Ballistic Injuries In The Emergency Department

Abstract

According to 2007 data, gunshot wounds from homicides, suicides, and accidents caused 31,000 deaths in the United States, with even higher numbers of serious, nonfatal injuries. In recent years, new evidence on effective treatment of patients with gunshot wounds has come from military settings and is being adapted for civilian emergency departments (EDs). Effective, evidence-based management of ballistic injuries in the ED is vital. This issue reviews the physics of ballistics as it relates to the tracts and patterns of tissue injury caused by different types of firearms and missiles, and it takes a regional approach to reviewing the current evidence for managing gunshot wounds to the head, neck, thorax, abdomen, genitourinary (GU) system, extremities, and soft tissues. Current guidelines as well as new research and evidence regarding fluid resuscitation, airway management, evaluation strategies, drug therapies, and documentation are discussed.

Case Presentations

A 25-year-old man presents to the ED via ambulance after sustaining a single gunshot wound to the upper abdomen. There is no apparent exit wound. He is awake, in obvious pain and distress, with labored spontane-

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CME Objectives

Upon completion of this article, you should be able to:
1. Understand the physics of ballistic weapons and their projectiles.
2. Understand the difference between high-velocity, low-velocity, and shotgun weapons.
3. Perform a thorough history and physical examination of a patient with a gunshot wound.
4. Recognize life- and limb-threatening injuries that require immediate intervention and provide stabilizing treatment in the ED.

Prior to beginning this activity, see “Physician CME Information” on page 32.

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ous breathing. He was reportedly shot with a handgun at close range, and there was significant blood loss at the scene. He has decreased breath sounds on the left side and a mildly tender abdomen with a small wound over the left anterior lower chest. A FAST examination shows no free fluid in the abdomen and no pericardial effusion. A left-sided chest tube is placed, with 200 mL of blood out immediately, and subsequent chest x-ray shows a right hemothorax with a bullet lodged in the left lower lobe. You contact the trauma surgeon, who asks if you think the bullet traversed the diaphragm and if additional tests are needed before he arrives for surgery.

An 18-year-old man presents after being accidentally shot in the left leg with a shotgun while hunting with his family. He has multiple small- and medium-size wounds in his left thigh and lower leg. He is in excruciating pain, but he has good distal pulses, has an intact neurologic examination of that extremity, and is otherwise hemodynamically stable. An x-ray shows multiple metal fragments within the leg and midshaft fractures of the tibia and fibula. As you treat his pain and address the wounds, you wonder about the need for further vascular studies.

A 38-year-old man who was shot in the head is brought in by EMS with a laryngotracheal airway in place. He has a GCS score of 5 on arrival. His vital signs are normal except for a pulse of 115 beat per minute; his oxygen saturation is 94% via the airway. There appears to be only 1 wound and no other injuries elsewhere on his body. Before you send him to the CT scanner, you prepare to establish a definitive airway, but you wonder about the right drugs and ventilator strategy to help control his intracranial pressure.

### Introduction

Ballistics is the scientific study of the characteristics of projectiles (bullets or missiles), how they move in flight, and how they impart damage to tissue. Emergency clinicians play a critical role in the management of ballistic injuries. According to Centers for Disease Control and Prevention statistics, in 2007 there were over 31,000 firearms-related deaths in the United States, of which 40.5% were due to homicide and over 55% were due to suicides. Firearms-related injuries are much more common among men than women, and blacks are more than twice as likely to die from gun-related violence than whites.\(^1\)

There has been much debate over the differences in the method of management for wounds from low- and high-velocity weapons. Based on the available literature, the traditional teachings may be flawed. Understanding of terminal ballistics (a projectile’s action on tissue) has been revolutionized in the last 40 years due to high-speed photography and the development of ballistic gelatin.\(^2\) High-speed photography allows scientists to evaluate an object with great clarity, frame by frame, as it strikes another object. Ballistic gelatin was developed in the 1940s, and has subsequently undergone studies validating its use as a tissue surrogate.\(^3,4\) Nonetheless, ballistic gelatin does not account for the effects of skin or the varying densities of different tissues within a given anatomic location (bone, vessels, etc), and it has been found to overestimate the size of the temporary cavity.\(^5,6\) The goal of this issue of *Emergency Medicine Practice* is to discuss the physics of ballistic injuries with respect to the differences between low-velocity weapons and high-velocity weapons and to discuss the emergency department (ED) management of gunshot wounds to various areas of the body.
A literature search was performed using the following databases: PubMed, Web of Science, Ovid MEDLINE®, and The Defense Technical Information Center, as well as the Cochrane Database of Systematic Reviews. Searches were limited to those published in English. Search terms included, but were not limited to, the following: ballistics, penetrating injury, gunshot, firearms, emergency, emergency department, trauma, physics, biophysics, forensics, and forensic documentation. The search was further refined by defining the specific area of injury. The search returned 4200 abstracts, which were reviewed by the authors for relevance. The bibliographies of the relevant articles were also reviewed for additional publications. Various trauma-related guidelines were identified through www.guidelines.gov. The American College of Radiology (ACR) Appropriateness Criteria® of imaging modalities used in trauma were also reviewed.

Prospective randomized trials of treatment for gunshot wounds are inherently difficult to perform. Many of the studies with large patient numbers are observational or retrospective. Much of the trauma literature is based on case reports and case series.

The Advanced Trauma Life Support® (ATLS®) protocols were also reviewed. The 8th (and most recent) revision of ATLS® included extensive literature review as well as expert opinion, and much of the evidence for recent changes comes from the emergency medicine literature.

**Weapons, Ammunition, And Basic Terminology**

A firearm is a weapon designed to expel a projectile by the action of highly combustible, gas-generating gunpowder. This includes rifles, handguns, and shotguns, which are collectively referred to as small arms. Small arms are relatively simple mechanical devices that share the same basic anatomy, which consists of the handling portion (stock), the breech (the chamber where the bullet is seated and from which the combustive reaction is triggered), and the barrel, which acts as the projectile’s guide. The differences between small arms are largely delineated by the amount of pressure the breech can withstand and the length of the barrel.

Rifles are shoulder-fired weapons engineered to withstand the very high pressures (50,000-60,000 psi) generated from combustion of the gunpowder. They have long barrels (usually > 16 inches) with a spiraled groove cut into the inner lumen that imparts a spin on the bullet, enhancing inflight stability and accuracy. Handguns are basically small rifles with the same engineering features, but with smaller pressure tolerances (20,000-30,000 psi) and shorter barrels.

Shotguns are similar to rifles in their basic appearance, but differ significantly in their engineering. Shotgun projectiles generate less pressure in the breech, but their barrels are thin-walled and usually contain no rifling because their ammunition is made up of numerous spherical projectiles that are propelled simultaneously.

Ammunition is a term for complete cartridges containing the projectile of a firearm, commonly referred to as a bullet. For rifles and handguns, ammunition is more accurately called a cartridge or round, which includes the casing, primer, and propellant (gunpowder), as well as the bullet. The bullet is the actual projectile and is typically composed primarily of lead with a rounded or pointed tip, in various sizes, or calibers. The caliber denotes the width of the bullet itself in proportion of an inch or millimeter. Bullets come in a variety of designs that affect their energy transference, such as pointed tips, and round tips, hollow points, as well as full metal jackets (FMJ), partial metal jackets, and scored or “expanding” bullets.

A useful distinction among bullets subdivides them into 2 types: expanding bullets and nonexpanding solid bullets. Expanding types are designed to maximize tissue damage; nonexpanding solid bullets are designed to have greater penetration. The nonexpanding solid bullet has a pointed tip and is coated with a thin metal covering, or jacket (usually copper), and is referred to as an FMJ bullet. These are the bullets used by the United States military forces. There are 3 reasons for the design of FMJ bullets. First, for a given caliber, solid and expanding bullets commonly have the same weight. Military rifles have evolved over the last 150 years to smaller calibers, with lighter, faster bullets that have better stability in flight, allowing soldiers to carry more rounds and be more accurate marksmen. Second, jacketing limits the lead residue left behind on the bore of the rifle, which can cause dangerous mechanical malfunctions. Third, the jacketing allows the bullet to maintain its shape when it hits a target rather than expanding and fragmenting. Historically, this was felt to be more “humane,” by wounding rather than killing an enemy combatant. In addition, a wounded combatant requires more resources to care for than a dead combatant.

Expanding bullets are designed for hunting nondangerous animals and for self-defense and thus to kill or incapacitate at a lower velocity. They are typically soft-tipped (ie, lead only), which allows for nearly immediate deformation when hitting tissue and thus imparting most of their energy with less penetration of the victim. Expanding rounds vary greatly in design. They may have metal jacketing in some form; typically, the jacket covers most of the bullet except the tip, allowing for a combination of rapid expansion and increased overall integrity of
the bullet. The same distinction between solid and expanding bullets applies to handguns. Handguns are limited in their velocity and range due to barrel length and pressure tolerance of the breech, but this is partly compensated for by an expanding bullet design (such as hollow point). Hollow point tip bullets have an inward depression at the tip that deforms instantly upon striking any solid object. The bullet enlarges up to 3 times its initial diameter, creating a larger permanent cavity. The shotgun ammunition comes in 4 basic categories: birdshot, buckshot, slugs, and sabot rounds. Birdshot and buckshot shells contain numerous spherical projectiles (shot) that are housed within the shotshell. They are propelled and released simultaneously when fired. The difference between birdshot and buckshot is the size and metal composition; birdshot is typically made of smaller, softer lead or similar metal shot, whereas buckshot shells contain only a few tightly packed balls of a much larger diameter, and may be made of lead or steel.

Slugs are composed of a single, large, solid projectile that may or may not have rifling built into the lead itself (thus imparting a spiral path in flight, which increases accuracy). Slugs are used primarily for hunting large game in populated areas where a heavy, relatively low-velocity projectile will have limited range. Slugs also are used by police and military personnel because of their ample stopping power.

Weapons and their corresponding projectiles are generally categorized based on their velocity, i.e., low-velocity (usually shotgun and pistol bullets, < 2000 f/s) and high-velocity (usually rifle bullets or explosive fragment missiles > 2000 f/s). (See Table 1.) Although conceptually useful, these categories have some important limits. First, these values are not universally applied; for instance, the British use values of 1200 f/s for “high-velocity.” This lack of agreement has the unfortunate effect of less-rigorous scientific study. Second, these terms imply the weapons’ wounding capacity. Using this logic, it would be easy to infer that low-velocity wounds are less severe, yet they can be devastating wounds. Because of the frequency of use, low-velocity weapons cause nearly twice the number of deaths of high-velocity weapons.

**Ballistic Physics**

Ballistic physics is divided into 3 components: internal, external, and terminal (wound). Of these, terminal ballistics is the primary concern of emergency clinicians, but knowledge of the other components can prove to be a valuable resource for understanding the injury pattern. Conceptually, the science of ballistics is relatively simple, but over-simplification can lead to erroneous conclusions (such as mistakenly thinking bullets are sterile due to being heated).

**Internal ballistics** describes the path of the projectile from the breech to the muzzle (the end of the weapon barrel). Technological advances have revolutionized modern firearms into the devastating weapons they are today (smokeless powder, rifling, automated cartridge feeding, high-stress metallurgy). The differing range of pressures generated from the combustion of gunpowder is what distinguishes the various weapons. Rifles can withstand more pressure than a handgun, and a handgun can withstand more pressure than a shotgun. Rifling, which is a helical groove carved into the inner lumen of the barrel, imparts a spin on the bullet to prevent yawing (the deviation of a projectile’s path). Clinically speaking, internal ballistics have little relevance to treating tissue damage other than noting that the technological advances have led to faster, more accurate projectiles that can enable the projectile to impart more energy onto its target.

