

Critical Decisions In Emergency Medicine™

Reprinted from Volume 13 ■ Number 7 ■ March 1999

Lesson 14

Ballistic Wounding

Objectives

On completion of this lesson, you should be able to:

1. Explain the fallacy of using individual concepts such as velocity or kinetic energy to estimate potential clinical injuries and guide wound care management.
2. Describe the interactions of various body tissues and organs with penetrating projectiles.
3. Review potential mechanisms of injury from various types of firearms.
4. Review basic wound care principles involved with gunshot wounds.
5. Identify which wounds require excision and drainage.
6. Identify which wounds should not have primary closure in the emergency department.

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Penetrating injuries from gunshot wounds are a major cause of morbidity and mortality in this country as well as a significant financial burden to the health care system. Total yearly system costs from firearm injuries in the United States have been estimated to be between \$20 and \$126 billion, and in-hospital costs have been estimated between \$1 and \$4 billion a year.¹⁻³ Firearm injuries are the second leading cause of traumatic death in the United States.³ These injuries also are very disruptive to the function of emergency departments. The interventional demands of patients presenting with such wounds are often immediate and severe. Such patients can rapidly destabilize and consume the resources of emergency departments, operating rooms, and intensive care units. In addition, management of penetrating injuries is complex and in many ways differs significantly from other forms of trauma. Appropriate management is not always intuitively obvious and may differ from patient to patient.

Ballistics is a science that describes the actions of projectiles in flight. Ballistic principles are those of physics and geometry, although when applied to living creatures, biologic principles also are involved. Health care workers who specialize in penetrating trauma often develop an interest in ballistics. Understanding ballistic principles can help us understand and manage victims of firearm injuries. However, incorrect application of ballistic principles or assimilation of half-truths or an abundance of misinformation about ballistics may actually be worse than having no knowledge whatsoever.

Case Presentations

A 31-year-old convenience store worker is transported to a trauma center after sustaining a reported isolated gunshot wound to the head during a robbery attempt. He was found by EMS personnel awake at the scene approximately 10 minutes after the event and remained arousable during transport. In the emergency department, the patient is found to have an intact primary survey and is verbal on the AVPU scale. Secondary survey is positive for a circumferential wound on the left side of his forehead just below the scalp line. He is not bleeding but has a large amount of dried blood over his mid-face area and hair. Mid-facial structures are intact, and pupils are 4 mm symmetrically and reactive. A cervical collar is in place, and the patient is arousable and oriented although sleepy. Just above the rim of the posterior occipital aspect of the cervical collar there is noted by palpation a swollen area with no laceration defect. The remainder of the secondary survey is unremarkable, with no other injuries found. Neurologic examination is nonfocal, with a Glasgow Coma Scale score of 16. The patient remains sleepy but oriented. He is able to report that he was shot with a small revolver-type handgun of unknown caliber.

A 22-year-old woman is transported to a trauma center after being shot in the right side of her chest with a shotgun from a reported distance of 2 to 3 feet. Bystanders reported that the angle of the shotgun was head on and that her left-handed assailant was standing directly in front of her. EMS personnel report that the patient was intubated in the field and became more hypotensive with increasing respiratory distress during the long transport. On arrival, blood pressure is 80/60 and pulse is 145. While a right chest tube is being placed and an initial 400 cc of blood started, the patient loses vital signs and exhibits ventricular fibrillation. Examination reveals that the endotracheal tube is in place, with air movement in both lung fields and symmetrical chest expansion with ventilation; there is no further drainage from the chest tube.

Critical Decisions

- What is the significance of low-velocity versus high-velocity wounds?
- Which caliber and configuration of projectiles are the most damaging?
- Which tissues are at most risk of injury?
- Under what circumstances do lower energy injuries cause damage away from the wound track?
- What factors place a patient at increased risk of infection?
- What factors place a patient at risk of neurovascular injury?
- What should be the approach to wounds caused by weapons with greater wounding potential?

An EMS unit responded to the scene of a hunting accident, where a 41-year-old man had been shot accidentally by another hunter. The victim was found supine, conscious, tachycardic, and moderately hypotensive (80/50) with minimal active bleeding from the wound and an estimated blood loss of 1 unit. He complained of abdominal pain; physical examination revealed quiet bowel sounds, guarding, and rebound. The paramedics reported the entry wound as anterior and located in the mid-left abdomen lateral to and just below the umbilicus.

The victim reported that he was standing upright in an overgrown, flat field and facing and waving at the other hunter, who was standing on a small rise about 500 meters away. The other hunter reportedly mistook the victim's raised arms for antlers and fired in his direction. The weapon was a military-style assault rifle often used for hunting. The paramedics applied a field dressing to the entry site, started two large-bore (14 gauge) antecubital IV lines, and administered a fluid bolus. During transport to the trauma center, the patient required 3 L of IV fluids. He became increasingly tachypneic and required supplemental oxygen. On arrival, the patient is generally stable with an intact airway and blood pressure restored to 120/80. He has decreased breath sounds on the left without tracheal deviation or other atypia. Pulse oximetry reveals an oxygen saturation of 85%, and the patient is a nonsmoker. One of the paramedics had brought a sample cartridge provided by the other hunter. Inspection reveals it to be a military-style "full metal jacket" .223 (5.56 mm) caliber cartridge.

