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Penetrating Thoraco-abdominal Injury

Penetrating trauma to the torso can present a complex diagnostic and therapeutic challenge. Injuries can occur to the precordium, the thoraco-abdominal region, abdomen, flank, back, and pelvis. Injuries often occur simultaneously in several body cavities. Each of these body regions may require a different approach for both diagnosis and treatment. Penetrating injury from the nipple line to the inguinal ligaments anteriorly and from the tip of the scapula to the inferior gluteal folds should prompt suspicion of intra-abdominal injury. The degree of hemodynamic stability dictates the initial approach to these patients. Mandatory exploration of all penetrating thoraco-abdominal injuries was once thought to be standard of care; however, this is no longer true. The following article will provide an updated guide for the evaluation, management, and disposition of patients with penetrating thoraco-abdominal trauma.

— The Editor

Introduction

Trauma is the leading cause of death for persons aged 1-44 years,[1] with torso trauma accounting for a large proportion of these deaths. Hemorrhage, which accounts for 30%-40% of all trauma deaths, occurs most commonly following chest or abdominal trauma.[2-4] The percentage of patients with penetrating trauma varies widely depending on the location and environment in which the injury occurs. In urban trauma centers, penetrating abdominal trauma comprises 35% of the population, while only 12% of those in suburban or rural setting are penetrating.[5] Penetrating chest injuries account for 1%-13% of thoracic trauma admissions.[6] A review by Mandal and Sanuzi found a 6.4% incidence of cardiac injury in patients with penetrating chest trauma.[7]

Mechanism

Firearm injuries generally are classified into low- or high-velocity injuries. Low-velocity (< 600 m/s) injuries typically are caused by handguns while high-velocity (> 600 m/s) injuries tend to be caused by military or hunting weapons. The degree of injury depends on the type of bullet, velocity, and energy transferred to the tissue.[8] Stab wounds (SW) generally are considered to be a low-energy mechanism and thus have minimal tissue damage and only affect structures penetrated. Knowledge of the type of weapon used will allow care providers to have a better understanding of potential injuries and the subsequent evaluation and management required.

Chest Trauma

Penetrating chest injuries account for as much as 13% of thoracic trauma.[6] Both stab wounds and gunshot wounds (GSW) can cause a wide variety of injuries. (*See Table 1.*) Published studies report that as much as 85% of penetrating chest trauma can be managed by tube thoracostomy or observation alone.[9] The

Executive Summary

- Penetrating trauma to the torso can present complex diagnostic and therapeutic challenges.
- Physicians must have a high degree of suspicion for shock in patients with penetrating thoraco-abdominal trauma who appear stable.
- Physicians must quickly assess for tension pneumothorax, large-volume hemorrhage, and pericardial tamponade in patients with penetrating chest trauma.
- Studies show as many as 85% of penetrating chest trauma can be managed by tube thoracotomy or observation.
- Mandatory surgical exploration for penetrating torso trauma is no longer valid.
- Studies show that ultrasound is more sensitive than chest x-ray and is as sensitive as computed tomography for diagnosing pneumothorax.

remaining patients may require surgical exploration and/or emergency department thoracotomy (EDT). The anatomic boundaries of the precordial "box" are defined as the area inferior to the clavicles, superior to the costal margins, and median to the midclavicular line.[10] Injury to this region should prompt consideration and evaluation of cardiac injury.

All patients should be evaluated immediately in a systematic manner assessing airway, breathing, and circulation. An initial set of vital signs and blood work also should be obtained. Patients who present hemodynamically unstable require emergent intervention. The emergency physician must quickly assess for life-threatening conditions that require immediate intervention (tension pneumothorax, large-volume hemorrhage, pericardial tamponade) and address these issues expeditiously.

Table 1. Thoracic injuries following penetrating trauma

- Hemothorax
- Pneumothorax/tension pneumothorax
- Hemopneumothorax
- Pulmonary contusion
- Cardiac laceration
- Pericardial effusion/cardiac tamponade
- Diaphragm injury
- Rib fracture
- Intercostal artery laceration

Physical Exam. Decreased or absent breath sounds may indicate pneumothorax/tension pneumothorax or large-volume hemothorax requiring tube thoracostomy. Several authors have described potential inaccuracies of physical exam alone in penetrating thoracic trauma. Chen et al retrospectively demonstrated that auscultation alone had a low sensitivity of 58%, but a 98% specificity for hemopneumothorax after penetrating chest trauma.[11] Bokhari et al prospectively demonstrated a 50% sensitivity, 100% specificity, and 100% positive predictive value (PPV) for auscultation alone following penetrating chest trauma.[12] Both authors concluded that auscultation is a good test to diagnose a hemothorax/pneumothorax, but not exclude it. Additionally, the PPV of physical exam for the detection of abnormal breath sounds in penetrating chest trauma does not require radiographic confirmation prior to treatment.

