Initial Management and Resuscitation of Severe Chest Trauma

Bruno Bernardin, MD[a,b,c,*], Jean-Marc Troquet, MD[c,d]

KEYWORDS

• Thoracic trauma • Severe • Management • Unstable • Blunt
• Penetrating

The chest is the site of confluence of 3 of the most important life-sustaining systems: the airway, the respiratory system, and the cardiovascular system. The potential for severe injuries by application of traumatic forces is huge. Among severely traumatized patients, 25% of deaths are thought to be secondary to chest trauma.[1] Motor vehicle crashes (MVCs), or pedestrians struck by motor vehicles, cause the majority of severe thoracic injuries.[2] In a crash, the unrestrained driver of a vehicle has about a 50% chance of sustaining a chest injury.[1] Penetrating chest trauma has the same potential for dire consequences, given the anatomic proximity and the associated harmful intent of the majority of armed assaults.

The cornerstone of care in severely injured patients consists of interventions that should be familiar to any emergency physician (EP) involved in trauma management: intubation, support of ventilation/oxygenation, and installation of thoracostomy tubes. In either blunt or penetrating injuries, 80% to 85% of chest trauma patients will respond to these maneuvers.[3–5]

The goal of this article is to provide a review of major thoracic injuries and to provide guidance in the initial management and resuscitation of victims of severe chest trauma. The authors cover injuries that are immediately or rapidly life threatening: ruptured airways, pneumothorax with or without tension, flail chest and pulmonary contusions, rupture of major blood vessels, and cardiac trauma. Bony and soft-tissue injuries, with

The authors have nothing to disclose.
[a] Department of Medicine, McGill University, Room A4.62, Royal Victoria Hospital, 687 Avenue Des Pins, Montreal, Quebec, H3A 1A1, Canada
[b] Emergency Trauma Fellowship, Montreal General Hospital, McGill University Health Center, Room B2 117-3, 1650 Avenue Cedar, Montreal, Quebec, H3G 1A4, Canada
[c] Emergency Department, Montreal General Hospital, McGill University Health Center, Room B2 117-3, 1650 Avenue Cedar, Montreal, Quebec, H3G 1A4, Canada
[d] Department of Family Medicine, McGill University, 517 Avenue des Pins, Montreal, Quebec, H2S 1S4, Canada
* Corresponding author. Emergency Department, Montreal General Hospital, McGill University Health Center, Room B2 117-3, 1650 Avenue Cedar, Montreal, Quebec, H3G 1A4, Canada.
E-mail address: bruno.bernardin@mcgill.ca

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the exception of rib fractures, are not discussed. The focus is on civilian, nonwarfare-related situations, with mechanisms of injury such as MVCs, falls, stabbings, and shootings. Blast injuries, more common in warfare situations, are not addressed directly in this article.

Each type of injury, grouped by system. is discussed separately. The authors present an approach to the resuscitation of the unstable patient presenting with undisclosed injuries following chest trauma, given that EPs are confronted with unidentified problems and must act before a final diagnosis is known. Important differences between penetrating and blunt trauma are outlined whenever necessary.

AIRWAY ISSUES: TRACHEOBRONCHIAL INJURY

Respiratory distress in trauma patients can originate from airway compromise or from a respiratory (pulmonary, chest wall) injury. Profound shock can also present as respiratory distress from circulatory insufficiency. Identification of upper airway trauma and compromise is usually straightforward and should be dealt with accordingly, usually by relief of the obstruction and by securing a definitive airway. For all patients, endotracheal intubation should be performed if any of the usual indications are met.

Identification of lower airway injury is more complex. It is a rare injury, with reported rates between 0.5% and 2% in patients arriving alive to hospital.[6–10] In a recent review of 12,187 patients seen over 15 years in a major trauma center in Toronto, Kummer and colleagues[11] found only 14 cases (0.11%). The presenting signs and symptoms vary greatly depending on the size and site of defect, pleural communication, and the ensuing air leak.[12] Many subtle presentations will manifest only as mediastinal air seen on computed tomography (CT) scan whereas the most dramatic ones are catastrophic, with respiratory distress and associated difficulties in ventilation and oxygenation.[11]

Larger defects result in dyspnea (with or without respiratory distress) and pneumothorax, possibly with tension. Intervention will be directed initially toward the pneumothorax, as the tracheobronchial injury (TBI) is often not yet suspected. Persistent pneumothorax or air leak after placement of a chest tube should alert the physician to the possibility of a TBI.[13,14] Insertion of a second chest tube is required in these cases. TBI must be suspected if a patient deteriorates rapidly following endotracheal intubation. Because of positive pressure ventilation and loss of negative intrathoracic pressure on inspiration, air leak is increased, followed by increasing difficulties with oxygenation and ventilation.

Smaller injuries initially go unnoticed, especially if the patient is breathing spontaneously. The prevalence of subcutaneous emphysema is reported to be 35% to 85%. Hemoptysis is less frequent, seen in fewer than 25% of cases.[15] TBI becomes suspected when radiological evaluation shows mediastinal air, isolated or with pneumothorax. Mediastinal air can also originate from other injuries[16]: penetrating face or neck wound with air tracking down, lung parenchyma laceration, esophageal injury, deep penetrating torso wound, or retroperitoneal injury with air tracking up the diaphragmatic hiatus. It is rare to identify the site of injury even on CT scan. Most occur within 2 cm of the carina, with predominance for the right main stem bronchus, followed by the lower trachea.[6] Left-sided defects are often better tolerated, and consequently diagnosed later (median 30 days for left side compared with 1 day for right side and 3 days for trachea).[6] This occurrence might possibly be due to the existence of greater peribronchial tissue surrounding the left main stem bronchus, which can limit air leak.[17]

Bronchoscopy is indicated in all cases of suspected TBI, with two goals in mind. With severe injury, it can be used to advance the endotracheal tube distal to the defect to decrease air leak, at times into the unaffected main stem bronchus if necessary, ensuring adequate ventilation.[15,18] Bronchoscopy also diagnoses precisely the location and size of the injury and plans possible surgical repair. Early mortality in cases of TBI results from either ventilation-oxygenation difficulties or from severe associated injuries, which frequently coexist.[6,11] Early thoracic surgery involvement is mandatory for treatment.

BREATHING

The most severe presentations resulting from thoracic trauma are respiratory distress and/or hypoxia. Injuries to consider in these cases are tension pneumothorax (TPTX), simple or open pneumothorax, and flail chest. Massive bleeding into the chest cavity can also result in respiratory impairment. Finally, pulmonary contusions usually accompany important chest injuries.

