

OTOLARYNGOLOGY/HEAD AND NECK SURGERY COMBAT CASUALTY CARE IN OPERATION IRAQI FREEDOM AND OPERATION ENDURING FREEDOM

Section III: Ballistics of Injury



Critical Care Air Transport Team flight over the Atlantic Ocean (December 24, 2014).

Photograph: Courtesy of Colonel Joseph A. Brennan.

Chapter 9

WEAPONS AND MECHANISM OF INJURY IN OPERATION IRAQI FREEDOM AND OPERATION ENDURING FREEDOM

DAVID K. HAYES, MD, FACS*

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**Colonel, Medical Corps, US Army; Assistant Chief of Staff for Clinical Operations, Southern Regional Medical Command, 4070 Stanley Road, Fort Sam Houston, Texas 78234; formerly, Commander, 53rd Medical Detachment—Head and Neck, Balad, Iraq*

INTRODUCTION

This chapter is divided into four sections. It first examines the shifts in weapons used in the combat zones of Iraq and Afghanistan, and compares them to mechanisms of wounding in prior conflicts, including comparing the lethality of gunshot wounds to explosive devices. The second section reviews the various mechanisms of blast injury and presents a classification system of these injuries. The section also includes a specific discussion of tympanic membrane rupture as an indicator of other injuries, and a brief review of the evolution of closed head injury surveillance during the conflicts. The third section reviews the ballistics of bullets and other projectiles, and the fourth section discusses the most common small arms weapons used during the conflicts.

Weapons have shaped tactics in armed conflict since the first battles were recorded. Though insurgent and coalition forces used hundreds of different weapons in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF), the signature weapon of these conflicts was the improvised explosive device (IED). In a report from the Center for Strategic and International Studies, Cordesman et al reported there were 86,217 IED incidents and 2,192 deaths among coalition forces in Iraq alone from June 2003 through September 2010.¹ Data from the Defense Manpower Data Center show explosive devices caused 34,647 total US casualties in OIF and OEF combined from October 2001 to May 2012, while

small arms weapons caused just 6,013 casualties during the same time.² Mortars and rocket-propelled grenades, although highly destructive, injured 5,458 and killed only 341 US soldiers during the same time (Table 9-1). In a review of wounding patterns in Iraq and Afghanistan from 2005 to 2009, Belmont et al reported explosive mechanisms accounted for 74.4% of combat casualties—higher than in any previous US conflict (Table 9-2).³⁻⁸

Despite the disruptive capacity of IEDs, they proved to be less lethal than small arms fire. Evidence suggests rifles and machine guns remained the most lethal weapons in conventional ground warfare.² In OIF, there were 3,095 recorded US soldier injuries from gunshots, and 670 of these soldiers died of their wounds (after excluding deaths from non-hostile fire). Lethality, the probability that a combatant will die if wounded by a specific weapon, was 21.6% from small arms fire. There were 23,793 recorded injuries from explosive devices (primarily IEDs but also small numbers of hand grenades and mortar fire; not including rocket fire) in US soldiers, and 2,212 died of their wounds. Lethality was 9.3% for explosive devices—roughly half that of small arms wounds. These lethality rates, however, did not hold true for every battle or campaign when considered separately. In a prospective study of combat injuries sustained by soldiers in a single US Army brigade combat team during 15 months of the “surge” (2007–2008), Belmont

TABLE 9-1

CASUALTIES IN OPERATIONS IRAQI FREEDOM, ENDURING FREEDOM, AND NEW DAWN BY CAUSE FROM OCTOBER 7, 2001 THROUGH MAY 7, 2012

Mechanism of Injury	OEF Hostile Deaths	OEF Non-Hostile Deaths	OEF Hostile WIA	OIF Hostile Deaths	OIF Non-Hostile Deaths	OIF Hostile WIA	OND Hostile Deaths	OND Non-Hostile Deaths	OND Hostile WIA	Totals
Artillery, mortar, or rocket	26	0	830	211	4	2,700	13	0	80	3,864
Explosive device	851	14	9,813	2,195	17	21,581	14	0	162	34,647
Grenade	1	0	0	0	0	70	0	0	0	71
Gunshot	387	19	2,368	670	110	2,425	7	2	25	6,013
Rocket-propelled grenade	51	1	1,155	53	1	773	4	0	18	2,056

Data sources: (1) Defense Manpower Data Center. (2) Chivers CJ. Why do bullets kill more soldiers in Iraq? *New York Times*. August 19, 2009. http://siadapp.dmdc.osd.mil/personnel/CASUALTY/gwot_reason.pdf. Accessed May 10, 2013.

OEF: Operation Enduring Freedom; OIF: Operation Iraqi Freedom; OND: Operation New Dawn; WIA: wounded in action

TABLE 9-2

HISTORICAL MECHANISMS OF COMBAT WOUNDS

Conflict	GSW (%)	Explosion (%)
Civil War ¹	91	9
World War I ²	65	35
World War II ²	27	73
Korean War ³	31	69
Vietnam War ⁴	35	65
OIF/OEF ⁵	19	81

GSW: gunshot wound

OEF: Operation Enduring Freedom

OIF: Operation Iraqi Freedom

Data sources: (1) Bellamy RF, Zajtcuk R. Assessing the effectiveness of conventional weapons. In Zajtcuk R, ed. *Textbook of Military Medicine, Part I: Warfare, Weaponry, and the Casualty*, Vol. 5, *Conventional Warfare: Ballistic, Blast, and Burn Injuries*. Washington, DC: Office of the Surgeon General, Department of the Army; 1991: 53–82. (2) Beebe GW, DeBakey ME. Death from wounding. In: *Battle Casualties*. Springfield, IL: Charles C Thomas; 1952: 74–147. (3) Reister FA. *Battle Casualties and Medical Statistics: U.S. Army Experience in the Korean War*. Washington, DC: The Surgeon General, Department of the Army; 1973. (4) Hardaway RM. Viet Nam wound analysis. *J Trauma*. 1978;18:635–643. (5) Owens BD, Kragh JF Jr, Wenke JC, Macaitis J, Wade CE, Holcomb JB. Combat wounds in Operation Iraqi Freedom and Operation Enduring Freedom. *J Trauma*. 2008;64:295–299.