Chest Radiographs. The accuracy of detecting a hemothorax/pneumothorax is increased with the addition of a chest x-ray (CXR).[11,12] (*See Figure 1.*) Many patients present without initial signs or symptoms of intrathoracic injury following penetrating thoracic trauma. These patients have been termed "asymptomatic" and their management varies between institutions and practitioners.[13] As many as 12% of asymptomatic patients will have a delayed presentation of either a pneumothorax (PTX) or hemothorax (HTX).[14]

Most agree that asymptomatic patients can be managed with observation and serial CXR; however, the appropriate time of observation and the interval between serial CXRs remains controversial. Some authors have suggested as few as 3 hours in between CXR, while others recommend 48 hours.[13-18] In 1980, McLatchie and colleagues demonstrated a 10% incidence of delayed HTX or PTX following penetrating chest trauma. The authors recommended 48 hours of in-hospital observation and serial upright CXR to safely exclude delayed complications.[18] A decade later, Kerr and colleagues compared 6-hour and 24-hour follow-up CXR in asymptomatic patients following penetrating thoracic trauma. Four of 105 patients developed a PTX or HTX within 6 hours of admission. None of the remaining 101 patients developed a delayed PTX or HTX between 6 and 24 hours.[16] The authors concluded that the previous "6-hour rule" was valid. Two subsequent studies have attempted to demonstrate the safety of a 3-hour

Figure 1. Hemothorax following gunshot wound

observation period. Shatz et al compared expiratory anteroposterior CXR films on admission and at 3 and 6 hours.[15] No patient developed a PTX on the 6-hour study that was not present on the 3-hour CXR. The authors concluded that the 6-hour film provided no additional information and patients can be safely discharged home after a negative 3-hour film. Seamon et al evaluated upright posterioanterior CXR at 3 and 6 hours following asymptomatic penetrating chest trauma; no patient developed a delayed PTX or HTX on the 6-hour film that was not apparent on the 3-hour CXR.[13] The authors suggested that it is safe to discharge an asymptomatic patient home after 3 hours, and it is cost effective. Clearly, some period of observation is wise, though the exact duration needed has yet to be defined.

Ultrasound. The use of ultrasound (US) in the setting of penetrating chest trauma is increasing. The Focused Assessment for Sonography in Trauma (FAST) has been shown to be highly reliable for the early detection of hemopericardium in precordial penetrating trauma.[19-21] Ma et al demonstrated a 100% sensitivity, 99% specificity, and 99% accuracy in diagnosing pericardial fluid.[19] Using a standard 3.5 MHZ probe, Boulanger et al demonstrated no false negative pericardial effusions.[20] (*See Figure 2.*) A 1996 study by Rozycki et al evaluated US in patients with possible cardiac injuries.[21] The authors demonstrated a 100% sensitivity, specificity, and accuracy for identification of cardiac injuries. Additionally, the mean time for performance of the procedure was less than 1 minute and, when indicated, the time to operative intervention was just slightly more than 12 minutes from time of US. The authors concluded that US was a rapid and accurate technique for diagnosing hemopericardium. Rozycki et al then conducted a prospective multicenter trial that demonstrated similar results.[22] The authors concluded that US not only is rapid and accurate for the diagnosis of pericardial fluid following penetrating precordial trauma, but also should be the **initial** modality for evaluation.

Penetrating chest trauma that occurs "inside the box" increases the index of suspicion for cardiac injury. However, when the site of injury is located "outside the box," physicians may be less likely to consider the possibility of a cardiac injury. Degiannis et al demonstrated a higher mortality from cardiac injuries when the wound entrance was "outside the box."[23] Additionally, Claassen et al reported a small case series of patients with cardiac injuries with wound entrances "outside the box."[24] The authors' conclusion stressed the consideration for cardiac injuries even when the penetrating wound is not located within the precordium.

The use of US also has been found to be reliable for the detection of traumatic pleural effusions and hemothoraces.[19,25,26] Ma et al demonstrated that intercostal oblique views were 96% sensitive, 100% specific, and 99% accurate in diagnosing free pleural fluid.[19] Sisley et al compared the accuracy of US and CXR for traumatic effusions.[25] US had a higher, although not statistically significant, sensitivity, 97.5% vs. 92.5%. Both modalities had a specificity of 99.7%. However, US had a significantly decreased time to diagnosing traumatic effusion as compared to CXR (1.30 minutes vs. 14.18 minutes, $P < 0.0001$). Similarly, Ma and Mateer evaluated 240 patients for the ability of US to detect HTX compared to CXR.[26] The authors found the same statistical results using both modalities (sensitivity 96.2% and specificity 100%) and suggested that US may expedite the diagnosis and treatment in patients with major trauma.

Numerous studies have demonstrated the supine antero-posterior CXR is insensitive for diagnosing PTX when compared to computed tomography (CT).[27-29] In contrast, studies have shown that the use of US to be more sensitive than CXR and as sensitive as CT in diagnosing PTX.[29,30] The sonographic signs of a PTX first were described in 1987 by Wernecke and colleagues.[31] Normal pleura is seen as an echogenic stripe between the parietal and visceral layers. During normal respiration in patients without a PTX, these two layers move, giving a "lung sliding" appearance.[32] Additionally "comet tails," vertical, narrow-based, laser-like hyperechogenic reverberation artifacts, are present on an US of normal lung.[33] In patients with a PTX, both of these signs are absent due to air between the two pleural layers reflecting the soundwave.[33,34] Other US findings suggesting the presence or absence of a PTX include the seashore sign and stratosphere sign. Using M-mode, the seashore sign is described as a linear, laminar pattern superficial to the pleura and a grainy or "sandy" appearance deep to the pleural line.[35] Its presence excludes the diagnosis of a PTX. The stratosphere sign is an M-mode pattern described as a linear, laminar pattern above and below the pleural line. It suggests a lack of lung sliding and the presence of a PTX.[35]