Pneumothorax and Occult Pneumothorax

A pneumothorax occurs when air accumulates between the visceral and parietal pleura. In blunt trauma this results from either lung parenchymal injury from deceleration forces, laceration by a rib fracture, or if an alveola ruptures from increased intrathoracic pressure following crush injury. In penetrating trauma, direct damage to the pleura and lung tissue allows communication between both spaces, with or without communication outside the chest wall.

The clinical manifestations of pneumothorax are proportional to many factors: its size, communication or not with the atmosphere, size of any chest wall defect, presence of associated injuries (rib fractures, flail chest, pulmonary contusions, hemothorax), as well as the premorbid condition of the patient. Physiologically, pneumothoraces can result in hampered oxygenation, ventilation, and even circulation in its more severe form with presence of associated tension, although a very important proportion is asymptomatic. Physical examination is notoriously unreliable for diagnosing the majority of traumatic pneumothoraces.

The exact incidence of traumatic pneumothorax is unknown. Various imaging modalities, namely supine chest radiography (CXR), upright CXR, ultrasonography, and CT scan, each have different sensitivities in identifying pneumothorax. With the increased use of CT scanning in trauma patients, the phenomenon of occult pneumothorax has appeared. The incidence of this phenomenon depends on the population studied and is directly proportional to the severity of the injuries. Studies in the general trauma population report an incidence of occult pneumothorax of around 2% to 7%.[19,20] Ball and colleagues[21] examined supine CXR and CT findings in 405 blunt trauma patients with an Injury Severity Score (ISS) of 12 or more. These investigators found 26% of patients with pneumothorax, of which 76% were occult when the CXR was read in the acute resuscitation setting by the trauma team.

Clinicians have also started to use an extended component of the focused assessment with sonography for trauma (E-FAST) for the detection of pneumothorax in the acute setting. Thoracic ultrasonography has shown a higher sensitivity than supine CXR for diagnosing pneumothorax. While results are promising, the exact significance of this higher diagnostic accuracy remains uncertain, as many occult pneumothoraces do not need to be drained.

Traumatologists agree that pneumothoraces in any unstable patient or those found on supine CXR should be drained, usually by insertion of a chest tube. However, there has been much debate on the most appropriate management of occult pneumothoraces in stable patients, especially for those undergoing positive pressure ventilation (PPV). The advantage of immediate drainage versus observation and insertion of chest tube only if there is clinical deterioration remains unknown. There is growing evidence and consensus that occult injuries can be safely observed even during PPV, reflected by the fact that this is now accepted by the Eastern Association for the Surgery of Trauma (EAST).[22–24]

The method of choice for drainage of traumatic pneumothorax has classically been and remains insertion of a large-caliber chest tube (size 32F and larger). Some investigators have advocated the use of a smaller chest tube, but this can only be used for stable patients with isolated pneumothorax and no other thoracoabdominal injury. Twenty percent of traumatic pneumothoraces have an associated hemothorax,[25] and smaller chest tubes can obstruct easily and become nonfunctional in the presence of even small quantities of blood in the chest cavity.

Tension Pneumothorax

Textbook and Advanced Trauma Life Support teaching focuses on a rather universal, but somewhat inaccurate, picture of the signs and symptoms of tension pneumothorax (TPTX): respiratory distress, deviated trachea, decreased breath sounds, and hypotension.[26–29] CXR findings are often described as revealing a mediastinal shift away from a large pneumothorax. This shift leads supposedly to kinking of the vena cava and decreased venous return, resulting in hypotension and, if not treated, circulatory arrest.

It must be recognized that TPTX has a different presentation, depending on whether the patient is awake and ventilating spontaneously or unconscious and on PPV.[30] These differences are well established in both animal experimental models[31–37] and human case reports.[30,38] An awake patient is able to mount a compensatory response by increasing his respiratory rate, tidal volume, negative inspiratory pressure, and chest expansion.[39] The physiologic insult is primarily hypoxic with progressive respiratory decompensation; hypotension is the terminal event of hypoxic cardiac failure or respiratory arrest. On the other hand, sedated and ventilated patients cannot compensate, and show a greater degree of impeded venous return from both the intrapleural pressure and the PPV. The deterioration is much more rapid, resulting in more rapid cardiogenic shock once the central venous pressure equals the intrapleural pressure, and causing complete obstruction of venous return.[31,40]

Reviews of case series and reports of patients with TPTX show that tracheal deviation, oxygen desaturation, and hypotension are actually inconsistent findings in (awake) spontaneously ventilating patients (<25% each).[30] By contrast, hypotension and low Sa_{O_2} are almost universally seen in PPV patients[38,41]; deviated trachea, a late finding, is found more frequently than in awake patients but not as consistently (60%).[30,42,43]

Many investigators state that clinicians should not seek radiologic confirmation if suspecting a TPTX: "the radiograph of a tension pneumothorax is one that should never be seen".[39,44,45] Discernment should be used in most cases; this is certainly true for the patient hypoxic and hypotensive in extremis, for whom immediate chest decompression must be done. The same holds true for a patient on PPV who suddenly deteriorates with falling Sa_{O_2}, rapidly becomes hypotensive without a clear reason, becomes difficult to bag, or shows raised peak inspiratory pressures on a ventilator.[46] Identification of the affected side is not always easily done[47]; for this reason if decompression of the suspected side does not yield positive results, the other side of the chest should be drained immediately.[48] In a relatively stable patient (normal blood pressure, appropriate oxygen saturation) in whom TPTX is suspected, it is reasonable to confirm the diagnosis by immediate portable radiograph while continuously monitoring the patient. This method will exclude etiology mimicking pneumothorax, such as lobar collapse, right main stem intubation, diaphragmatic herniation, and so forth, and thus avoid unnecessary thoracostomy.

The presence of mediastinal shift on CXR does not equate with tension either. In one study of 170 pneumothoraces, there were 30 CXRs with mediastinal shift and no patient exhibited clinical features of true tension, though all were subsequently managed with thoracostomy.[49] There are also many cases of loculated pneumothoraces causing tension physiology, which had no mediastinal shift on CXR.

Needle Decompression

Indications to perform immediate decompression of a hemithorax are:

- Traumatic arrest
- Loss of blood pressure or pulse during resuscitation
- Increased difficulty to bag/raising peak ventilatory pressures combined with hypotension
- Hypotension or hypoxia/respiratory distress with decreased/absent breath sounds on one side or palpable subcutaneous emphysema.

