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AHC Media

Gunshot Wounds: Management and Myths

Whether urban, suburban, or rural in location, every emergency department manages the victims of gunshot wounds, some more frequently than others. It is essential to follow the principles of the management of penetrating trauma and not get distracted by impressive wounds.

An understanding of ballistics will allow the emergency medicine provider to anticipate the extent of certain injuries and expected complications; a practical knowledge of forensics aids in proper documentation and preservation of evidence.

This article will review and clarify certain controversies and myths regarding the management of patients with gunshot wounds. Although not an all-inclusive treatise on the management of gunshot wounds, newer approaches to penetrating abdominal trauma and spinal immobilization will be discussed. A review of the management of penetrating trauma to the neck will discuss the zones of the neck and whether these zones still dictate management. In addition, some unique clinical conditions and complications will be addressed.

— The Editor

Introduction

Penetrating trauma is the second leading cause of injury-related deaths.[1] For every firearm-related death, there are four nonfatal injuries.[1] Annually, 60,000–80,000 nonfatal gunshot wounds occur in the United States. While many of these patients will require transfer to a trauma center for definitive management, the initial care and stabilization will occur in the emergency department to which they initially present.

Ballistics: Beyond Velocity

In ballistics, a distinction is made between low- and high-velocity weapons, with a velocity of more than 2000 ft/sec usually being designated high velocity. This distinction is not always precise, as the British consider any speed greater than 1100 ft/sec as high velocity, while American studies have used various values including 2000 ft/sec, 2500 ft/sec, or 3000 ft/sec.[2] Generally, high velocity corresponds to a kinetic energy (KE) greater than 750 ft-lb (hunting and military rifles). Most civilian gunshot wounds are from low-velocity weapons such as handguns. Shotguns are low-velocity weapons but act as high-velocity devices at close range, which is defined as less than 14 feet.[3] At close range, the wadding from the shotgun also becomes a projectile.[4]

When bullets penetrate tissue, the injury is directly related to the amount of energy transferred to the target. The energy that a bullet possesses is derived from the kinetic energy equation where $KE = mv^2$ (mass times velocity squared). While velocity is a key contributor to injury, more significant is the efficiency of energy transfer. This energy transfer depends on the bullet's physical characteristics, including deformation, fragmentation, mass, stability, path, and tissue characteristics.[1]

The designation of a high-energy wound remains subjective and is ultimately

Executive Summary

- While velocity is a key contributor to injury, more significant is the efficiency of energy transfer. This energy transfer depends on bullet's physical characteristics, including deformation, fragmentation, mass, stability, path, and tissue characteristics.
- Tissues that have a large amount of elasticity and relatively low density, such as the skin, can be spared from serious injury with gunshot wounds.
- In low-velocity gunshot wounds with a fracture, antibiotic prophylaxis is still recommended, as contamination is not always apparent, along with appropriate wound and fracture treatment. In minor, uncomplicated gunshot wounds where an entry wound and exit wound are identified without contamination, antibiotics and operative wound debridement are unnecessary.
- Bullet emboli can be characterized as arterial, venous, or paradoxical. The majority of bullet emboli are arterial in nature.

judged on the physician's exam. If this designation is decided on velocity alone, it only recognizes potential injury and not actual damage.[1] There is little clinical ability to measure the actual amount of energy delivered.[1] As the bullet passes through the tissue, a temporary cavity forms secondary to the stretching of the tissues due to a momentary acceleration of the surrounding tissue in all directions away from the tract of a missile. This temporary cavity results from the bullet propelling the walls of the permanent cavity outward.[2] As the bullet passes through the tissue, a vacuum forms behind it. The size of this cavity is proportional to the amount of kinetic energy transferred from the bullet, as well as the size of the bullet. Controversy exists regarding the maximum size of the temporary cavity.[1] Bullets that shatter, fragment, or tumble have a slower exit velocity and impart more energy to the affected tissues, resulting in more cavitation.[5] The vacuum that is created pulls foreign debris, such as dirt, bacteria, and clothing particles, into the wound, causing contamination. This cavity collapses because of the resultant vacuum effect, then reforms and collapses repeatedly with diminishing amplitude until all motion ceases. The force that results from the repeated dispersal of this rebounding energy can injure surrounding structures. The damage of the temporary cavity is caused by the outward movement of the tissue, which stretches and tears the surrounding tissue.

Eventually, the temporary cavity completely collapses due to the vacuum and forms a small permanent cavity. This permanent cavity is the hole through which a bullet penetrates and its direct path.[2] Bullet deformation and fragmentation are significant contributors to the permanent cavity.[6] In uncomplicated, low-velocity gunshot wounds, damage outside the permanent track is only a few cells deep. The widespread myth that a bullet damages tissue in direct proportion to its velocity still exists.[2] The axiom to treat the wound, not the weapon, should be followed.[2]

In addition to the velocity and mass that a bullet possesses in causing injury, the characteristics of the bullet are important. A jacketed bullet has increased velocity, but its decreased mass and deformity lead to less tissue damage.[2] In the initial 12 cm of a soft-tissue path, there is little difference between high- and low-velocity wounds caused by full metal jacket bullets. Yaw is defined as the angle between the long axis of the bullet and its direction of flight. Faster, more stable bullets tend to yaw deeper into the target.[7] Without deforming, yaw, or fragmentation, a substantial amount of the wounding potential is unspent. This is a classic example of a bullet's velocity not necessarily correlating with the resulting wound.[1] Open-tip bullets may have a hollow or soft point. Hollow-point bullets have a hole in the jacket at the bullet's tip, whereas soft-point bullets have some of the lead core of the bullet exposed at the bullet tip.[8] These characteristics weaken the bullet tip, causing it to flatten on impact. Subsequently, flattening increases the bullet's diameter, resulting in a mushroom-shaped projectile. These bullets inflict more damage to the tissue at the same striking energy because the deformed tip will transfer more energy to the tissue.[4] Further injury within the body is encountered when the bullet traverses the body, loses kinetic energy, and begins to tumble.