et al reported that 27 of 341 soldiers injured by an explosion died (explosive lethality: 7.9%), compared to 2 of 35 soldiers injured by small arms fire (gunshot wound [GSW] lethality: 5.7%).⁹

The war in Afghanistan was not the same as the Iraq war moved 1,500 miles west. Marked shifts occurred in enemy tactics and effectiveness as each theater evolved. From 2005 to 2007, explosive mechanisms of injury were far more common in Iraq than in Afghanistan. The percentage of injuries reported from blast exposure increased significantly in Afghanistan between the years 2007 (59.5%) and 2008 (73.6%), eventually nearly equaling that in Iraq.³ Defense Manpower Data Center data suggest that GSWs were less lethal to US troops in Afghanistan (14.0%) than in Iraq (21.6%), whereas the lethality of IEDs was nearly the same (8.1% in Afghanistan; 9.3% in Iraq). The reasons behind the former discrepancy remain unclear. Chivers examined the data and offered, “One explanation might be the presence of reasonably skilled snipers in Iraq, and the near absence of them in Afghanistan. Sniper shots are generally more lethal than other gunshot injuries because of their placement.”² Insurgent snipers were active in the Sunni triangle in 2006–2007. Five combatants shot by a sniper who survived an initial GSW were treated at the 332nd Emergency Medical Group

in Balad between October 2006 and May 2007 (author’s personal notes during deployment to Balad, 2006). It is also likely that in Afghanistan the inferior quality of weaponry, aged ammunition, and its use by poorly trained or untrained combatants also made these weapons less accurate and less effective at inflicting lethal wounds.

Medical professionals played a key role in the ability of coalition forces to adapt and survive on the battlefield during OIF and OEF. Data on injury patterns reported from medical units in Baghdad and Balad quickly made its way into laboratories, where improved protective equipment was developed and training was revised. More effective body armor designed to distribute ballistic impact forces away from vital areas was fielded. Combat lifesaver training and the development and rapid fielding of the combat tourniquet combined to limit hemorrhage during the critical few minutes following an injury, saving many lives. New training reemphasized eye and hearing protection. Lessons learned in Vietnam and refined in Iraq proved the value of highly trained medics capable of starting intravenous lines under fire and using advanced airway techniques on medevac Black Hawk helicopters. The forward deployment of surgeons at firebases and outposts, and the quality of care at hospitals in Balad, Baghdad, Bagram, Kandahar, and other sites enabled high survival rates.

As the wars progressed, coalition tactics and improved armor rendered IEDs less effective against better protected coalition forces. US and coalition injury rates decreased. Data reported by Cordesman et al showed 165 service members killed in action (KIA) in 9,053 IED events from July through December 2007, for a kill rate of 1.82%. In 2008 during the same period, there were 20 KIA in 2,849 IED events, for a kill rate of 0.70%, and in 2009 during the same period there were 8 KIA in 1,107 IED events, for a kill rate of 0.72%.¹ However, despite the defensive adaptations by the technologically superior coalition military force, a determined insurgency strained medical units. Casualties among local national forces and civilians continued unabated. Coalition medical forces dedicated themselves to treating all casualties that reached them, both on moral grounds and as part of a campaign to engage and win the support of local populations. Such strategies paid off. The decision to treat injured Iraqi children at the 332nd Emergency Medical Group resulted in a drop in mortar and rocket-propelled grenade (RPG) attacks near the hospital (author’s personal notes during deployment to Balad, 2006).

Nonetheless, IEDs seemed ubiquitous to troops on the ground. Effective as much for their emotional impact as for their ability to temporarily

disrupt and disorganize an opposing force, IEDs also proved indiscriminate. Nearing the end of US involvement in the conflict in Iraq, insurgent willingness to use IEDs showed their disregard

for noncombatants. For many Iraqis, use of these weapons affirmed that insurgents were terrorists, and persuaded a majority of the civilian population to turn against them.

EXPLOSIVE DEVICES

Blast Injury

In spite of improved body armor and combat tactics, explosive devices created the vast majority of the most complex trauma injuries on the battlefield. Despite being highly trained in managing severely injured polytrauma victims, most US surgeons who deployed to Iraq during the initial phases of combat lacked experience with the wide constellation of injuries often created by an IED. By 2004, US and British medical teams had learned much about the potential to miss “unseen” trauma when focused on life-saving measures and large visible wounds. Small penetrating wounds were sometimes the only clue to underlying life-threatening injuries.¹⁰ Tissue trauma at the cellular level from the blast pressure wave (primary blast injury) was causing occult damage to ocular, aural, pulmonary, cardiovascular, musculoskeletal, and neurologic systems (Figure 9-1). IEDs packed inside animal carcasses and laden with grease created severe burns and delayed wound healing problems (Figure 9-2). Late sequelae from IEDs, including traumatic brain injuries from repeated blast exposure, often went unrecognized.



Figure 9-1. Polytrauma from an improvised explosive device: inhalation and surface burns, penetrating fragment wounds, penetrating skull injury, concussion, and deafness from a blast exposure.

Significant advances in the understanding, prevention, and management of blast injuries came from battlefield research by individual physicians and by the Joint Combat Casualty Research Team.¹¹ Standardized clinical descriptions of blast injuries permitted comparisons that led to the development of effective clinical guidelines for evaluation and treatment of blast victims. Use of standard descriptive terminology to classify blast injuries and an awareness of all the potential mechanisms of injury by every member of the team proved essential in identifying latent causes of morbidity when treating these patients, and enabled research and continued improvement in clinical outcomes.

Blasts generate multiple potential mechanisms for causing injury that can incapacitate or kill¹²:

- The blast pressure wave can cause direct tissue injury through intense compression and shearing forces.
- Energized debris or fragments can cause penetrating and blunt injury.
- Acoustic energy can cause cochlear damage and hearing loss.
- Light energy can cause retinal damage and blindness.
- Thermal energy can cause burns.
- Toxic substance exposure can cause contact and inhalational injury or systemic poisoning.
- The acute intensity of the event can cause immediate and delayed psychological trauma.



