Thoracic Trauma

Bradley M. Dennis, MD[a,*], Seth A. Bellister, MD[b],
Oscar D. Guillamondegui, MD, MPH[a]

KEYWORDS

• Chest trauma • Thoracic trauma • Pneumothorax • Hemothorax • VATS
• Rib fractures • Pulmonary contusion

KEY POINTS

- Management of chest wall injuries requires multidisciplinary approach highlighted by multimodal pain management and occasionally operative intervention.
- Rib fixation is an evolving field that require additional study to delineate the most appropriate candidates for this therapy.
- Pneumothorax should be treated immediately with tube thoracostomy if tension physiology is present. Otherwise, symptomatic or enlarging pneumothoraces or hemothoraces should be evacuated.
- Retained hemothoraces of more than 300 mL in volume should be preferentially treated with videoassisted thoracoscopic evacuation unless prohibitive operative candidate.
- Tracheobronchial injuries are definitively diagnosed bronchoscopically and should be treated by surgical repair, if possible, after securing the airway.

CHEST WALL INJURY

Chest wall injury is one of the most common in trauma, present in 10% or more of all trauma admissions.[1] It is also a significant marker of mortality, injury severity, and associated injuries.[1–3] In isolation, chest wall injury is a powerful predictor of pulmonary deterioration and complications.[3–5] The effect seems to be greatest in older populations with increased ventilator days, and pneumonia and acute respiratory distress syndrome rates compared with younger cohorts with similar injury patterns.[4–7]

Flail chest, most commonly defined as 3 or more consecutive ribs fractured in multiple locations, can significantly alter chest wall mechanics and result in serious respiratory complications. Flail segments can cause paradoxic chest wall motion, which

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[a] Division of Trauma, Surgical Critical Care, and Emergency General Surgery, Department of Surgery, Vanderbilt University Medical Center, 1211 21st Avenue South, 404 Medical Arts Building, Nashville, TN 37212, USA; [b] Division of Trauma, Surgical Critical Care, and Emergency General Surgery, Department of Surgery, Vanderbilt University Medical Center, 1211 21st Avenue South, 404 Medical Arts Building, Nashville, TN 37212, USA
* Corresponding author.
E-mail address: Bradley.m.dennis@vanderbilt.edu

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can effect respiratory mechanics throughout the respiratory cycle (**Fig. 1**).[8] The impact of this injury is significant. More than 80% of patients with flail chests require admission to the intensive care unit (ICU) and nearly 60% will require mechanical ventilation with a 20% tracheostomy rate. The injury has a significant effect on in-hospital complications because 20% will develop pneumonia and up to 7% will develop sepsis.[9]

This diagnosis is suspected in patients with chest wall pain after injury. Crepitus, chest wall asymmetry, paradoxic breathing, and dyspnea are often present. Chest radiographs can identify many rib fractures, particularly significantly displaced fractures. Sternal fractures and nondisplaced rib fractures are often only identified with computed tomography (CT) imaging.

The management of these injuries requires a multidisciplinary approach with 3 primary components: pain management, respiratory therapy, and mobility. Anesthesia, nursing, and respiratory and physical therapy all play significant roles in the successful management of patients with chest wall injury.

Pain management consists of 3 basic categories: nonregional analgesia, regional anesthetics, and surgical fixation. Surgical fixation will be discussed elsewhere in this review. Nonregional analgesia, primarily oral and intravenous analgesics, is often the initial therapy for pain management for mild to moderate chest wall injury. Because of the relative dearth of clinical research in this area, this initial approach is essentially an adaptation of postoperative pain control approaches. Recent emphasis on reducing opioid use has increased the push for multimodal analgesia. Multimodal analgesia is defined as simultaneous use of a combination of analgesics that each have different mechanisms of action and thus target different receptors in the peripheral and/or central nervous system.[10] A recent joint practice guideline from the Eastern Association for the Surgery of Trauma (EAST) and the Trauma Anesthesia Society noted very limited data describing multimodal analgesia in management of blunt thoracic trauma. However, they were able to conditionally recommend the use of