Tissue characteristics also affect the subsequent injury pattern. Tissues that have a large amount of elasticity and relatively low density, such as the skin, can be spared from serious injury with gunshot wounds.[1,2] Lungs have a much lower density, absorb less energy and, as a result, suffer less of an injury. This explains the relatively low frequency of operative intervention in penetrating chest trauma. Dense organs with low elasticity, such as bone, absorb more energy, resulting in more injury. Other organs, such as the liver and spleen, are injured when the kinetic energy transferred exceeds the elasticity of the tissue. In gunshot wounds to the head, the temporary cavity that is created is modified by the containment of the cranium due to its limited elasticity. As a result, because of the skull, the brain receives a shearing force rather than a large temporary cavity, thus behaving differently than an unconfined soft tissue.[4]

Contrary to popular opinion, exit wounds are not always larger than the entrance wounds. Lower KE missiles tend to have similar-sized entrance and exit wounds and cause damage primarily to the structures that are directly in the missile's path.

Higher KE missiles are more prone to cavitation, causing significant injury to the tissues adjacent to the path of the missile. The cavitation results in nerve damage, thrombosis or vessel injury, and fractures of bones within the vicinity of the missile's path. These higher KE missiles result in exit wounds that are substantially larger than their corresponding entrance wounds.

In managing gunshot wounds, the emergency medicine provider has an opportunity to optimize the evaluation, documentation, and evidence collection while simultaneously providing appropriate care. Document the appearance of the wound, but do not speculate on the direction of fire.[2] Entrance wounds tend to be oval to circular with a punched-out, clean appearance. An abrasion ring of reddish damaged skin often may surround these wounds.[9] These wounds should also be evaluated for soot and debris prior to cleaning. Exit wounds are more irregular and less consistent in shape, including stellate, slit-like, crescent-shaped, and circular. Cavitation produces larger exit wounds, as does increased yaw of the bullet.

It is important to describe and document injuries objectively and accurately, and to omit opinion.[10] In a study at a Level I trauma center in California, the documentation was poor in 70% of cases, and evidence was improper or inadequately secured in almost 40% of cases.[10] A detailed description of wounds is preferred to trying to identify and differentiate entrance vs. exit wounds. Such differentiation is best avoided, and there may be significant medicolegal implications if done incorrectly. The anatomic location, shape, size, and associated findings such as soot or powder burns should be noted. Documentation should include any treatment to the wounds. Consider photographing the wounds, if possible. A practical, common-sense approach includes cutting around, but not through, bullet holes when removing a patient's clothing. The chain of custody must be preserved. Bullets should be handled carefully, and any wadding or loose pellets should be saved as well.

Spinal Immobilization in Victims of Gunshot Wounds

The role of spinal immobilization in victims of gunshot wounds is controversial and has been challenged repeatedly in the trauma literature. On the contrary, in blunt trauma, the role of cervical spine immobilization both in the pre-hospital arena and subsequently the clinical and radiographic evaluation in the emergency department has been extremely well studied.[11,12] Advanced Trauma Life Support (ATLS) stresses to assume a cervical spine fracture in any patient with an injury above the clavicle, without any distinction between blunt and penetrating trauma.[13] In contrast, the Pre-Hospital Trauma Life Support (PHTLS) course and text states that spinal immobilization is not indicated in penetrating trauma unless a neurological deficit or complaint is present.[14]

In penetrating trauma, time to definitive treatment is important, as the value of scoop-and-run prehospital strategy has been demonstrated to be advantageous in an urban environment. The time delay caused by spinal immobilization was 5.5 minutes under optimal conditions with experienced prehospital providers.[15] Another study showed a delay from 2 to 5 minutes.[14] For such a delay to be acceptable, this stabilization must clearly demonstrate a substantial value to the patient in terms of mortality or morbidity. Recent recommendations from the PTLS executive committee state that the minimal potential benefits of spinal immobilization are outweighed by the risk of airway compromise, difficult intubation conditions, and the inability to have continued assessment of the anterior neck for development of life-threatening conditions.[16] Concerning findings such as crepitus, tracheal deviation, or expanding hematoma can be missed with routine cervical spine immobilization.[14] The use of protocols mandating immobilization after a gunshot wound to the head is unnecessary, and these protocols may compromise airway management.[17]

