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### STATEMENT OF FINANCIAL DISCLOSURE

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# Penetrating Torso Trauma

*Penetrating trauma is a common presenting complaint with the potential for devastating consequences. The diagnostic and therapeutic management of penetrating injuries to the chest and abdomen has undergone substantial evolution. The authors discuss the advances in the care of patients with penetrating chest and abdominal trauma.*

*— Ann M. Dietrich, MD, Editor*

## Introduction

In the United States, the leading cause of death among people younger than 46 years of age remains traumatic injury.[1] In the past several decades, many case series and reviews have documented an increase in penetrating trauma throughout the United States. Penetrating abdominal trauma affects approximately 35% of patients admitted to urban trauma centers and roughly 1-12% of those admitted to suburban or rural centers.[2] Approximately 9% of trauma-related deaths occur secondary to injuries to the thorax, but only one-third of these involve a penetrating mechanism.[3,4]

## Mechanism

Penetrating torso trauma can be the result of an accident or an intentional action. Intentional penetrating trauma can be self-inflicted or caused by an assault. In general, penetrating trauma is seen most commonly in urban violence, domestic violence, and war.

Most penetrating injuries to the torso usually are a result of firearms or stab wounds. In a recent review of urban penetrating trauma in the United States, there was a nearly even distribution between gunshot wounds (GSWs) and stab wounds.[5] Given this, it is important to keep in mind the difference in injury patterns associated with each type of injury. Stab wounds are associated with low energy, and therefore typically only cause tissue damage to the tract that is directly in contact with the weapon. GSWs can be divided loosely into two distinct patterns: those of low velocity and those of high velocity. Understanding the type of weapon used allows for a better prediction of potential injury patterns and the subsequent evaluation and management that might be required.

## Prehospital Management

Many of the deaths that occur on the scene of a trauma usually are secondary to exsanguination. In the setting of penetrating thoracic and abdominal wounds, bleeding is very difficult if not impossible to control. This is contrary to extremity wounds and junctional bleeding, which can be temporized quickly with tourniquets and wound packing. Given this, the first priority becomes minimizing

## EXECUTIVE SUMMARY

- Routine spine immobilization in penetrating trauma is not of benefit and may be harmful. This may be related to the injuries themselves, or decreasing the ability of providers to care for the patient by obscuring the injury, making necessary life-saving procedures more difficult, and delaying transportation to definitive surgical care.
- The indications as recommended by the Eastern Association for the Surgery of Trauma (EAST) organization are to perform an emergency department (ED) thoracotomy in: 1) patients who present pulseless to the ED with or without signs of life (SOL) after penetrating thoracic injury; 2) patients who present pulseless to the ED with or without SOL after penetrating extrathoracic injury; and 3) patients who present pulseless to the ED with SOL after blunt injury.
- In penetrating abdominal trauma due to gunshot wounds, the most commonly injured organs are the small bowel (50%), colon (40%), liver (30%), and vascular structures (25%). With stab wounds, the most commonly injured organs are the liver (40%), small bowel (30%), diaphragm (20%), and colon (15%).

time in the field and expediting the patient's transfer to definitive care.

The notion of placing a patient with penetrating trauma in spinal immobilization with cervical collars and backboards has stemmed from the idea of protecting the patient from an occult cervical spine injury. However, the rate of occult cervical spine injury in patients who sustain penetrating torso trauma is extremely low. No study has shown spinal motion restriction to be beneficial regarding mortality or neurologic injury, even when patients with direct neck injuries were included.[6] Thus, unless there is a neurological deficit or the mechanism of injury is highly concerning for cervical spinal injury, routine spinal motion restriction in penetrating trauma is not of benefit and may be harmful. Some studies have suggested that this may be related to the injuries themselves, while others suggest that immobilization hampers the ability of providers to care for the patient because it can obscure injury, make necessary life-saving procedures more difficult, and delay transportation to definitive surgical care at a trauma center.

The adage of "2 liters of crystalloid" as a first-line method of aggressive resuscitation to maintain a normal blood pressure also has fallen out of favor. In a study, Bickell et al demonstrated that for patients with penetrating torso trauma, allowing for hypotension and delaying aggressive fluid resuscitation prior to operative intervention improves outcomes.[7] Permissive hypotension in this setting theoretically allows for clot stabilization while mobilizing for definitive hemorrhage control. Attempts at normalizing blood pressures can result in clot dislodgment and worsening hemorrhage.[8] In 2002, Dutton et al also demonstrated the benefits of permissive hypotension by titrating initial fluid therapy to a lower than normal systolic blood pressure (SBP) during active hemorrhage.[9] They showed that targeting an SBP of 70 mmHg vs. 100 mmHg did not affect mortality, thus supporting the notion of permissive hypotension in the hemorrhaging patient until definitive source control can be achieved. Based on this and similar studies, current recommendations encourage permissive hypotension for the hemorrhaging trauma patient.[10,11] A prehospital strategy of using a palpable radial pulse and appropriate mentation to guide fluid resuscitation has been employed to aid with decreasing the risks associated with normotension in the trauma patient.