Classic teaching recommends needle decompression of a hemithorax with placement of a large-bore intravenous catheter in the anterior second intercostal space followed by placement of a chest tube.[29] Some investigators have raised doubts about the usefulness, efficacy, and reliability of this procedure,[30] especially in the prehospital setting.[50,51] Instead, immediate open blunt dissection and thoracostomy in the mid-axillary line has been suggested. There are indeed cases reports of failed decompression of a hemithorax in the presence of a tension pneumothorax[47,50,52–54]; this can result in not recognizing the persistent presence of TPTX.[55] Needle decompression can fail for a variety of reasons.[48] The needle can be misplaced in the chest wall, outside of the pleural cavity, leading the clinician to believe there is no pneumothorax. The needle can be placed in a subcutaneous emphysema pocket or, worse, in lung tissue/bronchus; this leads the physician to believe the pneumothorax has been relieved. However, with no improvement in the patient's clinical status, as the pleural cavity remains under tension the EP may believe the pneumothorax was not responsible for the patient's condition and true thoracostomy may be delayed, with dire consequences. Finally, the needle may be placed through a vascular structure such as a subclavian or internal mammary vessel, resulting in hemorrhagic complications.[56] Marinaro and colleagues[57] demonstrated in a group of 30 patients whose chest wall thickness was measured by CT scan that insertion of the standard 5-cm cannula anteriorly would not reach the pleural space in 33% of the patients, while Lander and colleagues[58] demonstrated, by similar CT measurements, that in 18% of patients neither an anterior nor lateral approach would succeed. Another study asking physicians where they would perform a needle thoracotomy revealed that 32% incorrectly identified the second intercostal space while 95% of responders placed the needle medial to the midclavicular line,[59] resulting in a greater risk of complications.[56,60]

The minimal recommendations would be that in a context where a TPTX is suspected, if needle decompression is attempted it must be followed by immediate open blunt dissection and thoracostomy in the mid-axillary space, no matter the result of needle placement. Placement of a chest tube is secondary once the pleural space is decompressed.

Pulmonary Contusions

The incidence of pulmonary contusion in trauma populations is hard to define, as its reported occurrence depends on the population studied. Pulmonary contusions result from high-energy mechanisms of trauma with rapid deceleration, compression, shear, or inertial forces,[61] most commonly from MVCs and falls from great height.[62] Blast injuries can also result in contused lungs.[63] Damage to the lung parenchyma in the form of alveolar hemorrhage and lacerations is followed some hours later by filling of aleveoli with mucus and edema fluid.[64,65] This process leads to loss of compliance, decreased oxygen diffusion, ventilation-perfusion mismatch, and shunting. There is also experimental evidence that noncontused lung tissue will be affected some hours after injury.[66]

Clinically the patient will exhibit shortness of breath, decreased oxygenation, and increased work of breathing proportional to the degree of contused lung. One needs to remember that pulmonary contusions are dynamic processes: symptoms and signs will often progress over the next hours as pathophysiological changes evolve in the lungs.[67,68] Symptoms will typically peak at 72 hours after injury.[64]

These dynamics need to be remembered when considering CXR findings. Although the diagnosis is relatively straightforward in the context of important chest trauma with infiltrates or consolidations on plain CXR, studies have shown that up to 50% of patients with pulmonary contusions have a normal CXR on arrival whereas 92% have a positive CXR at 24 hours.[69] Another study showed that 6 hours after the injury, 21% of patients with lung contusions did not show it on CXR.[70]

CT scanning performed early is more sensitive than CXR for the diagnosis of lung contusions.[70] Many patients with normal CXR exhibit parenchymal changes on CT performed shortly after. Some investigators have found that the percentage of contused lung volume measured on CT scan is predictive of the need for mechanical ventilation or of the risk of acute respiratory distress syndrome,[71,72] the cutoff mark being somewhere between 18% and 30% of lung volume, but the patient numbers were small. It is unclear whether this is truly useful for management. These studies were done with earlier-generation scanners less sensitive than present-day machines, which are now overly sensitive for pulmonary contusions. In fact, Deunk and colleagues[73] found that patients with contusions demonstrated only on CT scan, with no contusions apparent on initial CXR, have a similar prognosis and rate of complications to patients who do not have pulmonary contusions on CT.

Treatment is supportive. Management is guided by the patient's oxygenation capabilities and secondarily by ventilation. Proper monitoring in an intensive care unit (ICU) setting, supplemental oxygen, and pulmonary toilet are the most important initial steps in the care of these patients. In the spontaneously ventilating patient, proper analgesia for coexisting rib fractures is of vital importance. In cases where oxygen demands are beyond what can be provided with face mask or when respiratory muscle fatigue is evident, consideration should be given to noninvasive positive pressure ventilation (NPPV).[74] However, the main problem remains patient selection; many patients need intubation for other injuries. In patients who are appropriate for NPPV, this modality can avoid intubation in 82% of pulmonary contusion patients with acute respiratory failure.[75] It has been demonstrated that selective intubation will have good results and will increase survival.[76,77]

If NPPV is not possible or fails, intubation becomes necessary. The goal is to optimize oxygenation while minimizing further lung tissue trauma by using lower tidal volumes (6 mL/kg) and maintaining end-inspiratory plateau pressure below 30 cm H_2O.[78] The use of positive end-expiratory pressure and other alveolar recruiting techniques such as high-frequency/inversed ratio ventilation should be considered in patients whose oxygenation is still difficult while on mechanical ventilation.[79] If a patient cannot be properly ventilated or oxygenated while on a respirator it is mandatory to exclude, and treat appropriately, other complications of severe chest trauma such as pneumothorax and hemothorax.

The topic of fluid resuscitation and its relationship to pulmonary contusions is controversial. Experimental and clinical studies on the choice and quantities of fluids show conflicting results.[64] While proper fluid and blood product resuscitation is paramount in the polytraumatized patient, overhydration of patients can contribute to worsening lung edema. Prophylactic antibiotics and steroids have no role in the management of pulmonary contusions.[64]

Rib Fractures and Flail Chest

Rib fractures are one of the most common injuries in patients with chest trauma.[80] A significant force is usually required to cause a fracture of one or more ribs. Kroell and colleagues[81] showed that a 40% deformation of the chest wall was necessary to produce multiple rib fractures or flail chest. The lateral area of the chest wall, because of its architecture and diminished muscular support, is the most susceptible.[82] Rib fractures are a marker of potentially more severe concomitant injury. There is an association between lower (9th–12th) rib fractures and abdominal injuries.[83,84] There is also an association with pneumothorax and pulmonary contusions. Children, by contrast, suffer severe underlying pulmonary/intrathoracic trauma without rib fractures,[85] because of the greater flexibility of their rib cages.

