Chapter 1

Weapons Effects and Parachute Injuries

Just as with any medical topic, surgeons must understand the pathophysiology of war wounds in order to best care for the patient.

Treat the wound, not the weapon.

Epidemiology of Injuries

- Weapons of conventional war can be divided into explosive munitions and small arms.
  - o Explosive munitions: artillery, grenades, mortars, bombs, and hand grenades.
  - o Small arms: pistols, rifles, and machine guns.
- Two major prospective epidemiological studies were conducted during the 20th century looking at the cause of injury as well as outcome.
  - o During the Bougainville campaign of World War II, a medical team was sent prospectively 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.
  - o US Army and Marine casualties from the Vietnam War collected by the Wound Data and Munitions Effectiveness Team (WDMET) in Vietnam.

US Casualties, Bougainville Campaign (WW II) and Vietnam

Weapon	Bougainville %	Vietnam %
Bullet	33.3	30
Mortar	38.8	19
Artillery	10.9	3
Grenade	12.5	11
Land mine/booby trap	1.9	17
RPG (rocket propelled grenade)	—	12
Miscellaneous	2.6	—

The most common pattern of injury seen on a conventional battlefield is the patient with multiple small fragment wounds of the extremity.

Anatomical Distribution of Penetrating Wounds (%)

Conflict	Head and Neck	Thorax	Abdomen	Limbs	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	(32)*
Gulf War (US)	11	8	7	56	18+
Afghanistan (US)	16	12	11	61	—
Chechnya (Russia)	24	9	4	63	—
Somalia	20	8	5	65	2
Average	**15**	**9.5**	**7.4**	**64.6**	**3.5**

* Buttock and back wounds and multiple fragment injuries, not included
+ Multiple wounds
** 80% caused by fragments; range of hits 1–45, mean of 9

Mechanism of Injury

- For missile injuries, there are two areas of projectile-tissue interaction, permanent cavity and temporary cavity (Fig. 1-1).

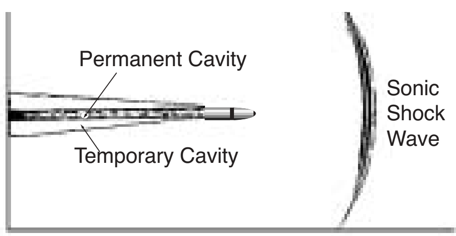

Fig. 1-1. Projectile–tissue interaction, showing components of tissue injury.

- o **Permanent** cavity. Localized area of cell necrosis, proportional to the size of the projectile as it passes through.
- o **Temporary** cavity. Transient lateral displacement of tissue, which occurs after passage of the projectile. **Elastic tissue**, such as skeletal muscle, blood vessels and skin, may be pushed aside after passage of the projectile, but then rebound. **Inelastic tissue**, such as 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.

Explosive munitions have three mechanisms of injury (Fig. 1-2):

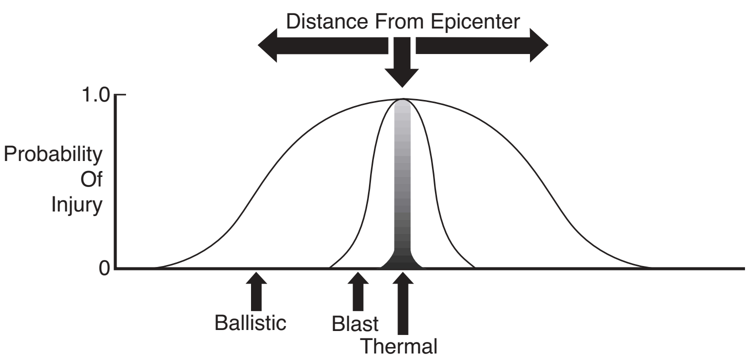

Fig. 1-2. The probability of sustaining a given trauma is related to the distance from the epicenter of the detonation.

- Ballistic.
  - o Fragments from explosive munitions cause ballistic injuries.
  - o Fragments are most commonly produced by mortars, artillery, and grenades.
  - o Fragments produced by these weapons vary in size, shape, composition, and initial velocity. They may vary from a few milligrams to several grams in weight.
  - o Modern explosive devices are designed to spread more uniform fragments in a regular pattern over a given area.

