile–tissue interaction: permanent cavity and temporary cavity (Fig. 1-3).
 - ◆ **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 stretch and then rebound after passage of the projectile with variable degrees of tissue injury and

Table 1-2. Anatomical Distribution of Primary Penetrating Wounds

Conflict	Head/Neck/Face (%)	Thorax (%)	Abdomen (%)	Extremity (%)	Polytrauma (%)	Other (%)
World War I	17	4	2	70	NR	7
World War II	4	8	4	75	NR	9
Korean War	17	7	7	67	NR	2
Vietnam War	14	7	5	74	NR	—
Northern Ireland	20	15	15	50	NR	—
Falkland Islands	16	15	10	59	NR	—
Gulf War (UK)	6	12	11	71	NR	—
Gulf War (US)	11	8	7	56	NR	18
Chechnya	24	9	4	63	NR	—
Somalia	20	8	5	65	NR	2
Military operations 2007–2017	8.3	0.6	0.7	5.4	69.6	15.4

Data source for recent military operations: Department of Defense Trauma Registry.

NR: not recorded

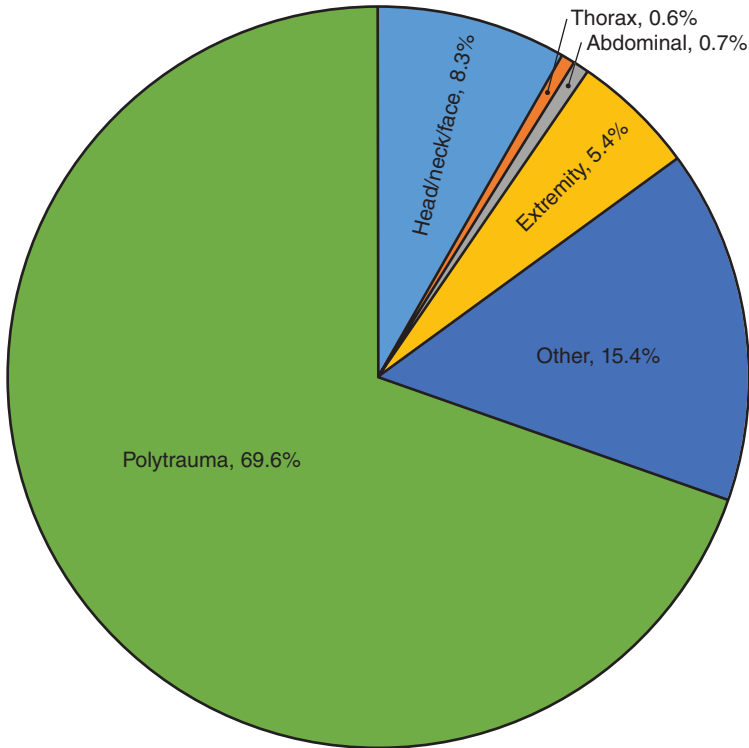


Fig. 1-1. Mechanism of injury, military operations 2007–2017.
Data source: Department of Defense Trauma Registry.

delayed necrosis. Inelastic tissue (eg, bone or liver) may fracture in this area.

- ◆ The shock (or sonic) wave, though measurable, has not been shown to cause damage in tissue.
- **Blast injuries (Table 1-4).**
 - Explosives 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