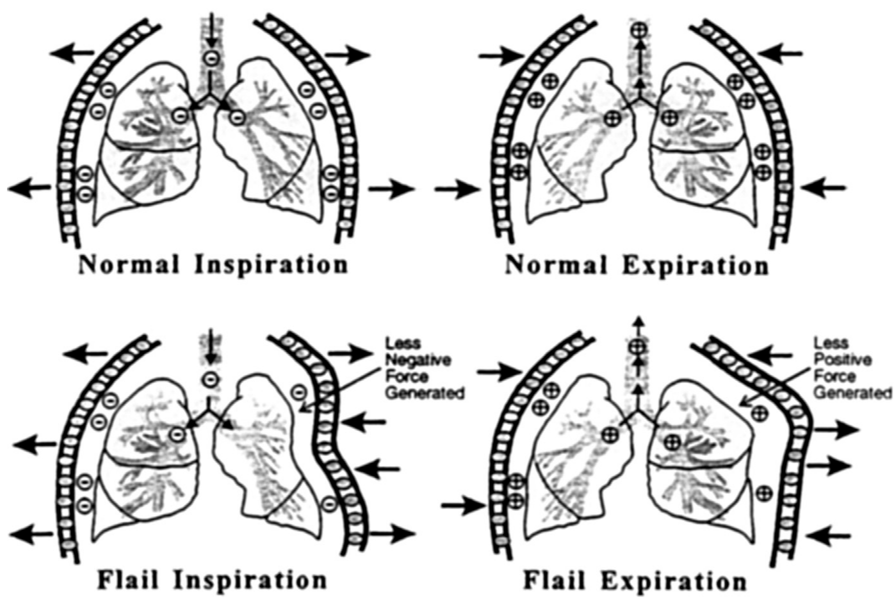

Fig. 1. Flail chest physiology. (*From* Mayberry JC, Trunkey DD. The fractured rib in chest wall trauma. Chest Surg Clin N Am 1997;7(2):253; with permission.)

multimodal analgesia over opioids alone in patients with blunt thoracic trauma.[11] This multimodal approach involving scheduled nonsteroidal antiinflammatory drugs, acetaminophen, and/or gabapentin and pregabalin with opioids as needed should be attempted for mild to moderate chest wall injury. Oral opioids are preferred to intravenous when possible. Additionally, when intravenous opioids are required, patient-controlled analgesia should be used if possible.[10] For patients requiring more aggressive pain control, lidocaine or ketamine infusions can be considered, although these modalities come with weaker recommendations.[10]

Regional anesthetic techniques should be considered to optimize pain control for patients with chest wall injury that are considered at higher risk of respiratory complications. This population includes more severe chest wall injury (>4 fractured ribs), over 45 years of age, insufficient respiratory effort (based on incentive spirometry or pulmonary function tests), and/or inadequate pain control with multimodal analgesia.[3–7,12–14] Regional anesthesia consists of intercostal nerve blocks, paravertebral blocks and thoracic epidural catheters (TEC).

The intercostal nerve block involves blocking the intercostal nerves individually with an injection of local anesthetic, typically bupivacaine. To ensure an adequate block and avoid missing overlapping innervating nerves, intercostal blocks require injection at the level of the fractured rib plus 1 rib above and below.[15] Identification of the appropriate location for injection involves manual palpation of the ribs, which can contribute to pain. Additionally, identification of landmarks becomes increasingly difficult above the seventh thoracic vertebral level. Local anesthetic toxicity and pneumothorax are risks with repeated injections.[15] A continuous infusion catheter with slow release of anesthetic has been developed to minimize these complications and increase the duration of pain relief. These catheters are placed in an extrathoracic, paraspinous location using manual palpation or ultrasound guidance. A long infusion catheter is placed and connected to an infusion pump that administers a continuous infusion of local anesthetic for up to 5 days. Truitt and colleagues[13,16] demonstrated in 2 studies that use of this technique significantly improved pain control at rest and after coughing, increased sustained maximal inspiratory lung volumes, and shortened duration of stay.