- o Fragments from exploding munitions are smaller and irregularly shaped when compared to bullets from small arms.
- o 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.

- Blast (see Fig. 1-2).
  - o The blast effects take place relatively close to the exploding munition relative to the ballistic injury.
  - o Blast overpressure waves, or sonic shock waves, are clinically important when a patient is close to the exploding munition, such as a land mine.
  - o The ears are most often affected by the overpressure, followed by lungs and the gastrointestinal (GI) tract hollow organs. GI injuries may present 24 hours later.
  - o Injury from blast overpressure is a pressure and time dependent function. By increasing the pressure or its duration, the severity of injury will also increase.
  - o Thermobaric devices work by increasing the duration of a blast wave to maximize this mechanism of injury. 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 such as a bunker.
  - o Air displaced on the site after the explosion creates a blast wind that can throw victims against solid objects, causing blunt trauma.
- Thermal.
  - o 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.

Common Misconceptions About Missile Wounds

Misconception	Reality
Increased velocity causes increased tissue damage.	Velocity is one factor in wounding. An increase in velocity does not per se increase 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 explored, due to the effects of the temporary cavity.	Elastic soft tissue (skeletal muscle, blood vessels, and nerves) generally heals uneventfully and does not require excision, provided the blood supply remains intact. Temporary cavity effects are analogous to blunt trauma.

Antipersonnel Landmines

- There are three types of conventional antipersonnel landmines available throughout the world: static, bounding, and horizontal spray.
  - o **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. 1-3).

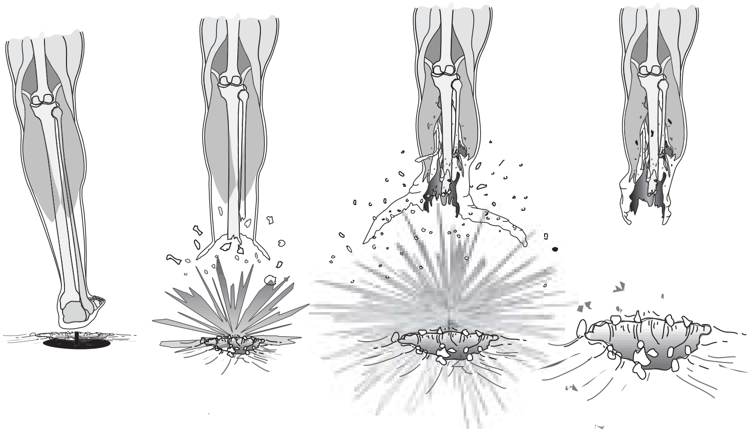

Fig. 1-3. Mechanisms of injuries caused by antipersonnel land mines.

    - ♦ Partial or complete traumatic amputation, most commonly at the midfoot or distal tibia.
    - ♦ More proximally, debris and other tissue is driven up along fascial planes with tissue stripped from the bone.
    - ♦ Factors influencing the degree of injury include size and shape of the limb, point of contact with the foot, amount of debris overlying the mine, and the type of footwear.
  - o **Bounding** mines propel a small explosive device to about 1–2 m of height and then explode, causing multiple small fragment wounds to those standing nearby. These landmine casualties have the highest reported mortality.

- o **Horizontal spray** mines propel fragments in one direction. This land mine can be command-detonated or detonated by tripwire. The US Claymore mine fires about 700 steel spheres of ¾ g each over a 60° arc. Horizontal spray mines produce multiple small-fragment wounds to those nearby.
- An unconventional weapon (improvised explosive device, or IED) is a fourth type of antipersonnel landmine. Either 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.
- Below are some examples of the characteristics of commonly encountered firearms seen throughout the world. The illustrations are of the entire path of missiles fired consistently at 5–10 m in range into ordnance gelatin tissue-simulant blocks. Variations of range, intermediate targets such as body armor, and body tissue will alter the wound seen.
    - o 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. 1-4).