Ballistics

Ballistics is the science or art of throwing missiles by use of an engine.⁴ More currently, ballistics is the modern science dealing with the motion and impact of projectiles, especially those discharged from firearms.⁴ The term comes from the Greek word *ballista*, which describes a mobile "engine" used by Roman troops to accurately hurl rocks and other projectiles. Modern ballistics as a physical science is divided into three categories.⁵ Internal ballistics is the study of the acceleration of a projectile from inside a weapon, such as the firing chamber of a rifle. External ballistics studies ballistics of flight. This area deals with design of projectiles that best resist the various slowing forces through air density media, thus retaining maximal energy. Terminal ballistics studies forces and projectile actions upon striking a target. In the case of live targets, this category becomes the study of the ballistics of wounding and involves both biological and physical principles.

Understanding ballistic principles as they apply to the function of wound production is a difficult and extensive topic fraught with controversy. Having partial knowledge, especially many generally held misconceptions, may be worse than having no knowledge at all. For a full understanding of this area, it is important to have some grasp of internal and external ballistics. However, it is not necessary

to have a thorough understanding of ballistics to provide adequate patient care for those who suffer penetrating injuries. The search for knowledge concerning a particular weapon or projectile should not replace appropriate immediate trauma management of the gunshot wound victim.⁶

Determinants of Wound Severity

The first four factors in Figure 1 directly affect the amount of crush and stretch injury that can be inflicted on a target. The fifth addresses the various body tissue interactions with the projectile and determines the actual amount of injury.

Velocity of Projectile

Critical Decision: *What is the significance of low-velocity versus high-velocity wounds?*

This is a trick question. Never discuss wounding in terms of "low" and "high" velocity.⁷⁻¹¹ Authors who do so demonstrate lack of knowledge and failure to adequately understand ballistic principles. It is more correct to evaluate wounding based on the principle of the interaction of various tissues with projectiles. Damage is related to direct contact and tissue stretching. Velocity is only one of several factors that can affect wounding, such as caliber, construction, and mass of projectile. It is incorrect to use velocity as a shorthand attempt to estimate the wounding potential of a particular projectile.^{10,11} Doing so can lead to significant errors in estimating the seriousness of an injury. Unfortunately, physicians as eminent as John Hunter may have, as early as the 1760s, contributed to this error by stressing the importance of velocity in writings concerning gunshot wounds.¹²

Likewise, it is incorrect to attempt to estimate injuries based on any other single variable such as bullet caliber, "kinetic energy," or "wounding potential" (mass and velocity) of a projectile. Such attempts ignore the fact that bullets of equal caliber, kinetic energy, or wounding potential can produce wounds of very different severities depending on bullet shape, internal and external construction, and, of equal importance, which tissues they traverse.^{10,13,14} The differing interactions of various body tissues with penetrating projectiles represent the key to understanding wounding.

The American College of Surgeons, in its Advanced Trauma Life Support (ATLS) courses, divides wounding into an anatomic factor and an energy transfer factor.^{15,16} Anatomic factor refers to the wound track, describing damage that occurs by direct contact with the projectile. The predominant mechanism of such injury is crushing of tissue (permanent cavity-wound track).¹⁷ This is the usual mechanism of injury in so-called low-velocity wounds such as handgun injuries, stab wounds, and other similar mecha-

Figure 1. Determinants of wound severity

At least five factors affect the wounding potential of a particular projectile:

- The mass and velocity of the projectile at the time of impact^{5,10}
- The length of the wound track⁵
- Angle of yaw during impact and transit^{5,20,21,24}
- Caliber, construction, and configuration of the projectile⁵
- Density, strength, and elasticity of the target tissue^{11,21,24}

nisms. Trauma inflicted from projectiles with higher wounding potential, such as those from long rifles, can involve energy transfers from the projectile to the target. They can damage adjacent structures that are away from the direct wound track of the projectile. The chief mechanism in energy transfer is that of stretch (temporary cavitation) of tissues surrounding the wound track.^{8,10,13,16-18} Remember, however, that the transfer of energy alone does not determine wounding. It is the individualized response of particular tissues and organs to this stretching trauma that determines damage.^{10,13}

Many current articles and texts review and explain stretching injury by means of aerodynamic forces (eg, drag, recession, lifting forces), yaw (eg, precession, nutation, projectile deformations), fragmentation, and target heterogeneity. Often mistitled “high-velocity” injuries have also been reputed to produce wounding far distant from the wound track by shock (sonic pressure) waves.¹⁹ However, sonic pressure waves as a mechanism of gunshot wound injury have been refuted by experts in the field since as early as 1947.^{8,11,17,18,20}

There are no shorthand descriptors to differentiate between wounds caused by handguns and those caused by rifles and shotguns. In fact, it is not clinically relevant to do so. It is more correct to refer to wounds based on mechanisms such as crush injury versus stretch (cavitational) injury. It is likewise more correct to study wounding based on the interactions of projectiles with the various tissues exposed to these mechanisms.

Caliber and Configuration of Projectile

Critical Decision: Which caliber and configuration of projectiles are the most damaging?