Paravertebral blocks offer broader, dermatomal, coverage, and avoid manual palpation of the fractured ribs. The technique involves blocking the nerve root in the paravertebral space as it exits the thoracic vertebrae. Although technically easier than TEC placement, there is a small pneumothorax risk.[17] Because it does not enter the epidural space, paravertebral blocks offer some distinct advantages compared with TEC, namely, no urinary retention, no systemic vasodilation, and accessibility to those with thoracic spine fractures or moderate coagulopathy.[17] In a small randomized trial, paravertebral block and TEC were found to be equally effective at relieving pain and improving respiratory function in patients with unilateral rib fractures with similar pulmonary complications and duration of ICU and hospital stay.[18]

TEC are the regional anesthetic modality of choice for patients with bilateral chest wall injury, and ideal for patients with more than 2 fractured ribs. The procedure is technically more challenging than the other regional approaches, however.[15,17] A catheter is inserted at the vertebral level that corresponds with the midpoint of the fractured ribs. The epidural space is entered and a local anesthetic and/or a narcotic (eg, bupivacaine and fentanyl) are infused.[17] This epidural location eliminates the risk of pneumothorax as well as local anesthetic toxicity. It does, however, carry certain unique risks, including dural puncture and spinal cord injury, hypotension, urinary retention, pruritus, and motor block limiting mobility.[15,17] Spinal epidural hematoma is a rare but significant complication of TEC insertion and removal. As such, coagulopathy, thrombocytopenia, anticoagulation, and antiplatelet therapy are contraindications to placement or removal. Deep sedation or severe head injury are also relative contraindications to placement of TEC. Outcomes for use in chest wall injury are somewhat mixed. Early studies demonstrated improved analgesia compared with other approaches.[12,19,20] Subsequent studies revealed that mortality and pulmonary complications were not significantly different with TEC use.[18,21] More recently, however, reductions in mortality have been seen with more widespread use of TEC.[22,23] These mixed data resulted in a conditional recommendation for epidural analgesia over opioids alone for patients with blunt chest trauma.[11] Rib fixation is also an option for managing pain in patients who are refractory to medical management, as will be discussed elsewhere in this article.

Respiratory therapy is arguably the most important component of the management of chest wall injury. Aggressive pulmonary hygiene is necessary to clear airway secretions and prevent atelectasis. Pneumonia and respiratory failure are the major complications of poor pulmonary hygiene in patients with chest wall injury. Lung expansion and secretion clearance are key interventions in preventing pneumonia and respiratory complications.[24–26] Respiratory therapists and bedside nurses are critical personnel in preventing these complications.[27,28] Therapies to aid lung expansion include incentive spirometry and positive expiratory pressure therapy devices. Secretion clearance is achieved with vibratory mechanisms, coughing, and airway suctioning (nasotracheal or tracheal). Protocolized application of these therapies as initiated by both physicians and respiratory therapists may reduce hospital duration of stay and unplanned ICU admissions.[24,25,29]

Mobility is a key component to the management of trauma patients with chest wall injury, allowing for optimal ventilation and perfusion matching. Additionally, upright positioning encourages better diaphragm excursion and subsequently higher tidal volumes compared with supine positioning. Progressive mobility has been associated with decreased rates of deep venous thrombosis and pulmonary embolism, and lower pneumonia rates, less ventilator days, and shorter durations of hospital and ICU stays.[24–26,30–32]

Multidisciplinary clinical pathways for rib fracture management are beneficial. In a study by Todd and associates,[14] all patients over 45 years of age with more than 4 fractured ribs were entered into a clinical rib fracture pathway (**Fig. 2**).