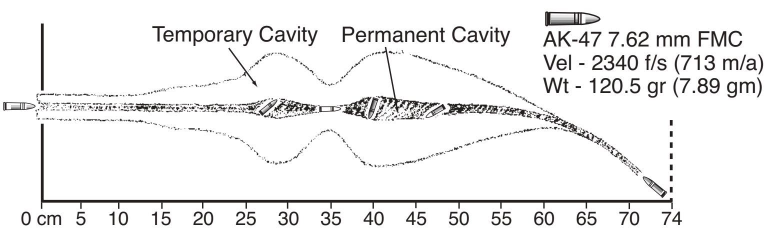

Fig. 1-4. Idealized path of tissue disruption caused by an AK-47 projectile, (10% gelatin as a simulation).

- 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).
- 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 cannalure (a groove placed around the mid section 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. 1-5).

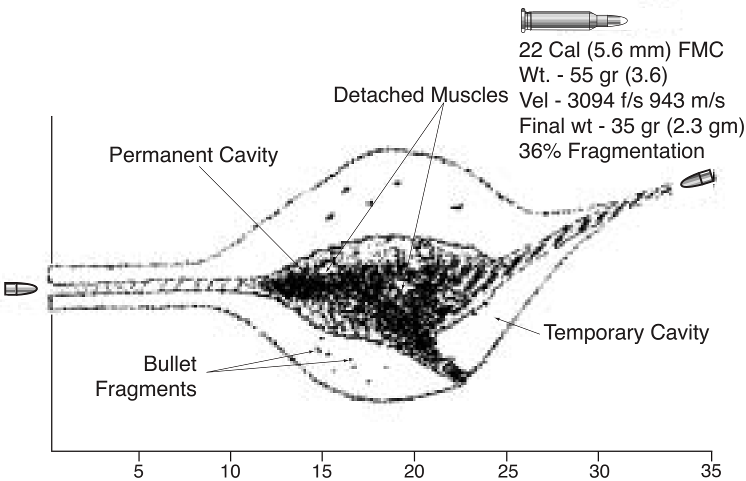

Fig. 1-5. Idealized path of tissue disruption caused by an M-193 bullet fired from the M-16A1 rifle (10% gelatin as a simulation).

- The 7.62 mm NATO 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. 1-6).

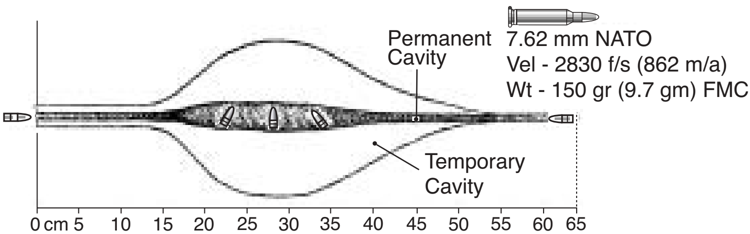

Fig. 1-6. Idealized path of tissue disruption caused by the 7.62 mm projectile, (10% gelatin as a simulation).

Armored Vehicle Crew Casualties

- Since the first large scale use of tanks during WWI, injuries to those associated with armored vehicles in battle have been a distinct subset of combat casualties.
- Tanks, infantry fighting vehicles, armored personnel carriers, armored support vehicles, and "light armored vehicles."
  - o Light armored vehicles tend to use wheels rather than tracks for moving and have lighter armor. The main advantage for these vehicles is to allow for greater mobility.

Compared to infantry, injuries to those inside or around armored vehicles are characterized by:

- **Decreased overall frequency.**
- **Increased severity of injury and mortality (up to 50%).**
- **Increased incidence of burns and traumatic amputations.**

- There are three main types of antiarmor weapons on the battlefield today.
  - o **Shaped charge** (Fig. 1-7a).
    - ♦ 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 RPG.