Figure 9-2. Extremity burns from an improvised explosive device packed with grease.

The commonly used classification of blast injury is listed in Table 9-3.

The magnitude of injury caused by a blast will vary by type of explosive, proximity of the victim to the blast, and factors affecting exposure (eg, body armor, directionality or path of the blast wave, walls, and enclosures). In a study of 53 casualties injured by IEDs in 23 incidents, Ramasamy et al observed catastrophic injuries to casualties caught in the blast corridor of formed-projectile type IEDs, but relatively minor injuries to personnel nearby.¹³ They reported primary blast injuries were uncommon, occurring in just two of the survivors in their study (3.8%), despite all casualties being in close proximity to the explosions.

Explosions in enclosed spaces, or blast waves that enter an enclosed space, have the potential to cause dramatically more severe injuries than blasts in the open. The walls of the enclosure act as reflecting surfaces. Reflected blast waves may combine with the incident wave to increase the magnitude of the associated overpressure. Detonations at the junction of two walls or near a corner amplify the effective pressure wave up to 8 times.¹²

Rupture of the tympanic membrane (TM) has been considered as an indicator of the intensity of the blast soldiers have been exposed to, and a potential predictor of underlying primary blast injury (PBI). Multiple authors dispute this conclusion and report a poor correlation between TM rupture and blast injury to other organs. They conclude that TM rupture is of no use as a predictive marker.¹⁴⁻¹⁷ This conclusion may be premature in light of the continuing evolution of knowledge about mild traumatic brain injury (mTBI).

Peters reported the pressure required for perforation of the TM to be 137 kPa for adults in cadaver studies, while the lung, colon, and intestines are damaged by pressure waves in the 400-kPa range. He concluded that the use of the TM perforation as an indicator of a PBI could miss up to 50% of pulmonary injuries, and cautioned that the lack of a TM injury following exposure to a blast does not preclude the need for further investigations.¹⁴ Leibovici and colleagues studied 647 survivors from 11 terrorist bombings in Israel between April 6, 1994, and March 4, 1996, and found 193 (29.8%) sustained primary blast injuries, including 142 with isolated eardrum perforation. They reported that no patient presenting with isolated eardrum

TABLE 9-3
TAXONOMY OF INJURIES FROM EXPLOSIVE DEVICES

Level	Mechanism	Injuries
Primary	Blast overpressure injury resulting in direct tissue damage from the shock wave coupling into the body	• Blast lung • Eardrum rupture and middle ear • Abdominal hemorrhage and perforation • Eye rupture • Nonimpact, blast-induced mTBI
Secondary	Debris (fragments) accelerated by the blast striking the body	• Penetrating ballistic (fragmentation) or blunt injuries
Tertiary	Physical displacement of the body into other objects	• Fracture and traumatic amputation • Closed and open brain injury • Blunt injuries • Crush injuries
Quaternary	Other effects of exposure to the blast	• Burns • Injury or incapacitation from inhaled toxic fire gases
Quinary	Clinical consequences of “post-detonation environmental contaminants”	• Illnesses, injuries, or diseases caused by chemical, biological, or radiological substances (eg, “dirty bombs”)

mTBI: mild traumatic brain injury

Data sources: (1) Bridges E, Biever K. Advancing critical care: Joint Combat Casualty Research Team and Joint Theater Trauma System. *AACN Adv Crit Care*. 2010;21(3):260–276. (2) US Department of Defense. *Medical Research for Prevention, Mitigation, Treatment of Blast Injuries*. Washington, DC: DoD; 2006: 9. DoD Directive 6025.21E. (3) Department of Defense Blast Injury Research Program Coordinating Office, US Army Medical Research and Materiel Command. *FY10–FY11 Report to the Executive Agent: Science and Technology Efforts and Programs Relating to the Prevention, Mitigation, and Treatment of Blast Injuries*. Washington, DC: DoD; 2011.

perforation subsequently developed signs of pulmonary or intestinal blast injury. Eighteen of 193 survivors in their study had isolated pulmonary blast injury with intact TMs.¹⁵ Harrison et al studied 167 patients who arrived at a tertiary US military hospital in Iraq after sustaining blast injuries from explosions over a 30-day period. Twenty-seven (16%) had TM perforation (13 of 27 had bilateral perforations). Twelve of 167 patients (7%) were diagnosed with primary blast injury. Six of 12 patients with PBI had TM perforation. The authors reported that the use of TM perforation as a biomarker for PBI resulted in a sensitivity of 50% (95% CI, 22%–78%) and specificity of 87% (95% CI, 81%–92%).¹⁶ Radford et al reviewed records of 143 survivors of the four blasts in the London bombings on July 7, 2005. In their study, 51 patients had isolated TM rupture with no other primary blast injuries, while only 11 patients had TM rupture and other acute primary blast injuries. The authors concluded that TM rupture did not act as an effective biomarker of underlying blast lung.¹⁷

Leibovici and Radford propose that in a mass casualty event, patients with isolated TM rupture and an otherwise normal examination and normal chest radiograph can be monitored for a short period and safely discharged with arrangement for routine follow-up by an otolaryngologist.^{15,17} However, the preceding studies^{14–17} focus primarily on organs other than the brain. In contrast, Xydakis et al reviewed 682 blast victims transported between October 1 and December 31, 2005, to the Air Force Theater Hospital, Balad, Iraq, evaluating 210 US soldiers consecutively for both TM perforation and loss of consciousness. They observed a significant association between TM perforation and loss of consciousness (relative risk: 2.76; 95% CI, 1.91–3.97) and concluded that there was an association between TM perforation and concussive brain injury.¹⁸ Until further study demonstrates conclusive evidence in either direction, it seems most prudent for physicians treating blast survivors with TM perforation to maintain a high index of suspicion for concomitant neurologic injury.