The literature supports a minimal incidence of cervical spine injuries in isolated gunshot injuries to the head. In a retrospective series of 174 patients, Lanoix et al reported no cervical spine injuries in patients with isolated gunshot wounds to the head.[18] Kennedy et al and Chong et al also found an absence of cervical spine injuries in their patients with isolated gunshot-wound injuries to the head.[19,20] In addition, Kaups and Davis concluded that there were no indirect spinal injuries in their patients with isolated gunshot injury to the cranium.[17] These studies excluded patients with gunshot wounds to the face and neck. Other researchers have found it is not uncommon to find an associated spinal injury; however, it is very rare to find an unstable fracture with a penetrating injury.[21] Barkana et al and Connell et al recommended that in fully conscious patients with a penetrating neck injury without a clear neurological deficit, neck stabilization is not required.[21,22] Conversely, Demetriades et al found that 8% of patients with gunshot wounds to the face had cervical spine injuries and recommended spinal immobilization if the bullet passes through the neck, exit wounds are absent, or any focal neurological deficits are present.[23] In a retrospective study of gunshot wounds to the head, neck, or torso, Klein et al identified cervical spine fractures in 13% of patients with an absence of neurological deficit on clinical exam.[24] Barkana et al did allow for immobilization in patients with combined penetrating and blunt trauma.[21]

The questions concerning the necessity of spinal immobilization extend beyond the cervical spine. Cornwell et al evaluated thoracolumbar immobilization for trauma patients with torso gunshot wounds and concluded such immobilization was rarely beneficial.[25] In fact, patients without a spinal injury had a higher mortality than patients without an injury to the vertebral column

in their study.[25] This finding stresses the need for rapid transport to a site for resuscitation and definitive treatment. Connell et al stated that awake patients with isolated penetrating trauma to the thorax and no neurological deficit do not require spinal immobilization; however, their study was small, and the majority of injuries were from stab wounds.[22]

The practice of spinal immobilization of patients with gunshot wounds needs to be reexamined. With the retrospective design of many of these studies and the relatively small numbers of spinal injuries, the definitive answer concerning the necessity of such spinal immobilization remains unclear. The potential downsides of spinal immobilization, such as delayed transport times and delayed discovery of complications, must continue to be assessed and balanced against potential benefit.

The use of a structured exam (tenderness to palpation, deformity, and any neurological deficit) to identify those patients requiring further studies was 100% sensitive for all clinically relevant injuries in a study by Inabi et al.[26] Currently, the radiological evaluation of patients with gunshot wounds to the neck must be individualized.

Are the Zones of the Neck Obsolete?

Traditionally, penetrating injuries to the neck are divided by anatomical distributions. Roon et al first described these anatomical zones in an effort to standardize reporting and improve outcomes and assessments.[27-29] Zone I is the area extending from the clavicle to the cricothyroid membrane. The aortic arch and its branching vessels, as well as the lung apex, esophagus, trachea, brachial plexus, thoracic duct, and vertebral arteries can be injured in zone I. Injuries to zone I may require transthoracic as well as transcervical approaches for definitive repair. Zone II extends from the cricothyroid membrane to the angle of the mandible and is the largest, most-exposed area. The important structures in zone II include the carotid arteries, jugular veins, larynx, proximal esophagus, and hypopharynx. Zone III is from the angle of the mandible to base of the skull. Zones I and III are difficult to explore surgically due to certain anatomic considerations. Therefore, vascular injuries in zones I and III are usually identified utilizing CT angiography in stable patients.

Despite the recommended anatomical management of penetrating neck injuries, the effects of stress waves and cavitation from bullets can cause significant injury beyond the immediate path of the projectile.[30] Tender et al presented a case in which a single bullet caused a variety of injuries, including to the vertebral artery, external jugular vein, cervical vertebrae, hyoid bone, and spinal cord.[31] Subsequently, the injuries caused by bullets may involve more than one zone, despite the location of the entry wound.

Regardless of the zone of injury, the initial resuscitation begins with stabilization of vital signs and a quick and careful physical examination. The physical examination should focus on the three major organ systems commonly involved in penetrating neck injury: airway, vascular system, and upper digestive tract. The clinician must evaluate and secure the airway in all penetrating neck injuries. If stridor, difficulty in breathing, or neck swelling is present, early intubation is mandated, since the airway may be lost if bleeding and swelling continue. A cricothyroidotomy can be performed if there is a compromised airway or failed intubation. If an injury is below the cricothyroid membrane, an emergent tracheotomy can be performed, usually one ring below the injury. Vocal quality should be noted as well. The neck and upper chest should be examined for subcutaneous emphysema. Also, the larynx and trachea should be palpated for tenderness and crepitus.

Vascular injury in the neck is important to identify. Hematoma is the most common sign of vascular injury, followed by shock and external bleeding.[27,32,33] Once a vascular injury is identified, the decision must be made to arrange for definitive treatment. Narrod et al found that the common carotid artery was the most injured vessel in penetrating neck injuries, followed by internal and external carotid, respectively.[34] Devastating neurological sequelae can be seen following carotid artery injuries. Therefore, it is of the utmost importance that carotid artery injuries be identified and treated properly. If there are signs of bleeding from the carotid artery that are causing alterations in vital signs, direct pressure is applied to control hemorrhage while arrangements are made for emergent surgery. Those patients with gunshot wounds to the neck who have unstable vital signs should undergo immediate surgical exploration. Likewise, individuals with active bleeding, evolving cerebrovascular accident, hemoptysis, hematemesis, and expanding hematoma should also mandate immediate surgical exploration.