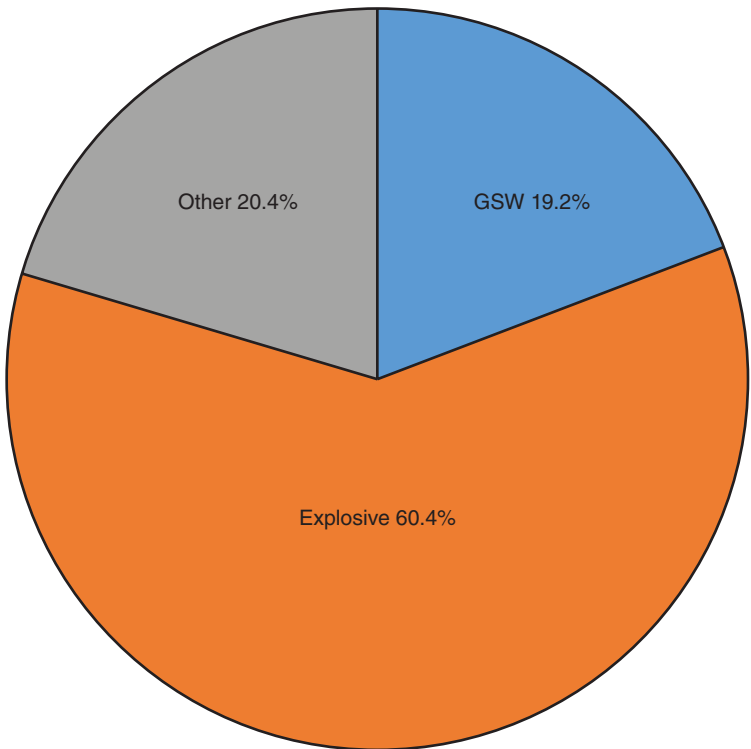


Fig. 1-2. Anatomical distribution of penetrating injury, military operations 2007–2017.

GSW: gunshot wound

Data source: Department of Defense Trauma Registry.

blast wave is reflected and sustained by fixed objects and confined environments (eg, rooms, vehicles, etc), which may potentiate the effects of blast energy. By the same mechanism, water—a noncompressible medium—transfers more blast energy than air, and underwater blast may cause 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

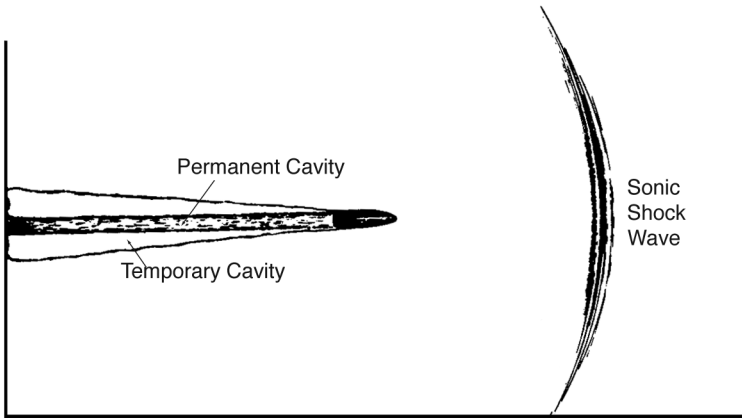


Fig. 1-3. Projectile–tissue interaction, showing components of tissue injury.

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 the amount of tissue damage.
Projectiles yaw in flight, which can create irregular wounds.	Unless a projectile hits an intermediate target, the amount of yaw in flight is insignificant. Yaw occurs after striking tissue.
Exit wounds are always larger than entrance wounds.	It may be difficult to distinguish between entrance and exit wounds. Wound trajectories must be carefully assessed to avoid missed injury.
Full metal-jacketed bullets do not fragment, except in unusual circumstances.	The 5.56-mm rounds from M-4 and M-16 rifles reliably fragment at the level of the cannellure 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 initial debridement of foreign bodies and necrotic tissue only. Wounds often require subsequent debridement due to extensive contamination, embedded debris, and progression of necrosis.

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, gastrointestinal tract, middle ear	Tympanic membrane rupture and middle ear damage (common) Blast lung (pulmonary barotrauma) (uncommon) Abdominal hollow viscus perforation and hemorrhage (rare)
Secondary	Results from flying debris and weapon casing and content fragments	Any body part	Penetrating chest trauma Eye penetration (can be occult)
Tertiary	Results when bodies are thrown by blast wind or crushed by fallen structure	Any body part	Fracture, traumatic, amputation, solid organ injury, traumatic 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) Radiation illness Inhalational injury