The added morbidity and mortality with each additional fracture is being more and more recognized,[86,87] especially in elderly patients in whom each additional rib fracture will accompany a relative increase in mortality rate of 19% and pneumonia rate of 27%.[88] Six or more rib fractures is associated with increased mortality from all other injuries.[89] The presence of more than 4 rib fractures increases morbidity or potential surrogate markers of such (ventilator and ICU days) in those older than 45 years, although their relatively small numbers limit the validity of these conclusions.[90,91] The pain of rib fractures will hamper proper ventilation, oxygenation, and clearing of secretions, all of which compounds associated injuries such as pulmonary contusions. Although a history of lung disease does not increase complications of rib fractures in the general population,[92] it has been recognized to result in a higher number of complications in patients older than 65 years.[93]

Patients who suffer from flail chests, the presence of 3 or more contiguous ribs fractured at 2 sites, can present in various degrees of respiratory distress. The presence of a flail segment is associated with increased mortality compared with a similar number of fractures without flail.[94] Respiratory insufficiency in flail chest results from the underlying pulmonary contusion,[76] not from the paradoxic movement of the chest. The ventilatory inefficiencies, the decreased clearing of secretions and associated atelectasis, and increased risk of pneumonia also contributes to shunting and hypoxia.[95]

Treatment of rib fractures and flail chest is supportive, aimed at pain control to allow pulmonary expansion and toilet and to provide sufficient oxygenation with supplemental oxygen as needed.[76,77] Failure of oxygenation or ventilation mandates intubation, either on presentation or later on as the symptoms of the underlying pulmonary contusions progress.

Proper analgesia can be difficult to achieve in the case of multiple rib fractures. Many modalities are available: oral or intravenous narcotics, intercostal rib blocks, paravertebral catheter analgesia, and epidural catheter analgesia. Many studies have shown the efficacy of the epidural route in controlling pain in these circumstances. It may also decrease the incidence of pneumonia according to some reports.[96,97] However, one study suggests that epidurals are associated with an increased length of stay and increased total of complications in elderly patients (mean age 77 years) who were less severely injured (ISS <9).[98] Surprisingly the EAST published guidelines recommending epidural analgesia in blunt trauma patients with multiple rib fractures.[99] The most appropriate type of pain control has not clearly been demonstrated, given the current available data.[100] Lack of superiority of epidural delivery was recently documented by Carrier and colleagues.[101] Their systematic review of 8 prospective controlled trials, totaling 232 patients, comparing epidural analgesia/anesthesia with parenteral opioids or intrapleural analgesia could not find any benefit in mortality, length of stay in ICU, or length of stay in hospital. Carrier and colleagues were able to find only that the number of days on mechanical ventilation was reduced when comparing epidural anesthesia with parenteral opioids in 73 patients. The apparent lack of benefit might well result from the small total number of patients studied so far. The authors can state that epidural anesthesia/analgesia is an effective mode of pain control for traumatized patients with multiple rib fractures, but its application is limited and has not been shown to be superior to other modes in terms of reducing morbidity or mortality.

CIRCULATION

In thoracic injuries, circulation issues can be divided into two main categories: hemorrhagic shock due to blood loss, and pump failure due to TPTX or direct cardiac injuries (blunt or penetrating).

Hemothorax

Hemorrhagic shock is the second most frequent cause of death in trauma patients and is the leading cause of early in-hospital trauma deaths.[102] In the thoracic cavity, bleeding usually comes from injuries to the chest wall (in particular intercostals or mammary arteries), the thoracic spine, the lung parenchyma, the great vessels, or the heart. Injuries to intra-abdominal organs (in particular the liver and spleen) can also cause hemorrhage in the chest cavity when the diaphragm is lacerated or ruptured. The common pathway of all such injuries is the accumulation of blood in the pleural space (a hemothorax). Its clinical presentation is variable and is not always easy to diagnose on clinical examination.

In the stable patient, the diagnosis is typically made on CXR; at least 150 to 200 mL of blood need to be present in the chest cavity for the upright CXR to identify a hemothorax.[103] As many CXRs done in trauma are performed on the supine patient, it has been shown that portable CXR on a supine patient has a sensitivity of 40% to 60% in ruling out hemothorax. E-FAST can identify as little as 20 mL of fluid in the pleural cavity, and has shown sensitivities of greater than 96% in detecting hemothorax. In addition it has been shown to be a much quicker procedure, taking about 1 minute to perform, compared with 15 minutes for a CXR. In the unstable patient with blunt trauma the diagnosis should always be suspected, and insertion of bilateral chest tube is warranted in these patients as both a diagnostic and therapeutic measure.

Because the majority of pulmonary blood supply derives from the low-pressure pulmonary vessels, expansion of the lung with apposition of the visceral and parietal pleura is usually all that is required to control these sources of bleeding.[14] Drainage of blood also prevents the formation of empyema, a common complication of retained blood in the chest cavity.

A massive hemothorax is defined as the presence of 1500 mL or more of blood in the thoracic cavity, and is the classic indication to proceed with an urgent thoracotomy. This concept, however, has been challenged for some time. It is now becoming evident that the clinical status of the patient is a more important indicator of the need for a thoracotomy. Early preparation of the patient for thoracotomy has led to better outcomes, and thresholds varying from 500 to 1000 mL of blood have been suggested by some investigators.[104,105]

Volume replacement remains the initial therapeutic modality for hemorrhagic shock. The use of massive transfusion protocols has been shown to be beneficial.[106] Early surgical consultation, in particular for penetrating trauma, is recommended. Angiography can be considered for the diagnosis and treatment of intercostal vessel injuries.

Aortic injury must be considered in patients who are hemodynamically unstable, or in stable patients with a significant mechanism or other confirmed thoracic injuries. For stable patients, the diagnosis can be made on contrast chest CT. For unstable patients, a transesophageal echocardiogram, performed in the emergency department (ED) or in the operating room, can assess both the heart and the aorta.