Kirkpatrick and colleagues evaluated the Extended FAST (EFAST) for diagnosing post-traumatic PTX.[36] US was compared to both CXR and CT scan. US had a higher sensitivity with similar specificity when compared to CXR. Rowan et al prospectively evaluated 27 patients for the presence of traumatic PTX

Figure 2. Pericardial effusion following penetrating chest trauma

Courtesy Scott Weingart, MD, Mount Sinai School of Medicine, Elmhurst Hospital Center comparing CXR and US while using CT as the gold standard.[29] Eleven patients were found to have a PTX on CT scan. US diagnosed all 11 patients with only 1 false positive, a patient with significant bullous disease on CT scan. CXR diagnosed only 4 of the 11 PTX. The authors concluded that US was more sensitive than CXR and as sensitive as CT for diagnosing post-traumatic PTX.

Computed Tomography. CT has become routine for evaluation of traumatic thoracic injury. Many institutions have protocolized the workup of trauma to include full body scans and, as such, many injuries that previously were not seen now are being diagnosed. As a result, injuries not seen on supine CXR, specifically pneumothorax, termed occult PTX (oPTX), are being diagnosed at a higher frequency.[29,36,37] Occult PTX is concerning especially for patients with diminished cardiopulmonary reserve or those who require positive pressure mechanical ventilation; left untreated they can progress to a tension PTX and become life threatening.

Much debate exists as to the proper management of the oPTX. Many believe if patients are asymptomatic, not on mechanical ventilation, and the oPTX remains stable in size, close observation is safe.[38-40] However, patients on mechanical ventilation are at a higher risk of complication and the development of a tension PTX.[41] Thus, some clinicians believe the risk of an untreated oPTX progressing to a tension PTX is too high when a patient is on positive pressure mechanical ventilation, and believe a prophylactic chest tube should be placed.[42-44]

Others believe that a prophylactic chest tube in the mechanically ventilated patient is not mandatory.[38,39] Collins et al reported safe treatment of oPTX with close observation for patients on mechanical ventilation. In their study, only 20% of patients on positive pressure ventilation required chest tube placement due to progression of the initial oPTX.[38] Similarly, Brasel et al demonstrated 22% of mechanically ventilated patients with an initial oPTX required a chest tube for a worsening PTX.[39] The authors concluded that observation alone is safe for patients with oPTX on positive pressure ventilation. It has been suggested that the size of the initial oPTX is not predictive of progression to a tension PTX and should not be used as a guide.[45] For those patients who require operative intervention, it is imperative that the anesthesia provider be aware of the oPTX in case the patient has an acute intra-operative decompensation.

Diaphragm Injuries. The diaphragm traditionally has been an organ that was difficult to evaluate without surgical exploration. Some studies suggest that diaphragmatic injuries occur in 7% of patients following penetrating torso trauma while others studies have rates as high as 40%.[46,47] Missing penetrating diaphragm injuries have significant implications for long-term morbidity and mortality.[48,49] Degiannis and colleagues evaluated 45 patients with diaphragmatic injuries after penetrating trauma.[48] Thirty-five percent of patients had their injury missed during their initial hospital admission. When comparing mortality rates between the early diagnosis and delayed diagnosis groups, those having a delayed diagnosis had a 25% rate of mortality as compared to 3% in the early group. CT has been advocated as an alternative to surgical exploration for diagnosing diaphragm injuries. Early studies using spiral CT demonstrated variable sensitivities and specificities in diagnosing diaphragmatic injuries.[50-53] With the increasing availability of multi-detector row CT (MDCT) with high-resolution axial, coronal, and sagittal reformatted images, the use of CT to diagnose or exclude diaphragm injuries has increased. (*See Figure 3.*) Stein et al evaluated 803 patients following penetrating torso trauma.[54] There were 67 (8.3%) patients with a diaphragm injury. MDCT diagnosed 55 (82.1%) of the diaphragm injuries, while excluding 95.9% of patients without an injury. Only 2 false positives and 4 false negatives were found using MDCT. A 2009 study by Bodanapally et al found an 87.2% sensitivity and 72.4% specificity using MDCT for diagnosing penetrating diaphragm injury.[55] Although MDCT is not a perfect test for the diagnosis or exclusion of a diaphragm injury, it offers an accurate test for diagnostic evaluation for patients who do not have a specific indication for operation.

Figure 3. Diaphragm injury after penetrating trauma

ED Thoracotomy

Few things are as controversial as the use of EDT following penetrating injury. EDT has the ability to immediately salvage patients who otherwise certainly would die. EDT first was described in 1966, when Beall and colleagues described the procedure as a component of the resuscitation of moribund patients with penetrating chest trauma.[56]

Indications and Outcomes. All would agree on certain indications for EDT, such as the patient with penetrating chest trauma who arrests in the resuscitation bay. Current indications include: cardiac arrest following witnessed penetrating thoracic trauma with < 15 minutes of pre-hospital cardiopulmonary resuscitation (CPR); witness penetrating non-thoracic trauma with < 5 minutes pre-hospital CPR; persistent severe post-injury hypotension with cardiac tamponade or intrathoracic hemorrhage.[57]

The outcome of EDT will vary with the indication. If EDT is performed on every patient who presents with cardiac arrest regardless of mechanism, outcomes will be poor. A meta-analysis by Rhee et al demonstrated EDT had a survival of 8.8% following penetrating trauma.[58] When the authors subcategorized patients, survival was 16.8% for SW and 4.3% for GSW. Isolated SW to the heart had the greatest survival at 19.4%. Patients with thoracic injuries had a greater chance of survival than those with abdominal injuries, 10.7% vs. 4.5%. The authors also evaluated the presence of signs of life (SOL). SOL were defined as cardiac electrical activity, respiratory effort, or pupillary response. Patients who arrived to the ED with SOL had an 11.5% rate of survival compared to 2.6% for those who had no SOL on arrival. Absence of SOL in the field yielded a survival rate of 1.2%.