## Initial Evaluation and Resuscitation

All patients who sustain penetrating torso trauma require an immediate systematic evaluation assessing airway, breathing, circulation, and initial vital signs. The physician then should obtain a brief history, including the nature of the penetrating injury. Some of the important information includes the time of injury, type of weapon, distance from the weapon, number of wounds, initial vital signs, current vital signs, and amount of blood at the scene. The time and effort necessary to ascertain this information should never delay patient care. The mnemonic AMPLE can be used to facilitate a quick and focused history to ascertain the patient's allergies, medications, past medical history, last meal, and any events that preceded or are related to the injury. However, when the clinical scenario allows, gathering injury-specific information can be useful in the initial evaluation and resuscitation of the patient.

Patients who sustain stab wounds should be asked about the type of weapon used, in particular its length and position or trajectory during the stabbing, which allows the physician to form an idea of a possible injury pattern. Likewise, those who have sustained GSWs should be asked about the type of gun used and the number of shots heard because this will allow the physician to begin forming a differential of potential injuries.

If possible, laboratory investigations should include, at a minimum, a type and screen, venous gas, and pregnancy test, followed by a highly organized approach to the evaluation and treatment based on regional anatomy. This requires complete exposure of the patient and a thorough and immediate inspection for penetrating wounds, paying particular attention to areas where these wounds can hide, such as the axilla, groin, and perineal areas. The continued approach ensues with principles learned from advanced trauma life support (ATLS),[10] which includes obtaining intravenous (IV) access, administering blood and fluid resuscitation, as well as preventing hypothermia. It is important to stress the idea of "hypotensive resuscitation,"[8] in which there is the delay of aggressive resuscitation until operative intervention can occur, which has been demonstrated to lead to improved outcomes.[11] Although several thresholds have been mentioned in the literature as an appropriate goal for blood pressure, the European Guidelines for Management of Major

Bleeding recommend "a target systolic BP of 80-90 mmHg until major bleeding has been stopped in the initial phase following trauma in patients without brain injury."[12] Prior to obtaining definitive hemorrhage control, ensuring resuscitation with blood products early, if available, through large bore IV access to maintain a systolic blood pressure of ≤ 90 mmHg, or to the minimum level for appropriate mentation, has clear benefits to prevent increased bleeding. This is directly related to the dislodgment of intraluminal clot and reversal of any vascular spasm seen in completely transected vessels.[7,8]

Patients who present with life-threatening hemorrhage should prompt consideration of an early activation of the institution's massive transfusion protocol (MTP). For patients who require MTP, the principle of a balanced transfusion should be considered and implemented when feasible. While the ideal exact combination of blood products is still controversial, a packed red blood cell (PRBC) to fresh frozen plasma (FFP) ratio of 1:1 or 1:2 has been recommended, as well as a PRBC:FFP:platelet ratio of 1:1:1.[13-18]

At this point, identification of any life-threatening conditions that require immediate intervention (tension pneumothorax, large-volume hemorrhage, pericardial tamponade) should be addressed expeditiously. The next step involves a focused diagnostic search for injuries, which will require prompt operative intervention. The use of both anterior-posterior and cross table lateral radiographs can provide essential information in the initial assessment of the patient with penetrating GSW trauma to provide data on possible injuries, retained bullets, and trajectories. For example, a retained bullet seen in the left hemipelvis with a single entrance wound in the right lower quadrant of the abdomen provides the knowledge of a known transpelvic GSW injury and the possible associated injuries that can be seen with this injury pattern. Additionally, early extended focused assessment with sonography in trauma (E-FAST) should be part of the initial evaluation.

The traditional FAST exam is a rapid test that sequentially surveys four basic sonographic views to evaluate for blood or fluid and includes the pericardial, perihepatic, perisplenic, and pelvic spaces. The E-FAST adds to these basic views by providing information about the thorax, specifically assessing for the presence of a pneumothorax or hemothorax by examining the thorax anteriorly in two separate views, as well as at the flanks. The cardiac window has been shown to be the most sensitive and specific in the setting of penetrating precordial wounds;[19] however, in trained hands, the ultrasound can detect as little as 200 mL of fluid in Morison's pouch, and as little as 20 mL in the pleural space.[20-23] While the E-FAST exam is crucial in the evaluation of trauma patients, it is important to recognize the limitations, since patient selection is of paramount importance. Patients who are obese or those with isolated retroperitoneal bleeding, pre-existing ascites, or pericardial effusions can be diagnostic dilemmas, and these factors should be considered when using the E-FAST exam.[24]

## Emergency Department Thoracotomy

If arrest occurs at any point during the initial assessment of the patient with penetrating torso trauma, the need for an emergency department thoracotomy (EDT) is clear. An EDT is one of the most dramatic, and has the potential to be one of the most therapeutic, surgical interventions performed in the trauma patient. However, it also remains one of the most controversial procedures. The indications for its use continue to be a point of debate, and the survival rate remains far less than 50%.[25]