**External ballistics** describes the projectile from the point when it leaves the barrel until it hits its target (muzzle to target) or the study of the projectile in flight. While this aspect of ballistics lends itself to more traditional aspects of physics, it can be divided into the 2 components that have the most effect on a projectile - gravity and drag.

The effects of gravity can be visualized by the trajectory of any object in flight (parabolic curve). Even though all objects will drop to the ground at the same rate, faster rounds have a flatter trajectory, making them easier to aim and thus, more accurate. Drag (the resistance to a traveling object’s passage through air) affects a projectile’s velocity downrange. Drag can be limited by making a bullet more aerodynamic,

<table>
<thead>
<tr>
<th>Table 1. Gun Velocity Categories</th>
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<tbody>
<tr>
<td><strong>Velocity</strong></td>
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| Low velocity | • < 2000 f/s (usually handguns)  
• Smaller zones of injury  
• Wounding potential significant despite “low velocity”  
• Associated fractures often behave similarly to closed fractures  
• Soft tissue/superficial injury often amenable to ED wound care |
| High velocity | • > 2000 f/s (rifles)  
• Larger zones of injury; cavitation, deeper penetration  
• Ammunition used and distance from target plays significant role in wounding  
• Associated fractures are common, devastating; consider infected |
| Shotguns | • < 2000 f/s (low velocity)  
• Highest kinetic energy transference  
• Highest rate of compartment syndrome  
• Highest infectivity rate  
• Double mortality rate versus rifle, handgun |
nor the dominant factor in energy transference, as seen with the effectiveness of low-velocity shotgun wounds and handguns using hollow-point rounds.

The zones of injury were first described by Wang and are conceptually linked to the mechanisms of ballistic wounding. The first zone is the permanent cavity, which is the primary wound cavity consisting of dead, crushed tissue. The second zone is the contusion zone, consisting of tissue adjacent to and encircling the permanent cavity. The tissue here is in an inflammatory state. It is swollen and bathed in a milieu of inflammatory mediators and cellular debris. The third zone is the concussion zone, or temporary cavity. Damage here occurs by stretching, shearing, or compression and is dependent on the cavity in which the missile travels and the tissue contents. Inelastic tissues such as bone, liver, and brain are highly susceptible to injury because they have little intrinsic ability to dissipate the energy transferred even if they are remote to the primary injury path.

Secondary wounding is caused by missiles as well as wound infections. Secondary missile wounding occurs when the projectile strikes and breaks an object and accelerates some portion of that object through adjacent tissue. Examples of secondary missiles are bone fragments or objects such as clothing or buttons. Secondary missiles tend to move at much slower velocities, but can be equally destructive if they damage vital adjacent tissues (such as an artery). Contrary to popular belief, missiles are not sterile due to the heat they retain.

As a bullet with an elongated, narrow, pointed configuration. For example, birdshot and buckshot are composed of spherical projectiles and therefore have poor aerodynamic profiles with rapid loss of velocity as well as dispersion of the shot; hence, much of their energy is dissipated after about 25-50 yards.

Terminal (or wound) ballistics is the component of ballistics that studies the interaction of penetrating projectiles with living tissue and is therefore an emergency clinician’s primary interest. Ballistic missile wounding occurs by 2 primary mechanisms, described by the cavities created by the missile: the permanent cavity and temporary cavity. (See Figure 1.) As a missile penetrates the skin, it crushes and destroys the tissue in its path (creating a permanent cavity) while simultaneously imparting a shock wave that radiates outward from this path. This shock wave causes tissue to stretch and shear outward, followed by subsequent collapse and reverberation. The size of the permanent cavity is determined by the caliber of the bullet and its corresponding fragments. The temporary cavity is transitory, lasting only milliseconds, and its size is determined by the velocity of the missile. Higher velocities create larger temporary cavities, ranging up to 10-30 times the size of the missile’s permanent cavity. There is also a measurable pressure wave that travels in front of the missile, but it has not been found to impart any significance towards the wounding mechanism.

There are 3 relevant principles in appreciating the extent of the wounding mechanism: energy transference, zones of injury, and secondary wounding. When a bullet strikes skin, the process of energy transference starts. The ability of the missile to transfer its kinetic energy is the primary determinant of tissue damage. (See Table 2.) Although clearly important, the projectile’s velocity is neither the only

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Table 2. Variables Of Missile Energy Transference

<table>
<thead>
<tr>
<th>Variable</th>
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<tbody>
<tr>
<td>Projectile velocity</td>
</tr>
<tr>
<td>Entrance profile</td>
</tr>
<tr>
<td>Caliber</td>
</tr>
<tr>
<td>Projectile design</td>
</tr>
<tr>
<td>Distance traveled within the body and anatomic structures impacted</td>
</tr>
<tr>
<td>Tissue elasticity</td>
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</tbody>
</table>

Table 3. Zones Of Injury Of Ballistic Wounding

<table>
<thead>
<tr>
<th>Zone of Injury</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary wound tract</td>
<td>Permanent cavity; dead, crushed tissue</td>
</tr>
<tr>
<td>Contusion zone</td>
<td>Tissue adjacent to primary wound tract; in inflammatory state with cellular debris</td>
</tr>
<tr>
<td>Concussion zone</td>
<td>Temporary cavity; tissue damage occurs by stretching, shearing, and compression. Inelastic tissues (liver, bone, brain) are most susceptible due to little intrinsic ability to dissipate transferred energy even if remote to the path of injury</td>
</tr>
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</table>
travels through tissue, a vacuum is created when the permanent and temporary cavities are formed. This vacuum pulls in potential infective sources such as clothing, dirt, and skin flora. Other potential inoculum include components of the cartridge or shotgun and devitalized bone fragments.22

Prehospital Care

Prehospital management of gunshot wounds varies somewhat based on the location of the injury, but almost all ballistic injury patients require immediate transport to a trauma center. Two large retrospective Canadian studies have suggested that direct transport to a Level I trauma center instead of a closer, non-trauma center results in better outcomes.23,24 Emergency medical services (EMS) providers should follow common ATLS® prehospital guidelines to control the airway, provide oxygen as needed, and control bleeding with direct pressure as well as obtain vital signs and intravenous (IV) access as soon as possible. Although EMS protocols will vary from region to region and each crew has varying capabilities, the EMS crew should perform lifesaving procedures as indicated but should primarily do their best to minimize transport time to the nearest trauma center.

Many patients with penetrating brain injury will have a depressed mental status and difficulty maintaining an open airway. The EMS providers may be authorized to provide advanced airway care in these patients, but recent literature suggests that out-of-hospital intubation in traumatic brain injury (TBI) may be associated with worse outcomes.25 Transport times and the proficiency of EMS with intubation will play a role in the decision to establish a prehospital airway. The wide array of supraglottic devices available offer easy-to-use and viable alternatives to prehospital intubation.

Because gunshot wounds to the chest can be immediately life-threatening, EMS providers must be able to rapidly treat and transport these patients to the nearest center capable of managing thoracic ballistic trauma with minimal on-scene time. Emergent life-saving interventions such as intubation and needle decompression should be the only procedures performed that may delay transport.26

Abdominal gunshot wound patients should be evaluated for hemodynamic stability, as they are at risk for life-threatening bleeding and many other injuries. If there is concern for a pelvic bleeding injury, pelvic compression may provide some prehospital stabilization of bleeding, but this should not delay prompt transportation.

Extremity gunshot wounds should be assessed for arterial bleeding and ischemia, specifically. If bleeding is found, attempt hemostasis by either direct pressure or use of a tourniquet. Prehospital tourniquet use had been discouraged for some time because the prevailing logic was that the constriction applied to control bleeding also led to occlusion of collateral flow, thereby worsening distal ischemia. However, recent evidence stemming from the conflicts in Afghanistan and Iraq supports the contrary: tourniquet use may prevent exsanguination and promote hemodynamic stabilization. A recent study by Kragh et al found that prehospital tourniquet use, when shock was not present, was strongly associated with survival compared to patients who did not receive them.27

Emergency Department Evaluation

History

If the patient’s overall status permits, certain historical information may help the clinician in management. If the patient is unable to provide any historical information, EMS personnel or friends/family present may be able to assist with providing information. Per ATLS® protocol, an “AMPLE” history should be taken at a minimum (see Table 4) along with the following questions:28

• What type of weapon was used? Handguns are low-velocity weapons and typically involve less kinetic energy transfer than high-velocity rifles or the variable force and pattern of shotgun injuries. If the patient or witness can tell you the type of gun used, it may help you anticipate unseen injuries.

• How far away were you from the weapon at the time it was fired and at what angle were you when it hit? This may help to anticipate the missile’s trajectory and possible pathway through the body in order to determine which skin wound is the likely entrance wound and to anticipate potential injury patterns and locations.

• How many shots did you hear? There may only be 2 visible surface injuries, which can lead you to assume entry and exit wounds, but if there were 2 shots fired, possibly neither bullet found an exit track and both are still inside the patient. This will also prompt you to continue to look for more missile wounds that may not initially be visible.

Curiosity will often lead the emergency clinician to ask about the circumstances of the ballistic injury, but these details are rarely helpful except to determine whether the wound was self-inflicted, which will require later psychiatric evaluation after the traumatic injuries are addressed and the patient is stabilized. For more information on assessing depressed and suicidal patients in the ED, see the September 2011 issue of Emergency Medicine Practice, “The Depressed Patient And Suicidal Patient In The Emergency Department: Evidence-Based Management And Treatment
Strategies.” Tetanus status should be obtained, and prophylaxis is indicated for most gunshot wounds.

**Physical Examination**

Assessment of patients with ballistic trauma should proceed according to the ATLS® protocol, with stabilization of the airway and rapid attention to immediately life-threatening injuries. Often, history, examination, and treatment must occur simultaneously. Certain initial impressions such as agitation or combativeness, hypoxia or respiratory distress, diaphoresis, and an unwillingness to lie flat may suggest pending hemodynamic collapse.28 Full exposure of the patient – including the back – is necessary to evaluate the number of wounds present. Vital sign abnormalities (hypoxia, tachycardia, hypotension) suggest a serious underlying injury. Initially, normal signs can be insensitive as an indicator of significant injury and need to be continually reassessed for deterioration.

The primary survey is performed immediately upon arrival, with an orderly evaluation of immediately life-threatening injuries, starting with the airway and progressing to assessment of breathing and circulation. Often, a team approach is utilized for the sake of efficiency. After addressing the ABCs, further evaluation of neurologic disability and complete exposure of the patient take precedence before proceeding to the secondary survey. At any point, note the life- or limb-threatening injuries and address treatment of those specific injuries.28

Many vital structures are at particular risk from ballistic trauma, including the lungs, heart, great vessels, esophagus, and tracheobronchial tree; failure to address these immediately can lead to death. The location of the external wounds may suggest a track for the projectile, but physical examination is generally inadequate to determine the direction and extent of the penetrating projectiles due to the cavitation effects of the projectile through body tissues. A small external wound may belie massive internal injuries that are not immediately evident on history and physical examination. Penetrating projectiles are frequently known to ricochet on bony structures, thus altering the trajectory of the permanent cavity produced. High-velocity ballistic missiles create a large temporary cavity that can lead to significant tissue damage.