A preassessment–postassessment comparison of the pathway revealed significantly shortened ICU and hospital durations of stay (2.4 days vs 3.7 days, respectively). Logistic regression analysis showed an 88% reduction in pneumonia and a 63% reduction in mortality.[14]

A more controversial approach to chest wall injury is rib fixation. This has been a topic of increasing debate for many years now. Proponents of the rib fixation point to decreases in ICU duration of stay, duration of mechanical ventilation, pulmonary function tests, tracheostomy rates, and treatment costs.[33–42] Opponents have pointed to no improvements in mortality, mixed results in terms of pain control, few long-term outcome data, virtually no studies comparing rib fixation with multimodal analgesia, and questionable indications for operation.[34,40,43,44] Schuurmans and associates[40] recently performed a systematic review of operative versus nonoperative management of flail chest. Three small, randomized, controlled trials were identified, totaling 123 patients.[36,37,41] There was no difference in mortality between the operative and nonoperative groups, although the authors note that the sample size is underpowered to adequately determine this outcome. Of note, the relative risk of pneumonia was decreased by 55% in the operative management group. Duration of mechanical ventilation was reduced by an average of 6.5 days; ICU duration of stay and hospital

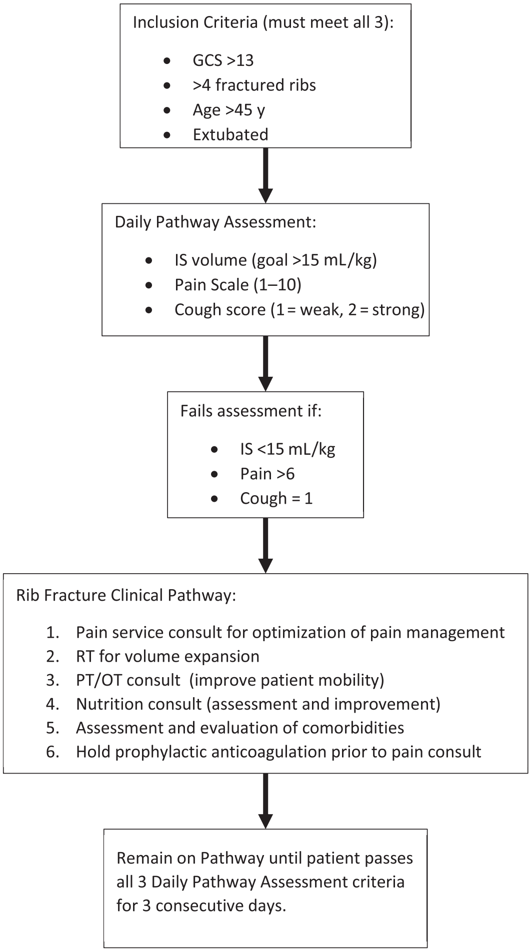

Fig. 2. Rib fracture management clinical pathway. Daily pathway assessment performed on morning rounds. Intubated patients may be included in clinical pathway if eye and motor components of GCS are intact and extubation is anticipated within next 7 days. GCS, Glasgow Coma Scale; IS, incentive spirometry; OT, occupational therapy; PT, physical therapy; RT, respiratory therapy. (*Adapted from* Todd SR, McNally MM, Holcomb JB, et al. A multidisciplinary clinical pathway decreases rib fracture-associated infectious morbidity and mortality in high-risk trauma patients. Am J Surg 2006;192(6):806–11; with permission.)

duration of stay were also shortened by 5.2 and 11.4 days, respectively.[40] A Cochrane review noted similar findings as well as a decrease in tracheostomy rates and improvement in chest wall deformity.[34]

Among the most common points of contention regarding operative fixation of chest wall injury are the indications for fixation.[44] Flail chest is considered among the most widely accepted indications for operative management.[33,34,37,41–43,45,46] A recent EAST practice management guidelines conditionally recommended rib fixation in patients with flail chest. A very low quality of evidence and risk of bias were reasons cited for only giving a conditional recommendation.[47] Other indications include significant chest wall deformity, inadequate pain control, and fracture nonunion.[45,48] **Table 1**

Table 1
Relative indications and contraindications for rib fixation

Relative Indications	Contraindications
Pain refractory to medical management	Respiratory failure not related to chest wall injury
Flail chest causing respiratory compromise	Significant pulmonary contusion
Respiratory failure owing to chest wall instability	Other injuries requiring prolonged intubation
Rib fractures with fragments impinging on vital structures	Patients unable to tolerate surgery
Impaired pulmonary function tests owing to chest wall deformity	
Symptomatic rib fracture nonunion or malunion	

shows the common indications and contraindications for rib fixation. The majority of the published outcomes involve ventilated patients. As a result, guidance for the management of nonintubated patients is greatly lacking.