Procedural Technique. EDT is part of the initial resuscitation and occurs simultaneously with the primary assessment and evaluation including endotracheal intubation, intravenous access, and rapid volume infusion. A left anterolateral thoracotomy is the incision of choice. Extending the patient's left arm parallel to the head and neck will facilitate proper exposure. Advantages of the incision include its rapid access, the ability to perform in the supine patient, and the ability for extension into the right hemithorax (clam-shell) for additional exposure.

The incision begins at the lateral border of the left sternocostal junction inferior to the nipple and is continued to the latissimus dorsi. Some prefer to start the incision over the sternum; however, this increases the risk of transecting the internal mammary artery. The incision should be placed at the 4th or 5th intercostal margin, just below the nipple in the male or the infra-mammary fold in the female. It is important to curve the incision to follow the 4th or 5th rib. A common mistake is to bring the incision straight down from the xiphoid process and not follow the curvature of the ribs. This will make it more difficult to place the Finochietto retractor to spread the ribs. The incision is carried through skin, subcutaneous tissue, and the serratus anterior muscle until the intercostal muscles have been exposed. Once the intercostal muscles have been exposed, a scalpel or scissors is used to cut through the muscle and enter the thoracic cavity. The incision should go along the superior aspect of the rib to avoid injuring the intercostal neurovascular bundle. Care should be taken to not lacerate the lung or heart while entering the thoracic cavity. A Finochietto retractor then is placed to spread the ribs. Extension of the incision to right hemithorax ("clam-shell") if needed can be quickly accomplished using a Lebsche knife. If one performs a "clam-shell," the internal mammary arteries almost always are divided and must be ligated.

Pericardiotomy. Once inside the thoracic cavity, the pericardium should be opened routinely because one cannot visually exclude cardiac tamponade. The pericardium is incised, using scissors, anteriorly and opened parallel to the left phrenic nerve. The opening should extend superiorly to the aortic root and then inferiorly to the apex of the heart. Blood clots should be removed and the myocardium should be examined thoroughly. Cardiac bleeding should be controlled immediately with digital pressure while preparing for better temporizing measures. Inserting a Foley catheter, blowing up the balloon, and using gentle traction also can achieve temporary control of hemorrhage. Excessive pressure on the Foley may cause the balloon to tear through the myocardium, creating a much larger injury. Other options include staples or temporary sutures to stop acute hemorrhage while preparing for definitive repair in the operating room.

Cardiac Massage. Bimanual internal cardiac massage should begin immediately if there is true cardiac arrest. The preferred method is a hinged clapping motion with the wrists apposed and ventricular compression proceeding from the apex to the base of the heart. This is best accomplished by cupping the left hand and placing it over the right ventricle. The fingers of the right hand are held tightly together to form a flat surface supporting the left ventricle. The right hand compresses the flat surface against the cupped surface supported by the left hand.

Aortic Cross Clamping. Many people recommend aortic cross clamping following an EDT, but this procedure can be difficult and time consuming. An alternative is manual compression applied along the spine by the posterior hand performing cardiac massage. Although the procedure makes intuitive physiological sense by preferentially shunting blood to the most important areas, i.e., the brain and myocardium, it simultaneously occludes blood flow distally causing ischemia in those regions. Additionally, placement of an aortic cross clamp radically increases after load, which places significant strain on the left ventricle. In a situation of near arrest or full cardiac arrest, cardiac output is already low or non-existent; this additional strain of aortic cross clamping may be more detrimental than helpful.

Abdominal Trauma

Penetrating abdominal trauma comprises 35% of abdominal injury in inner-city trauma centers, while only 12% of those in suburban or rural setting.[5] The death rate from penetrating abdominal trauma ranges from 0-100%. Those with violation of anterior abdominal wall fascia without peritoneal injury have a 0% mortality rate, while those with multiorgan injury presenting with hypotension, base deficit less than -15 mEq/L HCO_3, temperature less than 35° Celsius, and coagulopathy have a dramatically increased mortality rate.[59] Overall mortality rates for patients with penetrating abdominal trauma is approximately 5% at most Level 1 trauma centers.

During the past 40 years, non-operative management (NOM) of selective abdominal SW has become accepted. In contrast, abdominal GSWs still are commonly treated with mandatory surgical exploration; however, this practice may be changing.

Support for NOM is based on the high incidence of a negative or non-therapeutic laparotomy. Unnecessary laparotomy for SW ranges from 23% to 53% while for GSW it ranges from 5.3% to 27%.[60] Additionally complications including visceral injury, small bowel obstruction, wound infection, myocardial infarction, and even death can occur in up to 41% of negative or non-therapeutic laparotomies.[61-63] When deciding to pursue surgical exploration vs. NOM, one must take into account patient hemodynamics, specific mechanism of injury (SW vs. GSW vs. shotgun), as well as diagnostic capabilities of the institution.