The inability to design a prospective randomized trial for EDT remains the largest barrier to creating a standardized algorithm with clear indications. Over the years, many general recommendations have been created based on retrospective reviews of data from different institutions. In 2001, the American College of Surgeons Committee on Trauma (ACS COT) established guidelines for performing an EDT.[26] The committee stated that an EDT is best applied to those with penetrating cardiac injuries who arrive at the hospital with signs of life (SOL), where SOL are defined as the presence of any of the following: pupillary response, spontaneous ventilation, presence of carotid pulse, measurable or palpable blood pressure, extremity movement, or cardiac electrical activity.[26] Additionally, the guidelines recommend that EDT should be performed for noncardiac thoracic and exsanguinating abdominal vascular injuries; however, both of these patient populations have low survival rates. Furthermore, blunt trauma patients who suffer a cardiac arrest rarely should have an EDT performed because of low survivability and poor neurological outcome. Only patients who arrive to the hospital with vital signs and then have a witnessed cardiac arrest should have an EDT following blunt trauma.[25]

Recently, both the Eastern Association for the Surgery of Trauma (EAST) and the Western Trauma Association (WTA) have published guidelines for EDT indications and patient selection. The indications as recommended by the EAST organization are to perform an EDT in: 1) patients who present pulseless to the emergency department (ED) with or without SOL after penetrating thoracic injury; 2) patients who present pulseless to the ED with or without SOL after penetrating extrathoracic injury; and 3) patients who present pulseless to the ED with SOL after blunt injury.[27] These EAST guidelines are summarized in Table 1.

## Resuscitative Endovascular Balloon Occlusion of the Aorta

Resuscitative endovascular balloon occlusion of the aorta (REBOA) provides a tool that may be beneficial in selected patients for the management of noncompressible torso hemorrhage. Recent advances in technology have designed smaller femoral access sheaths, which may allow for more rapid placement. Unfortunately, there is limited high-grade evidence to guide REBOA use, and there is a substantial complication risk.

In 2013, Mehta et al published a study that showed that endovascular aortic occlusion for ruptured abdominal aortic aneurysms was feasible, with

similar outcomes in both hemodynamically stable and unstable patients.[28] This and similar work in the area of endovascular techniques has led to the evolution of REBOA for traumatic arrest and severe hypotension secondary to hemorrhagic shock.

REBOA supports proximal aortic pressures and minimizes hemorrhage until definitive hemostasis can be achieved, very similar to EDT. It is still in its infancy with regard to use in the trauma patient with truncal noncompressible hemorrhage. In general, the indications are very similar to those for EDT. In a joint policy statement regarding the clinical use of REBOA published in 2018, the ACS COT and the American College of Emergency Physicians (ACEP) identified indications for REBOA.[29] REBOA is indicated for:

- Traumatic life-threatening hemorrhage that is located below the diaphragm in patients who are in hemorrhagic shock and who are not responsive to resuscitation or are transiently responsive to resuscitation.
- Patients who arrive in arrest as a result of an injury that is caused by presumed life-threatening hemorrhage below the diaphragm. Although there is no evidence available regarding the duration of the arrest and the use of REBOA, the policy statement says that REBOA should be used in the same time frame as resuscitative thoracotomy would be.[29]

Regarding balloon catheter inflation, the joint policy statement indicates the following:

- For the control of severe intra-abdominal or retroperitoneal hemorrhage, or for those in traumatic arrest, inflation of the balloon catheter may be at the distal thoracic aorta (Zone 1).
- For patients who have severe pelvic, junctional, or proximal lower extremity hemorrhage, inflation of the balloon catheter may be at the distal abdominal aorta (Zone 3).[29]

Recent data published by DuBose et al showed that in centers where REBOA is being used, there is a higher mean blood pressure on admission to the hospital when compared to those patients undergoing open aortic occlusion (AO).[30] Given that REBOA access via femoral arterial cannulation is much less invasive than EDT with better tolerance, the authors inferred that REBOA "may offer a better option at a graded response to significant noncompressible hemorrhage."[30] However, despite this, there has been no significant difference between REBOA and open AO with regard to overall mortality. In addition, ACS COT and ACEP issued guidelines on REBOA use and implementation. REBOA guidelines from the Advanced Trauma Life Support (ATLS) Subcommittee, American College of Surgeons Committee on Trauma, and International ATLS working group indicate that protocols regarding REBOA should be developed in concert with vascular surgery. Also, ideally, REBOA should be performed by an acute care surgeon or interventionalist with REBOA training. Of critical importance, the guidelines require that an acute care surgeon must be immediately available to address the specific cause of hemorrhage and prevent the serious complications, such as spinal cord or truncal ischemia, from prolonged occlusion of the aorta.[29]

Emergency physicians who have added critical care certification and who are trained in REBOA may perform REBOA in conjunction with an acute care or vascular surgeon who is trained in REBOA if the surgeon is immediately available to provide definitive control for the source of bleeding. In addition, emergency physicians who have significant and documented experience and training with REBOA from military deployment may train and perform the procedure in conjunction with REBOA-trained acute care or vascular surgeons, with the same stipulation that the surgeon be immediately available to provide definitive control of bleeding. Lastly, physicians who are certified in emergency critical care and trained in REBOA must not perform the procedure unless there is a surgeon immediately available.[29]