Most penetrating injuries to the neck occur in zone II.[27] Prior to the advent of computed tomography, many stable patients who sustained a penetrating neck injury to the zone II area underwent mandatory exploration. As technology has advanced with CT, the need for mandatory exploratory surgery has decreased. Gracias et al performed a retrospective case series with the hypothesis that CTA used as an early diagnostic tool could eliminate further studies or procedures in stable zone II neck injuries. Most of the patients in this study had gunshot wounds. Data obtained from this study suggested that CT scanning in stable patients with penetrating trauma to the neck appears safe and reliable. Color flow Doppler ultrasound offers another option for evaluation of vascular injury in neck trauma.[30] Demetriades et al found it 100% sensitive and specific for clinically significant injuries in a study of 82 patients.[35] Extensive subcutaneous emphysema, hematoma, and operator variability were documented limitations of the study.

While not obsolete, the zones of the neck are becoming more descriptive terms for communication

between providers rather than a guide to clinical decision-making and management, as these zones had previously been.[36] The combination of a precise physical exam combined with the newer-generation scanners for computed tomographic angiography (CTA) may provide the necessary information for selective surgical intervention.[36] Multislice helical computed tomographic angiography (MCTA) is a sensitive, noninvasive diagnostic test that effectively evaluates vascular trauma and, possibly, aerodigestive tract injuries, although the latter requires further study.[37]

Abdominal Gunshot Wounds: OR for All?

Wounds from stabbing implements occur nearly three times more often than wounds from firearms, but gunshot wounds have a significantly greater associated mortality rate and are responsible for 90% of the deaths from penetrating trauma.[38] Unlike stab wounds, gunshot wounds have unclear trajectories, cause more tissue destruction, and produce deeper wounding.[39] Abdominal gunshot wounds enter the peritoneal cavity in approximately 80% of cases, and in more than 90% of those involving penetration, there is intraperitoneal damage.[39] The frequency of organ injury caused by gunshot wounds is greatest for the small bowel, followed by the colon, and then the liver.[38]

The nonoperative management of abdominal blunt trauma has evolved over the past several decades and is a well-accepted practice. In a similar fashion, the nonoperative management of stab wounds to the abdomen has gained acceptance.[39,40] In contrast, the current management of gunshot wounds to the abdomen in most centers involves mandatory surgical exploration. Many surgeons believe that the physical exam is unreliable with gunshot wounds to the abdomen, and the incidence of significant injuries is high, so immediate operative intervention is the best management. Some high-volume trauma centers have been slowly adopting a selective nonoperative management of gunshot wounds to the abdomen.[40]

There has been great debate about the management of penetrating abdominal trauma. Patients with hemodynamic instability or a physical examination consistent with peritonitis after gunshot wounds should be taken to the operating room. Patients with viscus or omental evisceration sustain up to an 80% incidence of major intraperitoneal injury, rendering laparotomy a reasonable next step in management. Recovery of blood via a nasogastric tube or emesis may reflect a violation of the stomach or duodenum, but is an unusual occurrence. Likewise, examination of the rectum or vagina may reveal hemorrhage that is the result of intraperitoneal or retroperitoneal trauma. In any case, these patients should be strongly considered for an urgent surgical exploration.

In those select patients who present with hemodynamically stable vital signs, absence of peritonitis, and a reliable physical exam, nonoperative management can be considered.[41] Nonoperative management is becoming more favorable because it avoids the morbidity and mortality of an unnecessary laparotomy; morbidity is reported to be as high as 41%.[39,42,43] In addition, an unnecessary laparotomy increases the hospital length of stay and significantly increases the cost of care.[39] To be evaluated for nonoperative management, two questions must be answered:

- Did the projectile enter the peritoneal, retroperitoneal, or pelvic cavity?
- If it did, is there an injury that will require laparotomy to repair?

Serial examinations must be performed when a patient with penetrating injury is observed. Local exploration is not an option, as all gunshot wounds are assumed to have violated the peritoneum until proven otherwise.[39] Velmahos et al showed that one-third of patients with anterior abdominal gunshot wounds and two-thirds of those with posterior abdominal gunshot wounds did not have significant underlying injuries.[41] If a decrease in hemoglobin, hemodynamic instability, or abdominal tenderness develops, then nonoperative management needs to be abandoned.[40,41] If the patient will be unable to have a reliable examination secondary to head injury, spinal cord injury, sedation, or other factors, nonoperative strategies are impossible. Furthermore, a nonoperative approach also requires an experienced surgeon to be available for repeated examinations. This may not be possible in a busy trauma center or in a small hospital with limited staff. These patients require a minimum of 24 hours of observation, as no patients failed after that time period. Of those who failed, most demonstrated signs within 12 hours.[44]

The expected rate of delayed laparotomy is 4%, with an expected rate of unnecessary laparotomy of 14%.[41]

Abdominal CT has drastically changed the way trauma is managed. CT allows accurate three-dimensional determination of missile trajectory in penetrating injury, including its proximity to crucial structures.[41] CT also clearly defines certain injuries that may not need laparotomy for repair. CT has been helpful when the bullet trajectory is indeterminate, and has shown a sensitivity and specificity of 90.5% and 96%, respectively, for identifying intra-abdominal injury.[45,46]