Caliber, as related to firearms, is defined as “[Fr. *Calibre*, from Latin—*qua libra*, what pound, weight, size] the size of a bullet or shell as measured by its diameter, or the diameter of the bore of a gun.”⁴ Caliber is most commonly measured in either hundredths of an inch or its equivalent in millimeters. Although it is often referred to in the lay press and the medical literature, caliber is a very poor predictor of wounding potential.²⁰ In Figure 2a, all of the projectiles pictured have a similar caliber—approximately 0.30” or 7.62 mm. However,

visualization alone suggests that these different cartridges have significantly different wounding potentials. Figure 2b depicts two projectiles having similar caliber (0.22” or 5.56 mm). However, one bullet is fired from “22” handguns and rifles, and the other is the standard round fired from the M-16 rifle. Again, visualization alone suggests that these two projectiles, both of similar caliber, have significantly different wounding potentials. Other factors such as mass and velocity of the projectile, as well as shape and design, will have much more effect on wounding potential than caliber.

In general, the goal of a ballistics designer is to create a projectile mass and shape that retain maximal kinetic energy and longitudinal velocity during flight, with rotational velocity that resists the negative forces of air, and maintain a true flight path. Such a design, however, is not optimized for wounding potential upon entering a target. Therefore, at the time of target penetration, the designer would like to change the rules and have the projectile redesigned to suddenly deliver the maximal wounding potential possible.²¹ The extreme example of this would be a projectile that enters and does not exit, thus delivering all its wounding potential to the target. This is most common with shotgun wounds. Likewise, a projectile that stops suddenly, as when striking a high-density object such as bone, will deliver all of its wounding potential to this one area. Even if the total wounding potential of a projectile is small, such as a handgun bullet, in such circumstances it can be quite damaging (ie, if it fractures the bone).²¹

Until the late 1800s, the easiest way to produce such projectiles was to use unjacketed or partially jacketed lead, which deformed on impact (Figure 3). Thus, the ballistically sound design of the projectile was suddenly converted to an unsound shape with significantly increased wounding potential. This was the mechanism for projectiles such as the historical “dum dum” (from Dumdum, an arsenal near Calcutta, India) round.^{4,19} This practice was banned for military ammunition by the 1899 and 1907 Conventions of the Hague,¹⁹ which required a “full metal jacket” for all military rounds, as advocated by Kocher and introduced by Rubin about 1880.¹⁴ However, hunting ammunition and some handgun ammunition still use unclad or partially clad rounds. Special projec-

Figure 2a. These projectiles are, from left to right, .30 M-1 carbine, 7.62x39 mm, .30-30 Winchester, 7.62x51 mm NATO, .303 enfield, .30-06 M-1. Although significantly different in multiple parameters, these projectiles all have approximately the same caliber, emphasizing the point that caliber alone is of little value in estimating wounding severity.



Figure 2b. These projectiles are, from left to right, .22 rimfire (used in handguns and rifles) and 5.56 mm (.223) M-16. They are of similar caliber but are otherwise significantly different. Again, caliber alone is a poor determinant of wounding potential.



tile designs (eg, “hollow point,” “wad-cutter,” explosive) and changes in the manner in which projectiles are clad (Teflon-coated, semi-jacketed) are examples of how designers legally or illegally attempt to increase penetration or wounding, or both. Additionally, military projectile designers have found ways around the rule while keeping a metal jacket, thus increasing wounding potential. Some of these “tricks” cause projectiles to deviate from “true flight” in high-density media (such as the human body), which causes the wound track to not approximate a straight line between entry and exit (Figure 4).¹⁸ Also, the casing of some military rounds will fracture during passage through body tissues, thus creating multiple wound tracks and increased injuries.¹⁸

Shotgun projectiles, being spheres, are among the most ballistically unsound objects. There may be minimal injury from a shotgun blast at some distance from the target because the projectiles have poor flight characteristics and lose significant wounding potential before arriving at the target. However, close-range shotgun injuries are the most devastating. Because they are ballistically unsound, the projectiles deliver their wounding potential from the moment of impact; they produce massive wounds, beginning with wide crush pattern at the entry site. Because shotgun pellets almost never exit, they deliver maximal energy to the target. Pellets striking a high-density target media at close range have the potential to deviate from the original flight path by as much as 45°. For example, a close-range shotgun blast to the right side of the chest can potentially yield pellets in the left side of the chest and heart.

Properties of Tissues

Critical Decision: *Which tissues are at most risk of injury?*

The human body is a heterogeneous collection of organ systems and structures of differing strength, elasticity, and density.²¹ Long bones are the strongest structures in the human body, but they are not very elastic. They also are among the most dense, although organs such as the liver, spleen, and brain have higher density. These soft tissue organs also are very plastic, which means that if they are severely deformed they will not resume their former shapes. This contrasts with more elastic structures such as lungs, muscle, tendons, ligaments, and skin and to some extent organs such as the heart and bladder. These structures are designed to stretch and move.