Blunt Cardiac Injury

Blunt cardiac injury (BCI) is involved in up to 20% of all deaths due to motor vehicle collision.[107] The reported incidence of BCI in all blunt thoracic trauma patients ranges from 20% to 76%.[108–111] It encompasses a wide spectrum of clinical manifestations, ranging from an asymptomatic myocardial bruise to cardiac rupture and death.[112,113] Because the right heart rests closest to the anterior chest wall, it is the most frequently involved area to be injured.[107,114] Injuries to more than one chamber occur in more than 50% of cases.[115] Common injury patterns include crush injuries, deceleration injuries, direct precordial impact, or transmitted forces from compression of the abdominal cavity. Crush injuries can sometimes cause penetrating injuries when sternal or rib fractures result in cardiac punctures or lacerations.

BCI is thought to be overdiagnosed because of the lack of an appropriate gold standard.

To address these issues and to propose an approach to the patient with BCI, the EAST published its guidelines on this topic in 1998 and classified BCI according to the sequelae of the injury[116]:

1. BCI with free wall rupture. These patients usually die at the scene. For the few who make it to the ED, the prognosis is poor even when diagnosed early (usually on echo).
2. BCI with septal rupture. These injuries are rare and often occur in combination with valvular injuries; they present with signs of valvular failure and congestive heart failure. Treatment is usually surgical.
3. BCI with coronary artery injury. Lacerations of the coronary arteries typically lead to hemopericardium and tamponade, and are usually fatal. Coronary artery dissections and thrombosis can lead to myocardial infarction.
4. BCI with cardiac failure. While the aforementioned 3 entities can lead to cardiac failure, BCI can also be caused by direct injury to the cardiac muscle, leading to cardiac dysfunction and contractility.
5. BCI with complex arrhythmias. These patients often need immediate treatment because if untreated, the dysrhythmias will lead to congestive heart failure and, potentially, death.
6. BCI with minor electrocardiogram (ECG) or cardiac enzyme abnormalities. These patients are usually asymptomatic and will not require any treatment.

BCI should be suspected in patients with significant blunt trauma to the chest. In such patients the initial assessment includes an ECG[116] to assess for the presence of arrhythmia, ST abnormalities, signs of ischemia, and heart block. E-FAST should be done to assess for the presence of hemopericardium and tamponade, as well as to assess the patient's volume status. BCI can be ruled out in patients who have a normal ECG, a normal E-FAST examination, and who are hemodynamically stable.[116] In hemodynamically unstable patients BCI should be considered, but should remain a diagnosis of exclusion until all other causes of this instability have been ruled out.

Patients with hemopericardium should be resuscitated rapidly and prepared for urgent surgical treatment. ED thoracotomy might be required if their clinical status deteriorates, knowing that in such a context the survival rate is marginal. Those who remain unstable and who have dysrhythmias should be managed according to Advanced Cardiovascular Life Support protocols. Repeat E-FAST should be performed in patients who fail to improve or whose status worsens, as hemopericardium may not always be present initially.

The use of biomarkers remains a controversial topic in the assessment of patients with possible BCI. Many studies have shown that in stable patients with normal ECG, an elevated creatine kinase MB level is nonspecific for the diagnosis of BCI.[114,117–120] Troponin I and troponin T have been shown to be more specific, but still lack adequate sensitivity to have clinical utility as a screening test.[121–123] This lack of sensitivity is explained by the fact that in trauma one can often see an elevation of these biomarkers, due to catecholamine release, reperfusion injury after hypovolemic shock, microcirculatory dysfunction, or oxidative injury. Troponin can also be negative in patients with dysrhythmias, and therefore a normal troponin level does not exclude the need for cardiac monitoring and eventual need to treat the dysrhythmias. For patients who are unstable or have dysrhythmias, biomarkers should be considered if there are signs of cardiac ischemia or myocardial infarct. In such patients one has to consider that the cardiac injury might have preceded, and therefore be the cause of, the trauma.

In stable patients with a normal ECG, cardiac echocardiography does not help the clinical management and is therefore not indicated.[115,124] In all other situations (unstable patient and/or abnormal ECG), echocardiography identifies the cause(s) of the cardiac dysfunction (wall motion abnormalities, septal injuries, valvular rupture or dysfunction, thrombus), and assesses the need and response to volume resuscitation and ionotropic support. For this procedure a transesophageal echocardiogram is preferred, and can often be done intraoperatively if necessary.[125] **Fig. 1** provides a flow diagram to illustrate the assessment of possible blunt cardiac assessment.

Penetrating Cardiac Injury

Penetrating cardiac injuries are highly lethal. It is estimated that the probability of arriving alive at the hospital after suffering such an injury is between 6% and 19.3%.[126,127] Most common injuries are to the right ventricle (due to its anterior location), followed by the left ventricle.[128–130] Atrial injuries are less common and usually less severe.

Penetrating cardiac injuries typically result in hemorrhagic shock and/or cardiac tamponade. Hemorrhagic shock is responsible for the majority of deaths at the scene.[131] However, it is important to remember that because of the poor compliance of the pericardium, as little as 50 mL of blood can lead to tamponade and, therefore, lethal injuries can occur with very little amount of blood loss. Similarly to blunt trauma, clinical signs are not reliable for diagnosing tamponade in penetrating cardiac trauma.

The cardiac box, defined as the space inferior to the clavicle, superior to the costal margin, and medial to the midclavicular lines, is the area where penetrating injuries to the chest are most dangerous. However, injuries outside this area do not rule out cardiac injuries. Patients with potential cardiac injuries require immediate and rapid