Additional discussion of the physics and pathophysiology of blast injury to major organ systems is provided by Garner and Brett in *Anesthesiology Clinics*¹² and by C L Horrocks in the *Journal of the Royal Army Medical Corps*.¹⁹

Closed Head Injury

By 2005 it was clear to military physicians that the Glasgow Coma Scale score and a history of loss of consciousness alone were not sufficiently sensitive to identify many potentially serious brain injuries. The significantly higher frequency of explosive or blast at-

tacks in Iraq compared to past military conflicts created a new set of concerns about the risks and dynamics of closed head injury.^{20–22} A standardized, objective scale of exam findings was needed to identify and quantify the injuries occurring and to enable data collection to support the development of preventive measures and treatments.

The Military Acute Concussion Evaluation (MACE) was developed by the Defense and Veterans Brain Injury Center (<http://www.dvbic.org/>) as a concussion screening tool for the battlefield and was first distributed for clinical use by military personnel in August 2006.²³ This standardized instrument became the most widely used tool for evaluating soldiers suspected of having mTBI in military operational settings. The intensive educational program that accompanied the MACE's deployment elevated awareness and increased recognition of traumatic brain injury both on the battlefield and at home. Data from the Defense and Veterans Brain Injury Center show the dramatic increase in cases of mTBI diagnosed after 2005 (Figure 9-3).

The data also revealed that 30% of injured OIF/OEF veterans were found to have traumatic brain injury, with an even greater percentage meeting mTBI criteria when the mechanism of injury was blast re-

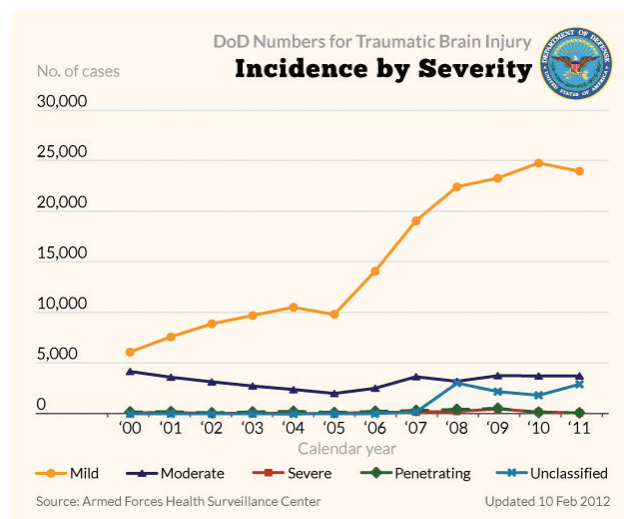


Figure 9-3. Brain injury incidence by severity, 2000–2011. The numbers represent medical diagnoses of TBI that occurred anywhere US forces were located, including the continental United States; not all are deployment related.

Data source: Defense and Veterans Brain Injury Center. <http://www.dvbic.dcoe.mil/dod-worldwide-numbers-tbi>. Accessed 27 June 2014.

Figure reproduced from: Armed Forces Health Surveillance Center.

lated. Guidelines for combat casualty care continue to evolve, but prudent practice warrants a concussion evaluation for anyone who sustains a direct blow to the head, anyone within 50 m of a blast, anyone involved

in a vehicle crash or rollover, and anyone suspected of having a head injury. Initiation of the MACE and a 24-hour rest period are recommended if any red flags are identified.

SMALL ARMS WEAPONS

Ballistics

Understanding the mechanism of injury in wounds caused by small arms fire necessarily requires a basic knowledge of ballistics and a specific understanding of how tissue reacts to penetrating projectiles. Ballistics is a broad field of science that deals with the physics of flight, including considerations of the mechanical properties of projectiles that affect flight. In this chapter, the term “projectiles” is used when referring to properties of bullets and other flying objects such as shrapnel or shattered bone fragments. The term “bullets” is specifically used when the discussion may not apply to other types of projectiles, as in the case of spin caused by the grooves cut in a barrel. Ballistics of small arms weapons is classically separated into internal, external, and terminal ballistics.

Internal Ballistics

Internal ballistics is the study of what happens between when the cartridge is fired and when the bullet leaves the muzzle. During this phase the bullet acquires its maximal kinetic energy. The maximal velocity and energy that can be imparted to a bullet is limited by the current understanding of metallurgy and the technology of bullet and bore manufacturing. The basic 50-caliber bullet is 80 years old and the M16/14 family of weapons is 30 years old. However, the design of bullets and rifles—including cartridge and propellant; bullet composition, shape, metal jacket, and weight distribution; and barrel configuration—continued to evolve during the wars in Iraq and Afghanistan. Examples are the replacement of the lead core with a copper alloy in the M855A1 bullet to reduce use of lead bullets due to environmental concerns; the addition of a steel cone to the tip of some bullets to improve penetration of hardened surfaces; and a faster burning propellant to improve velocity in shorter rifles and reduce muzzle flash.²⁴

The kinetic energy (KE) of a projectile is determined by its velocity (v) and mass (m):

$$KE = \frac{1}{2} (mv^2).$$

Small increases in the expansion rate of gases from the burning propellant and resulting increases in muzzle velocity have a large effect on KE. However, the igni-

tion of the propellant and intense pressures in the chamber produce extreme temperatures that soften, deform, or melt metal projectiles. The chamber pressure of an M16 is 52,000 psi, and the expanding gas may reach 5,200°F.^{25,26} Thus, the physical properties of the metals used limit the amount of KE that can be imparted to a bullet before it loses its integrity. Muzzle velocity is generally classified as low (<1,000 fps), medium (1,000–2,000 fps), and high (>2,000 fps). The practical limit in rifles is around 4,000 fps (Table 9-4).²⁷ The speed of sound in air is approximately 1,140 fps.

Despite concerns over environmental contamination, the most commonly used metal in bullets continues to be lead, which has high density (mass) and is cheap to obtain. Its disadvantages are a tendency to soften at temperatures associated with velocities greater than 1,000 fps, causing it to lose shape, smear the barrel, and decrease accuracy. Lead has a melting point of 621.5°F (327.5°C) and tends to melt completely at temperatures associated with velocities greater than 2,000 fps. Alloying lead with a small amount of antimony raises the melting point, but adds cost.