When the direct contact force of a projectile passes through an elastic structure such as skin or lungs, the tissue expands along with the energy release (temporary cavitation) but returns to its former shape as energy is absorbed. In this situation, wounding tends to be restricted to those parts of elastic structures that the projectile actually contacts (permanent cavity–crush).²¹ For example, a bullet transiting a lung might not cause extensive damage unless it severs a vascular structure or directly damages other structures by contact or causes a pneumothorax via the hole produced in the pulmonary envelope. Likewise, skin, tendons, and ligaments resume their former positions after passage of the projectile, and damage usually is restricted to areas the projectile struck along the wound track or to stretching that exceeds the tolerance of that particular tissue.

A projectile that strikes a plastic structure such as the liver, however, will cause significant deformation of the organ (temporary cavity). Because the organ is not elastic, the temporary cavity will become permanent. There will be significant damage to parts of the liver lateral to the wound

track all along and at some distance radially away from the track of the projectile.

High-strength structures such as long bones tend to resist higher amounts of cavitation forces. However, if significant force is applied that exceeds the tensile strength of the bone, it can fracture. This interaction most commonly occurs when a projectile passes in very close proximity to the bone or actually hits the bone, releasing a significant amount of its wounding potential. Such an event also can produce secondary missiles and shards of bone that are accelerated through the body in various directions away from the wound track.

Thus, two projectiles of the same wounding potential and construction can, by encountering different types of tissues during transit along different wound tracks, produce significantly different amounts of actual wounding. It is these differing interactions with a penetrating projectile by various tissues that determine wounding.

Fragmentation of Projectile

Critical Decision: *Under what circumstances do lower energy injuries cause damage away from the wound track?*

Handgun wounds are most commonly associated with wound track (crush) injury and with little if any damage away from the wound track (Figure 5). Exceptions would be fractures and secondary missile injuries that can occur if a bullet strikes bone. Such a pattern is often seen when a projectile shot from a small handgun strikes a long bone of an extremity. Damage can occur away from the wound track with larger caliber handgun projectiles or any so-called low-velocity projectile that penetrates to a plastic structure such as the liver or spleen; the result is tissue-deforming cavitation (stretch) injury. Any bullet, handgun or otherwise, can hit and damage vascular structures along the wound track. Thus, pulse deficits are a major concern with such injuries.

Entry, Exit, and Location

The presence and location of entry and exit wounds and the location of retained penetrating foreign bodies can be of clinical importance (and, eventually, medical-legal importance) during stabilization and emergency department inter-

Figure 3. Projectile construction of unjacketed or partially jacketed lead deforms on impact with higher-density media such as human tissue. This results in increased cross-sectional diameter, which in turn increases the *potential* for both crush injuries (permanent cavity–anatomic factor) and stretch injuries (temporary cavity–energy transfer factor) depending on other projectile characteristics.



vention. It could even be said that management of firearms-related injuries, like real estate, is determined by “location, location, location.”

Skin-site firearms-related wound apertures often are misinterpreted in the emergency department or trauma resuscitation room by clinicians who are unfamiliar with the forensic aspects of gunshot wound examination.^{22,23} It is critically important to avoid mislabeling wound apertures as entry or exit unless overwhelming data exist to support such an interpretation.^{22,23} It is much better to simply describe the characteristics of the wound and avoid, in clinical documentation, such labels as entry or exit unless the examiner is absolutely sure the labels are correct.

Significant clinically relevant information can be obtained from skin-site wounds. One of the most important findings is whether there are even or odd numbers of wounds. If a patient has an odd number of skin-site wounds, look carefully for hidden skin-site wounds when stabilizing procedures are completed. An odd number can suggest a retained penetrating foreign body; a radiographic search should be instituted for its location. A significantly deformed metallic foreign body discovered on a radiograph can sometimes be consistent with a fragmented projectile. Consider the possibility that the visualized fragment was retained and other fragments exited, thus producing unexpected numbers of skin-site wounds. Fragmented projectiles are clinically important because they suggest multiple wound tracks, increased volume of tissue crushed, and increased potential for numbers of organ systems damaged. If radiographs taken in close proximity to the area of the skin-site wound are negative, search more remote areas; projectiles can, in certain cases, travel in unsuspected paths and end up in unexpected locations and cause unanticipated injuries.²⁴ Retained foreign bodies also can end up in unsuspected locations by missile embolization, in which the missile enters the vascular space, fails to exit, and is transported somewhere else.²⁴ Missile embolization can result in unanticipated physical findings such as stroke-like syndromes without signs of head-related injury or vascular compromise of extremities or other areas.

Also, there are many cases of paired skin-site wounds and radiographic findings of retained metallic foreign body. If the visualized foreign body is entirely undeformed in this situation, one possible answer is retained foreign body from a previous event. Obtain a history of previous gunshot wounds whenever possible.