Inaba et al performed a prospective study utilizing triple contrast helical CT in hemodynamically stable patients with penetrating trauma to the torso to help demonstrate the presence or absence of peritoneal violation and any associated injury.[47] When utilizing triple contrast CT scan, the most common finding of peritoneal violation was intraperitoneal fluid, with additional findings including pneumoperitoneum, intraperitoneal organ injury, a wound track that extended into the peritoneal cavity, or an intraperitoneal bullet fragment. Based on these definitions of peritoneal violation, they found that 34% of their 200 patients had peritoneal violation diagnosed by CT, despite having no clinical or radiographic findings to suggest peritoneal perforation, a high sensitivity (97%) and negative predictive (98%) value for the detection of peritoneal

violation. Among the patients without CT findings of peritoneal violation, more than half of the patients were discharged within 24 hours and did not require later treatment. Therefore, triple contrast multidetector CT is another tool to help determine whether or not peritoneal violation has occurred.[47]

Even with operative intervention, laparoscopic techniques are being used with greater frequency for the diagnosis and management of traumatic injuries. This procedure allows examination of the anterior intra-abdominal structures. In patients who sustain a penetrating wound to the left thoracoabdomen, there have been studies indicating there is a high likelihood of diaphragm injury.[40] In patients found to have a diaphragmatic injury, 31% had no signs of peritonitis and 40% had a normal chest X-ray.[39] Laparoscopy should be performed for all patients with left thoracoabdomen gunshot injury. However, there are limitations to the utilization of laparoscopic surgery. The retroperitoneum and posterior diaphragm cannot be adequately visualized by laparoscopy. In addition, it is difficult to visualize all aspects of the small and large intestines. Therefore, the indication for laparoscopy is reserved for determining whether there has been peritoneal penetration. If a peritoneal wound is found during laparoscopic surgery, a laparotomy should be undertaken to fully explore the abdominal cavity and its contents for injuries.

An intestinal perforation and spillage is a significant complication after penetrating trauma to the abdomen. Anaerobes and coliforms are the predominant organisms found. Antibiotics given prophylactically have been demonstrated to be effective in decreasing the incidence of intra-abdominal sepsis and should be given as soon as such an injury is suggested. A single pre-operative dose of a broad-spectrum antibiotic, or a combination of antibiotics that covers both aerobic and anaerobic organisms, such as piperacillin-tazobactam (3.375 mg IV), is recommended.[48]

The enthusiasm for selective nonoperative management of gunshot wounds to the abdomen is based on the high incidence of nontherapeutic or negative laparotomy from low-velocity civilian gunshot wounds (5.3%-27%).[40] Also, selective nonoperative management saved slightly more than $1 million per year at one large trauma center, with a complication rate of less than 1%.[41] It is anticipated that the selective nonoperative management of gunshot wounds to the abdomen will continue to evolve; however, it is expected that this type of management will continue to be limited to major trauma centers due to the personnel requirements and the necessary expertise.

Gunshot to the Extremities: Are Antibiotics Necessary?

The role of antibiotics in gunshot injuries has been widely debated. It is imprudent to consider injuries inflicted by guns to be sterile. Thoresby and Darlow documented the contamination of wounds from bacteria and foreign bodies that were drawn into the wound by the temporary cavitation or vacuum effect caused by a low-velocity bullet as it passed through tissues.[49-51] Direct contamination can also occur in an uncovered, open wound.

With low-velocity gunshot wounds to the extremities, the rates of infection appear to be low. Knapp et al reported a 2% infection rate in patients with fractures that were treated with both intravenous first-generation cephalosporin and aminoglycoside or with an oral fluoroquinolone.[51,52] They concluded that patients with fractures caused by low-velocity gunshots that involved extra-articular long bones, except those of the distal tibia, could be treated effectively with oral antibiotics.[49] In addition, Hollman and Horowitz found no cases of infection or osteomyelitis in their patients who sustained femoral fractures caused by low-velocity gunshot wounds who were treated with a first-generation cephalosporin for 48 hours.[49,53]

Some authorities even argue that antibiotics may not play a role in preventing infections. Howland and Ritchey reviewed 72 patients with fractures caused by low-velocity gunshots who were treated with antibiotics and found two infections in 42 patients.[54] Therefore, they did not recommend the routine use of antibiotics, provided that wound debridement had been satisfactory and the injured extremity was immobilized.[49]

Marcus et al reported minimal difference in infection rates in patients with injuries caused by low-velocity gunshots that did and did not receive antibiotics.[55] Similarly, Dickey et al reported no statistically significant difference in the infection rates between 36 patients treated with 24 hours of IV cefazolin and 37 patients who received no antibiotics.[56] Antibiotics may not be necessary for those individuals suffering gunshot injuries to the extremities if these injuries are properly debrided and immobilized.