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 penetrating wounds caused by fragments from the casing and contents of the explosive device and secondary debris (eg, dirt, rocks, body parts). Fragments produced by explosive weapons vary in size, shape, composition, and initial velocity. Close proximity injuries can result in decapitation, dismemberment, and extreme tissue devastation. Extremity injuries predominate in survivors.
- ◆ **Tertiary blast injuries** are blunt force trauma caused by physical displacement of the victim against a standing object, or crushing of the victim under a fallen structure, resulting in fractures, brain injury, or solid organ injuries. Entrapment can lead to compartment syndrome and crush syndrome (rhabdomyolysis).
- ◆ **Quaternary blast injuries** are caused by thermal, chemical, and/or radiation effects (eg, burns, inhalation injuries).
- Casualties injured by explosives are cared for using standard trauma management principles; however, the complex nature of combined barotrauma, penetrating, blunt, and burn injury must be understood and thoroughly investigated to avoid missed injuries.
- The blast wave effects rapidly dissipate as distance from the epicenter increases (Fig. 1-4).
- Blast exposure may also occur in weapon systems operators, such as when firing 81-mm and 120-mm mortar weapons systems. Repeated blast exposure during training and combat operations may be associated with cognitive impairment and chronic symptoms.
- Blast pressure gauges have been utilized in combat operations with a goal of determining the specific pressures associated with injury. In general, the pressure measurements have not correlated well with injuries sustained; however, safety guidelines recommend

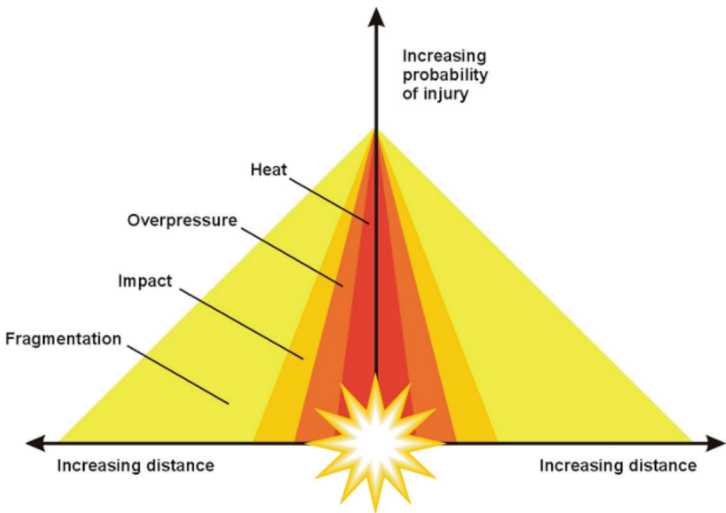


Fig. 1-4. The probability of sustaining a given trauma is related to the distance from the epicenter of the detonation.

maintaining single exposure limits of 4 psi or less, with peak overpressure exposure less than 15 psi.

- The tympanic membranes are most sensitive to injury by the blast wave, while higher pressure may lead to injury of the lungs and the gastrointestinal (GI) tract hollow organs. GI injuries may have a delayed presentation due to perforation of an ischemic segment of bowel.
- Injury from blast is proportional to both the peak blast pressure and the duration of sustained blast pressure. An increase in either peak pressure or duration will contribute to increased severity of injury.
- **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 burns occur as the result of combustion when the device explodes.
 - Patients who were in close proximity to a blast may have sustained burns in addition to open wounds, complicating resuscitation as well as 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 injury to the lower limb(s):
 - ◇ 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 (Fig. 1-5).
 - ◆ 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.