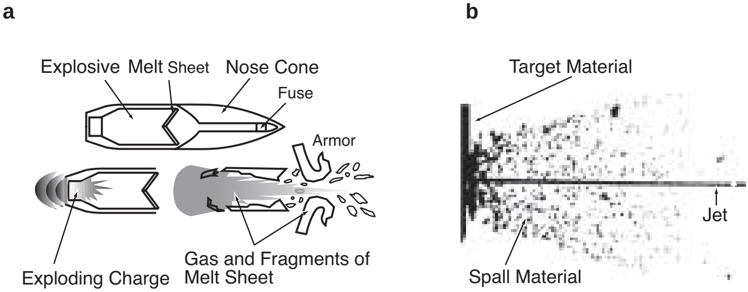

Fig. 1-7. (**a**) Disruptive mechanisms of the shaped-charge warhead, (**b**) diagram taken from photograph of an actual detonation of shaped-charged warhead against armor plate caused by antitank land mines.

- ♦ Shaped charges range in diameter from the 85 mm RPG-7 to the 6-in diameter tube launched, optically tracked, wire guided (TOW) missile.
- ♦ If the armor is defeated by the shaped charge, there are two areas of behind-armor debris.
  - ◊ First, there is the jet of the shaped charge itself. This may cause catastrophic wounds to soldiers who are hit, or it may ignite fuel, ammunition, or hydraulic fluid.
  - ◊ There is a second type of debris, 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 of the compartment (Fig. 1-7b).

o **Kinetic energy round.**

- ♦ The kinetic energy (KE) round is a large, aerodynamically shaped piece of hard metal (such as depleted uranium or tungsten) shaped like a dart. Fragments of depleted uranium should be treated during initial wound surgery as any retained metal foreign body should. There is a hypothetical risk, over 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 surgery. The metal is usually encased in a carrier or sabot that falls away from the projectile after it leaves the barrel.

- ♦ Injuries to those inside a vehicle are due 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.

o **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 fractures of the upper and lower extremities and spine are common (Fig. 1-8).
- ♦ A modification of the shaped charge is the Miznay-Schardin antitank mine that creates a projectile or large metal slug to cause damage to the vehicle. This is less likely than a conventionally shaped charge to be broken up by intermediate targets.

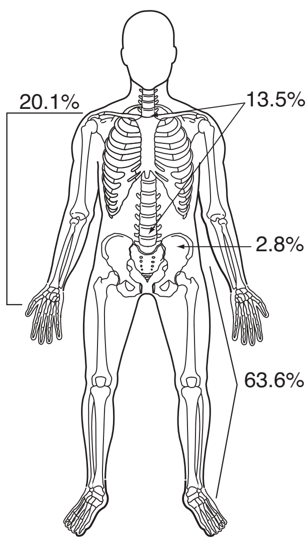

Fig. 1-8. Distribution of fracture sites sustained within an armored vehicle that had detonated a land mine (Soviet data from Afghanistan, early 1980s).

Mechanisms of Injury (Fig. 1-9)

- **Ballistic** injuries take place as the result of defeated armor as described above.

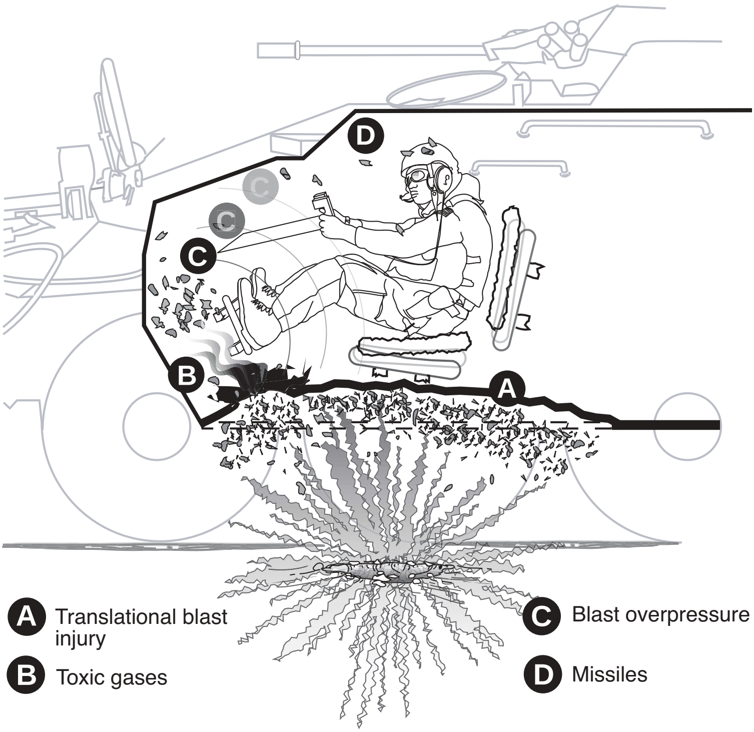

Fig. 1-9. Injuries sustained as a result of defeated armor, (**a**) translational blast injury, (**b**) toxic gases, (**c**) blast overpressure, (**d**) penetrating missile wounds.