Additionally, none of the published randomized studies compare operative fixation with current nonoperative multidisciplinary approaches. One study mentioned a comparison with TEC use.[41] In another study, nonoperative management included securing plaster over the fractured ribs, essentially splinting—a practice abandoned in the United States long ago.[36] Using modern multidisciplinary approach to chest wall trauma, patients managed nonoperatively were found to have better outcomes compared with surgical management. The duration of mechanical ventilation (3.1 days vs 6.1 days), ICU duration of stay (3.7 days vs 7.4 days), hospital duration of stay (16.0 days vs 21.9 days), and pneumonia rates (22% vs 63%) were all significantly less in the nonoperative group compared with the operative group.[43] Although a small, retrospective study, these findings may suggest that more modern approaches to critical care and rib fracture management have reopened the question of the role of surgery in chest wall injury.

Pieracci and coworkers[39] conducted a study that evaluated outcomes of early rib fixation (<72 hours after injury) as compared with a modern nonoperative, multidisciplinary approach. In this study, the authors noted a 76% reduction in odds of respiratory failure, 82% reduction in odds of tracheostomy, and a 5-day reduction in duration of mechanical ventilation.[39] This study is compelling, not in its results, which are similar to previous studies, but rather in its design. It is the first study to actually compare surgical fixation with the current best available multidisciplinary practices for nonoperative management of chest wall injury. Additionally, it describes outcomes for rib fixation for expanded indications beyond flail chest only. Other surgical indications in the study were 3 or more severely (bicortical) displacement, 30% or greater hemithorax volume loss, and failure of medical management.[39] It is unclear how, or if, these expanded indications or the earlier operative timing explain the differences in outcomes from the previous multidisciplinary study, but it certainly leaves open the question as to the best approach for managing patients with severe chest wall injury.

There are multiple different types of fixation systems in existence, including wire cerclage, clamping braces, external plate and screw fixation, and intramedullary fixation.[35] The most commonly used technique for rib fixation is the external plate and screw system.[35] Just as there are multiple commercially available fixation products, there are multiple surgical approaches to rib fixation. Traditionally, fixation has been performed through a single lateral thoracotomy-type incision. Modifications have been made to this technique based on unique fracture patterns (anterior, bilateral, flail, etc).[48–50] More recently, minimally invasive techniques have been reported, but no comparison of outcomes has been performed at this time.[51,52]

LUNG INJURY

Pulmonary Contusion

Pulmonary contusion often occurs in conjunction with chest wall injury. The contused lung is often damaged and unable to participate in the gas exchange of respiration.[53–55] If large enough in volume, this condition can result in significant respiratory distress. In flail chest, pulmonary contusions are frequently present and contribute to respiratory compromise. There are few clinical signs of pulmonary contusion. Concomitant injuries should raise a suspicion for the possible presence of pulmonary contusion and lead to further investigation. Chest radiographs and CT scanning are the 2 methods of diagnosing pulmonary contusions. The appearance of pulmonary contusion on chest radiographs is often delayed. CT scanning has proven to be a more accurate method for diagnosing pulmonary contusions. In a study by Miller and colleagues,[56] CT scans identified 100% of pulmonary contusions compared with just 38% identified by chest radiographs. Rodriguez and coworkers[57] noted in a study of more than 1000 patients with pulmonary contusion that more than 73% of contusions were seen only on CT imaging. In addition to early diagnosis, CT imaging can also determine the total contused lung volume. Pulmonary contusions have been identified as an independent risk factor for respiratory complications.[58,59] Miller and associates[56] found that patients with severe pulmonary contusions (contused lung $\geq$20% of total lung volume) developed acute respiratory distress syndrome at much higher rates (82% vs 22%; *P*<.001) than those with moderate contusions (<20% contused lung volume). The treatment of pulmonary contusion is supportive. Historically, judicious fluid administration was advocated to prevent “fluffing out” of contusions. As fluid management strategies have shifted away from aggressive crystalloid resuscitation, so has the concern of worsening pulmonary contusions. For severe contusions, intubation and mechanical ventilation may be necessary. For the most severe injuries, life-threatening hypoxia owing to pulmonary hemorrhage can result. Advanced ventilator modes, including extracorporeal membrane oxygenation, may be necessary.[60]