Treatment Guidelines

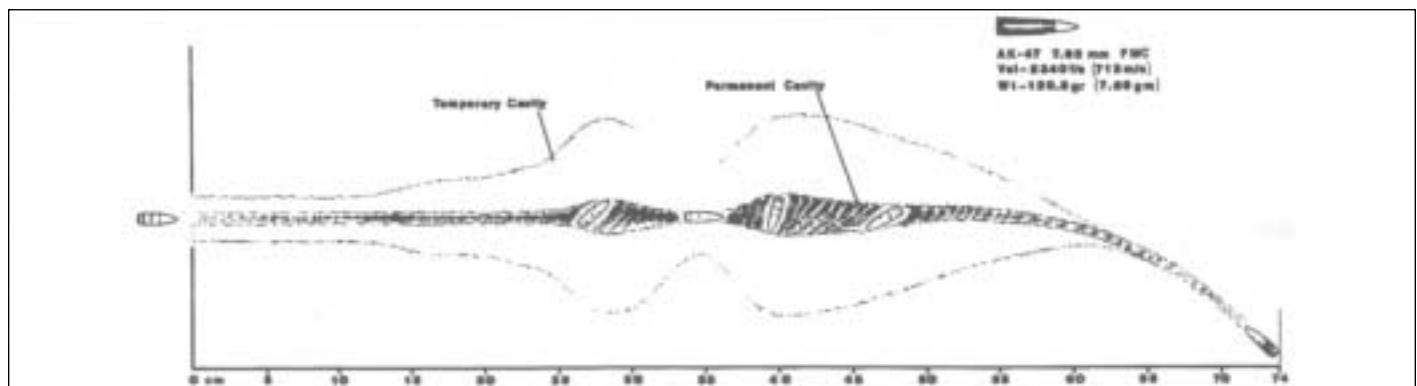
Critical Decision: *What factors place a patient at increased risk of infection?*

Contamination of gunshot wounds has been of concern since some of the first surgical case reports of gunshot wound management were documented.^{19,25-27} Studies performed in the late 1800s and early 1900s demonstrated that bullets are not sterilized by the heat of firing or the heat created by friction from transit through air-density media.²⁶⁻²⁸ More recent research confirms this fact.^{10,28,29} Therefore, there are no differences in the sterility of bullets based on their velocity, as is often suggested in print.

The first few centimeters of a wound track may be contaminated with skin and skin flora, particles of clothing, and other foreign bodies pushed into the wound.²⁵ It has been suggested that “lower velocity” projectiles tend to blunt dissect their way through tissues, thus producing an increased risk of foreign body contamination. It also has been suggested that contaminants are “sucked” into the entry site by vacuum forces created by passage of so-called higher velocity bullets. Most experts have concluded that there are no significant differences in wound track contamination by various projectiles based on velocity.

Emergency management of soft tissue gunshot wounds is controversial.^{8,25,29-34} It is important to make management decisions based on clinical findings and avoid decisions based on theoretical considerations concerning certain types of weapons or projectiles. Handgun or other entry wounds may require local wound care such as simple excision of the entry area to inspect the wound track, remove contaminating foreign debris, and promote good drainage.^{29,33} A retained hematoma can be a nidus for infection, so adequate drainage is important.^{19,27} Exit wounds can be treated in a similar fashion to improve drainage.^{29,33} There is no need to widely excise or “core out” deeply penetrating wounds, especially so-called high-velocity wounds, because of the alleged severe tissue disruption.^{18,24,29,32,33} Because establishing adequate wound drainage is a critical aspect of initial wound management,²⁹ gunshot wounds should never be primarily closed by an emergency physician. Cosmetically disfiguring gunshot wounds, such as those to the face, without underlying injury, may represent a special circumstance. However, wound repairs should always be evaluated and performed by the appropriate consultants.^{35,36}

Figure 4. Wound profile produced by the Russian AK-47/Chinese SKS military bullet (7.62x39 mm) full metal jacket bullet. This is the most widely used “assault rifle” bullet in the world. It does not deform in tissue and travels about 26 cm before beginning to yaw. This explains the clinical finding that most wounds caused by this bullet resemble those made by much lower velocity handgun bullets. From Fackler ML. Gunshot wound review. *Ann Emerg Med.* 1996;28(2):199. Reprinted with permission.



Projectiles that cause increased skin disruption upon entry, including shotgun pellets, cause increased contamination from skin debris and other contaminants. Shotgun blasts from close range can contaminate wounds with debris from the shells. Such wounds are at increased risk of subsequent infection.

Deeply penetrating projectiles generally are not removed, especially if they are lodged in soft tissues such as muscle. Abdominal penetrations that produce hollow viscus injuries are at significant risk for peritoneal cavity contamination and infection, and most authors advocate abdominal exploration and debridement for penetrating gunshot wounds that traverse the peritoneum. Projectiles in the chest or abdomen may be removed if they are encountered during emergency stabilizing or exploratory surgery, but surgery is not undertaken specifically to remove them.

Superficial foreign bodies can be removed if they are involved in wound excision or exploration or if they lie just under the surface and are causing discomfort or disfigurement. Consider removing lead-containing projectiles that are lodged in intraarticular space, disk space, bursal locations, or other fluid-filled spaces to avoid plumbism (lead poisoning).^{24,37} Lead fragments in soft tissue usually become encapsulated with fibrous tissue and do not cause plumbism.²⁴

Antibiotic Prophylaxis

Prophylactic antibiotics are commonly used in the initial management of penetrating injuries, especially gunshot wounds. However, there are little scientific data to support this controversial practice.^{8,11,30-32,34,38,39} Purported differences between requirements for civilian versus military gunshot wounds further cloud the picture.^{11,19,25,30} In general, prophylactic antibiotic administration must never be used as a panacea or a replacement for good wound care, which includes visualization, decontamination, excision, and drainage. Prophylactic antibiotic administration in the emergency department might be considered for wounds that appear to be significantly contaminated and when initial wound care has been delayed. Antibiotics have long been recommended for gunshot wounds associated with hollow viscus injury.^{34,39}