The use of REBOA is not without risk. Some of the risks reported in the literature include complications secondary to bleeding, incorrect balloon positioning, arterial injury or rupture, increasing ischemic burden, and even cardiovascular collapse with acidosis seen with balloon deflation.[31] Secondary to the inability of prehospital providers to manage REBOA devices during transport, and the lack of evidence to support safe duration of aortic occlusion, transfer of patients with REBOA is not recommended. Thus, REBOA should not be placed in emergency departments in institutions where the patient cannot receive definitive surgical care and hemostasis at that same institution.

**Table 1. Summary of Eastern Association for the Surgery of Trauma (EAST) Guidelines for Emergency Department Thoracotomy (EDT)**

| Patient Presentation | Recommendation |
|---|---|
| Patients who present pulseless to the ED with signs of life after penetrating thoracic injury | Strongly recommend EDT |
| Patients who present pulseless to the ED without signs of life after penetrating thoracic injury | Conditionally recommend EDT |
| Patients who present pulseless to the ED with signs of life after penetrating extra-thoracic injury | Conditionally recommend EDT |
| Patients who present without signs of life after penetrating extra-thoracic injury | Conditionally recommend EDT |
| Patients who present pulseless to the ED with signs of life after blunt injury | Conditionally recommend EDT |
| Patients who present pulseless to the ED without signs of life after blunt injury | Conditionally recommend *against* EDT |

## Anatomical-Based Evaluation

When evaluating patients with penetrating torso trauma, it is crucial to divide

the body into zones of regional anatomy, thus allowing for treatment based on the different physiology associated with the different anatomy. In general, the thorax can be thought of as an entity distinct from the abdomen, with the exception of the thoracoabdominal region, defined by the fourth intercostal space superiorly (nipple line) and the costal margin inferiorly around the torso.[32] Within the thorax itself is the so-called "box," a region where a penetrating injury is considered to be of extraordinarily high risk for cardiac and great vessel injury. This has been defined as the area of the anterior chest bordered by the clavicles superiorly, by the midclavicular line laterally, and inferiorly by the line drawn between the points where the midclavicular lines intersect with the costal margins.[33]

When considering the abdomen, it can be thought of in three distinct regions: anterior abdomen, back/flank, and thoracoabdominal. The anterior abdomen is defined as the area extending from both anterior axillary lines laterally, and bordered by the inferior costal margin superiorly, and the pelvis inferiorly. The back is defined as the area extending from the tip of the scapula to the iliac crests and medially to the posterior axillary line. The flank is defined as the area that extends from the sixth intercostal space to the iliac crest, between the anterior and posterior axillary lines.[32]

Considering these anatomical divides allows for a more predictable approach to possible injury patterns and organ involvement. (*See Table 2.*)

**Table 2. Anatomical Regions and Organs Affected**

| Anatomical Region | Possible Organs Affected |
|---|---|
| Thorax | Heart, lungs, great vessels, diaphragm |
| Thoracoabdominal | Diaphragm, liver, spleen, stomach, bowel |
| Back/Flank | Colon, retroperitoneum |
| Anterior Abdomen | Colon, liver, spleen, stomach, small intestines, vascular structures, pancreas, bladder |

## Penetrating Thoracic Trauma

Penetrating thorax injuries make up 13% of all chest trauma cases.[34] Both GSWs and stab wounds can result in multiple different injuries; however, the majority of these (as much as 85%) can be managed by tube thoracostomy or simple observation.[35] In general, it is relatively uncommon that acute operative intervention is necessary in the management of chest trauma. The overall patient population can be divided into three distinct groupings. The first is the group of patients whose injuries are so severe that they die at the scene. Next is the group of patients who will require urgent thoracotomy for potentially fatal injuries. These injuries typically are discovered after initial resuscitation and with the aid of diagnostic studies. Last is the group of patients who will be managed with resuscitation, workup, and either observation or tube thoracostomy. This last category comprises the majority of patients who sustain penetrating thoracic injuries.

### Radiographs

Chest radiography remains the initial investigation of choice. Regarding penetrating thoracic trauma, it has been demonstrated that the majority of injuries that will require intervention, such as hemothorax, pneumothorax, or hemopneumothorax, are missed by physical exam, specifically auscultation, alone.[36] The sensitivities of auscultation, pain or tenderness, and tachypnea were 50%, 25%, and 32%, respectively.[37] The poor sensitivity of physical exam mandates obtaining a chest radiograph in penetrating thoracic trauma. The negative predictive values of auscultation, pain or tenderness, and tachypnea are less than 91%,[37] resulting in many of these patients having hemopneumothorax in the absence of any clinical findings. The overall sensitivity and specificity for detection of traumatic lesions on chest radiograph have been quoted as 78.8% and 85.7%, respectively, dramatically superior to that of physical exam alone.[38]