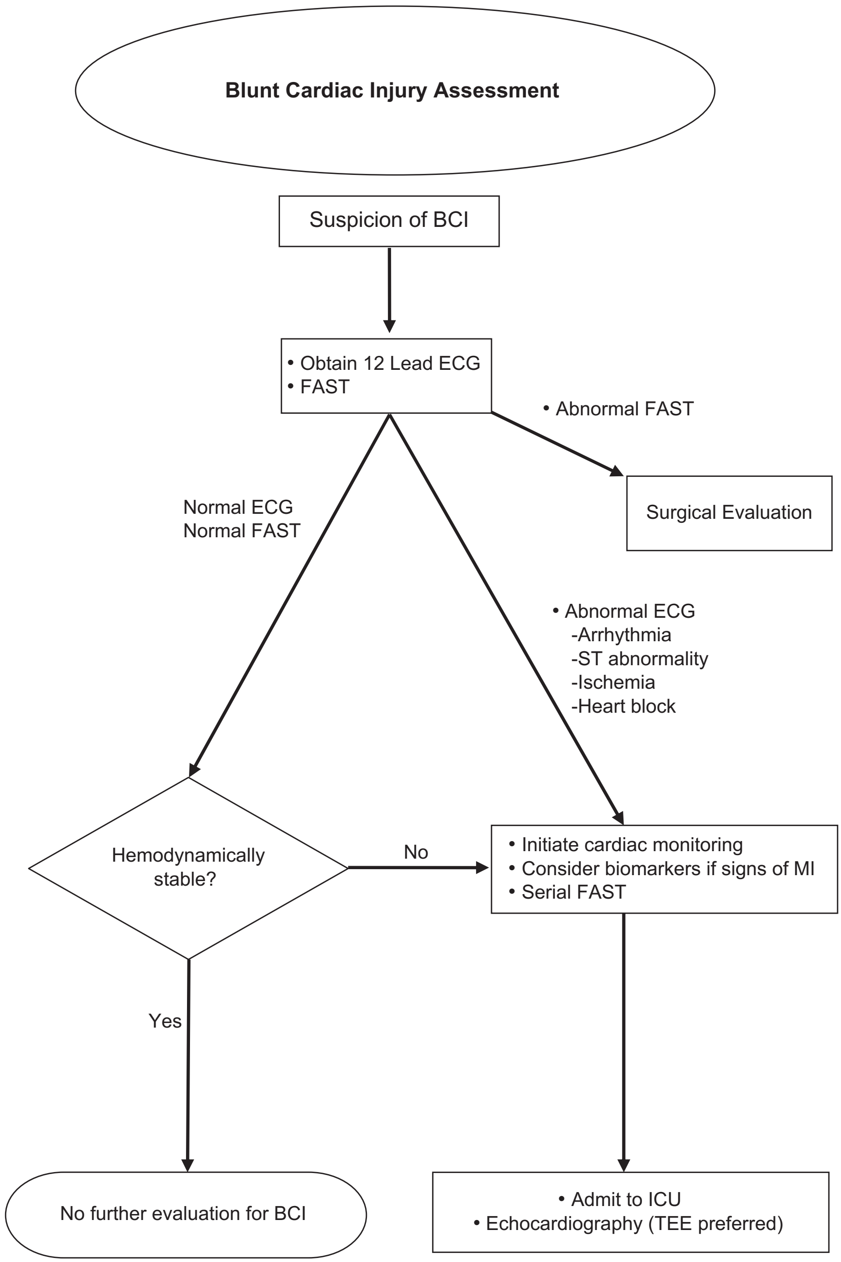

Fig. 1. Assessment of blunt cardiac injury (BCI). ECG, electrocardiography; FAST, focused assessment with sonography for trauma; ICU, intensive care unit; MI, myocardial infarction; TEE, transesophageal echocardiography.

evaluation in the ED (**Fig. 2**). After a thorough physical examination, patients require an immediate FAST examination of the heart, pericardium, and thorax to identify possible hemopericardium, tamponade, hemothoraces, and pneumothoraces.[132,133] The added benefit and need of a portable CXR in these patients must be weighed against

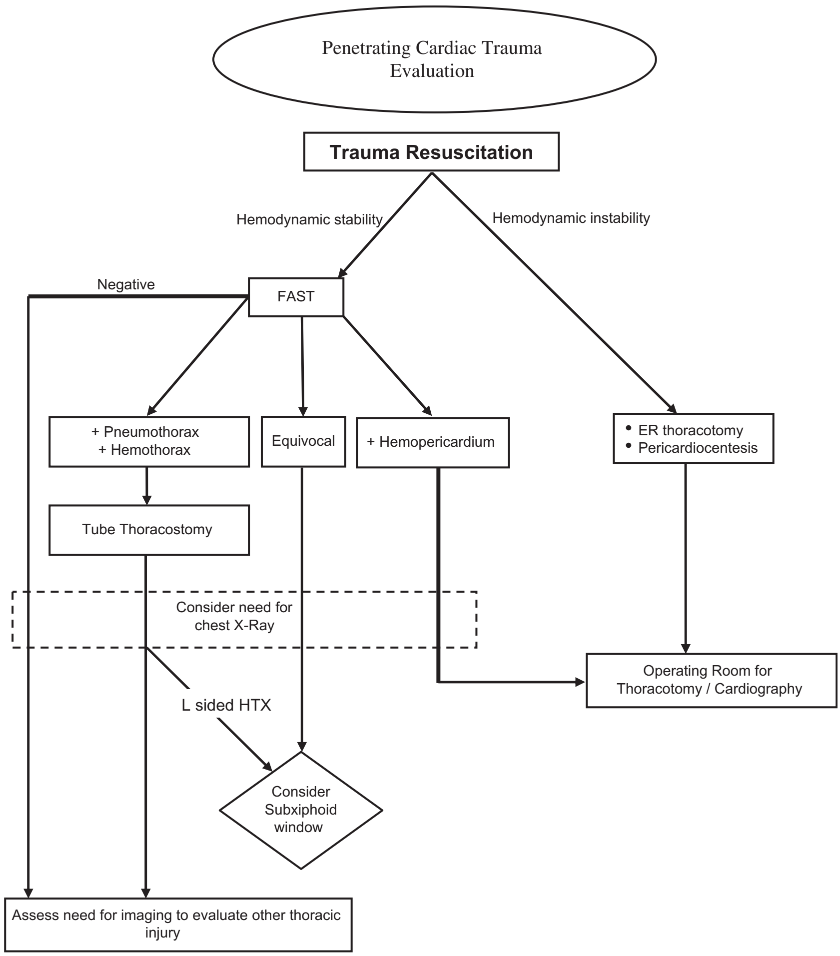

Fig. 2. Assessment of penetrating cardiac trauma. ER, emergency room; HTX, hemothorax.

the high sensitivity of bedside ultrasonography. The proficiency of the physician at performing the ultrasound procedure and the quality of the images generated must also be taken into account.

Patients with hemopericardium, even when stable, require urgent thoracotomy and cardiorrhaphy. Patients with left-sided hemothoraces could have a self-draining hemopericardium and are at risk of decompensating without warning. In such a case, a subxiphoid window can be performed to evaluate the pericardium. The same can be done if the result of the FAST is equivocal. If the patient becomes unstable at any time during the evaluation, an emergency thoracotomy can be performed in institutions that have the adequate surgical capacity to assume the care of these patients.