Pneumothorax

Pneumothorax is a common injury in both blunt and penetrating thoracic trauma. Typically, pneumothorax is not an immediately threatening condition, but there is potential for progression that can evolve to life threatening. Simple pneumothorax is characterized clinically in a variety of presentations. Although some patients may present asymptomatically, many present with ipsilateral chest pain, absent or diminished breath sounds, hyperresonance to percussion, shortness of breath, dyspnea, and subcutaneous emphysema of the chest wall. Hypoxia and tachypnea may also be present.

Tension pneumothorax presents in much more dramatic manner. The physical examination findings of simple pneumothorax are present, but with added physiologic derangements of obstructive shock. Tachycardia and hypotension are the result of increased intrathoracic pressure causing decreased venous return to the heart. Tracheal deviation away from the affected side, distended neck veins, and an elevated hemothorax also result from the building pressure from accumulating air within the hemothorax. Respiratory distress and cyanosis ultimately result if not identified and treated promptly.

A third, and much rarer, type of pneumothorax is the open pneumothorax. This diagnosis is the result of a penetrating wound that creates a direct connection between the pleural space and the outside world. This equilibrates the intrathoracic pressure with atmospheric pressure and disrupts the physiologic pressure gradient that drives respiration. Alternatively, the negative intrathoracic pressure generated during inspiration draws air into the chest via wound. The wound subsequently closes down creating a large pneumothorax. This so-called "sucking chest wound" can occur in a variety of traumatic mechanisms, including blast injuries, high-velocity gunshot wounds, slash injuries with large soft tissue defects, and impalement.

The diagnosis of a simple pneumothorax is confirmed by chest radiographs or CT scan. With the increasing prevalence of CT imaging in the evaluation of blunt trauma patients, some pneumothoraces are now identified that are not seen on radiographs. These 'occult' pneumothoraces are not altogether uncommon, occurring in 15% to 20% of blunt trauma patients and even up to 17% of penetrating trauma patients.[61–63] Ultrasound imaging has also emerged as a means to diagnose pneumothorax. On ultrasound examination, normal lung seems to slide along the thoracic wall. Ultrasonographic findings, such as comet tail artifacts or B-lines (**Fig. 3**), are created between the water and air interface of the visceral pleura in normal lung.[64] Pneumothorax is identified by the absence of lung sliding, loss of comet tail artifacts, the presence of A-lines, and the "lung point sign" all suggest pneumothorax. A-lines are artifacts reflecting off the parietal pleura that appear as equally spaced, hyperechoic horizontal lines (**Fig. 4**). These are present in pneumothoraces, but not visible when B-lines are present.[64,65] The so-called "lung point sign" is created by the intermittent contact between the lung and the chest wall in the setting of pneumothorax (**Fig. 5**). Although it lacks some sensitivity (66%), it is 100% specific for pneumothorax when present on ultrasonographic examination.[66] Negative predictive values for lung sliding and comet tail artifacts approach 100% for each finding.[64] Sensitivity and specificity of the combined finding of absent lung sliding with present A-lines is 95% and 94%, respectively.[65] Tension pneumothorax should be diagnosed based on clinical presentation and should not be confirmed with imaging studies. Rather, the diagnosis should be suspected and treatment rendered immediately. This is applicable to any patient in extremis with suspected pneumothorax.