TABLE 9-4

MUZZLE VELOCITY, CALIBER, AND ENERGY OF SMALL ARMS WEAPONS*

Weapon	Caliber	Muzzle Velocity (ft/sec)	Energy (ft-lb)
38 pistol	0.38 (9.6 mm)	855	255
M9 Beretta	9 mm	935	345
357 pistol	0.357 (9 mm)	1,410	540
44 Magnum	0.44 (11.2 mm)	1,470	1,150
AK-47	7.62 mm [× 39 mm]	2,330	1,470
M16A2	.223 (5.56 mm)	2,800	1,500
M24	7.62 mm [× 51 mm]	2,850	1,535
Winchester rifle	0.243 (6.2 mm)	3,500	1,725

*Estimates can vary widely depending on the ammunition. Bullet design and manufacture affect the muzzle velocity and energy of the projectile. Poor-quality or older propellant may burn slowly, resulting in far lower muzzle velocity than published.

A significant advance in single projectile design came in 1881, when a Swiss army major, Eduard Rubin, invented the copper-encased bullet.²⁸ Encasing lead in another metal soft enough to seal the bullet in the barrel but with a high enough melting point to hold it together allowed development of greater propellant forces and higher muzzle velocities. Copper, with a melting point of 1,984°F (1,085°C), works well for this purpose and continues to be the most commonly used “jacket.”

External Ballistics

External ballistics is the study of what happens between when a bullet leaves the muzzle and when it strikes the target. A bullet's range, time of flight, and trajectory are determined by the muzzle velocity and the rate at which the bullet loses energy by slowing down. As noted previously, muzzle velocity is largely responsible for a bullet's starting KE. The rate at which a bullet loses energy is principally determined by three factors: mass, drag, and shape. These factors are combined in the ballistic coefficient (BC) for a given projectile, which can be described as the density of the projectile divided by resistance caused by the projectile's drag and shape (BC: lb/in²). In basic terms, the BC of a bullet is a measure of its ability to overcome air resistance in flight. A bullet with a high BC arrives at the target faster and with more KE than a bullet with a low BC. Most bullets fired from handguns have expended significant KE at 100 yards (Figures 9-4 through 9-7). High-velocity military bullets can still have over two-thirds of their velocity and significant KE at 300 yards.²⁹



Figure 9-4. An Iraqi National Guard soldier with transfacial low-velocity gunshot wound to face. The 6-mm bullet (see Figure 9-7), likely fired from a bolt action rifle, was either fired from several hundred yards, or the gun powder in the cartridge had lost its potency.

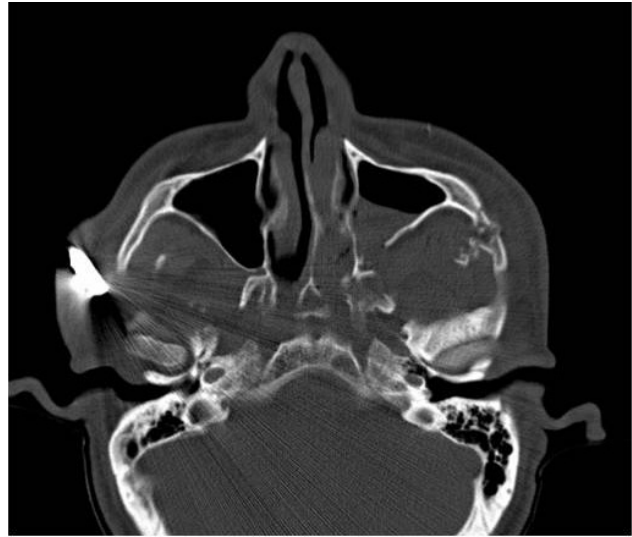


Figure 9-5. Computed tomography scan of soldier in Figure 9-4 demonstrating minimal injuries from a transfacial low-velocity gunshot wound to face.

The trajectory and wounding capacity of a bullet are highly dependent on its stability during flight. How quickly a projectile loses KE to drag and how much KE it “gives up” upon striking the target is significantly influenced by variations of flight, including: yaw (deviation of the projectile in its longitudinal axis), tumble (forward rotation around the center of mass), and deformation (Figure 9-8). These characteristics of flight are affected by the bullets' physical properties, whether by design or by chance.

Bullet designs favor a flat, dense base to hold the projectile together under the intense pressure created by the expanding propellant, and a pointed tip to reduce the projectile's drag during flight. The physics



Figure 9-6. Same patient, bullet impacted in fractured zygoma being removed.

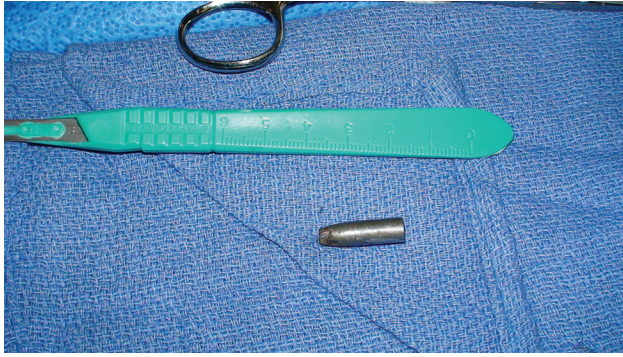


Figure 9-7. Same patient, 6-mm bullet extracted.

of projectiles in flight results in a tendency to travel with their center of mass forward. Thus placement of a bullet's center of mass toward the rear is inherently unstable and results in a propensity to flip over. With yaw or material imperfections, molecules of air (or any medium being traversed) impact the leading edges of a bullet unevenly, generating forces that deflect the tip further to the side. The more dense the medium, the greater this force. The result is a tendency for bullets to destabilize, tumble, and fly base-first. This tendency is counteracted by causing the bullet to spin by rifling, or cutting spiral grooves into the barrel. Centrifugal forces created by spinning the bullet offset the tendency to tumble in low density air and keep the bullet flying point-first, which improves accuracy and reduces loss of KE from drag. Contact with tissue that is several hundred times denser than air generates a dramatic increase in the imbalance of forces acting on the tip of the bullet. If the imbalance overcomes the stabilizing force of spinning, the bullet tumbles.