Anterior Abdomen. The anterior abdomen anatomically is defined as the region inferior to the costal margin, superior to the inguinal crease between both anterior axillary lines. Standard practice warrants that patients who present to the emergency department with penetrating abdominal trauma and hemodynamic instability require immediate operative exploration. Those who are stable on admission require further diagnostic work up. The remainder of this article will focus on this patient population.

Mandatory exploration for the hemodynamically stable patient with an anterior SW, in the absence of peritonitis, severe abdominal pain, or evisceration, no longer is practiced. Selective non-operative management for this patient population has become accepted during the past few decades. In contrast, mandatory surgical exploration for GSW to the anterior abdomen has long been considered standard of care.[64] It was believed that "exploratory laparotomy should be performed in all GSWs of the abdomen when even the slightest question of penetration exists"[65] and "regardless of physical examination or estimated trajectory."[66] This concept stemmed from the high incidence of intra-abdominal injuries associated with GSW;[67] however, studies did not distinguish between therapeutic and non-therapeutic laparotomy. Thus, many patients may have had injuries that did not require surgical intervention. Recently, many authors began to recommend conservative management for GSW to the anterior abdomen.[68-72] Demetriades et al demonstrated a reduction from 27% unnecessary or negative laparotomies to 5% with the introduction of conservative management.[69]

Initial Management. Initial management of all patients with penetrating anterior abdominal penetrating wounds should concentrate on airway, breathing, circulation, and establishing large bore intravenous access. In addition, full patient exposure with complete physical exam is paramount to identify all injuries. Clinicians often focus on the most obvious injury and forget to examine other areas, specifically the axilla and groin regions. Peripheral pulses should be evaluated to exclude major vascular injury. Often patients, specifically young adults, may appear hemodynamically stable, but in fact are in significant shock. Initial laboratories, including a lactate and base deficit from an arterial blood gas, may help identify these patients early and allow for more aggressive management. Patients who are hemodynamically unstable should proceed to the operating room. Once it is determined that the patient does not require immediate laparotomy, further diagnostic evaluation and monitoring is warranted. Serial physical exams, US, diagnostic peritoneal lavage (DPL), local wound exploration, and CT scan are among the options for clinicians.

Physical Exam. A study by Alzamel and Cohn demonstrated that patients with anterior abdominal SW managed with serial physical examinations alone will demonstrate the need for operative intervention within 12 hours of injury.[73] The authors concluded that after 12 hours of observation, asymptomatic patients may be discharged home safely from the emergency department. Demetriades and Rabinowitz evaluated the utility of serial abdominal exams in 306 patients with anterior abdominal SW.[74] All patients were monitored with hourly vital signs and frequent abdominal physical exams. Only 11 (3.6%) of patients required a delayed exploratory laparotomy. The authors concluded that many patients with an anterior abdominal SW can be managed non-operatively. A 2001 study by Gonzalez et al used DPL findings to determine who is safe for discharge following abdominal SW.[75] A cutoff of 1000 RBCs/mm^3 was used to determine who could be sent home. Patients who met the criteria were sent home and had no delayed complications.

Physical exam also has been demonstrated to be useful in determining the need for operative exploration following anterior abdominal GSW. It has been suggested that physical exam can reliably detect significant intra-abdominal injuries and should be managed similarly to SW to the anterior abdomen.[69] Another study by Demetriades et al demonstrated the rate of unnecessary laparotomy decreased from 41.6% to 10.0%, using a strategy of conservative management based on serial physical exams (performed by senior level residents or attendings) and not mandatory exploration.[70] However, most centers do not have the resources that would allow such practice. Subsequently, various radiographic modalities including DPL, US, and CT scan are used to evaluate patients in a more timely manner.

Local Wound Exploration (LWE). Wound exploration of anterior abdominal SW can be performed safely in the emergency department with the use of local anesthetic. Using sterile technique, the wound is surgically extended allowing for inspection of the fascia,[76] and if no evidence of fascial penetration is found, patients can be safely discharged with local wound care instructions.

Thompson et al evaluated the utility of LWE in 300 patients with anterior abdominal SW.[76] Using LWE, 97 patients were found to have no peritoneal violation and subsequently were discharged from the hospital. No patient was found to have delayed presentation of a missed injury. In 2009, the Western Trauma Association published management guidelines including LWE for anterior abdominal stab wounds.[77] One hundred thirty-two patients had LWE as part of their evaluation. Fifty-four patients showed no evidence of peritoneal violation, of which 31 were discharged directly from the emergency department. The additional 23 patients had adjunctive studies, all of which were negative, and eventually were discharged home. LWE was found to have 100% sensitivity and negative predictive value to rule out peritoneal violation. It is important, to remember that LWE must be technically adequate and provide enough exposure of the wound to follow the wound tract.[76] Simply probing the wound is not reliable enough to rule out peritoneal violation.[78] Additionally, LWE may not be effective in obese patients and those with a tangential wound track.[77]

Ultrasound. The use of US in the setting of anterior abdominal trauma has been described and evaluated widely. It is a non-invasive test that can be performed at the bedside and easily repeated if necessary. Multiple studies have evaluated its sensitivity, specificity, and positive predictive value. Sensitivities have ranged from 46%-67%, specificity from 94%-100%, and positive predictive value from 92%-100%.[20,79-81] In the presence of hemoperitoneum, the right upper quadrant is most commonly the view that is positive.[82] (*See Figure 4.*) Based on these findings a positive FAST is a strong predictor of injury and patients should proceed directly to the operating room for an explorative laparotomy. However, a negative FAST cannot exclude an intra-abdominal injury and further diagnostic studies are warranted, as approximately 30% of patients will have injuries requiring operation.[79] For patients with a negative FAST and who are hemodynamically stable, triple contrast CT scan (see below) should be the next imaging modality.