As previously mentioned, history, physical exam, and plain chest X-ray comprise the essentials of the initial diagnostic workup for thoracic trauma. A large proportion of these patients will not present with signs of dyspnea, tachypnea, or hypoxia during the initial workup and will appear relatively "asymptomatic." However, as much as 12% of these "asymptomatic" patients will have a delayed presentation of a pneumothorax or hemothorax.[39] When determining the necessary observation time of patients with penetrating thoracic injuries but no overt signs and symptoms of a pneumothorax or hemothorax, it has been demonstrated that after three hours of observation followed by a repeat chest X-ray, no patients developed delayed hemothoraces or pneumothoraces after the three-hour mark.[40] Thus, it is safe and cost effective to discharge patients after this observation time.

### Ultrasound

What was once considered to be a novel diagnostic tool, ultrasound has fast become an essential part of the standard trauma workup. The FAST has been shown to be extremely reliable in the early detection of hemopericardium in precordial penetrating trauma.[41] Rozycki et al evaluated ultrasound in patients with possible cardiac injuries.[41] In that study, the authors demonstrated a 100% sensitivity, specificity, and accuracy for the identification of cardiac injuries. From this, the authors concluded that ultrasound was a rapid and accurate technique for diagnosing hemopericardium. Rozycki et al then conducted a prospective multicenter trial that demonstrated similar results.[42] Ultrasound is not only rapid and accurate for the diagnosis of pericardial fluid following penetrating precordial trauma, but it also can rapidly assist with the diagnosis of pneumothorax and hemothorax.

Ultrasound also has been studied in the evaluation of traumatic pneumothorax, comparing chest X-ray

to ultrasound, and using computed tomography (CT) as the gold standard. In a prospective study by Rowan et al in 2002, ultrasound was more sensitive than supine chest X-ray. The sensitivity and negative predictive value of ultrasound were found to be 100% when compared to CT.[43] Thus, the E-FAST has become the standard of care in the initial evaluation of the patient with penetrating thoracic trauma in conjunction with the chest radiograph.[44,45]

### Computed Tomography

The clinical utility of thoracic CT with IV contrast in penetrating chest trauma remains somewhat controversial. In hemodynamically stable patients, it has been demonstrated to be an effective screening tool. A negative thoracic CT effectively rules out the presence of a life-threatening injury. Strumwasser et al[46] found thoracic CT to have a 99% negative predictive value and specificity in triaging hemodynamically normal patients with penetrating chest trauma. With this, providers can be confident in their decision that this patient population will not have an injury that requires operative management.

Because chest CTs are being performed at increasing rates, there also has been an increase in the number of clinically insignificant injuries and incidental findings identified.[47] This adds an additional aspect to emergency care that must be addressed within the system. All incidental findings or nontrauma related findings on imaging must be disclosed to the patient and appropriate follow-up/additional testing arranged.

Following identification of injuries, specific interventions should be undertaken. If an immediate, life-threatening injury is identified, prompt intervention, such as emergency tube thoracostomy for large pneumothoraces, and adequate drainage of hemothorax, is indicated.

Although the majority of thoracic trauma can be managed nonoperatively, 15% require operative management, and surgery should not be delayed when necessary. Operative exploration should be considered if the tube thoracostomy drainage exceeds 1,000 to 1,500 mL immediately, or if there is an output of approximately 200 mL per hour for two to four hours or ongoing resuscitation (blood transfusion, persistent hypotension).

**Table 3. Organs Injured in Abdominal Gunshot Wounds**

| Organs Injured in Abdominal Gunshot Wounds | Incidence |
|---|---|
| Small Bowel | 50% |
| Colon | 40% |
| Liver | 30% |
| Vascular Structures | 25% |

**Table 4. Organs Injured in Abdominal Stab Wounds**

| Organs Injured in Abdominal Stab Wounds | Incidence |
|---|---|
| Liver | 40% |
| Small Bowel | 30% |
| Diaphragm | 20% |
| Colon | 15% |

## Penetrating Abdominal Trauma

At inner-city trauma centers, penetrating abdominal trauma comprises 35% of abdominal trauma.[48] GSWs remain the most common cause of penetrating abdominal trauma, followed by stab wounds, and then shotgun wounds.

The difference between stab wounds and GSWs also becomes an important distinction for management. In penetrating abdominal trauma due to gunshot wounds, the most commonly injured organs are the small bowel (50%), colon (40%), liver (30%), and vascular structures (25%).[49] (*See Table 3.*) With stab wounds, the most commonly injured organs are the liver (40%), small bowel (30%), diaphragm (20%), and colon (15%).[49] (*See Table 4.*)

Despite the region of the penetrating injury, patients who are hemodynamically unstable or have diffuse abdominal tenderness should be taken emergently for laparotomy. Any patient who is hemodynamically stable but has an unreliable clinical exam (for example, patients with traumatic brain injury, intoxication, or altered mental status) should have a complete diagnostic investigation,[50] either with imaging or laparotomy. The decision about which imaging study is best suited for a particular injury pattern will be discussed in the following sections.