The patient presenting to the ED with penetrating injury to the neck from a gunshot wound can have a variety of presentations. Airway involvement may be indicated by dyspnea, crepitus, air bubbling from a wound, dysphonia, or hemoptysis. Great vessel involvement may be obvious, presenting with “hard” signs of vascular injury such as active hemorrhage, expanding hematoma, pulse deficit, or a bruit or thrill. (See Table 5.) However, great vessel involvement may be more insidious, presenting only with “soft” signs of vascular injury such as a nonpulsatile hematoma, nervous system ischemia, or proximity to a major vessel. Esophageal injury may be asymptomatic initially but may also present with dysphagia, hematemesis, drooling, or odynophagia.

Emergency clinicians often refer to the areas of the body at risk for cardiac and mediastinal injuries as “the box,” which is the area bounded superiority by the clavicles and sternal notch, inferiorly by the costal margins, and laterally by the nipple line. However, injuries outside of the box, such as posterior and lateral chest wounds, can traverse the mediastinum as well.27 While a thorough physical examination is always necessary, in many of these cases, diagnostic tests are required to delineate the extent of injuries.

Rapid reversal of hypoxia is often necessary, with supplemental oxygen and airway control if the patient is unable to protect his own airway or respiratory distress is present. Immediately perform an evaluation of the lungs to ascertain shortness of breath, pleuritic chest pain, and decreased breath sounds concerning for pneumothorax or hemothorax. Obvious deformities of the chest wall, asymmetric chest rise, and tracheal deviation can be initial signs of a significant pneumothorax. Many of these findings on physical examination warrant placement of a large (36 French) thoracostomy tube before proceeding with further management or while other members of the trauma team continue their evaluation.28

Listen for muffled heart sounds and assess for jugular venous distension as indicators of a traumatic cardiac tamponade. Hypotension is an ominous sign for hemorrhagic shock and ongoing internal bleeding from cardiac or great vessel injuries. Diminished distal pulses can also be an indicator of vascular or cardiac injury.

**Table 5. Hard And Soft Signs Of Penetrating Gunshot Injury**

<table>
<thead>
<tr>
<th>Hard signs</th>
<th>Soft signs</th>
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<tbody>
<tr>
<td>Active hemorrhage</td>
<td>Nonpulsatile hematoma</td>
</tr>
<tr>
<td>Expanding hematoma</td>
<td>Nervous system ischemia</td>
</tr>
<tr>
<td>Pulse deficit</td>
<td>Proximity to a major vessel</td>
</tr>
<tr>
<td>Bruit or thrill</td>
<td></td>
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**Table 4. “AMPLE” History**

| A – Allergies                  | Hard signs                      |
| M – Medications                |                                  |
| P – Past medical history       |                                  |
| L – Last meal (what time)      |                                  |
| E – Events surrounding the time of injury | Soft signs                       |
|                                |                                  |
Chest wall crepitus or the sensation of a foreign body in the throat heightens the concern for esophageal or tracheobronchial injury. Because diaphragmatic injuries can occur in up to 19% of penetrating thoracoabdominal trauma cases and in up to 59% of patients with gunshot wounds to the left lower chest, examination of the abdomen for peritonitis is also warranted early in the primary survey. 

Undress the patient completely to evaluate for the location of the wound(s) and other injuries. Log-roll the patient to assess for entrance or exit wounds posteriorly, and consider a rectal examination to assess for gross blood and rectal tone.

Documentation of the pulse strength and character as well as the skin temperature, color, and capillary refill in comparison to the unaffected limb is essential. Pay special attention to presence or absence of these hard signs of vascular injury since they generally warrant operative management. (See Table 5, page 7.) Angiography in these patients may lead to the complications associated with unnecessary testing and surgical exploration. Some authors have suggested that soft signs do not correlate with a vascular injury at all.

Early realignment of a grossly deformed extremity is recommended to provide hemostasis and pain relief. If a bleeding vessel is visualized, hemostasis should be obtained by direct pressure or tourniquet. Clamping of a vessel is not recommended due to the risk of further injury to the vessel and unintentional injury of adjacent nerves. Wounds should not be explored digitally or with instruments unless gross decontamination of clothing or debris is required.

Arterial pressure indices (APIs) can be used to improve diagnostic accuracy for vascular injuries and are readily performed at the bedside. The APIs are calculated by dividing the systolic blood pressure (SBP) distal to the injury of the extremity in question by the similarly located SBP of the uninjured extremity. An API is considered abnormal if the result is < 0.9, and studies have suggested that API is 95% sensitive and 97% specific for a major arterial injury. An API of < 0.5 suggests a serious single-segment or multisegment arterial injury.

Management Of Gunshot Wounds

To The Head

The mortality associated with penetrating ballistic brain injury is high. Zafonte et al performed a 7-year prospective study and found that 36% of patients with gunshot wounds to the head were dead on arrival to the ED or expired in the ED. Of those who survived to hospital admission, 41% expired in the first 48 hours, an overall 77% mortality in the first 48 hours. Before 2001, no standardized guidelines existed for the care of the patient with penetrating head injury. In 2001, the Eastern Association for the Surgery of Trauma (EAST) introduced a set of guidelines directed specifically to the care of the patient with penetrating brain injury. These guidelines provide some important direction for both initial resuscitation and surgical care of these patients.

Early and appropriate resuscitation is imperative for the victim of penetrating head trauma. A single episode of hypotension is associated with worse outcomes for the severely brain-injured patient. While early and aggressive resuscitation is standard, the selection of the appropriate resuscitation fluid is a subject of much debate.

Albumin administration has been associated with worse outcomes in severe TBI patients and is not used in trauma resuscitation. However, the advent of modern synthetic colloid solutions may lead to changes in the current resuscitation algorithms. Although potentially promising experimental data exist, no large randomized controlled trials show a mortality benefit to synthetic colloid solutions.

Hypertonic saline resuscitation continues to be a subject of much research and interest. Prehospital studies using hypertonic saline in severe TBI patients show no benefit over isotonic solutions. Potential benefits of hypertonic saline resuscitation include lower fluid volumes, limited edema formation, and reduced inflammation. However, no current large trials exist that show a survival benefit of hypertonic saline over conventional trauma resuscitation. With the current literature not identifying a clearly superior resuscitation fluid, it is prudent to recommend using the fluid that the emergency clinician’s center is most comfortable with to ensure safe and rapid resuscitation. For a more complete discussion of fluid management in traumatic hemorrhagic shock, see the November 2011 issue of Emergency Medicine Practice, “Traumatic Hemorrhagic Shock: Advances In Fluid Management.”

Neuroimaging

Noncontrast computed tomography (CT) scan is the imaging modality of choice for penetrating brain injury. Cranial x-rays provide no additional information and are not recommended as an initial or additional study in penetrating brain injury. Due to the metal content of many ballistics, magnetic resonance imaging is currently not a prudent choice for the initial evaluation of these patients.

Antibiotics

The early use of prophylactic antibiotics is recommended in the treatment of penetrating brain injury. Although there are no randomized controlled studies comparing the use of antibiotics to nonuse of antibiotics, comparison of infection rates from the preantibiotics era suggest that antibiotics are effective. From military literature, it appears that antibiotics have been routinely used in penetrating
Clinical Pathway For The Management Of Gunshot Wounds To The Head

• Primary survey per ATLS® protocol
• Neurosurgery consultation

Need for airway protection?

YES
Intubate

Consider neuroprotective strategy (Class III)
• Lidocaine, 1.5 mg/kg
• Fentanyl, 1-3 mcg/kg
• Elevate the head of the bed 30° postintubation
• Maintain end-tidal CO₂ at a level of 35

NO
Continue to monitor for deterioration

• Give crystalloids and/or blood products as appropriate
• Avoid hypoxia at all times

Secondary survey for other injuries and neurologic status

Obtain CT scan of the brain

Consider:
• Mannitol/hypertonic saline for increased ICP
• Seizure prophylaxis, dilantin 20 mg/kg
• Antibiotics: ceftriaxone 1 g IV + metronidazole 500 mg IV +/- vancomycin 1 g IV
(See pages 8-10)

Class Of Evidence Definitions

Each action in the clinical pathways section of Emergency Medicine Practice receives a score based on the following definitions.

Class I
• Always acceptable, safe
• Definitely useful
• Proven in both efficacy and effectiveness

Level of Evidence:
• One or more large prospective studies are present (with rare exceptions)
• High-quality meta-analyses
• Study results consistently positive and compelling

Class II
• Safe, acceptable
• Probably useful

Level of Evidence:
• Generally higher levels of evidence
• Non-randomized or retrospective studies: historic, cohort, or case control studies
• Less robust RCTs
• Results consistently positive

Class III
• May be acceptable
• Possibly useful
• Considered optional or alternative treatments

Level of Evidence:
• Generally lower or intermediate levels of evidence
• Case series, animal studies, consensus panels
• Occasionally positive results

Indeterminate
• Continuing area of research
• No recommendations until further research

Level of Evidence:
• Evidence not available
• Higher studies in progress
• Results inconsistent, contradictory
• Results not compelling


Abbreviations: ATLS®, Advanced Trauma Life Support®; CPP, cerebral perfusion pressure; CT, computed tomography; ICP, intracranial pressure; IV, intravenous.

This clinical pathway is intended to supplement, rather than substitute for, professional judgment and may be changed depending upon a patient’s individual needs. Failure to comply with this pathway does not represent a breach of the standard of care.

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head injuries since 1946. Prophylactic antibiotics are used by the majority of neurosurgeons during even minor neurosurgical procedures. In addition, prophylactic antibiotics have been shown to reduce infection during clean neurosurgical procedures. It is therefore reasonable to conclude that antibiotics are indicated in penetrating head injury.

No studies exist to demonstrate the best antibiotic choice in penetrating injury. In 1991, a survey of neurosurgical care was performed, which indicated that cephalosporins were the preferred antibiotics for penetrating head injury. No current United States guidelines exist to direct antibiotic choice in penetrating brain injury. Current British guidelines recommend IV cefuroxime plus IV metronidazole as a first-line antibiotic regimen. Other experts recommend a combination of IV ceftriaxone, metronidazole, and vancomycin in penetrating brain injuries. Antibiotics should be chosen in conjunction with the consulting neurosurgeon; however, early initiation of a broad-spectrum antibiotic with good cerebral penetration (such as ceftriaxone) is recommended.

**Antiepileptic Drugs**

The use of antiepileptic drugs (AEDs) to control posttraumatic seizures remains controversial. Of primary interest in the ED is the control of early (<1 week) posttraumatic seizures. Current recommendations from the American Academy of Neurology support the use of phenytoin for the prevention of early posttraumatic seizures. This recommendation is supported by a large blinded randomized trial showing successful reduction in seizures with phenytoin in the first week after severe head trauma. However, a later study in children demonstrated a very low posttraumatic seizure rate in the first 48 hours and no reduction of seizures with the addition of phenytoin. More-recent studies have looked at other AEDs, as compared to phenytoin, and show varying results. There are no good studies that provide recommendations for the new-generation AEDs over the standard phenytoin therapy.