Figure 4. Blood in Morrison's pouch

Courtesy Scott Weingart, MD, Mount Sinai School of Medicine, Elmhurst Hospital Center

Flank/Back. The flank is anatomically defined as the region between the anterior and posterior axillary lines, superiorly by the sixth rib and inferiorly by the iliac crest. The back is the region between both posterior axillary lines, inferior to the tips of the scapula. In contrast to anterior abdominal SW injuries, the frequency of posterior injuries requiring operative intervention is low.[83,84]

Most injuries are in the retroperitoneum, an area than tends to self-tamponade well. Although some authors originally argued that injuries to this region mandate surgical exploration, the high rates of negative and non-therapeutic laparotomies have questioned this practice. However, for many, the concern for an occult colon injury presenting in a delayed fashion and the associated morbidity, pushed for early operative exploration.[83-85] More recently, for patients who remain hemodynamically stable, an initial non-operative approach including various radiographic modalities has emerged.

Many authors believe that GSWs to the back require surgical exploration.[69,86] Unlike SWs to the back, a non-operative approach to GSW has not been widely accepted. However, in 1997, Velmahos et al evaluated selective conservative management for GSW to the back.[87] The authors demonstrated that initial clinical examination had a sensitivity and specificity of 100% and 95%, respectively, for detecting significant intra-abdominal injury. Additionally a 24-hour period of observation was suggested as an adequate amount of time to monitor asymptomatic patients. Using this approach, the unnecessary laparotomy rate decreased from 70% to 4%.

Initial Management. Initial management for penetrating back and flank trauma is similar to that for anterior penetrating injury. However, for patients who do not require immediate surgical exploration, the diagnostic evaluation differs somewhat. Penetrating injuries to the back may not lend themselves to be effectively evaluated using FAST or DPL. Additionally local wound exploration of posterior or flank wounds never should be done in the emergency department. Unlike the anterior abdomen fascial planes, those posteriorly are not well defined and simple LWE cannot determine extent of injury. Additionally, if a wound has self-tamponaded, probing can dislodge the clot, causing massive hemorrhage without the ability to obtain hemostatic control. Thus, CT has become the diagnostic modality of choice for evaluating the retroperitoneum following penetrating injury in hemodynamically stable patients.[83,88] It can determine retroperitoneal violation as well as evaluate for isolated solid organ injury that can be managed non-operatively. High sensitivity (89%-100%) and accuracy (97%-98%) as well as low rates on non-therapeutic laparotomies have been reported with CT use in this clinical situation.[89-92]

CT for Penetrating Abdominal Trauma

CT is the standard of care for diagnosing intra-abdominal and retroperitoneal injuries following blunt abdominal trauma. Its use to evaluate hemodynamically stable patients with penetrating abdominal trauma has evolved over time. (*See Figure 5.*) Phillips et al were the first to describe the use of CT with rectal contrast for the evaluation of penetrating back and flank pain.[90] Fifty-six patients were evaluated using CT. The authors classified CT reads into five categories: negative, low-risk, high-risk, indication for angiography, and positive. Forty-two patients had either a negative or low-risk CT