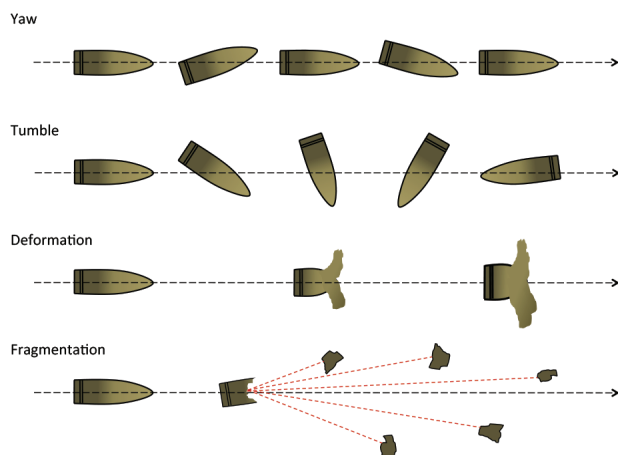


Figure 9-8. Variations in projectile flight.

Terminal Ballistics

Terminal ballistics is the study of what happens when a target is hit. The maximal wounding capacity of a projectile is determined by the KE it possesses at the moment of impact. However, high velocity bullets do not necessarily cause greater tissue damage than lower velocity bullets of equal mass. Military rifle bullets spin and are fully jacketed, pointed, and non-expanding. A metal jacket impedes deformation and fragmentation, spin reduces yaw and tumble, and a pointed tip presents less surface area to the target. A fully jacketed 7.62-mm military bullet may create a smaller temporary and permanent cavity in tissue than a 7.62-mm civilian "hunting" bullet with a soft-point tip that deforms upon impact, resulting in a more extensive wound.

The practical effect of projectile strike is determined by the amount of KE the projectile transfers to the target and the rate of that transfer. This transfer of energy is affected by two factors: (1) projectile design (primarily weight distribution, shape, and stability) and (2) target tissue composition.

Projectile Design

Bullet design varies with the intended use. Bullets designed for penetrating large game animals, for example a rhinoceros or elephant, have long, parallel sides and blunt round noses to penetrate deeply without tumbling. These bullets will pass through a vital organ such as the heart and may exit the animal intact, while transferring minimal KE to the tissues. They create limited tissue damage while delivering a lethal injury. Their effectiveness relies upon the accuracy of the shot. Conversely, some military bullets (Figure 9-9) are designed to impart as much KE to the target as possible in as short a distance as possible by tumbling, deformation, or fragmentation. When accuracy is not relied on for effectiveness, the presence of an exit wound may indicate inefficient projectile design or low density target tissue.

Bullets that tumble are highly efficient at transferring KE and will cause widespread tissue damage. Small (lower mass) bullets destabilize easily and tumble more quickly than large ones. Lower velocity bullets and bullets with slower spin tend to yaw and strike the target at an angle. This destabilizes the bullet and increases the likelihood of tumbling within the target tissue. Tumbling results in a sharp rise in internal stress that can lead to fragmentation.

Fragmentation can increase transfer of KE to the target and dramatically increase the extent of a wound (see Figure 9-8). Thinning or weakening the jacket



Figure 9-9. 7.62 vs 5.56 military bullets.
Reproduced from: http://en.wikipedia.org/wiki/File:7.62x51_5.56x45.JPG

reduces the ability of a bullet to hold together, which results in higher rates of deformation and fragmentation, but also limits the KE and velocity of the bullet and the effective range of the weapon.

The Hague Convention of 1899 forbade the use of expanding, deformable bullets in wartime.³⁰ The declaration addresses the “Prohibition of the Use of Bullets which can Easily Expand or Change their Form inside the Human Body such as Bullets with a Hard Covering which does not Completely Cover the Core, or containing Indentations.” It states that, in any war between signatory powers, the parties will abstain from using “bullets which expand or flatten easily in the human body.” This agreement was not ratified by the United States. Subsequent adherence to the conventions may have had less to do with limiting harm than the fact that military assault rifles fire projectiles at over 2,000 fps and the bullets must be jacketed with copper to hold together.

Tissue Composition and Wounding

Target tissue composition dramatically affects the wounding potential of a projectile. Specific gravity (density) and elasticity are the primary tissue properties that determine how an organ will alter a projectile’s flight, the rate at which the tissue will absorb KE from a projectile, and the manner in which the tissue reacts. Higher density tissues absorb energy more rapidly



Figure 9-10. High velocity gunshot wound from a bullet fired by a sniper in Iraq, 2006. A small entry wound is accompanied by a large exit wound. The globe disintegrated. Multiple bone fragments acting as secondary projectiles entered the anterior cranial cavity through the orbital roof.

from a projectile, resulting in greater damage. Tissues of low elasticity resist deformation and will absorb energy until they fracture.

Given the same projectile mass and velocity, lung tissue, characterized by low density and high elasticity, will absorb less energy and sustain less damage than muscle, which has higher density and lower elasticity. The liver, spleen, and brain are dense and have essen-



Figure 9-11. A three-dimensional computed tomography reconstruction of the wound in Figure 9-9 demonstrating extent of tissue damage created by a high velocity gunshot wound impacting bone.

tially no elasticity, and are severely damaged by any projectile with sufficient energy to pass through them. Fluid-filled organs such as the bladder, heart, great vessels, or bowel may rupture due to pressure waves generated by a projectile moving through contained fluid. Bone, with very low elasticity, will fragment, sustaining severe damage. Projectiles striking bone may also fragment, creating numerous secondary missiles that each produce additional wounding (Figures 9-10 and 9-11).