In minor, uncomplicated gunshot wounds, where entry and exit wounds are identified with no contamination, antibiotics and operative wound debridement may be unnecessary given the low infection rate. Only 1.8% of these entry-/exit-type injuries become infected.[57] Handgun wounds without vascular injury are generally treated conservatively. These wounds require irrigation, debridement, and are left open with options for delayed primary closure or healing by secondary intention.[51,58] When a radiograph demonstrates an intact bullet and no fracture, with the bullet lying in soft tissue, then associated tissue damage is minor.[1] On the contrary, multiple bullet fragments suggest increased tissue damage, and such wounds will require more extensive debridement and antibiotics.[1] Antibiotics may also be beneficial if there are multiple injuries, gross wound contamination, significant tissue devitalization, large wounds, and a delay in treatment.[57]

Injuries to the extremities caused by high-velocity weapons have

notoriously high rates of infection because of the amount of devitalized tissue, which enables the proliferation of bacteria.[49]

At close range, shotguns behave as high-velocity weapons, and the wadding becomes a projectile itself. This radiolucent wadding introduces bacteria and incites an inflammatory response.[3,58] When high-velocity injuries are encountered, a complete and thorough wound debridement with removal of foreign material, fracture stabilization, and administration of 48-72 hours of IV antibiotics has been recommended.[58] Previously, the antibiotic of choice has been Benzyl penicillin due to its effectiveness against clostridia and beta-hemolytic streptococci.[59] A growing number of penicillin-resistant bacteria has led to the recommendation of cephalosporin prophylaxis in the treatment of injuries caused by high-velocity gunshots.[60] The addition of an aminoglycoside is suggested when there is extensive contamination. Whether to also provide coverage for methicillin-resistant *Staphylococcus aureus* (MRSA) has been discussed.

There is a slightly higher rate of infection in gunshot injuries to the hands and feet than in injuries to other anatomic locations.[49,61] There are also reports that indicate ankle fractures caused by low-velocity gunshots have an increased propensity to develop an infection.[49,52,56] Gunshot injuries to the hand, foot, and ankle, as well as intra-articular injuries, require antibiotics. Ganocy and Lindsey recommend 24-48 hours of prophylactic antibiotics for low-velocity intra-articular fractures with skin or material contamination.[62] For intra-articular hip fractures, Long et al recommend as many as 72 hours of IV first-generation cephalosporin and aminoglycoside. Gunshot wounds to the hip with a trans-abdominal pathway are at high risk for infection.[63]

In summary, antibiotic prophylaxis is necessary in high-velocity, shotgun, and intra-articular gunshot fractures. These wounds will also require surgical debridement. Given the higher rates of infection in gunshot wounds involving the hand, foot, and distal tibia, antibiotics are also warranted in these injuries. Currently, intravenous first-generation cephalosporins are recommended for at least 48 hours. If there are soft-tissue defects or cavitary lesions, then an aminoglycoside should be added.

In low-velocity gunshot wounds with a fracture, antibiotic prophylaxis is still recommended, as contamination is not always apparent, along with appropriate wound and fracture treatment.[1] In minor, uncomplicated gunshot wounds where an entry wound and exit wound are identified without contamination, antibiotics and operative wound debridement are unnecessary.[57]

It is clear that not all retained bullets need to be removed.[58] The prophylactic removal is recommended for any bullet that is intra-articular or intrabursal or located on the weight-bearing surface of palm or soles after swelling resolves.[58]

Retained Bullets: Should We Get the Lead Out?

The medical literature is replete with case reports of individuals sustaining lead toxicity from retained bullets. The most frequently encountered bullets and shotgun pellets are typically 50-100% lead, with an outer material made of alloy or metal harder than lead.[64] Most gunshot injuries with retained fragments occur when bullets are lodged in soft tissues. These bullets are quickly enveloped in a fibrous capsule, becoming isolated from the surrounding tissues and essentially inert.[65] Subsequently, these retained bullets are unlikely to produce elevated lead levels, as they undergo minimal degradation, and the potential for lead absorption from them is small. Projectiles that are retained in joints, in close proximity to synovial membranes, in intervertebral disc spaces, or in well-vascularized cystic structures are prone to undergo dissolution causing significant system lead absorption.[1] Subsequently, these projectiles should be removed. Synovial fluid is an appropriate solvent for exposed lead secondary to its pH level and presence of hyaluronic acid.[66] Bullet fragmentation also leads to increased lead levels.[67]

After absorption, lead circulates in the blood for approximately 30 days. From the blood, lead diffuses into soft tissues, including liver, kidneys, bone marrow, and brain. After 1-2 months, lead diffuses from these tissues into bone, with very little elimination. The half-life of lead in the blood is 30 days, but it is 20-30 years when stored in bone. In fact, 90-95% lead is stored in the bony skeleton.[63,67] Any hypermetabolic state such as pregnancy, infection, trauma, endocrinopathies, and alcoholism can lead to mobilization of lead into blood from bone, causing elevated lead levels.[64,68] Organs most sensitive to lead's toxicity are the kidneys, hematopoietic system, and the nervous system.[69] The developing brains of children and fetuses are extremely sensitive to elevated lead levels.[67] With lead poisoning, patients can present with a myriad of vague symptoms manifesting as encephalopathy, seizures, peripheral neuropathy, abdominal pain, nausea and vomiting, renal insufficiency, anemia, fatigue, weakness, myalgias, constipation, and loss of libido.[70] A clinician should suspect lead poisoning in the patient with microcytic anemia with basophilic stippling and abdominal pain.[67] Wrist drop is the classic peripheral neuropathy seen with lead poisoning. Interestingly, symptoms of lead poisoning from retained fragments can range from 2 days to 52 years after gunshot injury.[1,64,66] Therefore, the clinician must be aware of the possibility of lead toxicity when a patient with the history of retained missile presents with symptoms associated with lead toxicity, regardless of the gunshot injury date.