Figure 5. Triple-contrast CT scan of patient with penetrating flank wound

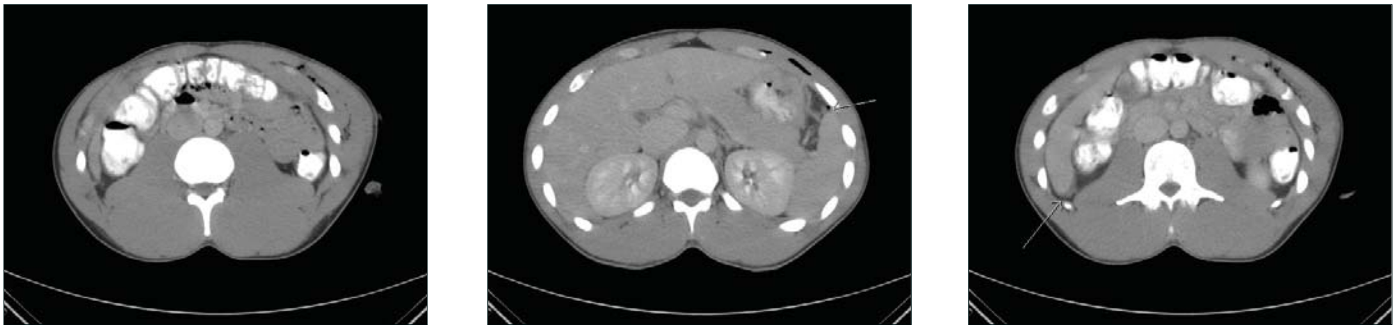

Image A: Soft tissue injury

Image B: Free intraperitoneal air

Image C: Free fluid (blood) around the tip of the liver

Figure 6. CT following anterior flank gunshot wound

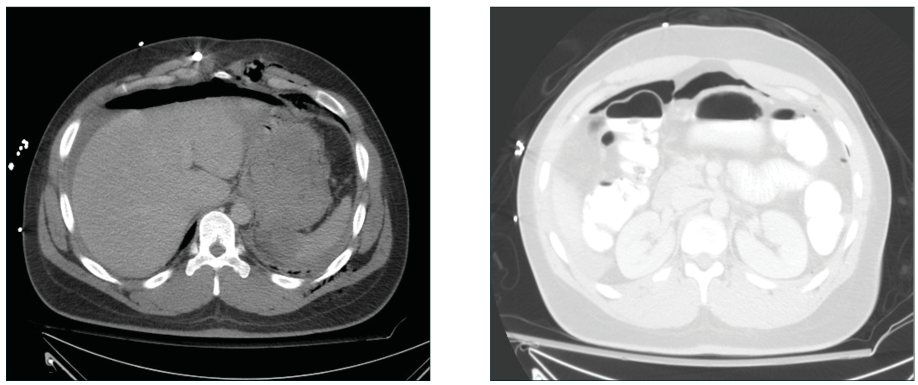

Image A: Free fluid around liver and spleen

Image B: Significant amounts of free intraperitoneal air

interpretation and all were successfully managed without an operation. Six patients required angiography, 8 patients had high-risk scans, and no patients had a positive read. Two patients with high-risk reads had non-therapeutic laparotomies. The authors concluded that the use of CT enema allows effective triage of patients who can be managed with observation while identifying a small number of patients who require surgical intervention. Over the next 20 years, there has been vast improvement in CT technology allowing for better resolution of organ and injury detail. (*See Figure 6.*) Since Phillips et al first described using CT with rectal contrast for penetrating back and flank injuries, additional reports have followed attempting to delineate who needs operative intervention and who does not.[91-93] Studies by Kirton et al and Hauser et al specifically looked at penetrating back and flank injuries.[91,93] No patient who had non-operative management based on CT findings required a delayed surgical intervention. Additionally, contrast CT indicated every injury that required operative intervention.

The diagnostic role of CT with rectal contrast has been expanded to include penetrating anterior abdominal injury. Early studies, with older generation CT, had shown low sensitivities for detecting gastrointestinal injuries and diaphragm injuries.[94] Recent studies have demonstrated high rates of sensitivity and specificity when using a triple contrast abdominopelvic CT scan for diagnosing injury following penetrating torso trauma.[95-97] The term "triple contrast" refers to oral and intravenous contrast with the addition of rectal contrast just prior to the CT scan.

A 2001 study by Chiu et al evaluated 75 patients with penetrating torso trauma using a triple contrast CT.[95] Ninety-six percent of patients (47/49) who had a negative CT scan were successfully managed non-operatively. Overall, triple contrast CT had a 94% sensitivity and 95% specificity for determining the need for laparotomy based on evidence of peritoneal violation. Its accuracy was 95%. The authors concluded that triple contrast CT can accurately exclude peritoneal violation and avoid an unnecessary laparotomy in those patients without a clear indication for operation. Shanmuganathan et al used triple contrast CT to evaluate 104 patients with penetrating torso trauma.[96] Ninety-seven percent (67/69) of patients with a negative CT scan were managed without operative intervention. CT had 100% sensitivity, 96% specificity, and 100% negative predictive value for predicting the need for laparotomy. Additionally, the majority of patients with a negative CT scan were discharged within 12 hours of admission. A follow-up study by the same authors with 200 additional patients with penetrating torso trauma had similar findings.[97] Based on these studies, patients who have penetrating torso trauma and a triple contrast CT scan without evidence of peritoneal violation can be discharged from the emergency department safely.

Others advocate that single contrast CT (intravenous only) is safe and effective for determining the need for operative intervention following penetrating torso trauma.[98,99] Ramirez et al demonstrated single contrast CT is predictive of significant injury following GSW to the torso with a 100% sensitivity and

NPV.[98] Additionally, CT has a 92% sensitivity and specificity for identifying stab wounds that require exploratory intervention. Using single contrast CT following penetrating torso trauma, 58% of patients were managed without an operation. The authors concluded that by using only intravenous contrast they can safely and effectively determine who requires operative intervention without additional morbidity and delay of oral and rectal contrast. Salim et al evaluated single contrast CT in 67 patients with anterior abdominal SW.[99] CT was found to have a 100% sensitivity, 81% specificity, and a 100% negative predictive value. As a result of the CT findings, almost 20% of patients had their management altered, including 7 patients being discharged home from the emergency department. Although, these studies suggest that single contrast CT is an effective modality for evaluating penetrating torso trauma in the hemodynamically stable patient, one must question how intravenous contrast alone assists in effectively diagnosing a subtle bowel injury. Many believe that bowel distention with oral and rectal contrast is paramount when evaluating for these injuries. As such, the authors of this article agree with the plethora of literature supporting the use of triple contrast CT scan and consider it the standard of care for hemodynamically stable patients with penetrating torso trauma who are initially managed non-operatively.

Conclusion

Penetrating torso trauma is a complex and difficult therapeutic challenge. Those who are hemodynamically compromised require emergent surgical intervention, while the hemodynamically stable patient requires further evaluation. Physicians must keep in mind the vast array of possible injuries and have a clear, organized, and timely management plan to identify those patients who require an urgent intervention. It is imperative to be able to recognize those patients who appear stable, but in fact are in significant states of shock.