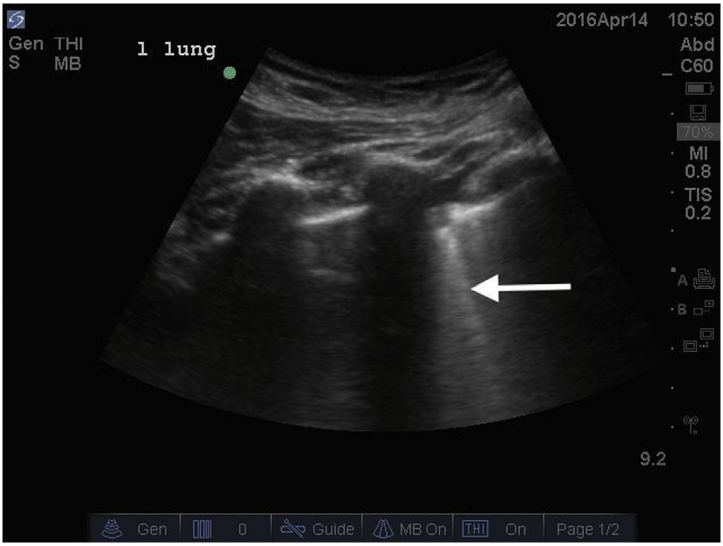

Fig. 3. Thoracic ultrasound imaging showing normal lung without evidence of pneumothorax. Comet tail artifacts, or B-lines (*arrow*), are created between the water and air interface of the visceral pleura in the absence of pneumothorax. (*Courtesy of* Jeremy Boyd, MD, RDMS, FACEP; Nashville, TN.)

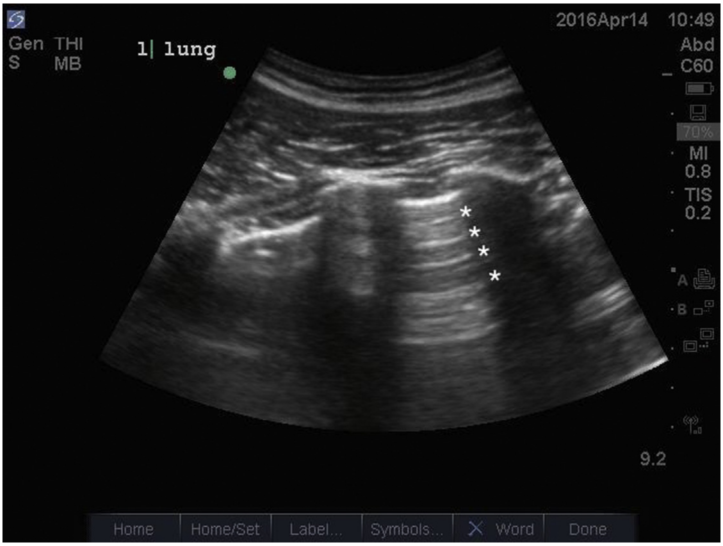

Fig. 4. Thoracic ultrasound examination suggestive of pneumothorax. A-lines (*asterisks*) are artifacts reflecting off the parietal pleura that appear as equally spaced, hyperechoic horizontal lines. These are present, but most often not visible when B-lines are present. (*Courtesy of* Jeremy Boyd, MD, RDMS, FACEP; Nashville, TN.)

The treatment of pneumothorax depends on patient stability. Unstable patients with pneumothorax require immediate decompression. Needle decompression or tube thoracostomy are the procedures of choice. Needle decompression occurs in the second intercostal space at the midclavicular line. Alternatively, needle decompression