**Elevated Intracranial Pressure Control**

Patients with penetrating brain injury are at risk for acute neurological deterioration due to elevated intracranial pressure (ICP) from brain edema resulting from the trauma. Though debated, use of additional premedications during rapid sequence intubation (RSI) — so-called “neuroprotective RSI” — may help blunt a rise in ICP during intubation and can be considered. (See Clinical Pathway For The Management Of Gunshot Wounds To The Head, page 9.) In addition, mannitol has traditionally been used to acutely reduce intracranial edema through osmotic pressure. More recently, hypertonic solutions of saline or crystalloids have been investigated for ICP reduction. Viallet et al studied 7.5% saline compared to 20% mannitol in 20 patients with TBI and persistent coma. This randomized trial showed fewer episodes of intracranial hypertension and a lower failure rate in the hypertonic saline group as compared to the mannitol group. Similarly, Ichai et al performed a randomized trial comparing mannitol to a sodium lactate solution of similar osmolarity in 34 patients with severe TBI. They also found that the sodium lactate solution was more effective in intracranial pressure reduction than mannitol. Unfortunately, no consistent recommendations exist for the concentration or dosage of hypertonic saline. Concentrations of hypertonic saline range from 3% to 23.4%. The current literature suggests, however, that hypertonic saline is likely more effective than mannitol for the reduction of intracranial pressure. For clinicians not experienced in administration of hypertonic saline, a reasonable initial dose (as demonstrated by Viallet et al) is 2 mL/kg of 7.5% saline solution.

A simple, noninvasive method to help decrease ICP is to raise the head of the bed 30° above parallel. This maneuver has been demonstrated to lower ICP without adversely affecting cerebral perfusion pressure or cerebral oxygenation, and it is recommended to be started within the first 24 hours after injury. Hyperventilation is no longer recommended as an ICP reduction strategy except in preherniation states. Current Brain Trauma Foundation guidelines can be found online at https://www.braintrauma.org/coma-guidelines/. They are summarized in Table 6.

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood pressure</td>
<td>Maintain SBP &gt; 90</td>
</tr>
<tr>
<td>Oxygenation</td>
<td>Maintain PaO₂ &gt; 60; avoid hypoxia</td>
</tr>
<tr>
<td>Hyperventilation</td>
<td>Insufficient evidence to support hyperventilation</td>
</tr>
<tr>
<td>Hyperosmolar therapy</td>
<td>Mannitol is recommended. Insufficient evidence to support hypertonic saline</td>
</tr>
<tr>
<td>Seizure prophylaxis</td>
<td>Phenytoin is recommended in the ED for prevention of early posttraumatic seizures</td>
</tr>
<tr>
<td>Antibiotics</td>
<td>Insufficient evidence to support prophylactic antibiotics</td>
</tr>
<tr>
<td>Steroids</td>
<td>No role for steroids</td>
</tr>
<tr>
<td>Therapeutic hypothermia</td>
<td>Level III recommendation for 48 hours of hypothermia</td>
</tr>
</tbody>
</table>

Abbreviations: ED, emergency department; PaO₂, arterial oxygen pressure; SBP, systolic blood pressure.

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and are relevant for both blunt and penetrating head trauma. These differ from some of the newest data and earlier discussion, reflecting existing controversies and areas of needed research.

**Management Of Gunshot Wounds**

**To The Neck**

The high concentration of critical anatomy located in the neck makes penetrating neck injuries potentially life-threatening. Penetrating neck injury caused by even a single bullet has the potential to cause multiple devastating injuries.

A rapid and thorough physical examination is important in penetrating neck injury, as it may provide important clues to the severity of injury. Some authors suggest that physical examination is a reliable indicator of injury in penetrating neck wounds, and certain asymptomatic patients may be evaluated with observation alone. In one study, patients with penetrating neck injuries whose physical examination did not show signs indicative of surgical injuries were also evaluated with CT scans. The authors concluded that CT scan added little information in patients determined by physical examination to be low-risk. The decision on whether to proceed with imaging versus purely observational management must be made in consultation with the surgeon. Typical practice patterns in the United States include liberal use of CT imaging in penetrating neck trauma, and the risk-to-benefit ratio of CT scan to identify serious underlying neck injury is low. If there is any question of a possible serious neck injury, a CT with angiography should be obtained to evaluate for vascular or aerodigestive tract injuries. All patients with penetrating neck injury violating the platysma should be observed for a minimum of 24 hours.

**Airway Management In Neck Injuries**

Neck wounds have the potential to make intubation extremely difficult by obscuring visualization due to bleeding and/or altered anatomy. Rapid sequence intubation is a commonly performed procedure in the ED; however, traditional teaching cautions against using paralytics in the patient with penetrating neck trauma. It is theorized that the addition of a paralytic may turn a spontaneously breathing patient into a patient that can neither be intubated nor ventilated, and therefore, a crash airway.

There are very few studies evaluating the management of the airway in penetrating neck trauma. More-recent literature indicates that RSI is likely a safe and effective way of managing the airway in penetrating neck injuries. One small study of 58 patients with penetrating neck injury requiring emergency airway control showed a 100% success rate in the 39 patients who were intubated using RSI alone. This same study noted 3 unsuccessful fiberoptic intubations that were then successfully intubated using RSI. No patients in this study required a surgical airway. In 2004, another retrospective review of patient charts showed successful intubation with RSI in the ED as well as a 90% success rate with prehospital blind nasotracheal intubation (BNTI). This study calls into question the traditional teaching that BNTI is contraindicated in patients with neck injury for fear of worsening an airway injury.

Although current literature indicates that RSI is a safe and effective method of managing the airway in patients with penetrating neck injury, these situations are highly variable and have the potential to be difficult intubations. A clearly defined backup strategy must be in place, including a variety of airway devices. In addition, preparation for an emergent surgical airway must be made, if possible, prior to inducing the patient for RSI (double setup). If the patient appears stable in the ED without signs of acute airway compromise or other indications for emergent intubations, it is prudent to transport the patient to the operating room for definitive airway management.

Extreme caution should be exercised in patients with penetrating neck injuries likely to have caused partial or total tracheal transection, as otorrhoeal or nasotracheal intubation attempts could lead to separation and retraction of the distal tracheal segment. If control of the distal segment can be maintained with a tracheal hook or other device, then a patient with an open tracheal injury may be directly intubated with an endotracheal or tracheostomy tube.

**Evaluation Of Neck Injuries**

Penetrating neck injuries are traditionally classified into 3 zones, which are described in Table 7. The zones provide a framework for discussing injuries with consulting services as well as indicating potential areas of needed research.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Anatomy</th>
<th>Structures at Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>Clavicle to cricoid cartilage</td>
<td>Great vessels (subclavian vessels, brachiocephalic veins, common carotid arteries, aortic arch, and jugular veins), trachea, esophagus, lung apices, cervical spine, spinal cord, cervical nerve roots</td>
</tr>
<tr>
<td>Zone 2</td>
<td>Cricoid cartilage to angle of mandible</td>
<td>Carotid and vertebral arteries, jugular veins, pharynx, larynx, trachea, esophagus, cervical spine, spinal cord</td>
</tr>
<tr>
<td>Zone 3</td>
<td>Angle of mandible to base of skull</td>
<td>Salivary and parotid glands, esophagus, trachea, vertebral bodies, carotid arteries, jugular veins, spinal cord, and other major nerves</td>
</tr>
</tbody>
</table>
Clinical Pathway For The Management Of Gunshot Wounds To The Neck

- Primary survey per ATLS® protocol
- Maintain C-spine stabilization

Airway protection required?

- Intubate or perform cricothyroidotomy as indicated

Unstable +/- hard signs of vascular injury?

- Secondary survey to include thorough neurologic examination
- Operative intervention +/- intraoperative arteriogram

Determine zone of injury

Zone 1
- CT angiography +/- bronchoscopy, esophagography, and esophagoscopy (Class III)

Zone 2
- Operative exploration or CT angiography +/- bronchoscopy, esophagography, and esophagoscopy (Class III)

Zone 3
- Arteriography or CT angiography +/- bronchoscopy, esophagography, and esophagoscopy (Class III)

Abbreviations: ATLS®, Advanced Trauma Life Support®; CT, computed tomography.

For class of evidence definitions, see page 9.
Valvular or conduction system injury
Lacerations leading to hemorrhagic shock
Massive hemothorax
Atrial lacerations or punctures
Ventricular lacerations or punctures
• Pulmonary lacerations

Potential Injuries
Pulmonary contusions
• 67
Hemorrhagic shock
Tracheoesophageal fistulas
Hemothorax
• 68,69
Partial tears
Complete transection
Esophageal perforation
Cardiac tamponade

...and many other injuries listed...

As with all trauma patients, the unstable patient with injury to any of the zones of the neck should be taken immediately to the operating room. However, the stable patient may undergo a series of imaging studies to better evaluate the extent of injury. Recent practice guidelines from EAST offer a Level I recommendation that selective operative management of zone 2 neck injuries is recommended to minimize unnecessary operations. Because it can be difficult to determine the zone(s) of injury based on the external gunshot wound, diagnostic imaging or operative management is required to visualize the zones that are injured.

Imaging options for arterial injury in the neck include angiography, CT angiography (CTA) and duplex ultrasonography. Angiography is useful because it can be both diagnostic and therapeutic; however, it is also a time- and labor-intensive test. Recent studies have shown that CTA is a reasonable alternative to angiography for imaging the vascular tree of the neck. In addition, CTA can provide information regarding the trajectory of the projectile as well as visualizing other injuries. A CT scan showing a trajectory remote from vital structures may obviate the need for further imaging or unnecessary surgery in a stable patient. The use of CTA has been shown to significantly reduce the number of negative neck explorations with no increase in mortality.

Duplex ultrasound has also been proposed as an imaging modality for vascular injury in penetrating neck trauma. Corr et al performed a prospective study in 1999 on 25 patients with penetrating neck injury, showing 100% sensitivity of duplex ultrasound as compared to angiography. Demetriades et al found similar results using ultrasound in 99 patients who also underwent angiography. They found a sensitivity of 91.7% and specificity of 100%. When only lesions requiring treatment were considered, both the sensitivity and specificity were 100%. In recent practice guidelines, EAST allows for use of CTA or duplex ultrasound instead of arteriography to rule out arterial injury (Level II recommendation).

Evaluation of the aerodigestive tract is accomplished by contrast studies or by direct visualization. Computed tomography evaluation of the trachea has been shown to reliably diagnose injury. Esophageal and pharyngeal injuries, however, can be difficult to evaluate, and there are often no physical examination findings on presentation. Delay of more than 24 hours in the diagnosis of esophageal injuries can lead to increased morbidity and mortality. Although CT scanning cannot reliably evaluate for esophageal trauma, some studies suggest that a CT scan showing a bullet trajectory remote to the esophagus can reliably risk stratify patients to a very-low-risk category suitable for 24-hour observation. In most patients sustaining gunshot wounds to the neck, however, it is likely that an esophagogram should be performed. Esophagography has a sensitivity approaching 100%. A strategy of esophagography followed by esophagoscopy was recommended by Weigelt et al for the identification and evaluation of esophageal injury. The clinical practice guidelines from EAST recommend either contrast esophagography or esophagoscopy to rule out an esophageal perforation that requires surgical repair.