The practice of mandatory surgical exploration for all penetrating torso trauma is no longer valid. Current practice of non-operative management for many of these injuries is now standard of care. The availability of US and the improvement of CT technology have enabled the emergency department physician to rapidly identify the hemodynamically stable patient who needs either surgical intervention/further observation and the patient who safely can be discharged home from the ED.

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CNE/CME Questions

1. Which anatomical border would not prompt suspicion of an intra-abdominal injury following penetrating trauma?
   A. Nipple line
   B. Inguinal ligaments anteriorly
   C. Tip of the scapula
   D. Clavicle
   E. Inferior gluteal folds

2. Most penetrating thoracic trauma requires operative intervention.
   A. True
   B. False

3. Focused Assessment for Sonography of Trauma (FAST) for pericardial fluid following penetrating chest trauma is:
   A. rapid.
   B. easily repeatable.
   C. highly sensitive and specific.
   D. the first diagnostic modality of choice.
   E. All of the above

4. Patients who present without symptoms of intra-thoracic injury following penetrating chest trauma require:
   A. an initial chest x-ray and observation alone.
   B. serial chest x-rays at least 3 hours apart.
   C. observation alone.
   D. an initial chest x-ray and discharge.

5. Which of the following findings on ultrasounds suggests the presence of a pneumothorax?
   A. Stratosphere sign
   B. Comet tails
   C. Lung sliding
   D. Seashore sign

6. Which of the following patients has the greatest chance of survival following ED thoracotomy?
   A. Stab to chest trauma with no "Signs of Life" in the field or on admission
   B. Witnessed cardiac arrest following blunt trauma
   C. Loss of "Signs of Life" in the emergency department and isolated stab to the heart with evidence of pericardial tamponade on ultrasound
   D. Gunshot wound to the chest with 5 minutes of pre-hospital CPR

7. Which of the following does not increase mortality following penetrating abdominal trauma?
   A. Hypothermia
   B. Acidosis
   C. Coagulopathy
   D. Hypotension on admission
   E. Fluid seen on ultrasound (FAST)

8. Which of the following is not an acceptable method for managing anterior abdominal stab wounds?
   A. Explorative laparotomy
   B. Local wound exploration
   C. Wound probing
   D. Serial physical exams
   E. Computed tomography

9. Which of the following is effective in evaluating penetrating flank/back injuries?
   A. Local wound exploration
   B. Serial physical exam
   C. Diagnostic peritoneal lavage
   D. Computed tomography
   E. B and D

10. Triple contrast CT scan for penetrating torso trauma:
    A. identifies all injuries.
    B. has high sensitivity and specificity for determining the need for laparotomy following penetrating injury.
    C. can identify patients who may be safely discharged from the emergency department.
    D. uses three times as much radiation as a traditional CT scan.
    E. B and C

Answers: 1. D, 2. B, 3. E, 4. B, 5. A, 6. C, 7. E, 8. C, 9. E, 10. E.

Trauma Reports CNE/CME Objectives

To help physicians:

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

CME Instructions

Physicians participate in this continuing medical education program by reading the article, using the provided references for further research, and studying the questions at the end of the article. Participants should select what they believe to be the correct answers, then refer to the list of correct answers to evaluate their knowledge. To clarify confusion surrounding any questions answered incorrectly, please consult the source material. *After completing this activity, you must complete the evaluation form that will be provided at the end of the semester and return it in the reply envelope provided to receive a credit letter.* When your evaluation is received, a credit letter will be mailed to you.

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CNE/CME Evaluation — Penetrating Thoraco-abdominal Injury

Please take a moment to answer the following questions to let us know your thoughts on the CNE/CME program. Fill in the appropriate space and return this page in the envelope provided. **You must return this evaluation to receive your letter of credit. ACEP members — Please see reverse side for option to mail in answers.** Thank you.

CORRECT ⬬ INCORRECT

1. In which program do you participate? ◯ CNE ◯ CME
2. If you are claiming physician credits, please indicate the appropriate credential: ◯ MD ◯ DO ◯ Other______________
3. If claiming nursing contact hours, please indicate your highest credential: ◯ RN ◯ NP ◯ Other__________

After participating in this program, I am able to:	**Strongly Disagree**	**Disagree**	**Slightly Disagree**	**Slightly Agree**	**Agree**	**Strongly Agree**
4. Discuss conditions that should increase suspicion for traumatic injuries.	◯	◯	◯	◯	◯	◯
5. Describe the various modalities used to identify different traumatic conditions.	◯	◯	◯	◯	◯	◯
6. Cite methods of quickly stabilizing and managing patients.	◯	◯	◯	◯	◯	◯
7. Identify possible complications that may occur with traumatic injuries.	◯	◯	◯	◯	◯	◯
8. The test questions were clear and appropriate.	◯	◯	◯	◯	◯	◯
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If so, how?______________________________________

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____

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Optional for ACEP members: In accordance with ACEP requirements, below we provide the option for ACEP members to submit their answers for this CME activity. If you wish to submit answers for this activity, please refer to this issue (Vol. 11, No. 6) and circle the correct responses.

1. A B C D E

2. A B

3. A B C D E

4. A B C D

5. A B C D

6. A B C D

7. A B C D E

8. A B C D

9. A B C D E

10. A B C D E