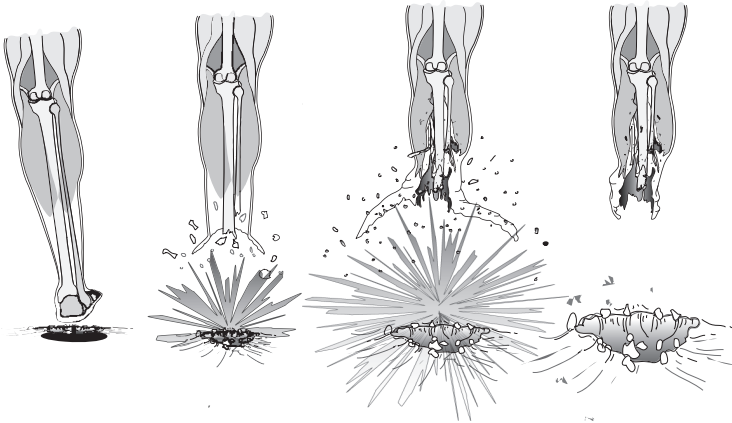


Fig. 1-5. Mechanisms of injuries caused by antipersonnel landmines.

- ◆ **Bounding** mines propel a small explosive device to about 1–2 meters of height and then explode, causing multiple 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 **improvised explosive device (IED)** is an unconventional weapon. Another piece of ordnance, such as a grenade or a mortar shell, may be used as the explosive component, or the device may be completely fabricated out of locally available materials.
 - ◆ The vehicle-borne improvised explosive device (VBIED) is a specific type of IED consisting of a non-tactical vehicle loaded with explosives and projectiles to inflict damage to personnel, vehicles, and infrastructure.
 - ◆ Similarly, a suicide-vest improvised explosive device (SVIED) utilizes individuals, often women and children, to inflict casualties via local or remote detonation.
 - ◆ Drone-dropped IEDs are a recent tactic involving release of an IED from a drone aircraft that may detonate before hitting the ground.
 - ◆ Injuries caused by IED may involve any imaginable type of impaled objects, including bone and body parts of a suicide attacker.
- **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 military 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 Russian-made AK-47 rifle is one of the most common weapons used throughout the world. For this particular bullet (full metal jacketed or ball), as shown in the gelatin block, there is a 25-cm path of relatively minimal tissue disruption before the projectile begins to yaw. In dynamic, live tissue injuries, however, the actual performance of the bullet may vary, and some wounds may demonstrate relatively minimal tissue disruption while others may have a large cavitation effect with extensive tissue necrosis (Fig. 1-6).

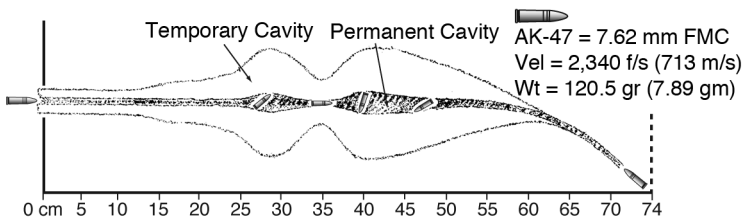


Fig. 1-6. Idealized path of tissue disruption caused by a bullet fired by an AK-47 (10% gelatin as a simulation). FMC: full metal case; Vel: velocity; Wt: weight.

- ◆ The AK-74 rifle is a smaller-caliber Russian-made assault rifle. The standard bullet does not deform in the tissue simulant, but does yaw relatively early (at about 7 cm of penetration).
- ◆ The M-4 and M-16 series rifles fire 5.56-mm full metal-jacketed bullets 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 cannellure (a groove placed around the midsection of the bullet) (Fig. 1-7).
- ◆ 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. 1-8).