Aortic Injuries

Blunt aortic injuries usually occur when rapid deceleration produces sudden shearing forces on the aorta. The proximal descending aorta is the area most at risk because the ligamentum arteriosum is a transition point between the fixed descending aorta and the (relatively) mobile aortic arch. Although these injuries are not common, they are often lethal and are responsible for 15% of deaths in MVCs.[134]

Patients with blunt aortic injuries can be divided into 3 groups:

1. Complete transection of the aorta. These patients typically die at the scene or shortly after their arrival at the hospital.
2. Full-thickness injuries. These patients have ongoing bleeding and are hemodynamically unstable.
3. Partial-thickness injuries with contained hematomas. These patients can often present as hemodynamically stable.

In all cases, hemodynamic instability can also be present because of concomitant injuries and hemorrhage of other organs.

The challenge for the clinician is to identify the stable patients with incomplete injuries before the aortic lesion progresses to complete rupture. Unfortunately, there are no specific clinical signs that allow for the rapid identification of aortic injuries. For this reason they should be suspected in any patient with the proper mechanism, that is, rapid deceleration, high-speed MVC with frontal or side impact, and falls from a great height.[135,136]

Aortic injuries often result in some amount of mediastinal hemorrhage that can lead to disruption of mediastinal structures. Radiographic signs of such disruption include downward depression of the left main stem bronchus, deviation of the nasogastric tube to the right, apical pleural hematomas, disruption on the calcium ring in the aortic knob, and mediastinal hematoma. Ekeh and colleagues[137–139] found that CXR can miss 11% of aortic injuries and therefore is not an acceptable modality to rule out such injuries.

Angiography is the accepted gold standard for the diagnosis of aortic injuries. However, this modality is not available in all centers, and when it is present is rarely readily available. Furthermore, patients who require evaluation of the aorta typically need CT imaging of other organs and systems. Contrast CT has a reported sensitivity of greater than 97%, a specificity of greater than 85%, and a negative predictive value 100%.[137,140–142] For these reasons and because of the progress made in CT technology, CT with contrast is now the modality of choice for evaluation of aortic injuries. In the stable patient, angiography is still indicated when the CT result is equivocal. It can also be used for operative planning when the CT is positive. The need and timing of the angiography should usually be discussed with the consulting vascular surgeon.

The management of patients with aortic injuries includes: (1) prevention and control hypertension that can lead to progression of the injury; (2) control coagulopathy, including the prevention and treatment of hypothermia and acidosis; (3) correction of other life threatening injuries—it is important to prioritize which injuries need to be managed first because many aortic injuries do not require immediate treatment; and (4) definitive repair of the aortic injury.

Urgent repair is indicated for patients with hemodynamic instability attributed to the aortic injury, contrast extravasation on CT or with rapidly expanding hematoma, large hemorrhages from chest tubes, and penetrating aortic injuries.

Digestive Tract

Injuries to the esophagus are rare in blunt trauma because it is a well-protected structure due to its location in the posterior mediastinum. These injuries usually result from a rapid increase in esophageal luminal pressure. In penetrating trauma, esophageal injuries are also rare but must be suspected in all penetrating traumas that cross the mediastinum.[143]

The diagnosis of esophageal injuries is rarely evident at initial presentation. There are no specific clinical signs or specific radiographic findings that suggest the diagnosis. The risk of complications, namely sepsis from leakage of digestive track content, requires a high index of suspicion and early diagnosis. Basically any patient with air in the mediastinum of unclear origin should be evaluated for potential esophageal injury. Gastroscopy is avoided, as it increases mediastinal contamination if an injury exists. A water-soluble gastrografin swallow is the initial test of choice. A barium study can then be performed if the initial gastrografin test is negative, as barium has a greater sensitivity for small perforations.[144]

PUTTING IT ALL TOGETHER: INITIAL APPROACH AND RESUSCITATION OF THE UNSTABLE PATIENT

Data Gathering: Initial History and Physical Examination

The history should focus on determining the mechanism (blunt, penetrating, or a combination of both) and on estimating the severity of the forces to which the patient has been submitted. Blast mechanisms are for all purposes equivalent to blunt mechanisms, but with a much more rapid onset of symptoms.[63,145–147]

Immediate assessment of vital signs and physical examination structured along the usual ABCs (Airway, Breathing, Circulation) will allow the EP to rapidly identify respiratory and/or hemodynamic compromise, which mandate immediate action. In blunt trauma, tenderness to palpation will confirm thoracic involvement, but physical examination has shown poor sensitivity in ruling out specific injuries.[148] Clues to potential injuries should nonetheless be sought: asymmetry of chest rise (flail chest), crepitus on palpation (rib injury), decreased or absent air entry (splinting from rib fractures, hemothorax or pneumothorax), and subcutaneous emphysema (pneumothorax or tracheobronchial injury). It has been shown that physical examination is not reliable for the diagnosis of hemothorax or pneumothorax in blunt or penetrating trauma.[149–153]

In penetrating torso trauma, the initial goal of the EP should be to find the location of all wounds to better determine the pathway of potential injuries.[154] This step is critical, as important resuscitative decisions including ED thoracotomy may need to be taken within the first seconds of the patient's arrival in the ED. The protocol at the authors' institution is to rapidly expose (including bilateral log roll) the patient as soon (or simultaneously) as he or she is placed on the ED stretcher, which takes less than 20 seconds when done properly; waiting for the patient to be connected to monitors and intravenous catheters can delay this crucial step by several minutes. The authors have encountered cases whereby the discovery of unforeseen (posterior) thoracic wounds drastically altered initial management.

Management of the Unstable Patient

There is a paucity of scientific literature to support the exact sequence of actions to be performed in severe chest trauma, especially in blunt trauma cases. A previously planned algorithmic approach will help the physician who is confronted with a potentially dying patient.[155]

Airway compromise, a respiratory rate greater than 30, oxygen saturation below 90% to 92%, tachycardia above 120 beats per minute, and hypotension below 100 systolic are all ominous signs that mandate immediate resuscitative action. On identifying the unstable patient, physicians should attempt to differentiate between respiratory and circulatory issues, though this is not always possible. Hemorrhagic shock can present with important tachypnea and/or desaturation, mimicking respiratory compromise, so simultaneous interventions to restore oxygenation, ventilation, and circulation should be initiated. The use of E-FAST and CXR can be of tremendous value, but in true critical situations there may not be time to perform these procedures. It must be accepted that in critical patients the physician may need to perform therapeutic actions such as a thoracostomy, which in retrospect may not have been needed. Failure to perform these actions when indicated could result in much more significant consequences and patient's demise.