Low velocity, low energy projectiles (<1,000 fps) that destabilize on contact with the target cause damage primarily by lacerating, crushing, or shattering tissue. These projectiles create a permanent cavity, or tract, that is generally apparent on initial examination. High velocity, high energy projectiles (>2,000 fps) passing through elastic tissues also create cavitation, a temporary cavity that may not be apparent on initial exam. Tissue ahead of the projectile, as well as to the sides, is compressed, creating pressure waves lasting a few microseconds. This overpressure does not

cause profound destruction at low velocity, but at high velocity, the shock waves generated can reach up to 200 atmospheres of pressure. The shock waves of the projectile displace surrounding tissue, which rapidly collapses back into place. The higher the energy of the projectile, the larger the temporary cavity created. This is one reason exit wounds, when present, tend to be larger than entry wounds.³¹

A previously held concept suggested that tissue displaced by cavitation is disrupted and irreversibly damaged. Military surgeons trained in the 1980s practiced wide debridement of all tissue that did not bleed. Hunt et al note that postinjury observation of wounds with a temporary cavity in an animal model demonstrates that the momentary stretch produced does not usually cause cell death or tissue destruction. Although vasospasm or injury from the heat of the projectile may cause reversible ischemia, they suggest that debridement of high velocity injuries should be confined to obviously devitalized tissue.³²

WEAPONRY

US Army units were most often equipped with M4 carbines, M16A2 rifles, M240 machine guns, M2 (50 caliber) heavy machine guns, M203 grenade launchers, or M19 automatic grenade launchers. US Marines used all of these, but were generally armed with the M16A4 rifle instead of the M16A2. Iraqi insurgents used a variety of weapons and ammunition on the battlefield, most commonly including AK-47 copies, RPK machine guns, and RPGs. The following are examples of some of the common weapons used in Iraq and Afghanistan. As noted in the preceding sections, the quality of the ammunition is at least as important as the weapon used, and no weapon is more effective than the soldier using it.

US Military Weapons

M16A2 and M16A4 Rifles

The M16A2 (Figure 9-12) and later generation M16A4 (Figure 9-13) were the standard Army-issue rifles in OIF/OEF and were carried by most US Army soldiers. These rifles are lightweight, air-cooled, gas-operated, magazine-fed, shoulder-fired weapons designed for either automatic or semiautomatic fire. When the A2 was updated to the A4, Colt added a rail on the upper receiver to permit a variety of scopes and optics systems to be added. A muzzle compensator fitted to the end of the barrel disperses the gas and lowers the flash signature of the weapon.²⁵

Length: 39.6 in

Weight: 8.79 lb (loaded with a 30-round magazine)

Bore diameter: 5.56 mm (.233 in)

Standard bullet: 5.56 mm × 45 mm NATO bullet (.233 in)

Muzzle velocity: 3,100 fps

Maximum effective range: 550 m.

M-4 Carbine and M-203 Grenade Launcher

The M-4 combat assault rifle (Figure 9-14) first entered US Army service in 1997 and is based on the M16A2. The rifle is the standard weapon used by some Army units such as the 82nd Airborne Division and special operations units, such as Army Rangers. With a shortened barrel and collapsible stock, the M-4 is better suited for close quarter marksmanship where light weight and quick action are required. Like the M16, the M-4 carbine can also be fitted with the M-203 40-mm grenade launcher.²⁵



Figure 9-12. M16A2 assault rifle.



Figure 9-13. M16A4 assault rifle with targeting scope. Balad, Iraq, 2007.

Length: 33.0 in (buttstock opened)
Weight: 7.5 lb (loaded with a 30-round magazine)
Bore diameter: 5.56 mm
Standard bullet: 5.56 mm × 45 mm NATO bullet (.233 in)
Muzzle velocity: 2,970 fps
Maximum effective range: 500 m.

The Colt M203 grenade launcher is a lightweight, single-shot, breech-loaded 40-mm weapon specifically designed to be attached to the M4 carbine and the M16A2 and A4 rifles. It is capable of firing a range of 40-mm high explosive and special purpose ammunition. The burning propellant propels the grenade from the muzzle at a velocity of 250 fps. The grenade's



Figure 9-14. M4 carbine with M203 grenade launcher attachment.

37,000-rpm right-hand spin stabilizes it during flight and applies enough rotational force to arm the fuse. The effective range is 400 m.³³

M-24 Sniper Weapon System

The M-24 (Figure 9-15) was a common sniper weapon used by the US Army in Iraq and Afghanistan. The rifle is a bolt-action, six-shot repeating rifle (five-bullet magazine). Used with either the M3A telescope or the metallic iron sight, it has a maximum effective range of 800 m. The M24 uses the Remington 700 action with a receiver adaptation to take 0.300 Winchester Magnum bullets.³⁴

Length: 43 in (1,092 mm)
Barrel: 24 in length (rifling: one twist in 11.2 in)
Weight: 12.1 lb (5.49 kg) empty without telescope
Bore diameter: 7.62 mm
Standard bullet: 7.62 mm × 51 mm NATO (.308 inch Winchester Magnum)
Muzzle velocity: 2,850 fps
Maximum effective range: 800 m (875 yd).

Insurgent Weapons

Kalashnikov AK-47

The AK-47 (Avtomat Kalashnikova; Figures 9-16 and 9-17) was adopted by the Soviet armed forces as the light infantry weapon of choice in 1949. It has subsequently been copied by the majority of the mem-



Figure 9-15. M24 bolt-action sniper weapon system.

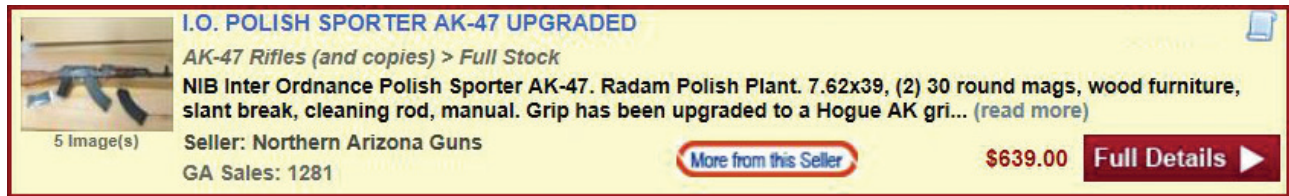


Figure 9-16. Internet advertisement for AK-47.