Prophylactic antibiotics also have long been used for patients discharged from the emergency department after initial management of minor gunshot wounds, although, again, controversy rages over when they are necessary.^{24,30-32} One recent study evaluated 3,390 patients presenting to emergency departments for minor gunshot wounds. Most of the patients (88%) were injured with handguns, and all were managed as outpatients.^{30,31} Approximately 57.5% of the patients were discharged without antibiotic therapy.^{30,31} Of all 3,390 patients, 62 (1.8%) developed subsequent wound infections. The factors most frequently associated with infection were presence of an entry and an exit wound (versus entry only) in patients wounded with handguns; multiple bullet penetrations; delay in seeking treatment or no initial treatment, including cleansing prior to presentation; larger wound diameter (1 to 2 cm); and failure to follow wound care instructions. The study did not report a difference in outcome based on management with or without antibiotics, but it did note an increase in the presence of abscesses at follow-up in patients who did receive antibiotic therapy, although the cause and the significance of this finding were unclear to the authors.³¹

According to current ATLS recommendations, the decision to use prophylactic antibiotics should be made by the

attending physician or surgeon who will be providing the patient's ongoing surgical supervision and care.⁴⁰

Rule Out Neurovascular Injury

Critical Decision: *What factors place a patient at risk of neurovascular injury?*

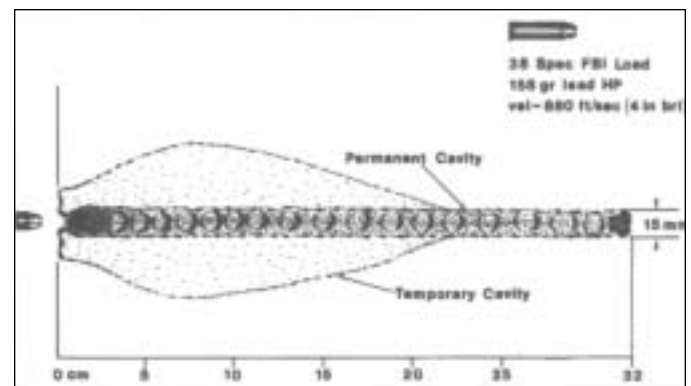
Emergency physicians must always attempt to rule out neurovascular injury from penetrating trauma. However, hallmark signs of neurovascular injury, such as pain, pallor, pulselessness, and paresthesia, may not be readily apparent. There are many reasons for this. The interactions resulting in neurovascular injury will occur either along or in proximity (determined by cavitation) to the actual wound track. Therefore, many clinicians attempt to estimate wound track in order to determine the potential for neurovascular injury. However, determining the actual wound track is often difficult. Never assume that a wound track will approximate a straight line between entry and exit. Wound track must be determined by combining available historical information, physical findings, and investigative tests. If the combination of these factors suggests the potential for neurovascular injury or if neurovascular compromise is noted, work-up should be pursued. Mechanisms for neurovascular injury are both primary, involving anatomic factors (crush injuries) and stretch (cavitational injuries), and secondary, consisting of compartment syndromes produced by penetrating injuries.^{12,24,32,38} Compartment syndrome-related neurovascular injuries can evolve over several hours with initial negative findings. Emergency physicians must be vigilant and perform frequent repeat examinations of gunshot wound victims and be prepared to measure compartment pressures and recognize the need for early fasciotomy in the emergency department.^{24,32,38} Nerve and vessel repairs are best performed in the operating room.

Rifle Wounds—Assume Maximal Injury

Critical Decision: *What should be the approach to wounds caused by weapons with greater wounding potential?*

Although general principles of trauma management apply to ballistic injuries, there are unique aspects of gunshot

Figure 5. Wound profile produced by the 38 Special 158-grain lead hollow-point bullet. This bullet was the standard load used by the FBI for many of the years that a revolver was used as the duty weapon. This bullet expands on striking tissue, and its diameter increases by about 50%. It produces a larger permanent cavity than nonexpanding handgun bullets and a larger temporary cavity. Still, the temporary cavity it produces is not large enough to add significantly to the bullet's disruption except in tissues, such as liver, that lack elasticity. From Fackler ML. Gunshot wound review. *Ann Emerg Med.* 1996;28(2):200. Reprinted with permission.



injuries that emergency physicians must consider. Most trauma-related injuries (both blunt and penetrating) evaluated and treated in emergency departments usually prove to be minor. If a patient is awake, alert, ambulatory, and conversant with no respiratory distress and has a negative secondary survey, then the injury is probably minor.