The Association of Occupational and Environmental Clinics recommends that patients with retained bullets should have baseline lead levels checked, followed by periodic testing, but they do not provide specific recommendations about the schedule of such testing.[67] A baseline lead level, a one week level, and a level at three months after injury have been recommended based on current literature.[67]

Table 1. Bullet Embolization

Suspect bullet embolization if:

- **There is a difference in the number of entry and exit wounds without intra-operative or radiographic confirmation of the presence of bullet within the appropriate cavity**
- **A radiograph demonstrating a bullet in an anatomical location is inconsistent with the presumed trajectory**
- **Serial radiographs demonstrate a "moving" foreign body**
- **The projectile is not visualized on expected X-rays**
- **Clinical signs and symptoms and radiological evidence do not correlate with the sustained injury**
- **There is acute limb ischemia remote from injury**

If after three months there is no significant increase in the lead levels, the retained bullet can be safely assumed to be inert unless symptoms develop.[67] Chronic lead toxicity may not have elevated levels. In addition to lead levels, the laboratory evaluation of lead toxicity includes the measurement of free erythrocyte protoporphyrin, with levels greater than 25 mcg/dL considered abnormal. In children and adolescents, the lack of lead lines on X-rays suggests an acute rather than chronic exposure.[67]

When managing patients with vague symptoms with a history of retained fragments and elevated lead levels, initial therapy for a patient is oral chelation. Once oral chelation is achieved, surgical removal of the bullet is undertaken.[1] Surgery before chelation can result in an increase of lead levels, as surgical stress mobilizes lead stores.[71]

Missile Embolization

Bullet embolization is a very infrequent complication of gunshot wounds. Only 0.3% of vascular trauma cases are complicated by bullet embolization.[72] Migratory bullets may penetrate a vascular or cardiac lumen by direct energy propulsion or may later erode into the vessel.[73] Most cases involving embolization were bullets of small caliber (0.22) and shotgun pellets from shotgun wounds.[72,74] With arterial bullet embolization, the thoracic aorta and its branches are the most common sites of origin.[72]

The majority of cases involve the lower extremities, as only one-fifth of cases involve the upper extremities and neck.[75] The incidence of embolization in left lower extremity is almost three times that of the right. This is likely due to the smaller angle at which the left iliac artery takes origin from the aorta. Moreover, bullet embolization is three times more frequent in the lower extremities than in the upper extremities.[76] Yet, there are case reports that show embolization to other anatomical locations. The factors that determine the direction of movement are force of blood flow, gravity, and the position of the body.[77]

A clinician should suspect bullet migration when there is a difference in the number of entry and exit wounds without intra-operative or radiographic confirmation of the presence of bullet within the appropriate cavity. (*See Table 1.*) Another consideration is when a radiograph demonstrating a bullet in an anatomical location is inconsistent with the presumed trajectory. Finally, serial radiographs demonstrating a "moving" foreign body should raise suspicion of bullet embolization.[78] Intravascular migration of a bullet may be delayed up to 14 years or it may occur soon after injury.[73]

Bullet emboli can be characterized as arterial, venous, or paradoxical. The majority of bullet emboli are arterial in nature.[73,78] When compared with venous bullet emboli, arterial emboli are reported to be more common, with a ratio of 2:1 or 4:1, but this may just represent the tendency of arterial emboli to be symptomatic rather than a true increased incidence.[72] Arterial bullet emboli are symptomatic in 70-80% of cases and result in distal ischemia.[72,75] Subsequently, these injuries are discovered early. Peripheral arterial embolization can lead to decreased or absent pulses, as well as changes in neurological status if migration leads to the cerebral vasculature. The sudden onset of decreased or absent peripheral pulse, unexpected peripheral ischemia, and unexpected neurological symptoms must raise suspicion for arterial embolization.[72] If the diagnosis remains unclear, a CT angiography outlining the vasculature may be performed to ascertain the anatomical location and assist with surgical planning. An arterial bullet embolus should be removed emergently if it is causing ischemic symptoms.[72]

A paradoxical embolus occurs when the bullet originates from the venous system and subsequently moves into the arterial circulation by accessing an intra-cardiac defect or through a traumatic communication created by the bullet. Flow through right-to-left shunts, such as patent foramen ovale, are increased with positive end expiratory pressure mechanical ventilation, which may contribute to this phenomenon.[78,79] Nevertheless, paradoxical bullet embolus mandates prompt evacuation.

Venous bullet emboli gain entry to the vasculature system from nearly any anatomical injury and produce clinical symptoms in only one-third of cases.[75] If suspected, evaluate the cardiopulmonary system for venous embolization.[75] More common areas that result in venous embolism include the chest, abdomen, head, neck, buttock, flank, and inguinal regions. Most foreign bodies travel in the direction of blood flow but retrograde emboli due to the effect of gravity have been reported in as many as 15% of injuries.[80] As a result of blood flow direction, a majority of these bullets can migrate to the right ventricle or pulmonary artery. The consequences of such a migration include cardiac valvular destruction, endocarditis, sepsis, venous thrombosis, thrombophlebitis, dysrhythmias,

and severe hypoxia secondary to pulmonary arterial emboli.[78] Such consequences mandate removal of the offending embolus, depending on the patient's stability to undergo such procedure. If a venous bullet is discovered early (< 6 weeks) to have migrated to the pulmonary artery, Shannon et al advocate mandatory extraction, but suggest selective observation is adequate in the asymptomatic patient with late discovery.[78,81] Kortbeek et al reviewed 32 cases of pulmonary artery emboli that were observed without complication, thereby making conservative management a viable option.[82] Given the recent advancements in endovascular surgery, retrieval may be an option in patients to help prevent late complications.