Blunt chest trauma

By answering a series of questions and taking the appropriate therapeutic actions, the physician will be able to successfully resuscitate the majority of severe, unstable chest trauma patients. Some of the steps may be done simultaneously. These questions include:

- Is the airway in jeopardy or is the patient nearing apnea? If so, immediate intubation is mandatory.
- Is the patient in respiratory distress of hypoxic? If so, the patient should receive high-flow oxygen by nonrebreather mask.
- Did the patient improve rapidly with high-flow oxygen? If yes, the clinician can pursue more calmly a more thorough diagnostic evaluation (with CXR and ultrasound evaluation of the chest).
- Is the patient also hypotensive? The combination of respiratory distress and hypotension in chest trauma highly suggests TPTX. Immediate chest decompression by thoracostomy is needed to salvage these patients[145,156] while simultaneous fluid resuscitation is undertaken.
  - Can the affected side be identified by the presence of deviated trachea, decreased air entry, obvious crepitus from rib fractures or subcutaneous emphysema, decreased chest expansion, or tenderness to palpation? If so, drain this side.
  - Is the patient still in distress after chest decompression or was the affected side not identifiable? Drain the contralateral side or perform bilateral thoracostomies from the start.[48]
- Examine the depth and pattern of breathing in combination with chest wall movement and integrity: is there compromise of respiratory mechanics from flail chest or multiple rib fractures? If yes, intubation and mechanical ventilation might benefit the patient.
- Is the patient still presenting gas exchange problems, as manifested by low oxygen saturation, or increased work of breathing? Obtaining bedside imaging can prove extremely useful as regards the diagnosis and appropriate treatment. Causes may include: lung collapse from hemothorax/pneumothorax; parenchymal damage from pulmonary contusions or lacerations; and alveolar filling with fluid, blood, or vomitus. Mechanical ventilation will benefit many of these injuries[145] except for pneumothoraces, which it may exacerbate. Major injuries to the chest such as pulmonary contusions and flail chest require time to improve, and the patient's status may often deteriorate in the subsequent hours, so aggressive management is warranted.[145] These patients should all be admitted to an ICU for proper monitoring.
- Is the patient hemodynamically unstable? TPTX as a cause should already have been dealt with. Fluid resuscitation, including blood products, should be well

under way through access by large-bore intravenous catheter. The sensitivity of the supine CXR for hemothorax is low, and as much as a liter of blood can be missed on such films.[24] E-FAST by well-trained operators can be used to assess the pleural spaces as well as the pericardial space; it is the most efficient way to rapidly assess the abdomen as well.

- Is there pleural fluid on E-FAST examination (or on CXR)? If so, insert a large-bore chest tube in the affected hemithorax and monitor blood output. The decision for urgent thoracotomy is based on the patient's physiologic status and response to volume resuscitation combined with the amount of immediate and ongoing blood drained from the chest.[24] Bilateral chest tube insertion may be indicated in a hypotensive patient to simultaneously diagnose and drain the chest cavities.[145,156] Taking this action would apply to the profoundly hypotensive patient or in pulseless electrical activity, to immediately relieve any tension physiology in the chest. It would also apply in cases where sonographic evaluation of the chest is impossible, the abdominal FAST is negative or equivocal, and the pelvis appears stable or has already been bound.
- Is there free abdominal fluid on the FAST examination? If so, involve immediately a general surgeon for possible laparotomy.

Penetrating trauma

Management of the unstable patient with penetrating chest trauma will be directly affected by the location of the wounds and types of injury (missile vs stab wound). It is therefore critical to identify all wounds very early on in the course of the resuscitation. Locations are referred to as transmediastinal, central (cardiac box), thoracoabdominal, or peripheral.[154] Decision branching points are also more straightforward.

Patients in respiratory distress or who are hypoxic are likely to have a large pneumothorax with or without associated hemothorax or tension physiology. These patients should be placed on high-flow oxygen and receive an immediate thoracostomy of the involved hemithorax. Intubation should be considered if the patient is too agitated to allow insertion of the chest tube. If insertion of the chest tube fails to improve the patient's condition, the physician should drain the contralateral hemithorax; this is especially important in gunshot wounds.

Managing hemodynamic instability in these cases revolves around rapidly obtaining large-bore intravenous access with immediate initiation of fluid resuscitation, with blood. The use of E-FAST is paramount to identify the presence of a pericardial effusion, which mandates operative exploration. If the patient is moribund or with worsening vital signs, an ED resuscitative thoracotomy should be done, as any delay decreases survival chances.[157] Otherwise it may be more appropriate to bring the patient immediately to the operating room for definitive surgical care.

Victims of gunshot wounds to the chest who are moribund but have a negative E-FAST for a pericardial effusion should be intubated and obtain bilateral thoracostomies, while simultaneously completing the rest of the FAST of the abdomen, because bullets can travel far from their point of entry. Urgent operative management is mandatory and should be directed according to the findings of the FAST and thoracostomies. Hypotensive but not moribund patients benefit from a similar approach, though a single chest tube can be inserted initially if the entry and exit wounds are on the same hemithorax. Transmediastinal gunshot wounds have a much higher likelihood of requiring a thoracotomy.[154]

In unstable stab wounds, the management is guided primarily by the location of the wound(s). Hypotensive patients with a central wound (in the cardiac box) who have a negative FAST of the pericardium should obtain a tube thoracostomy on the side of injury. The presence of a hemothorax should prompt immediate surgical exploration, as a ventricular laceration (with an associated pericardial laceration) could still be present and be draining blood directly into the chest cavity. In thoracoabdominal wounds a chest tube should be inserted in the wounded hemithorax, and a FAST should be done to identify the injured cavity and dictate the surgical approach.[154]

In all cases careful examination must be done to exclude other sources or areas of bleeding, as it is easy to be distracted by one obvious wound!

SUMMARY

Chest trauma is responsible for 25% of traumatic deaths. Rapid identification of injuries through an organized approach and stabilization based on patient physiology can prevent untimely death and morbidity. The incorporation of E-FAST will greatly facilitate the diagnostic approach. Therapeutic gestures such as tube thoracostomy and intubation play an important role in the initial stabilization of these patients. Further imaging with CT scanning allows for better definition of the majority of the injuries and has become the diagnostic modality of choice for aortic injuries. The majority of occult injuries (to CXR) can be easily observed. More than 80% of chest injuries may be managed nonoperatively, with supportive treatment. Prompt involvement of a thoracic surgeon is necessary in cases of ruptured airway, massive hemothorax, and penetrating cardiac trauma, as well as suspected esophageal injuries.

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