Ballistic injuries, by their very nature, can never be considered minor. The physician must always perform a full history and physical examination. The major, key point is to treat the *wound*, not the *weapon*,⁷ and not the *bullet*. Although most handgun-related injuries will prove to be minor, severe injuries not readily apparent may exist. Long-range shotgun injuries are usually minor, but close-range shotgun injuries are usually devastating. Rifle blast can produce a wide variety of injury patterns, with the area of greatest devastation being deep. Some authors have studied such wounding extensively with methodology called wound profiling, which can, among other things, determine the length of a wound track before maximal wounding begins.¹⁰ In general, all intermediate and long rifle projectiles that enter the trunk should be assumed to have produced maximal injury until proved otherwise. Even if a physician is unfamiliar with the ballistic properties of a particular wounding cartridge, the most important intervention at this juncture is to complete an ATLS protocol evaluation. Simultaneously, the physician must perform a secondary survey, obtain appropriate trauma radiographs and other diagnostic tests, and perform necessary stabilizing procedures. Remember, the final determinant of wounding is the interaction of the bullet with the various tissues it encounters along and adjacent to its wound track. Therefore, initial assumptions about potential wounding in a patient should be based on the best estimate of the tissue structures most likely affected, which should be based on the most likely wound track using all the information available at the time of the initial trauma evaluation.

There are caveats to these assumptions. Again, never assume that a wound track is a straight line between the entry and exit sites. Human beings are almost always moving in three dimensions during transit of a penetrating projectile; this alone guarantees variance from a straight line. Also, various aerodynamic slowing forces, the particular design of various bullets, and deviations caused by striking objects such as bone can cause alterations in a projectile's path. For example, a high-velocity, low mass, jacketed slug is unstable in high-density media (such as body tissues) and with deep body cavity penetration can deviate widely from initial flight path. This projectile also has a tendency to fracture as it yaws to 90° with penetrations greater than 12 cm, resulting in satellite fragments causing injury along different paths than that of the major portion of the projectile (Figure 7).¹⁸

Never make clinical decisions based on the assumption that the projectile followed a straight line from entry to exit. Particular organ system injuries may be missed if the search is restricted to the body areas defined by such a straight line. Search vigorously for injuries distant from those found on

the initial survey and distant from any straight line formed by the shortest distance between entry and exit. If wound track data are indeterminate, base the investigative workup on physical findings with continued observation and screening for occult injuries.

Summary and Case Resolutions

In the first case presentation, the key clinical pearl was that the patient remained awake and nonfocal after a gunshot wound to the head. This is most commonly associated with failure to penetrate the skull. Ballistically, what occurred was the apposition of the irresistible force and the immovable object. The small caliber projectile, after penetrating the scalp, scalloped along the potential space between skull and scalp and came to rest in the left occipital area with inadequate energy to exit. This was the "soft tissue mass" palpated during the secondary survey, a common scenario among survivors of gunshot wounds to the head. The bony structures resisted the impact energy of the projectile, which was deflected without bony damage. It is not impossible for a responsive patient to have suffered penetrating injuries to the brain, but it is not likely. Any patient with a potential penetrating head wound who is conscious and alert for more than 10 minutes after injury has a high likelihood of having a survivable injury.

This patient was at risk for infection. The injury did not involve brain penetration, so there was not a high risk of brain abscess and global infection. However, this was a penetrating injury from a lower energy handgun, and such wounds are likely to have foreign material such as pieces of clothing and skin surface material pushed into the wound track. If possible, such wounds should be inspected and possibly excised and drainage established at the entry site in an attempt to remove contaminating foreign bodies. Facial and head wounds are more difficult to debride, but fortunately the scalp is a vascular structure and has less of a chance to develop wound infections.

An additional clinical question was whether this was a soft tissue scalp injury only. A key point to remember is that energy was transferred on impact, so further evaluation was mandated. On subsequent CT, a small frontal subdural hematoma was found just under the impact site. It was drained without complication, and the patient remained neurologically intact. He was discharged from the trauma service after several days of observation with no neurologic deficits.

The presentation of the patient in the second case, by ATLS protocol, clearly required thoracotomy once a quick review showed that airway or ventilation problems were not causative of this finding. However, to which side of the chest should the thoracotomy have been directed? Absence of extreme or continued chest tube output (<1,500 mL) did not suggest destabilizing injury in the right chest. Ventricular fibrillation, which is a frequent finding when penetrating injuries to the heart lead to emptying of the ventricles, suggested a primary cardiac problem. The ballistic pearl from this case was that close proximity shotgun wounds often result in wide deviation in initial flight path of the pellets. Clinical management of shotgun injuries always mandates a search for pellet-related injury in areas not proximate and at angles lateral to the entry site. In a similar case with more subtle vascular or cardiac injuries, such a patient might have slowly exsanguinated while immediate attention was paid to the right chest injury, which could easily have been misinterpreted as the cause of the patient's initial findings.

The appropriate approach to this patient was an immedi-

Figure 6. Treatment guidelines

- No primary closure in the emergency department
- Perform fasciotomy when needed
- Perform arteriography to rule out arterial thrombus when hypesthesia, pallor, or weak pulse is present
- Consider whether prophylactic antibiotics should be administered
- Remove lead-containing projectiles in joint spaces to prevent plumbism

ate thoracotomy exposing the left chest. However, the patient could not be resuscitated. Inspection of the chest cavity noted a right hemothorax, managed with the appropriately placed chest tube. However, pellets from this head-on entry had deviated significantly from the initial flight path to enter the right ventricle, the superior vena cava, and the ascending aorta, resulting in irreversible exsanguination.