管理 Of Thoracic Gunshot Wounds

Thoracic ballistic wounds often injure multiple structures and require significant hospital resources to manage emergently. Major vascular injuries occur in 4% of penetrating chest trauma cases. If tracheobronchial injuries are present, the proportion of patients with major vascular injuries can be as high as 30% (not including cardiac injuries that occur in 3% of cases). Many patients with penetrating thoracic injuries do not survive to the ED, and those that do survive to the ED often require immediate interventions such as tube thoracostomy, intubation, and thoracotomy. Thus, the emergency

Table 8. Potential Thoracic Injuries

<table>
<thead>
<tr>
<th>Thoracic Structure</th>
<th>Potential Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest wall</td>
<td>• Rib fractures</td>
</tr>
<tr>
<td></td>
<td>• Flail chest</td>
</tr>
<tr>
<td></td>
<td>• Intercostal artery laceration</td>
</tr>
<tr>
<td>Heart</td>
<td>• Cardiac tamponade</td>
</tr>
<tr>
<td></td>
<td>• Hemorrhagic shock</td>
</tr>
<tr>
<td></td>
<td>• Ventricular lacerations or punctures</td>
</tr>
<tr>
<td>Lungs</td>
<td>• Pneumothorax</td>
</tr>
<tr>
<td></td>
<td>• Hemothorax</td>
</tr>
<tr>
<td></td>
<td>• Pulmonary lacerations</td>
</tr>
<tr>
<td></td>
<td>• Pulmonary contusions</td>
</tr>
<tr>
<td>Esophagus</td>
<td>• Esophageal perforation</td>
</tr>
<tr>
<td>Great vessels</td>
<td>• Lacerations leading to hemorrhagic shock</td>
</tr>
<tr>
<td></td>
<td>• Massive hemothorax</td>
</tr>
<tr>
<td>Tracheobronchial tree</td>
<td>• Complete transection</td>
</tr>
<tr>
<td></td>
<td>• Partial tears</td>
</tr>
<tr>
<td></td>
<td>• Tracheoesophageal fistulas</td>
</tr>
<tr>
<td></td>
<td>• Mediastinitis</td>
</tr>
</tbody>
</table>
Evaluation Of Thoracic Trauma

Focused assessment with sonography in trauma (FAST) examination has become a mainstay of early trauma management, as bedside ultrasound has become readily available in many institutions. The FAST examination should be performed early in the initial assessment of penetrating thoracic trauma as it can help accurately diagnose a pericardial effusion, hemoperitoneum, pneumothorax, and hemothorax and thus direct timely treatment to the most appropriate location. Bedside ED ultrasound of the pericardium has been shown in multiple studies to have excellent sensitivity, specificity, and accuracy (100%, 97%, and 97%, respectively). A false-negative examination is possible if the cardiac injury is not contained within the pericardium and is causing a massive hemothorax, but false-positive pericardial ultrasounds are rare. Case reports describing false-positive pericardial ultrasounds have been reported most frequently in the setting of a massive hemothorax or mediastinal injury. Tube thoracostomy to relieve the hemothorax followed by a repeat pericardial ultrasound may improve the diagnostic accuracy in these cases.

Recent improvements in the performance of bedside ultrasound have led to the expanded FAST (E-FAST) examination to include sonographic evaluation of the chest cavity to assess for pneumothorax and hemothorax. A positive ultrasound for a pneumothorax in a symptomatic patient suggests that decompression is warranted. The findings on ultrasound include a lack of lung sliding and the “seashore” or “bar code” sign.

Chest radiographs are necessary in all thoracic ballistic injuries, regardless of presenting symptoms. In many institutions, portable chest radiographs are frequently ordered on trauma patients, but they are notoriously less accurate than upright posteroanterior and lateral chest films. Nonetheless, portable films are the practical choice for more severely injured patients. Chest films can help determine the presence of most thoracic injuries to the lungs, bony chest wall, and vertebrae, and they can help locate the projectile as well.

In hemodynamically stable patients, CT is warranted if there is still suspicion for intrathoracic injuries after physical examination, FAST examination, and chest films. Computed tomography is highly accurate for diagnosing injuries missed clinically and on chest x-ray. With advances in CT technology and its widespread availability, many clinically important and occult diagnoses may be found only on CT. For example, Ball et al detected an occult pneumothorax on CT in 14.5% of 338 patients with a normal chest radiograph, 47% of whom required drainage. Similarly, Stafford found that 21% of 410 trauma patients with a normal chest film had a hemothorax in CT, and half of these patients required tube thoracostomy. As always, the emergency clinician should weigh the risks and benefits of CT versus observation based upon ED resources, the potential dangers of irradiation, and the likelihood of complications.

Treatment Of Thoracic Trauma

The management of penetrating thoracic trauma can be complex because so many structures are at risk for injury. Early involvement of a trauma surgeon is recommended, since the final common pathway for many of these patients is surgery or admission for close observation and serial examinations.

When the patient presents in extremis or loses vital signs in the ED, an emergency thoracotomy should be performed, if possible. Indications for emergency thoracotomy include loss of vital signs in the ED (or immediately prior to arrival), evidence of cardiac tamponade, and massive hemothorax. Emergency thoracotomy should not be performed if there are inadequate surgical resources available to definitively manage the patient.

Emergent needle decompression and tube thoracostomy are indicated in the presence of a clinically significant pneumothorax or hemothorax, respectively. Needle decompression should only be performed as a stabilizing procedure while preparing to place a thoracostomy tube. Many needle decompressions fail to get into the pleural space when placed in the classic anterior position of the second intercostal space in the midclavicular line because the chest wall in many adults may be too thick for standard IV catheters. The lateral chest wall at the fourth or fifth intercostal spaces in the midaxillary line has been found to be just as thick as the anterior chest wall. Angiocatheters are longer and stand a greater chance of penetrating the pleural cavity, but there are still many failures when this procedure is attempted. Therefore, needle decompression may be ineffective at temporarily relieving a tension pneumothorax, and a thoracostomy tube should be placed immediately if there is truly a concern for a tension pneumothorax. Chest tubes should be placed prior to imaging if there is any suggestion of instability, tension pneumothorax, or hemothorax.

Fluid resuscitation of the patient with hemorrhagic shock often starts with a crystalloid bolus, but immediate release of blood products (at least 6 units of packed red blood cells [PRBCs] and fresh frozen plasma [FFP]) should be obtained concurrently and started immediately, when available. Literature supports the role of permissive hypotension in the penetrating trauma patient to reduce the possibility of causing increased hemorrhage by dislodging a clot or tamponade that has occurred naturally. Blood products are recommended...
Clinical Pathway For The Management Of Gunshot Wounds To The Thorax

- Primary survey per ATLS® protocol
- Airway control as indicated
- Damage control resuscitation with 1:1:1 ratio of blood products (Class II)
  - Tranexamic acid, 1 g IV over < 10 min, followed by 1 g IV over 8 hours (Class I)
- Portable chest x-ray and FAST examination (Class II)

Stable?

- indications for thoracotomy?
  - Tension pneumothorax or possible hemothorax?
    - Thoracostomy tube
      - Massive hemothorax?
        - Thoracotomy
          - Consider pelvic injury or other source of instability
  - Thoracotomy and right-sided thoracostomy tube

- NO

Pneumothorax or hemothorax?
- YES
  - Thoracostomy tube
- NO

Intra-abdominal bleeding

- NO

Pericardial tamponade

Normal, negative

Stable?

- YES
  - Appropriate CT scans
  - Surgical consult and intervention as appropriate

- NO
  - Continue to secondary survey
  - Observe and evaluate

Abbreviations: ATLS®, Advanced Trauma Life Support®; CT, computed tomography; FAST, focused assessment with sonography in trauma; IV, intravenous.

For class of evidence definitions, see page 9.
at a 1:1 ratio of PRBCs, FFP, and platelets to prevent coagulopathy from developing or worsening. These patients should also be kept warm (> 34°C [> 93.2°F]) to prevent hypothermia from occurring and worsening coagulopathy.\(^9^0\)

The recent CRASH-2 trial of over 20,000 bleeding trauma patients from 40 countries worldwide concluded that providing early use of tranexamic acid decreased all-cause mortality and the risk of death due to bleeding compared to placebo and states that this medication may be a useful adjunct in the bleeding trauma patient.\(^9^0\)

Administration of prophylactic antibiotics in patients with penetrating chest trauma requiring tube thoracostomy has been debated. Sanabria et al performed a meta-analysis of 5 randomized controlled trials and found that patients given prophylactic antibiotics had a decreased frequency of pneumonia and posttraumatic empyema.\(^9^1\)

**Management Of Abdominal Gunshot Wounds**

Firearms injuries to the abdomen can affect multiple organs and can even traverse the diaphragm and cause thoracic injuries. Abdominal gunshot wounds may be isolated, but as in over one-quarter of these patients, there may be more than 1 injury present.\(^9^2\) Hollow-organ injuries are the most common, with the small bowel being the most commonly injured organ. Solid-organ injuries and genitourinary injuries are less common but must be considered and evaluated. Historically, many of these wounds mandated emergent exploratory laparotomy, but recently, more-conservative management plans have also been shown to have success.\(^9^2,9^3\)

There are 4 anatomic zones of the abdominal cavity, which can help suggest the type of injury potentially present.\(^9^2\) (See Table 9.) Regardless of the external site of injury and the initial tract of the projectile, injuries can occur in remote sites due to ricochet and cavitary effects of the projectile. Because of the many possible intra-abdominal injuries, management of patients with abdominal gunshot wounds is based initially on physical examination and hemodynamic findings. Clearly, the unstable patient, the patient with an eviscerating injury, or the patient with peritonitis on examination will likely require operative intervention,\(^9^4-9^6\) but many of these patients are initially hemodynamically stable or unable to be assessed because they are sedated and intubated. In these less clearcut cases, diagnostic studies must be performed to help identify which patients can be managed nonoperatively and which patients require urgent exploratory surgery.

Serial physical examinations and frequent vital sign re-evaluation are the most important diagnostic tests to perform, as the development of instability or peritonitis later in the course of the ED evaluation can direct an immediate need for surgical exploration. (See Table 10.) In patients who remain stable, laboratory and radiographic tests are required to determine a location of injury or the presence of intra-abdominal blood.

Typical laboratory studies that are obtained include complete blood count, blood gas, renal function, electrolytes, lactic acid, and urinalysis. A type and crossmatch for blood products may also be necessary, depending on the severity of the injury. Results of these laboratory studies alone are rarely indications to proceed to surgery, but significant base deficits, highly elevated lactate levels, and significant anemia may indicate the need for more aggressive or operative management.

Radiographic studies should always be obtained in the stable patient with an abdominal gunshot wound. The FAST scan is useful in the unstable patient to determine the presence of blood in the peri-

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**Table 9. Location Of Abdominal Zones**

<table>
<thead>
<tr>
<th>Abdominal Zone</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior abdomen</td>
<td>Between the anterior axillary lines; bound by the costal margin superiorly and the groin crease distally.</td>
</tr>
<tr>
<td>Thoracoabdominal area</td>
<td>From the nipple line superiorly to the inferior costal margin distally</td>
</tr>
<tr>
<td></td>
<td>between the tips of the scapulae and the posterior portion of the inferior costal margin. Injuries in the region increase the likelihood of chest, mediastinal, and diaphragmatic injuries.</td>
</tr>
<tr>
<td>Flanks</td>
<td>From the inferior costal margin superiorly to the iliac crests; bound anteriorly by the anterior axillary line and posteriorly by the posterior axillary line.</td>
</tr>
<tr>
<td>Back</td>
<td>Between the posterior axillary lines extending from the inferior scapular tips to the iliac crests.</td>
</tr>
</tbody>
</table>

**Table 10. Specified Physical Examination Findings To Suggest Injured Organ From Abdominal Gunshot Wound**

<table>
<thead>
<tr>
<th>Finding</th>
<th>Possible Injury Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vomiting blood</td>
<td>Esophageal or gastric injury</td>
</tr>
<tr>
<td>Gross blood on digital rectal examination</td>
<td>Colon or small bowel injury</td>
</tr>
<tr>
<td>Hematuria</td>
<td>Kidney, ureter, or bladder injury</td>
</tr>
<tr>
<td>Grey-Turner or Cullen sign</td>
<td>Retroperitoneal hemorrhage</td>
</tr>
<tr>
<td>Cool or pulseless extremities</td>
<td>Intra-abdominal or pelvic vascular injury</td>
</tr>
</tbody>
</table>
cardium and/or peritoneum, but a negative study does not rule out intra-abdominal organ injuries, particularly hollow-organ injuries. A positive FAST scan in the stable trauma patient does not necessarily warrant emergent operative intervention, but it may help direct further testing and evaluation, as intraperitoneal fluid found on FAST without other ultrasound or clinical findings may suggest hollow viscus or diaphragmatic injuries.92

Plain film radiography of the chest, abdomen, and pelvis is typically employed to determine intrathoracic injuries, and it can help provide information regarding the location of the projectile as well as the number of missiles within the abdominal cavity. Both anteroposterior and lateral films must be obtained to determine whether the projectile is in the abdominal cavity. (See Figures 2 and 3.) If the number of superficial wounds does not match the number or projectiles present on plain films, further imaging or thorough operative exploration is required.