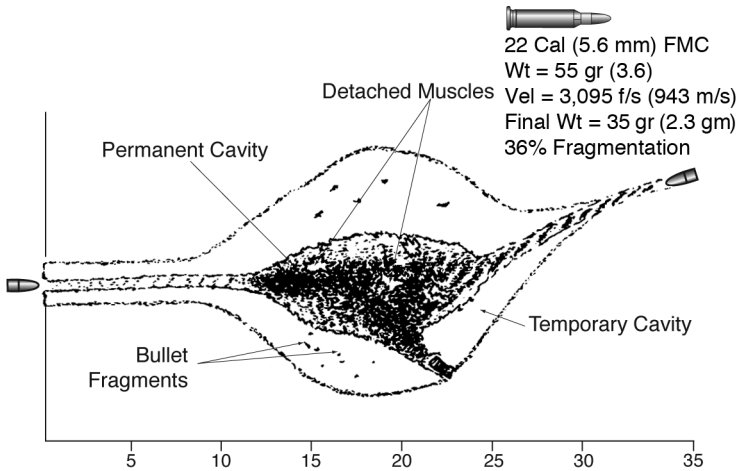


Fig. 1-7. Idealized path of tissue disruption caused by a bullet fired from an M-16 rifle (10% gelatin as a simulation). Cal: caliber; FMC: full metal case; Vel: velocity; Wt: weight.

- ◆ Larger-caliber weapons include machine guns (mounted or portable) and rotary cannons (Gatling-type with multiple barrels in a rotating cluster to allow greater sustained rate of fire) with a range of bullets, including .50 caliber (13-mm) rounds up to 30-mm rounds, which create correspondingly greater amounts of tissue disruption.

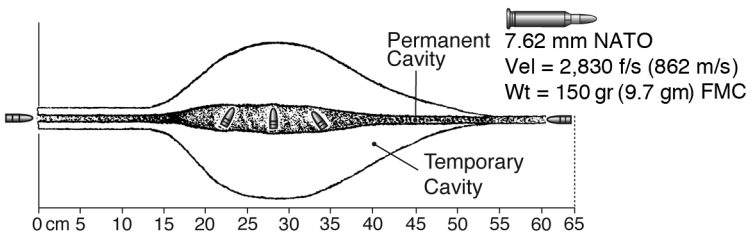


Fig. 1-8. Idealized path of tissue disruption caused by a 7.62-mm projectile (10% gelatin as a simulation). FMC: full metal case; NATO: North Atlantic Treaty Organization; Vel: velocity; Wt: weight.

● **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.
- Armored vehicle examples include mine-resistant ambush protected vehicles, tanks, infantry fighting vehicles, 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. 1-9a.

- ◇ 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. 1-9b).

◆ **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 many years that casualties with retained depleted uranium fragments may develop heavy

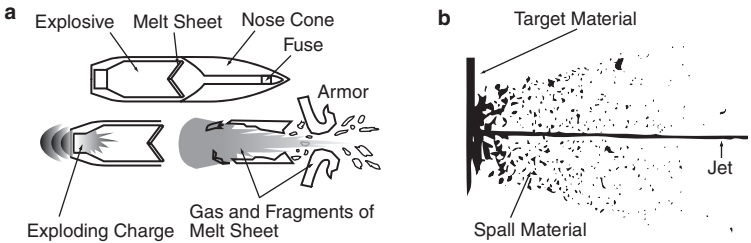


Fig. 1-9. (a) Disruptive mechanisms of the shaped charge warhead. (b) Diagram taken from photograph of an actual detonation of a shaped charge warhead against an armor plate caused by antitank land mines.

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.**
 - ◇ Antitank mines are those with a large explosive filler of 4–5 kg. Injuries are often due to blunt trauma from 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. 1-10).
 - Multiple injuries take place as the result of defeated armor (as described previously).
 - **Thermal:** Burns occur because of ignited fuel, ammunition, or hydraulic fluid, or as the direct result of the antiarmor device.
 - Two large studies, one on British World War II tank crewmen and one on 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 when a munition breaches a vehicle's armor, exposing the interior of the vehicle to the blast overpressure within a confined space. When explosions occur outside a vehicle, the blast wave may be dissipated by the vehicle's armor.

■ **Toxic fumes**, such as smoke inhalation, carbon monoxide, hydrogen fluoride or cyanide released as byproducts of combustion and vehicle fire-suppression systems, may cause chemical inhalation injury and hypoxia.