- **Thermal**. Burns occur because of ignited fuel, ammunition, hydraulic fluid, or as the direct result of the antiarmor device.
  - o Two large studies, one from British WWII tank crewmen and one from Israeli casualties in Lebanon, showed that about ⅓ of living wounded casualties have burns.

  - The severity of burns range from a mild 1st degree burn to full thickness burns requiring skin coverage. Most burns are superficial burns to exposed skin, most often of the face, neck, forearms, and hands. These are often combined with multiple fragment wounds.
- **Blast overpressure** occurs from the explosion occurring inside a confined space. One study from WWII showed 31% of armored crewmen casualties had ear injury due to blast overpressure, including ruptured tympanic membranes.
- **Toxic Fumes** are secondary to phosgene-like combustion byproducts in Teflon coated interiors of armored vehicles (antispall liners).
  - HCL is produced at the mucous membrane.
  - 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 q 2 h.
- **Blunt Trauma** is due to acceleration mechanisms.

Unexploded Ordnance (UXO)

- UXOs are embedded in the casualty without exploding.
  - Rockets, grenades, mortar rounds.
  - UXO must travel a distance (50–70 m) without arming.
  - Fuses are triggered by different stimuli (impact, electromagnetic, laser).
- **Notify explosive ordnance disposal immediately!**
- 31⁄31 victims lived after removal (from recent review).
- 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 **safe area**.
    - ♦ Revetment, parking lot, or back of building.
  - **Operate in safe area, not in main OR area.**
- Operative management.
  - Precautions for surgeon and staff.

    - ♦ Sandbag operative area, use flak vests and eye protection.
  - o Avoid triggering stimuli.
    - ♦ Electromagnetic (no defibulator, monitors, Bovie cauterizer, blood warmers, or ultrasound or CT machines).
    - ♦ Metal to metal.
    - ♦ Plain radiography is safe. It helps identify the type of ammunition.
  - o Anesthesia.
    - ♦ Regional / spinal / local preferred.
    - ♦ Keep **oxygen** out of OR.
    - ♦ Have anesthesiologist leave after induction.
  - o Operation: The surgeon should be alone with the patient.
    - ♦ Employ gentle technique.
    - ♦ Avoid excessive manipulation.
    - ♦ Consider amputation if other methods fail.
    - ♦ Remove en-block if possible.
- **The decision to remove a chemical/biological UXO is a command decision.**
- Immediately after removal, hand to explosive ordnance disposal (EOD) personnel for disposal.

Parachute Injuries

- Dependent on several factors: **Weather** (wind), **day/night, drop zone hazards/terrain,** low **drop altitude**, and **level of opposition** (enemy resistance) at the drop zone.
- Caused by improper aircraft exit, parachute malfunction, hazards (including enemy) on descent or in the landing zone, entanglements, or an improper parachute landing fall (PLF).
- Peacetime rate of injuries is 0.8%.
- Combat injury **rate** is historically higher (subject to above listed factors).
  - o As high as 30% overall.
  - o Majority of injuries are minor.
  - o 8% to 10% of total jumpers are rendered either combat ineffective or significantly limited.

Injury Site/Type	%	Injury Site/Type	%
Ankle	20	Sprain/Strains	37.7
Back	11.1	Contusions	30.1
Knee	10.7	Lacerations	14.7
Head/Neck	8.7	Closed Fractures	11.1
Leg	8.3	Concussions	2.0
Open Fractures	2.0	—	—

- **Fractures result in a higher percentage of removal from combat.**

Fractures of the calcaneus are associated with fractures of the axial skeleton (10%). Patients should be placed on spinal precautions until such injuries are ruled out.