Missiles found to be free-floating within a cardiac chamber should be removed to prevent embolization. Furthermore, if it cannot be clearly determined that the missile is deeply embedded within a chamber wall, removal should be undertaken. If the bullet is embedded in the chamber wall, then conservative management is appropriate.[83] Nagy's algorithm for selective management of cardiac missile embolus proposed conservative treatment of intracardiac missiles if smooth, firmly lodged, sterile, less than 5 mm, right-sided, and not associated with arrhythmia or valve dysfunction.[84]

Summary

Violence and penetrating trauma continue to be significant problems. With a working knowledge of ballistics, these injuries can be anticipated and more effectively managed and documented. The practice of spinal immobilization for patients with gunshot wounds needs to be reexamined by balancing the potential downsides of spinal immobilization, such as delayed transport times and delayed discovery of complications, against the potential benefits of protecting from a spinal fracture or cord injury. With continued advances in diagnostic imaging combined with a precise physical exam providing the necessary information for selective surgical intervention, the zones of the neck are becoming more descriptive terms for communication between providers rather than a dogmatic guide to clinical decision making.[36] The natural evolution with the extension of the selective nonoperative management of blunt trauma and stab wounds now being applied to gunshot wounds is becoming an accepted practice at some major trauma centers. This practice clearly decreases the high incidence of nontherapeutic or negative laparotomy from low-velocity civilian gunshot wounds; however, few centers have the personnel and expertise to routinely employ this management.

Although there is a common misconception that the heat generated by the firing of a bullet sterilizes the bullet, many gunshot wounds require antibiotics. In lead poisoning, symptoms are indistinct, and multiple organs are affected. A high index of suspicion must be maintained for these vague presentations in a patient with a retained bullet. Bullet embolization is a rare complication of gunshot wounds, but it must be considered when the injury or radiographic studies don't explain the clinical symptoms, especially if ischemic in origin. The application of the principles of managing penetrating trauma with the knowledge of management, myths, and complications of gunshot wounds will allow the medical provider to effectively handle these patients, even if it is a rare occurrence at their emergency department.

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CME/CNE Questions

1. Which of the following weapons does not behave as a high-velocity device?
   A. close-range shotgun
   B. hunting rifles
   C. most handguns
   D. military rifles
2. When evaluating and documenting wounds, such as exit and entrance wounds, which of the following is true?
   A. Exit wounds are always smaller than entrance wounds.
   B. It is best to simply describe the wounds rather than decide if they are entrance or exit wounds.
   C. Abrasion rings define exit wounds.
   D. Entrance wounds are classically stellate or irregular.
3. Proponents for not using mandatory spinal immobilization in gunshot wounds to the head cite the following disadvantage of immobilization:
   A. delayed recognition of important complications such as expanding hematoma or tracheal deviation
   B. easier airway management with immobilization
   C. more rapid transport using mandatory spinal immobilization
   D. provides false sense of security
4. With the traditional anatomic zones of the neck, zone I is:
   A. the area from the cricothyroid membrane to the angle of the mandible
   B. the largest most exposed area of the neck
   C. the area extending from the clavicle to the cricothyroid membrane
   D. devoid of important structures
5. Zone II extends from the cricothyroid membrane to the angle of the mandible and is the largest most exposed area of the neck. Injuries to this area are best managed with:
   A. mandatory surgical exploration
   B. emergent cricothyrotomy
   C. selective operative intervention.
   D. expectant management of the hemodynamically unstable patient
6. The selective nonoperative management of gunshot wounds to the abdomen requires:
   A. hemodynamic instability
   B. the ability to perform serial CT scans
   C. initial findings of peritonitis
   D. the ability of an experienced surgeon to perform serial physical exams
7. Gunshot injuries to the following areas are at an increased risk of infection *except*:
   A. shoulder
   B. hand
   C. foot
   D. ankle
8. A clinician must suspect lead poisoning in the patient with a retained bullet and which clinical scenario:
   A. pleuritic chest pain
   B. microcytic anemia with basophilic stippling and abdominal pain
   C. bilateral facial nerve palsy
   D. septic joint
9. A clinician should suspect bullet embolization when:
   A. there are an equal numbers of entry and exit wounds
   B. clinical signs and symptoms and radiological evidence correlate with the sustained injury
   C. acute limb ischemia remote from injury
   D. there is ongoing hemorrhage
10. The majority of bullet emboli are:
   A. paradoxical
   B. venous
   C. intra-articular
   D. arterial

CNE/CME Objectives

Upon completing this program, the participants will be able to:

- discuss conditions that should increase suspicion for traumatic injuries;
- describe the various modalities used to identify different traumatic conditions;
- cite methods of quickly stabilizing and managing patients; and
- identify possible complications that may occur with traumatic injuries.

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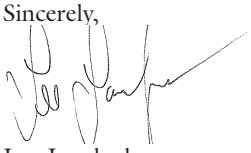

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