● **Inhalation injury.**

- There are three types of inhalation injury:
 - ◆ Upper airway (above glottis), caused by direct heat injury.
 - ◆ Lower airway (below glottis), caused by retained soot and chemicals within the airways.
 - ◆ Poisoning, caused by absorption of carbon monoxide, cyanide, or other toxin into the blood stream.
- Treatment of inhalational injury is supportive and may include early intubation, judicious fluid management, and possibly steroid administration if unresponsive. If available, bronchoscopic lavage may be used to remove debris.
- Triage considerations: Triage inhalational injury as immediate if hypoxia or pulmonary edema is present, consider triage as expectant if hypotensive and cyanotic. Reevaluate nonemergent patients every 2 hours.

● **Unexploded ordnance.**

- Unexploded ordnances (UXOs) may occasionally become embedded in a casualty without exploding.
- UXOs include rockets, grenades, mortar rounds.
- Some UXOs must travel a specific distance (50–70 m) or number of rotations in order to arm.
- Fuses are triggered by different stimuli (impact, electromagnetic, laser).

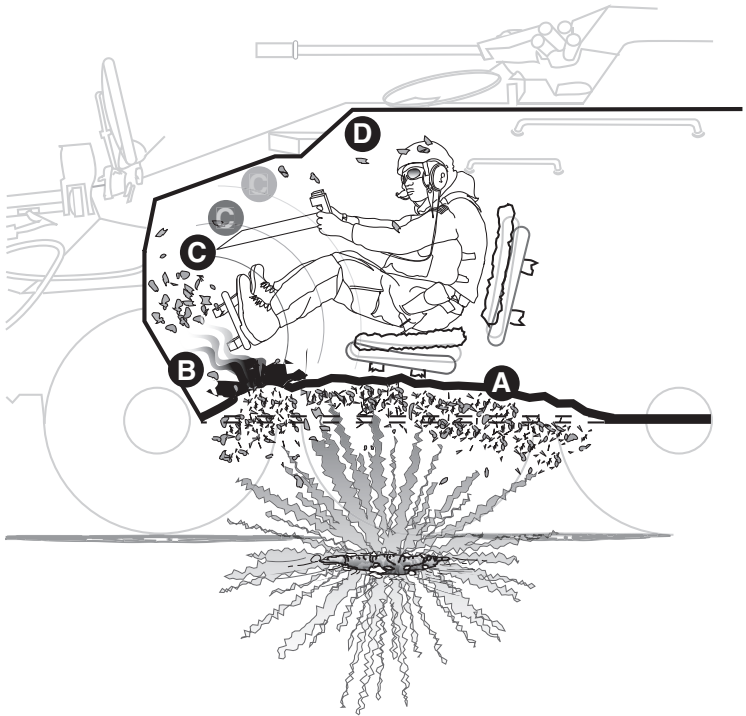


Fig. 1-10. Injuries sustained as a result of defeated armor, (A) translational blast injury, (B) toxic gases, (C) blast overpressure, and (D) penetrating missile wounds.

- **Notify explosive ordnance disposal team immediately!**
 - Thirty-two of 36 victims and all treating teams survived removal, with four casualties reported moribund on arrival who died before operation (historical review of US casualties).
 - No incident was identified in which a round exploded during transportation, preparation, or removal.
 - The casualty should be triaged as **nonemergent**, placed far from others, and **operated on last**.
 - Preplan for how to handle both transport and surgery.
 - 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, preferably with blast shielding, not in the main OR area.**
- Operative management.
 - ◆ Use blast protection for surgeon and staff.
 - ◆ Place sandbags around the operative area, use flak vests and ballistic eye protection.
 - ◆ Avoid triggering stimuli.
 - ◆ Avoid electromagnetic charge (do not use defibrillator, monitor, electrocautery, blood warmer, ultrasound or CT machines).
 - ◆ Plain radiography is safe. It helps identify the type of munition.
- Anesthesia.
 - ◆ General anesthetic is usually preferred. May utilize total intravenous anesthesia.
 - ◆ Avoid or minimize use of oxygen. Keep oxygen tanks at a distance.
 - ◆ 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 personnel for disposal.

For Joint Trauma System Clinical Practice Guidelines, go to http://jts.amedd.army.mil/index.cfm/PI_CPGs/cpgs/