The concept of nonoperative management of select types of penetrating abdominal trauma has evolved over the past several decades. The high incidence of nontherapeutic laparotomies (NTL), noted to occur in as many as 48% of laparotomies when performed for stab wounds and 45.3% when performed for GSWs, led to the pursuit of nonoperative management strategies.[51] Given the increased morbidity and cost associated with NTL, selective nonoperative management (SNOM) becomes a valid management principle in the care of the penetrating trauma patient.[52,53] Thus, when deciding to pursue surgical management vs. SNOM, in addition to the hemodynamics and mechanism, one also must consider the institution's support system (surgical and ED staff available for serial exams, room in the hospital for observation, etc.) and diagnostic capabilities.[54,55] The anatomical regions of the abdomen delineated previously (the thoracoabdominal region, the back/flank, and the anterior abdomen) will be used to facilitate identification and management strategies.

## Thoracoabdominal Penetrating Trauma

Trauma in the thoracoabdominal region gives rise to injuries in both the chest and the abdomen, including the diaphragm. Penetrating trauma in this area has the potential for significant injury, but it typically presents subtly. Even with the diagnostic adjuncts of multi-detector CT (MDCT) scanning, the specificity of CT findings suggesting a diaphragm injury still is just about 40%.[56] Thus, the evaluation for a diaphragm injury should include either thoracoscopy or laparoscopy.

Uribe and colleagues performed routine thoracoscopy and found diaphragmatic injuries in 32% of patients with

penetrating thoracoabdominal injuries.[57] Subsequent laparotomy found that 89% of those patients with diaphragmatic injuries also had intra-abdominal injuries that required surgical repair. Multiple studies have investigated the role of laparoscopy in the diagnosis and management of occult diaphragmatic injuries, and the incidence is approximately 24% of patients with penetrating thoracoabdominal injuries.[58,59]

The evaluation of stable patients with penetrating thoracoabdominal trauma should start with an upright chest X-ray and an E-FAST. A pneumothorax or hemothorax with a negative FAST would indicate thoracoscopy to evaluate the diaphragm. If there is a diaphragm injury, as would be expected in 24% of patients, laparoscopy or laparotomy is indicated to rule out any intra-abdominal injury. If the initial FAST is positive, laparotomy or laparoscopy should be performed to evaluate both the abdomen and the diaphragm.

## Back and Flank Penetrating Trauma

In stark contrast to the anterior abdomen, posterior penetrating injuries require intervention less frequently.[60] The likelihood of a significant injury is much lower than for other anatomic regions; however, these injuries can pose diagnostic challenges.

Most injuries will be in the retroperitoneum, an area of the body that generally tends to tamponade itself. The use of physical exam and FAST to assess for injury lacks sensitivity. Additionally, local wound exploration is not recommended[61] because the fascial planes are not well defined posteriorly, and local wound exploration does not aid with determining the extent of injury. In fact, it can worsen bleeding if a previously tamponaded bleed is dislodged.

Stable patients with back or flank penetrating trauma should undergo CT scan, since this is a reliable test for excluding significant injury.[32,62] These patients can be managed according to the CT findings, the majority of which lend themselves to nonoperative management. The addition of rectal contrast for the evaluation of penetrating back and flank trauma was first described by Phillips et al.[63] They concluded that the use of rectal contrast allowed for appropriate identification of the small number of patients who required surgical intervention. With the improved sensitivity of MDCT, it has become increasingly possible to follow wound tracts and obtain fairly accurate trajectory assessments, thus bringing into question the need for rectal contrast. In a large retrospective review examining single-contrast CT for triaging hemodynamically stable patients with penetrating torso trauma, the authors noted the overall sensitivity and specificity to be 98% and 90%, respectively.[64] This provided a positive predictive value of 84%, negative predictive value of 99%, and an overall accuracy of 93% in determining the need for an emergent exploration.[64] A series in 2018 found that single-contrast CT can show bowel injuries in patients with penetrating abdominopelvic trauma with accuracy comparable with that reported for triple-contrast CT.[65]

## Anterior Abdomen Penetrating Trauma

All patients sustaining anterior abdominal penetrating trauma who are hemodynamically unstable and/or present with evisceration require immediate operative exploration. However, penetrating wounds that present with hemodynamic stability pose a much greater challenge and require a careful, considerate approach.

In the 1960s, Shaftan challenged the idea of mandatory laparotomy for anterior abdominal stab wounds (AASWs), proposing an idea of "selective conservatism," which is management that is based on clinical evaluation.[66] This idea was demonstrated to be valid in a study by Alzamel and Cohn, in which they showed that AASWs with only serial physical exams will elucidate the patients in need of operative intervention within 12 hours of injury.[67] From this, they concluded that after 12 hours of observation, asymptomatic patients may be discharged home from the emergency department safely.