Computed tomography scans have become standard in the evaluation of the stable trauma patient with suspected intra-abdominal or pelvic injuries from gunshot wounds. Not only do CT scans assist in determining the location of penetrating injuries and the amount of blood present in the peritoneum, they also allow for evaluation of the missile path and help with decision-making for operative versus nonoperative management. Velmahos et al performed a prospective observational study of 100 patients with abdominal gunshot wounds who were hemodynamically stable and were initially planned to undergo nonoperative management.96 The investigators used CT scans with IV contrast only and found a 90.5% sensitivity and 96% specificity for determining the need for operative intervention. Twenty-six patients required exploratory laparotomy based on CT findings, and only 5 of these had a nontherapeutic laparotomy; none had postoperative complications. Two patients had missed injuries on CT but had clinical worsening and required surgical evaluation. Neither had a bad outcome because of the delay to surgery. Based on this study, many trauma centers have opted to drop oral and/or rectal contrast from their trauma CT protocols.

The availability and advances in CT and ultrasound have now largely relegated diagnostic peritoneal lavage (DPL) to an infrequently performed procedure in many facilities. Diagnostic peritoneal lavage is a highly sensitive, invasive test with a reported sensitivity of 96% for identifying intraperitoneal injuries caused by gunshot wounds,99 and it may still have utility in certain situations, particularly in unstable patients who cannot proceed to CT scanning. For example, in the patient who is intubated and cannot be clinically evaluated, a positive DPL can detect a possible hollow viscous injury. Likewise, in a patient with penetrating trauma to the lower thorax, flank, or back, a positive DPL can determine if there is an intraperitoneal injury. A grossly positive DPL in the unstable patient indicates that intra-abdominal bleeding may be the source of hemodynamic instability. A positive DPL in penetrating trauma is classically 5000 to 10,000 red blood

Figure 2. Kidney/Ureter/Bladder Radiograph Of Abdominal Gunshot Wound With Penetration Of Peritoneum

This patient suffered a penetrating wound to the abdomen; arrows point to 2 projectile fragments that can be seen in the left upper quadrant of this kidney/ureter/bladder image. Image used with permission of David Bruner, MD.

Figure 3. Computed Tomography Scan Of Abdominal Gunshot Wound With No Penetration Of Peritoneum

The above patient’s CT scan showed the projectile fragments to be outside of the abdominal cavity (arrow); an exploratory laparotomy showed no signs of violation of the peritoneum. Image used with permission of David Bruner, MD.
Clinical Pathway For The Management Of Gunshot Wounds To The Abdomen

- Primary survey per ATLS® protocol
- Airway control as indicated

Stable?

- Damage control resuscitation with 1:1:1 ratio of blood products (Class II)
- Tranexamic acid, 1 g IV over < 10 min, followed by 1 g IV over 8 hours (Class I)

Portable chest x-ray and FAST exam

Intra-abdominal bleeding?

- Stable?
  - YES
  - Portable chest x-ray and FAST exam
  - Intra-abdominal bleeding?
    - YES
    - Stable?
      - YES
      - Secondary survey
      - Appropriate CT scans
    - NO
      - Peritonitis?
    - NEGATIVE
      - Surgical consult and intervention as appropriate
    - POSITIVE
      - Re-evaluate, perform serial examinations, consider admission and observation
  - NO
    - Secondary survey
    - Appropriate CT scans
    - DPL (Class III), serial FAST examination, or operative intervention
    - Remains unstable?
      - YES
      - Operative intervention (Class III)
      - Consider angiography if pelvic bleeding is the likely source (Class III)
      - Surgical consult and intervention as appropriate
    - NO
      - Surgical consult and intervention as appropriate

Abbreviations: ATLS®, Advanced Trauma Life Support®; CT, computed tomography; DPL, diagnostic peritoneal lavage; FAST, focused assessment with sonography in trauma; IV, intravenous.

For class of evidence definitions, see page 9.
cells (RBCs)/mm³. A recent retrospective study by Thacker suggests the criteria for a positive test can be changed without missing clinically significant injuries. This study identified the following criteria as a positive DPL: 100,000 RBC/mm³ plus either > 500 white blood cells/mm³ or the presence of bile, or the presence of amylase in the peritoneal fluid.³⁹

**Interventional Radiology**

In circumstances where a vascular injury or isolated pelvic vascular injury is the primary source of hemorrhage, interventional radiology may be the diagnostic and therapeutic modality of choice. Interventional radiology can be therapeutic if the vessel can be embolized to help control the bleeding.

**Diagnostic Laparoscopy**

Laparoscopy can also be performed as a diagnostic procedure to gain direct visualization of the source of intraperitoneal bleeding, possible bowel perforations, and diaphragmatic injuries before proceeding to an open exploratory laparotomy in select patients. Laparoscopy, however, is limited as a diagnostic test because it can miss posterior diaphragmatic injuries, retroperitoneal structure injuries, and subtle hollow viscus injuries.¹⁰⁰

**Treatment For Abdominal Gunshot Wounds**

After thorough evaluation for other injuries requiring more emergent treatment, initial resuscitation of the abdominal gunshot wound victim begins with fluid resuscitation. Classically, crystalloid (lactated Ringer solution) is the initial resuscitative fluid used, but prompt use of blood products is the mainstay of appropriate fluid resuscitation. Recent literature suggests a low RBC:FFP ratio (as discussed on page 14) be instituted as soon as the need for blood products is determined. Likewise, hypotensive resuscitation is recommended while awaiting surgical intervention, when appropriate. With all ballistic trauma to the abdomen, immediate trauma surgery consultation or transfer is indicated. If the patient is not at a trauma center, stabilization with fluid and blood products is appropriate, but there should be no delay in transfer to a higher level of care. If the patient is unstable and requires transfer, CT imaging can be deferred, but all transfers should be discussed with the receiving surgeon.

Hemodynamically unstable patients or those with peritonitis after abdominal gunshot wound injuries should be appropriately resuscitated with fluid and blood products and referred for emergent exploratory laparotomy. Bleeding is controlled with pressure, when possible, and potentially unstable pelvic injuries are managed with compression of the pelvis with a pelvic binder or a tightly wrapped sheet. Patients with suspected pelvic bleeding may be selectively managed with angiography as noted above if an exploratory laparotomy is not deemed necessary.

Hemodynamically stable patients without peritonitis can be managed with a more selective approach, as time may allow for CT imaging to assess for the location of injury and to determine if the injuries present warrant exploratory laparotomy. Head, C-spine, thoracic, and abdominal CT scanning (“pan scan”) is occasionally warranted in the multiply injured patient or those in whom a full clinical evaluation is not possible because of intubation, but many of these patients will require surgical exploration.

**Selective Nonoperative Management For Abdominal Trauma**

In recent years, more cases of penetrating abdominal trauma have been managed successfully without proceeding to exploratory laparotomy. This management strategy is the surgeon’s prerogative and is clearly not the emergency clinician’s decision to make. Velmahos et al retrospectively reviewed 792 patients who underwent selective nonoperative management at 1 institution and found that only 4% required delayed laparotomy after worsening clinical examination; none of the patients had a bad long-term outcome. They noted that nonoperative management is only appropriate at institutions where there is always an on-call surgeon available, rapid transfer to the operating room is feasible at all hours of the day, and there are providers available 24 hours a day for serial examinations to assess for acute worsening.¹⁰¹

**Management Of Genitourinary Gunshot Wounds**

Only 10% of trauma patients have a GU injury, and only 15% of this subset is from penetrating trauma.¹⁰² Fortunately, there are few life-threatening GU surgical emergencies other than a shattered kidney or major lacerations of the renal vasculature. The majority (up to two-thirds) of GU injuries are to the external genitalia, and most patients have other, more urgent, nongenitourinary injuries.¹⁰³ In up to 45% of trauma cases, bladder injuries are due to gunshot wounds, but 90% of traumatic ureteral injuries are due to penetrating trauma.¹⁰⁴-¹⁰⁶ Only a small percentage (5%-10%) of direct kidney injuries are from penetrating trauma, but many of these injuries require complete nephrectomy.¹⁰⁷

The evaluation of GU trauma typically begins with an evaluation of the distal structures and proceeds more proximally to the kidneys. A thorough examination of the external genitalia for blood at the urethral meatus and an evaluation for gross hematuria may indicate the presence of an injury. A lack of external signs and a lack of microscopic or macroscopic hematuria do not rule out significant GU injuries, as a normal urinalysis is present in 25%
of upper GU injuries.\textsuperscript{105,106} If there is concern for a urethral injury, delay placement of a Foley catheter until after further testing in order to avoid making a partial urethral injury worse.

Upon examination, if there is concern for an upper or lower GU injury (or from the potential trajectory of the projectile), diagnostic imaging will likely be necessary. Testing for a GU injury should be delayed in patients who require further evaluation and treatment of more life-threatening injuries. A retrograde urethrogram or cystogram can help determine if there is a urethral or bladder injury and suggest whether the bladder injury is intraperitoneal or extraperitoneal. Retrograde CT cystography can also be performed to assess the extent of injury to distal structures, and the CT can be extended superiorly and should include IV contrast to evaluate for kidney involvement. To assess for contrast leakage proximally at the kidneys, it is indicated to delay abdominal CT scanning for 10 minutes after the IV contrast is administered.\textsuperscript{107} When other intra-abdominal or pelvic injuries that require surgical exploration are present, the ureters and kidneys can be directly visualized to assess for GU injuries.

When a GU injury is noted and other life-threatening injuries have been treated or excluded, consultation with a urologist for definitive management is indicated. Decompression of the bladder with a catheter is the mainstay of early management of bladder injuries in the ED, but most other injuries to the GU system require surgical management by a urologist. The bladder should be irrigated to help evacuate blood clots. The most important ED management strategy is simply to recognize and test for GU injuries and resuscitate appropriately.

Management Of Gunshot Wounds To The Extremities

The most important factors to consider with a firearm injury to the extremities are the possibility of vascular and nerve injuries, compartment syndrome, fractures and knowledge of the type of weapon used. Artery and nerve injuries are the major causes of mortality and long-term morbidity in extremity gunshot wounds.\textsuperscript{108} Although low-velocity injuries from handguns account for the majority of extremity injuries in the civilian population, high-velocity wounds and shotgun wounds have the greatest potential for devastating injury, largely because they have a higher percentage of kinetic energy transference, have a higher degree of wound contamination, have a higher risk for compartment syndrome, and more often have associated comminuted fractures with devitalized bony fragments.\textsuperscript{109,110} Shotgun injuries, overall, have been found to have twice the mortality rate of rifle or handgun wounds.