In the third case presentation, the primary survey was intact, although the patient seemed to be developing respiratory distress. However, the injury site was below the umbilicus, and the scene survey strongly suggested a flat or downward trajectory of the projectile with the patient standing erect and directly facing the weapon. Based on this information, the nature of potential chest injury was unclear. The answer lay in the peculiar nature of the projectile with which the patient was injured.

Chest x-ray demonstrated left hemothorax with a small fleck of metallic foreign body in the left lung field. A chest tube was placed and drained 600 mL of sanguineous fluid, after which the patient's respiratory rate dropped to 16 and oxygen saturation increased to 95%. On secondary survey, the patient was not able to move his legs to command. Log-rolling of the patient to facilitate inspection of his back (a maneuver that can be overlooked) revealed an exit wound in the left lower posterior flank at about the level of the L3 vertebral body. During palpation of the vertebral bodies, pain was localized to the T10-11 area. A second review of the chest x-ray subtly suggested a metallic density in this area that was missed on the initial quick look in the trauma room. Subsequent CT evaluation of this area demonstrated metallic fragments in the spinal canal along with some small bony fragments, although there was no major disruption of the vertebral bodies. Surgical findings included bowel contusion and one penetrated loop of small bowel, a splenic laceration, and a left renal contusion. The spinal canal was decom-

pressed and debrided by neurosurgery, but the patient remained paraplegic. The lung injury required no further intervention.

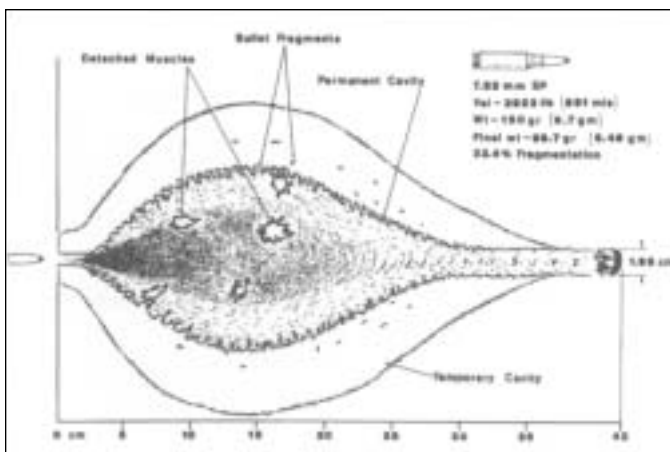
Such injuries should not be unexpected for this projectile. The internal wounds would not have been anticipated if the initial search had been restricted to the body areas defined by a straight line between entry and exit wounds. Always assume maximal injury until proved otherwise.

Ballistics is the science that describes the actions of projectiles transiting various density media. Terminal ballistics, as applied to human beings and other living targets, is the study of the interaction between projectile forces and tissues and organ systems to produce wounding. The forces of wounding are created when a projectile is launched (internal ballistics) and modified during flight (external ballistics). The appropriate application of ballistic principles to wounding requires some understanding of all three categories of ballistics, especially the interactions of projectile dynamics with the heterogeneous structures of the human body. Misapplication of these principles or an inappropriate focus on one mechanism of wounding, such as velocity or kinetic energy, in making clinical decisions on patient management is to always be avoided. Trauma management of gunshot and other projectile injuries does not require extensive knowledge of ballistics as long as the basic management principles of ATLS are followed.

About the Author

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Figure 7. Wound profile produced by the 7.62 NATO cartridge loaded with a soft-point hunting bullet. This cartridge is more commonly known as the .308 Winchester in civilian circles. This bullet expands to more than double its original diameter and loses about one third of its weight in fragments within an inch or so of striking tissue. These fragments cause multiple perforations of the tissue surrounding the bullet path, penetrating up to 9 cm radially. The large temporary cavity then displaces this tissue, which has been weakened by multiple perforations by fragments. The synergy between fragmentation and cavitation results in detachment of pieces of muscle and increases the permanent cavity dimensions. From Fackler ML. Gunshot wound review. *Ann Emerg Med.* 1996;28(2):196. Reprinted with permission.



Pearls

- Always treat the wound, never the alleged weapon or projectile!
- Close-range shotgun injuries are always devastating. Assume major structural injuries until proved otherwise. Be prepared to look for pellet injuries more laterally to impact point than you might expect.
- Handgun injuries most commonly produce wounds of contact along the wound track. Therefore, always assume neurovascular injury until proved otherwise.
- Handgun and shotgun wound tracks can be contaminated and should be inspected and possibly excised and drained.
- Avoid extensive excision away from the wound track as a treatment for so-called high-velocity injury patterns. Manage tissues intraoperatively based on clinical findings by inspection.

Pitfalls

- Never direct clinical management based solely on the characteristics of the alleged weapon or bullet, such as large caliber or high velocity.
- Never assume that a wound track is a straight line between entry and exit.
- Never guess whether a wound is entry versus exit unless you have extensive knowledge of wound forensics or unless eyewitness accounts document a particular pattern.
- Rifle wounds can produce deep structure injury that may not be immediately apparent, and the injury may be away from the wound track.

the North Carolina Governor's Terrorism Consequences Task Force.

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