It is generally accepted that only 50-75% of all AASWs enter the peritoneal cavity, and of those, only 50-75% will cause an injury requiring operative repair.[68,69] The notion that mandatory exploration is required for the hemodynamically stable patient with an AASW in the absence of peritonitis or evisceration is no longer practiced, and SNOM is the standard of care.

Regarding anterior abdominal GSWs, physical exams also have been demonstrated to be a useful tool in determining those in need of operative repair. Demetriades et al demonstrated that the rate of NTL decreased from 41.6% to 10% after implementing a strategy of conservative management based on serial physical exams.[70] These exams were performed by senior-level residents or attending surgeons, and eliminated the notion of mandatory exploration. However, this may not be a practical model at many trauma centers, which should be considered when deciding on management. Thus, in a mature trauma center with experienced trauma clinicians, serial physical examination is reliable in detecting significant injuries after penetrating trauma to the abdomen of hemodynamically stable patients, and it is a valid management tool where feasible.[71,72]

This concept has even started to become part of the management for anterior abdominal GSWs. Demetriades et al demonstrated a reduction of unnecessary or NTL from 27% to 5% with the introduction of selective conservative management.[73] The management of GSWs to the anterior abdomen had always been considered to require a mandatory laparotomy; however, approximately 30% of these injuries can be managed nonoperatively.[74,75]

### Initial Management

As with all trauma patients, the initial management of anterior abdominal penetrating trauma begins with standard airway, breathing, circulation, and the initiation of large bore IV access. Complete exposure of the patient with a detailed physical exam is of paramount importance because it is easy to become distracted by the obvious and miss other injuries in places such as the perineum and axilla. Patients who are hemodynamically unstable should proceed to the operating room; those who are deemed stable and not in need of laparotomy require further diagnostic evaluation and management, with serial

physical exams, local wound exploration, ultrasound, or CT scan.

### Local Wound Exploration

Given that serial physical exams require senior-level providers and 12 hours of observation to determine whether a patient can be discharged safely, the idea of peritoneal penetration as a criterion for discharge led to the notion of local wound exploration. For this technique performed in the ED, local anesthetic is infiltrated into the wound area, and an incision is made that allows for adequate evaluation of the wound tract to its distal extent.[76] A positive local wound exploration is defined as violation of either the anterior or posterior fascia. A negative local wound exploration is defined as one in which the fascia is noted to be intact and the peritoneum has not been violated. Only 11% of AASWs without an overt indication for laparotomy will require surgical care, and local wound exploration remains a validated method to exclude intra-abdominal injury in more than one-third of this patient population.[77] Patients with a negative local wound exploration study can be discharged safely with local wound care, since the sensitivity and specificity have been noted to be as high as 88% and 93%, respectively.[78]

### Sonography

The use of ultrasound in the evaluation of penetrating anterior abdominal trauma has been well described and evaluated. It is an easily accessible and noninvasive test that is performed at the bedside and can be repeated easily. As intended, FAST is used best as an adjunct to detect intra-abdominal fluid in the trauma patient quickly. The overall assumption with the traditional FAST is that all clinically significant abdominal injuries will be associated with hemoperitoneum. The test has facilitated point-of-care decision making, bringing immediate results to the patient's bedside when other assessments might prove to be prohibitive. A positive FAST, defined as free fluid in one of the windows, provides the clinician with a strong predictor of injuries and identifies patients who likely will require a laparotomy.

In a study by Udobi et al, when specifically looking at the anterior abdomen, both the specificity and positive predictive value were noted to be 100%.[79] However, the negative predictive value was found to be 59%[79] in this same study, thus limiting the overall accuracy of the test. In a multicenter study of AASW management by the Western Trauma Association, a positive FAST was defined as any evidence of hemoperitoneum. In this study, the sensitivity of FAST was 21%, the specificity was 94%, the positive predictive value was 50%, and the negative predictive value was 81%.[80] As evidenced by these and other studies, several factors limit the ability of FAST to identify injuries. These include poor accuracy in the very early post-injury phase, body habitus, hollow viscus injuries, and retroperitoneal injury. Thus, while it is valuable as an initial adjunct in the evaluation of abdominal penetrating injuries, FAST alone is not sufficient to use as the only diagnostic tool for determining management, particularly when the study is negative.[81] In these cases, when hemodynamics permit, CT scanning should be employed in the decision making of patient management.

### CT Scanning

Given that SNOM has expanded from blunt to penetrating trauma, using a CT scan has become the gold standard for evaluation of hemodynamically stable patients with penetrating abdominal injuries. The diagnostic role of a CT scan with rectal contrast also has been expanded to include penetrating abdominal injury. Previous studies have demonstrated improved rates of sensitivity and specificity when using a triple contrast abdominopelvic CT scan for diagnosing injury following penetrating torso trauma.[82-84] The term "triple contrast" refers to oral, IV, and rectal contrast.