Wounds to the shoulder have been found to represent 9\% of upper extremity gunshot wounds. Approximately 15\% of these wounds are associated with a vascular injury and up to 25\% involve injuries to the subclavian and axillary arteries.\textsuperscript{111} Forearm gunshot wounds have been found to account for up to 20\% of gunshot wounds overall, of which pulse deficits of the radial and ulnar arteries have been reported to be as high as 86\% and 83\%, respectively.\textsuperscript{111,112} Furthermore, penetrating forearm injuries are the most common cause of upper-extremity compartment syndrome, with a rate of 10\%.\textsuperscript{30,113}

Lower-extremity ballistic injuries have the highest rate of fractures. The majority involve the femur (22\%-49\%); the tibia accounts for 11\% to 14\%.\textsuperscript{5} Injuries to the hip and bony pelvis carry significantly higher morbidity and mortality due to related injuries to the abdominal and pelvic organs.\textsuperscript{114} Thigh wounds carry significant potential for vascular injury with high risk of massive hemorrhage, especially when the injury involves the medial aspect of the thigh or when a severe femur fracture occurs.

Injuries to the leg, especially the tibia, can be especially devastating. Overall, the majority of compartment syndromes are found in tibial trauma from both blunt and penetrating injuries. Gonzalez showed that 60\% of patients who developed compartment syndrome in penetrating lower extremity trauma had associated tibial fractures.\textsuperscript{115}

Vascular Injuries Of Extremities

An extremity vascular injury can cause hemodynamic instability from significant exsanguination and can affect the viability of the injured limb. Neurovascular structures in the extremities travel closely together, from proximal to distal, while traversing compartments that are well-demarcated by fascia and muscle tissue. The fascial separations can play a critical role in injury patterns because they may act as a conduit for the transfer of kinetic energy from the projectile and can impart immediate injuries distal to the permanent cavity and late complications such as compartment syndrome. The timing of presentation for treatment is critical, as studies have shown that delays of greater than 6 to 8 hours have infection and complication rates that are significantly higher than in patients who present early after sustaining a firearm injury.\textsuperscript{112}

A recent large review of the National Trauma Data Bank\textsuperscript{®} from 2002-2005 looked at isolated lower-extremity trauma with an arterial component and found that penetrating trauma accounted for 66\% of these injuries. The most commonly injured vessel is the superficial femoral artery, followed by the popliteal artery and the common femoral artery. The amputation rate from penetrating trauma is 5.1\% and is most frequently associated with a popliteal artery injury.\textsuperscript{116}
Clinical Pathway For The Management Of Gunshot Wounds To The Extremities

Hard signs of vascular injury, ischemia, or persistent, active hemorrhage?

Consult trauma/vascular/orthopedic surgeon and consider a tourniquet

Orthopedic fixation +/- intraoperative angiography, vascular repair

Assess risk for neurovascular injury

API ≥ 0.9 (Class III)

No pulse deficit

Observation/serial examinations

Consult trauma/vascular surgery

Operative repair

Serial imaging

Observation

Abbreviations: API, arterial pressure indices; CTA, computed tomography angiography.

For class of evidence definitions, see page 9.
Gunshot wounds to the proximal aspect of the upper extremity warrant evaluation for brachial plexus injuries. One study noted that shotgun injuries to the shoulder carried a 50% chance of nerve transection. The more proximal the vessel injury, the higher the risk for significant injury. Additionally, patients with an underlying vascular disease are susceptible to more problematic injuries and merit a higher degree of clinical suspicion for associated vascular injury. Traditionally, after physical examination, the gold standard for further assessment for a vascular injury has been conventional angiography. Historically, soft signs of vascular injury on physical examination were an indication to obtain angiography. However, other methods such as computed tomography angiography (CTA) have replaced conventional angiography in many circumstances. Conventional angiography’s advantage is that it has been consistently shown to have 99% sensitivity and 97% specificity. However, up to 95% of arteriograms are negative, they have a false-positive rate of 2%, they carry a complication rate of 1% to 3% (further arterial injury), and they often do not change management decisions. Prospective studies of CTA have shown sensitivities ranging from 99% to 100% and specificities of 87% to 100%. Duplex ultrasound offers some significant advantages to other study methods because it is readily available in many EDs, can be done at the bedside, is noninvasive, requires no radiation exposure or contrast material, and has a high degree of diagnostic accuracy in the experienced provider’s hands. Studies have shown sensitivities of 95% to 100%, with specificities of 97% to 98%.

In the patient with equivocal signs of vascular injury, choosing the best diagnostic imaging test can be difficult. If no hard signs are found but there is still a concern for vascular injury, many institutions advocate admission and serial examinations along with some form of diagnostic testing such as duplex ultrasound or CTA.

Nerve Injuries In Extremity Trauma
Peripheral nerve injuries due to trauma are rare, accounting for only 2% to 3% of all traumatic injuries.

Be wary of the penetrating neck injury. Unless you can definitively prove that the wound does not penetrate the platysma, the patient with a penetrating neck injury must undergo a series of imaging studies and/or a period of observation to ensure that no serious injury has occurred.

Be careful with your documentation of gunshot wounds. Your chart should contain only descriptions of the wound and factual information about the case. You do not know which wound is the entrance wound, as not all entrance wounds are smaller than exit wounds.

Be aware of the penetrating head injury. I’m aware that brain edema is a big problem in these injuries, so I avoided giving IV fluids to him.” Under-resuscitation of head injury leads to hypotension and results in increased morbidity and mortality. Fluid resuscitation should not be withheld for fear of brain edema. If edema is a serious concern, resuscitation with hypertonic saline can be instituted.

Studies have shown that application of RSI to patients with penetrating neck injuries is safe and effective. The emergency clinician should not avoid securing the airway in the trauma patient if it is needed; however, backup airway devices should be available in case of complications.

Be aware of the penetrating head injury. I’m aware that brain edema is a big problem in these injuries, so I avoided giving IV fluids to him.” Under-resuscitation of head injury leads to hypotension and results in increased morbidity and mortality. Fluid resuscitation should not be withheld for fear of brain edema. If edema is a serious concern, resuscitation with hypertonic saline can be instituted.

4. “The patient had a through-and-through gunshot wound to his arm. The wound on the front of the arm was smaller than on the back of the arm, so I documented in the chart that the entrance wound was located on the front of the arm.” Be careful with your documentation of gunshot wounds. Your chart should contain only descriptions of the wound and factual information about the case. You do not know which wound is the entrance wound, as not all entrance wounds are smaller than exit wounds.

5. “I didn’t give the patient antibiotics because bullets are sterile, due to the high heat associated with missile injuries.” Numerous studies have proven that bullets are not sterile, and even if they were, the vacuum created by cavitation facilitates inoculating the patient with infectious material such as clothing or other debris.
Realignment can provide hemostasis, reduce pain, and prevent further injury, such as compartment syndrome. Initial stabilization includes fracture reduction with the best possible anatomic realignment, soft tissue wound care, and appropriate splinting, with care to avoid constrictive dressings. Always reassess neurovascular status after these measures. If wounds are large, obviously contaminated, or involve the joints, IV antibiotics are indicated. Imaging of the injured area as well as the anatomic area above or below the wound should be performed.

A simple way to describe the fracture to an orthopedic consultant is to use the mnemonic NOLARD: Neurovascular status, Open versus closed, Location, Angulation/Alignment/Articular involvement, Rotation, and Displacement.

Always include the mechanism of injury and estimate the level of contamination as well. Definitive treatment of joint and bone injures often requires operative treatment, and bone injuries may need to be repaired to facilitate a vascular repair.

A study by Brown et al found that firearms-related injuries accounted for 15% of all fractures requiring surgery. Noble et al found that gunshot wounds accounted for 7.4% of peripheral nerve injuries overall (and as high as 84% in developing countries). Neurologic injuries are associated with a concomitant vascular injury in approximately 10% to 16% of cases.

Nerve injuries are notoriously difficult to assess in the immediate setting, and there is considerable controversy as to the best management of these injuries. If the injury is neuropraxic (the nerve remains intact but is transiently nonfunctional) or axonometric (axon alone is severed), these patients will usually regain function. Nearly 70% of individuals with a documented peripheral nerve injury go on to make complete recovery.

Focal neurologic findings have been suggested as risk factors for unrecognized vascular injury because of their proximity. Frequent reassessments of neurologic status are important because changes can also indicate development of compartment syndrome.

**Management Of Bone And Joint Injuries**

Bone and joint injuries are often grossly visible on examination and should be stabilized as soon as possible. Realignment can provide hemostasis, reduce pain, and prevent further injury, such as compartment syndrome.

Risk Management Pitfalls For Gunshot Wounds (Continued from page 22)

6. “Shotguns are low-velocity weapons, so I didn’t think it could be so serious.”

Shotguns are devastatingly effective at closer ranges, despite their “low” velocity and less-aerodynamic projectiles. Avoid making judgments solely on velocity classifications and adhere to the maxim “treat the wound, not the weapon.”

7. “He had a through-and-through wound in his leg, so I didn’t think he could get compartment syndrome.”

Compartment syndrome is a clinical diagnosis, and intracompartamental pressures should be measured to verify the diagnosis. Just because the patient has a big hole in his leg doesn’t mean that swelling doesn’t occur or he couldn’t have a hematoma that effectively serves as a tamponade.

8. “I saw a pulsatile bleeding vessel, and it was easy to see, so I clamped it off for hemostasis.”

Clamping of a vessel is ill-advised, as you’re likely to damage a closely approximated nerve and will damage the vessel end, making re-anastomosis more difficult. You could have used a tourniquet or direct pressure instead!

9. “The entrance wound appears on the anterior chest wall and the exit wound can be found in the lower back . . .”

When describing ballistic wounds, do not try to be a forensic pathologist or a detective. Simply describe the wound’s size and appearance, but do not describe it as an entrance or exit wound.

10. “He is awake and pain is under control, but his blood pressure is only 95/55 mm Hg. Do we need to give him another bolus of crystalloid to get his blood pressure back to normal?”

There are 2 pitfalls in this question. First, the primary resuscitative fluid in penetrating trauma should be blood products in an equal ratio rather than crystalloid or colloid. The second pitfall is attempting to maintain a “normal” blood pressure. Multiple studies have demonstrated that permissive hypotension is a useful prehospital and ED strategy that complements the idea of damage control resuscitation. If a patient is awake and alert and tolerating permissive hypotension, it is best to try to maintain the mean arterial pressure around 65 mm Hg or the SBP around 90 mm Hg to decrease bleeding. For more information about damage control resuscitation, see the November 2011 issue of *Emergency Medicine Practice*, “Traumatic Hemorrhagic Shock: Advances In Fluid Management.”
Fractures can occur from direct injury caused by the projectile, but bony fragments can also act as secondary missiles and lead to concomitant neurovascular injuries. Fractures caused by gunshot wounds are classified similar to other blunt trauma fractures. Incomplete fractures typically involve the epiphysis and metaphysis and have 3 patterns: drill hole (seen in cancellous bone injury), unicortical (usually in long bone metaphysis), and chip fractures. Complete fractures frequently involve the diaphyseal bone and have a butterfly pattern.\textsuperscript{34,113}

High-velocity gunshot wounds to the bone are the most significant because severe comminution and devitalized bone fragments are often present. Low-velocity gunshot wound fractures, however, often behave similarly to closed blunt-trauma fractures.