Reproduced from: <http://www.gunsamerica.com/Search/Category/8/Guns/Rifles/AK-47-Rifles.htm?ltd=all=1&t=&as=365&mn=0&mx=0&ffl=&ca=&co=&f=&sort=DisplayPrice&numberperpage=50&cid=8&lid=&dn=&ns=0&zipcode=&distance=0&limittostate=&> Accessed July 20, 2014.

ber states of the Warsaw Pact and many versions have been mass produced. Its simple design, compact size, easy maintenance, and durability are legendary. Although rugged and reliable, higher tolerances hamper its precision and consistency. It is gas-operated, can be fired on automatic and semiautomatic, and can be fitted with varied clip configurations with capacities from 30 to 100 bullets.³⁵

Country of origin: Soviet Union
Length: 869 mm (34.21 in)
Weight: 4.30 kg (9.48 lb) empty
Bore diameter: 7.62 mm
Standard bullet: 7.62 × 39 mm
Muzzle velocity: 2,330 fps
Maximum effective range: 328 yd (300 m).

Mauser Gewehr 98

The Mauser Gewehr 98 or model 98 (M98) rifle (Figure 9-18) is a manually operated, magazine-fed, controlled-feed bolt-action rifle with a 29-in rifled barrel. It can be fired using five rounds of ammunition in an internal magazine or loaded with one round at a time. Originally designed in the late 19th century, the Gewehr 98 has open front sights, a curved tangent-type rear sight, and a three-lug locking bolt, which locks into the receiver behind the magazine, making it strong and reliable. The controlled-feed bolt-action of the Gewehr 98 is a distinct feature and is regarded as one of the



Figure 9-17. AK-47 assault rifle.

major bolt-action system designs. Including variants manufactured by several nations, there were more than 14 million produced between 1935 and 1945.³⁶

Country of origin: Germany
Length: 43.7 in (111 cm)
Weight: 8.2 lbs (3.7 kg) to 9 lb (4.1 kg)
Caliber: 7.92 × 57mm Mauser
Muzzle velocity: 860 m/s (2,822 ft/s)
Effective firing range: 500 m (550 yd)
Type: bolt-action rifle
Capacity: 5-round stripper clip.

Simonov SKS

The gas-operated, clip-fed, semiautomatic Simonov SKS assault rifle (Figure 9-19) fires a 7.62 × 39 Soviet cartridge, which was plentiful in both Iraq and Afghanistan. The clip has a capacity of 10 bullets, and with a 20-in barrel, this rifle has effective range of over 400 yards and better accuracy than the AK-47. After the original Russian production, China, North Korea, and East Germany made their own versions and it is estimated as many as 15 million have been produced.³⁷

Country of origin: Soviet Union
Length: 1,021 mm (40.20 in)
Weight: 3.86 kg (8.51 lb) empty
Bore diameter: 7.62 mm
Standard bullet: 7.62 × 39 mm
Muzzle velocity: 2,410 fps
Maximum effective range: 437 yd (400 m).



Figure 9-18. Mauser bolt-action rifle, probably a Yugoslavian variant of the original German Gewehr 98.



Figure 9-19. Simonov SKS 1945 rifle.

Kalashnikov RPK Light Machine Gun

The RPK (Ruchnoy Pulemyot Kalashnikova) is a 7.62 × 39-mm gas-operated light machine gun (Figure 9-20) developed and fielded in the late 1950s. Based on the AK-47 design, it has a heavier and longer barrel and the receiver is strengthened, allowing the RPK to fire for extended periods of time without a major loss in accuracy from barrel heating. The weapon functions identically to the AK-47 and fires the same ammunition, but has modifications to increase the range. The RPK-74 is a newer version with upgrades that allow it to fire a higher velocity cartridge.³⁸

Country of origin: Soviet Union

Length: 1,040 mm (41 in) (RPK-74: 1,060 mm [41.7 in])

Weight: 4.8 kg empty (RPK-74: 4.7 kg empty)
Bore diameter: 7.62 mm (RPK-74: 5.45 mm)
Standard bullet: 7.62 × 39 mm (RPK-74: 5.45 × 39 mm)
Muzzle velocity: 2,444 fps (RPK-74: 3,149 fps)
Rate of fire: 600–650 bullets per minute
Muzzle velocity: 2,444 fps (RPK-74: 3,150 fps).

RPG-7

The RPG-7 (Figure 9-21) is a shoulder-fired, recoil-less antitank / antipersonnel rocket-propelled grenade launcher that can be found throughout the Middle East and Latin America. This weapon system launches fin-stabilized, oversized rocket-assisted grenades (85-mm in the PG-7 version, 70-mm in the PG-7M) from a 40-mm tube. The RPG-7 comes in multiple configurations, weighs about 17 lb and fires a variety of munitions. The standard grenade self-detonates at a maximum range of 920 m, about 4.5 seconds after firing.³⁹

Country of origin: Soviet Union

Length: 950 mm (37.40 in)

Weight: 7 kg (15 lb) empty

Bore diameter: 40 mm

Muzzle velocity: 115 m/s

Maximum velocity: 295 m/s

Maximum range: 1,100 m.

SUMMARY

The signature weapon of the wars in Iraq and Afghanistan was the IED. While evidence suggests rifles and machine guns remained the most lethal weapons in conventional ground warfare, the number of blast injuries far exceeded small arms wounds, and the long-term impact of blast injuries is still not fully appreciated. Significant advances have been made in neurological surveillance exams, recognition of clinical indicators for closed-head injuries, and treatment, but much work remains to be done. Despite the disruptive capacity of

IEDs, these weapons proved to be less lethal than small arms fire, and small arms weapons were ubiquitous in the combat zones. The wounding capacity of small arms weapons varies widely, and the treatment of these wounds must be tailored to the injury. Physicians charged with caring for persons wounded in future conflicts must understand the mechanisms of injury associated with both blast exposure and small arms fire to ensure they are properly prepared and their treatments are effective.



Figure 9-20. RPK light machine gun.



Figure 9-21. RPG-7 self-propelled grenade launcher.

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