In a study by Chiu et al in 2001, researchers examined 75 patients with penetrating torso trauma using triple contrast CT.[82] They successfully managed 96% of patients with negative CT scans nonoperatively. In this study, triple contrast CT had a 94% sensitivity and 95% specificity for determining the need for laparotomy based on evidence of peritoneal violation. This led the authors to the conclusion that triple contrast CT can accurately exclude peritoneal violation and avoid an unnecessary laparotomy in patients without a clear indication for an operation. Based on this and similar studies,[83,84] patients without evidence of peritoneal violation on CT scan can be discharged safely from the emergency department.

The administration of oral contrast has been noted to delay imaging up to 173 minutes,[85] which is time that can delay crucial interventions. The primary concern when evaluating this patient population remains determining whether the patient needs laparotomy, can be observed, or can be discharged safely. It is well known that patients with solid organ injuries and free fluid can be either observed or taken for laparotomy based on injury location, injury grade, hemodynamics, laboratory studies, and CT features. However, the concern remains the ability to identify hollow viscus injuries. It has been demonstrated that the most sensitive indicator for emergency exploration because of hollow viscus injury was the extension of wound tracts to or near a hollow viscus, not extravasation of enteral contrast itself.[84] This had led to using single contrast CT scans as a primary means of evaluating hemodynamically stable patients with penetrating abdominal trauma. Because oral contrast administration involves an abundance of possible associated logistic issues, many institutions perform single contrast CT scans. Recent reviews have noted overall sensitivities and specificities of determining the need for laparotomy to be 98% and 90%, respectively.[86] Regarding identification of hollow viscus injury specifically, single contrast CT scans have been demonstrated to have a sensitivity of 88% and a specificity of 72%, resulting in an overall accuracy of 81%.[87] Based on these and similar reviews, it has been deemed safe to evaluate hemodynamically stable patients with single contrast CT scanning.[88-90]

## Conclusion

Penetrating torso trauma represents a wide array of complex injury patterns and can present many difficult diagnostic and therapeutic management challenges.

Those patients who present with hemodynamic instability require immediate surgical intervention. Hemodynamically stable patients require further evaluation. Given the multitude of possible injury patterns, it is imperative that the physician has a clear and organized approach to identify those patients who require an intervention and to avoid an unnecessary intervention.

Mandatory laparotomy for penetrating torso trauma had long been considered the standard of care. However, in recent years, numerous studies have demonstrated that there is a subset of patients who are appropriate for SNOM. Stable, asymptomatic patients are candidates for CT scanning. Those with clear evidence of extracavitary trajectory can be discharged from the ED. Those with isolated solid organ injuries might be candidates for nonoperative management; however, this decision must include consideration of the institution and its capabilities.

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## CME/CE Questions

1. To guide resuscitation in the prehospital setting of penetrating trauma, the best approach is:
   a. Administering 2 liters of intravenous fluid bolus
   b. Administering 2 units of packed red blood cells
   c. Targeting normal systolic blood level ranges
   d. Targeting a blood pressure that allows for palpable pulses and appropriate mentation

2. During the initial assessment of a penetrating trauma, what should the patient priority be?
   a. A highly organized approach that includes an evaluation of the airway, breathing, and circulation, followed by a brief history, exposure of the patient, and subsequent intravenous access with blood and fluid resuscitation
   b. Obtaining a full and detailed history and physical
   c. Obtaining a full set of laboratory investigations
   d. Complete exposure of the patient

3. What is the most sensitive and specific window that comes from the E-FAST exam?
   a. Lung
   b. Cardiac
   c. Morison's pouch
   d. Splenorenal fossa

4. Which is the *most* appropriate candidate for an emergency department thoracotomy?
   a. A 25-year-old man in a high-speed motor vehicle collision who arrives to the trauma bay pulseless with no signs of life, with closed chest compressions provided by emergency medical services (EMS), and ventilation by bag valve mask
   b. A 36-year-old woman with a single stab wound to the chest who arrives to the trauma bay pulseless with no signs of life, closed chest compressions provided by EMS, and ventilation by bag valve mask
   c. A 29-year-old woman with multiple gunshot wounds to the abdomen who arrives to the trauma bay intubated but loses pulses during the initial evaluation in the emergency department
   d. A 42-year-old man with multiple gunshot wounds to the abdomen who arrives to the trauma bay pulseless with bilateral fixed and dilated pupils, intubated, with closed chest compressions provided by EMS

5. Which of the following is true of all penetrating trauma patients who arrive at the emergency department?
   a. They should have a cervical collar placed promptly and be placed on a backboard if not already done by EMS.
   b. They require cervical spine immobilization until the appropriate imaging is obtained.
   c. Any cervical collar should be removed unless the patient is reported to have fallen.
   d. The majority of patients with no neurologic deficits or mechanism concerning for spinal injury may be managed without spinal motion restriction.

6. When evaluating patients with penetrating trauma to the thorax, the most common injury pattern seen that requires intervention is a hemothorax/pneumothorax. What is the best way to diagnose and manage these patients?
   a. Obtain a chest X-ray with a repeat after three hours.
   b. Perform a full physical exam, since auscultation sensitivity is high.
   c. Observe for symptoms such as dyspnea, tachypnea, or hypoxia.
   d. Perform pulse oximetry to identify hypoxia.

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