Ballistic injuries to the joints can have devastating short- and long-term sequelae. An isolated gunshot wound to a joint is rare but requires immediate operative evaluation and management. These types of injuries are a risk for severe posttraumatic arthritis, and if left in place, retained fragments can lead to plumbism.\textsuperscript{125}

While arterial injuries are the greatest threats to life and limb, overall, skeletal muscle and soft tissue are the predominant tissue types injured in gunshot wounds. High-velocity and shotgun injuries are typically the most severe. Low-velocity wounds are not typically associated with significant tissue damage and are generally lower-risk for infection.\textsuperscript{125,126}

### Management Of Soft Tissue Injuries

Soft tissue wounds are often managed in the ED, either by the emergency clinician or a consultant. High-velocity and shotgun wounds are the exception, as they often need meticulous debridement and frequently require second-look procedures. Smaller, isolated wounds to skin, subcutaneous tissue, and muscle are very amenable to simple irrigation and debridement. A large retrospective review by Ordog et al examined outcomes of gunshot wound patients managed with simple wound debridement, antibiotic ointment, and oral antibiotics. They found only a 1.8% incidence of wound infections, and 60% of the patients in this study were managed as outpatients.\textsuperscript{127} A small, retrospective observational study by Byrne and Curran examined the rate of successful ED management of isolated gunshot wounds to the lower extremity. They found a significantly low rate of complications compared to inpatient management, as well as significant savings in terms of total inpatient hospital days.\textsuperscript{109}

When assessing injuries to the soft tissue and muscle of the involved extremity, general principles of wound care apply. The approach to wound closure must include evaluation of the degree of contamination, the timing of closure, the wound size and depth, and injury to underlying structures. Direct closure of the wound is generally not advised, so as to allow for an outlet of potential infection. Discharged patients will need to be followed for wound checks. Wounds that are large and/or deep, are not amenable to delayed closure, have significant potential cosmetic implications, or are > 8 hours old may require consultation and admission for operative treatment. In the interim, cover these wounds with saline-soaked gauze and consider a course of antibiotics. The extent of the wound should be noted, especially if the fascia is violated, as some surgeons use this to determine whether the patient needs to have formal operative debridement.\textsuperscript{128}

With many penetrating injuries, compartment syndrome is possible. In particular, lower extremity vascular injuries above the knee and proximal tibia fractures are at high risk for compartment syndrome.\textsuperscript{115} The gold standard to assess intracompartmental pressure is by direct measurement of pressures within the affected compartment as well as all adjacent compartments. Pressure measurements should be performed using sterile technique and within 5 cm of the fracture site to avoid a falsely low reading. A compartment pressure > 30 mm Hg is considered positive. When the threshold pressure is crossed, fasciotomy is indicated. Delays in fasciotomy can have dire consequences, as found by Ritenour, who noted in a study of combat casualties between January 2005 and August 2006 that patients undergoing fasciotomy after evacuation from Iraq had higher rates of muscle excision (25% vs 11%), amputation (31% vs 15%), and overall mortality (19% vs 5%) versus those who had a fasciotomy prior to evacuation.\textsuperscript{129}

### Documentation Of Gunshot Wounds

Emergency clinicians are uniquely situated to observe and record ballistic injuries before the wounds are disturbed by surgical or medical intervention. While documentation is very important for both medical and legal purposes, documentation should not compromise patient care or interrupt resuscitation efforts. When done properly, ballistic documentation can be performed quickly and accurately, but many EDs do not focus on the documentation aspect of ballistic injury. One study found that of 93 gunshot wounds treated at a Level I trauma center, the wound size was documented only 8.6% of the time. Additionally, wound shape was documented only 1% of the time, and anatomic location was documented only 39.8% of the time.\textsuperscript{130} Implementation of an easy-to-use, standardized gunshot wound description form was found to drastically improve gunshot wound documentation in this same trauma center.\textsuperscript{130} (See Figure 4 and Figure 5.)

Proper documentation of a gunshot wound in-
cludes the anatomic location, size, shape, and characteristics of the wound. Emergency clinicians should avoid speculating on the caliber of weapon or bullet type that caused the wound. In addition, wounds should not be described as “entrance” or “exit,” because this determination can be very difficult to make. Other characteristics of the wound should be described such as burns, bruising, abrasions, or soot around the wound edges. Carbonaceous material around the wound should be described as “soot.” The term “powder burn” is no longer considered accurate or appropriate terminology. Medical photography is an easy and accurate way to document ballistic injury. Consent must be obtained prior to obtaining pictures, and most hospitals have specific protocols addressing medical photography, which must be followed. Place a ruler in the photograph to provide a scale of measurement. If a ruler is not available, use a standard-sized, well-known object such as coin. All documentation should be purely factual. The emergency clinician should avoid recording any speculation or opinions in the medical chart. If the patient expresses an opinion that is pertinent to the record, this should be recorded in the patient’s own words and in quotation marks. Remember that the medical chart is a legal document and may be used as evidence in a criminal trial.

Controversies And Cutting Edge

Use Of Antibiotics

With the exception of an open fracture, antimicrobial treatment for penetrating extremity wounds is often a source of controversy. Generally accepted indications for empiric antibiotic therapy are associated fractures, shotgun injuries, or wounds with large associated soft-tissue involvement. Studies by Ordog and Dickey demonstrated that patients with low-velocity missile injuries can be successfully treated as outpatients, without antibiotics. When antibiotics are deemed necessary, Knapp et al found no difference in outcomes when comparing oral and IV antibiotics. Risk factors for infection include delays in wound care, inadequate wound care, wounds > 2 cm in length, gross contamination, poor patient compliance, diabetes, and vascular injury. Patients with grossly contaminated injuries, high-velocity weapon injuries, and shotgun injuries should be admitted for surgical debridement.

When fractures are present, antibiotics are indicated. In a study of 1104 open fracture wounds, Patzakis and Wilkins found the key to reducing infections was early antibiotic administration. Fackler stated that one should strive to achieve adequate circulating blood levels of a penicillin-spectrum antibiotic in all gunshot wound patients as soon as possible. Surgical debridement for open fractures is typically done within 6 hours, but recent studies have shown that extending this window up to 24 hours has shown no change in the rate of osteomyelitis as long as antibiotics have been started in the ED.

Cervical Spine Clearance

Many patients with gunshot wounds arrive with cervical collars in place despite a lack of neck trauma by history, and many more patients have cervical collars placed at the time of arrival to the ED. Two retrospective studies suggest that cervical collars do not need to be applied to patients with isolated gunshot wounds to the head because blast and fall injuries are generally not present, and the spinal stabilization only increases the difficulty with airway
control. Another study suggests that cervical collars do not need to be placed in patients with penetrating trauma to the head, neck, or torso if they are asymptomatic of spinal injuries.

**Thoracotomy**

Emergency department thoracotomy (EDT) can be a potentially life-saving intervention for patients with penetrating thoracic injuries, but it has been used in certain instances for penetrating abdominal injuries as well. While large studies are lacking because of the relative infrequency of EDTs, some retrospective analysis suggests that it may have a limited role for penetrating abdominal trauma when clamping of the aorta may allow time to find the source and stop the bleeding. A recent study of prelaparotomy EDT found that of the 50 patients with abdominal exsanguinations from penetrating trauma, 8 patients survived neurologically intact to hospital discharge, thus suggesting a role for EDT in penetrating abdominal trauma. Another recent study by Moore et al suggested that an EDT should be considered futile in any penetrating trauma when CPR has been ongoing for 15 minutes or more.

**Synthetic Blood Substitutes**

Synthetic hemoglobin-derived, disease-free, oxygen-carrying substitutes have been suggested to be useful in trauma patients when allogenic blood products are not available or in patients who cannot receive blood products. Several studies have addressed the use of these products over the last decade with primarily favorable results. For example, Gould et al first examined this topic by comparing a synthetic blood substitute (PolyHeme®) to allogenic blood transfusion in trauma patients. They found that there were no adverse side effects in the synthetic hemoglobin group, and they required fewer units of transfused blood. The synthetic group did, however, have a lower overall hemoglobin.

A recent multicenter trial evaluated the role of 6 units of synthetic hemoglobin within the first 12 hours of injury versus prehospital crystalloid and standard in-hospital blood product use in 714 trauma patients. This prospective trial found less allogenic blood product use in the experimental group and suggested that synthetic hemoglobin would be useful when blood products were not available. The study concluded that the synthetic blood product group did not have statistically different adverse events, but it did have a 3% risk of myocardial infarction compared to 1% in the allogenic blood product group. However, mortality was slightly higher in the synthetic group (13.4% vs 9.6%), and multiple organ failure was higher as well (7.4% vs 5.5%). This study suggests that if traditional blood products are not available, the risk-to-benefit ratio favors using synthetic hemoglobin.

**Summary**

Ballistic weapons cause many deaths and critical injuries worldwide. Knowledge of the physics behind these weapons can help emergency clinicians better understand the magnitude of their patients’ injuries. Understanding the type of projectile fired, the distance from the target, and the number of shots fired will help determine the pattern of injury. While the velocity of the projectile is important, the injury patterns are similar regardless of the speed of the bullet, and higher-velocity weapons do not necessarily impart greater injuries. The permanent cavity causes obvious tissue damage, but the temporary cavity can also have devastating effects to surrounding tissues. Each area of the body is at risk for various and different injuries depending on the tract of the bullet, and emergency clinicians must be aware of the specific risks with each region of the body and be prepared to treat accordingly. The field of ballistics and the physics behind penetrating injuries is improving. Newer techniques, such as ballistic gelatin, are able to better explain the various injury patterns, allowing the treatment of these wounds to improve, based on evidence.

**Case Conclusions**

The 25-year-old male with the gunshot wound to the upper abdomen and the left-lower-lobe injury was taken to the operating room immediately. On visual inspection during thoracotomy, he was found to have a diaphragmatic injury. He required a left-lower-lobe resection but did not have any other intra-abdominal injuries, and he recovered slowly over several weeks.

The 18-year-old male with the shotgun wound to the left leg had multiple small fragments in that leg and APIs of 0.8. Given the extent of his injuries, he was taken to the operating room by an orthopedic surgeon for an external fixator and to wash out and clean up his wounds. He had a preoperative CTA of his left leg that did not reveal a vascular injury. He was eventually discharged for further outpatient orthopedics care.

The 38-year-old man with a gunshot wound to the head was found at the CT scanner to have massive intraparenchymal hemorrhage and significantly increased ICP, collapsing the ventricles and causing herniation. The bullet was in his left temporal lobe. Despite attempts to control his ICP, his injuries were not survivable. Comfort care was provided, and he died in the ICU.

**Note**

The views expressed in this presentation represent those of the author and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, or the United States Government.
Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.

To help the reader judge the strength of each reference, pertinent information about the study, such as the type of study and the number of patients in the study, will be included in bold type following the reference, where available. In addition, the most informative references cited in this paper, as determined by the authors, will be noted by an asterisk (*) next to the number of the reference.


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5. For patients with elevated ICP, a reasonable initial dose of hypertonic saline is:
   a. 10 mL/kg of 7% saline solution
   b. 100 mL of 3% saline solution
   c. 2 mL/kg of 7.5% saline solution
   d. 50 mL/kg of 0.9% saline solution

6. Imaging options for arterial neck injury include all of the following EXCEPT:
   a. CT angiography
   b. Contrast-enhanced CT of the neck
   c. Duplex ultrasonography
   d. Angiography

7. Which of the following is not an indication for emergency thoracotomy after a penetrating gunshot wound to the chest?
   a. Loss of vital signs in the trauma bay
   b. Massive hemothorax
   c. Loss of protective airway reflexes
   d. Cardiac tamponade

8. Vomiting blood is indicative of what type of injury from an abdominal gunshot wound?
   a. Esophageal or gastric injury
   b. Colon or bowel injury
   c. Kidney injury
   d. Pelvic injury

9. Appropriate documentation of gunshot wounds includes all the following EXCEPT:
   a. Size
   b. Entrance versus exit wound
   c. Location
   d. Shape
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