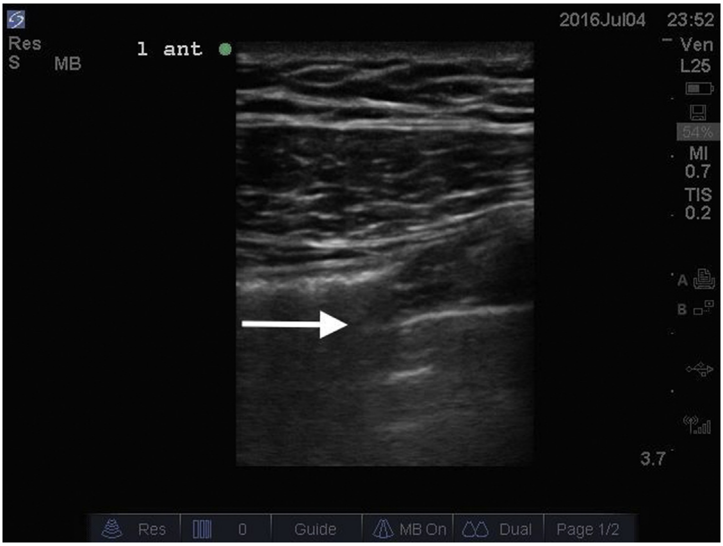

Fig. 5. Thoracic ultrasound examination showing the “lung point sign.” This ultrasonographic finding is created by the intermittent contact between the lung and the chest wall in the setting of pneumothorax. (*Courtesy of* Jeremy Boyd, MD, RDMS, FACEP; Nashville, TN.)

can be effectively performed in the fourth or fifth intercostal space at the anterior axillary line.[67,68] A metaanalysis by Laan and associates[69] demonstrated a lower failure rate (*P* = .01) for needle thoracostomy performed at anterior axillary location (13%) compared with midclavicular (38%) and midaxillary (31%). Questions regarding the effectiveness and durability of needle decompression have led others to advocate for tube thoracostomy as the primary treatment for tension pneumothorax.[70]

In stable patients, consideration should be given to the need for any pneumothorax evacuation. EAST practice management guidelines support observation without chest tube for occult pneumothoraces.[71] Even simple pneumothoraces that are small on chest radiographs can likely be managed with a 12- to 24-hour clinical observation period. Kong and coworkers[72] reported on the outcomes of 125 patients with pneumothoraces from stab wounds that measured less than 2 cm on chest radiographs. Only 4 (3%) required chest tube placement.

Larger, enlarging, or symptomatic pneumothoraces should be managed with tube thoracostomy. Size of the chest tube is an area of ongoing research. Inaba showed that smaller chest tubes (28-F or 32-F) were just as effective as larger tubes (36-F or 40-F) in evacuating pneumothoraces.[73] A recent, small, randomized clinical trial demonstrated that 14-F chest tubes were equivalent to 28-F chest tubes in terms of success evacuating pneumothorax and insertion-related complications.[74]

Open pneumothorax requires immediate treatment in the prehospital setting. An occlusive dressing secured on 3 sides is the preferred initial treatment for this injury.[75] In the prehospital setting, this may require the addition of needle decompression if tension physiology develops after the dressing is applied. In the emergency department, a chest tube should be placed away from the soft tissue defect. Operative repair of the soft tissue defect is required to reestablish the intrathoracic pressure gradients necessary for ventilation.

Hemothorax

Hemothorax can result from both blunt and penetrating mechanisms. Simple hemothorax is not directly fatal, but can be associated with significant morbidity. Failure to completely evacuate blood can result in retained hemothorax. This is associated with an empyema rate between 27% and 33%.[76,77] Additionally, fibrothorax can result and cause significant respiratory complications owing to entrapped lung. Massive hemothorax is a life-threatening condition that is associated with a high mortality rate and requires prompt intervention. Rib fractures with or without intercostal vessel laceration and lung laceration most commonly result in mild to moderate hemorrhage, but on rare occasion can cause massive hemothorax. Massive hemothorax is typically the result of more significant injuries, such as those involving the pulmonary vasculature, great vessels, or heart.

The initial treatment of hemothorax is the same whether simple or massive. EAST practice management guidelines suggest all hemothoraces should be considered for drainage regardless of size.[71] When considering drainage of a hemothorax, its effect on respiratory function should be the primary consideration. Although the optimal hemothorax size requiring drainage has not been demonstrated in the literature, consideration should be given to those with additional thoracic trauma. Multiple rib fractures, flail chest, and pneumothorax are concomitant injuries that warrant consideration for hemothorax drainage.[78]

After a chest tube is placed, the adequacy of the drainage should be assessed with daily chest radiographs. Patients with persistent opacities obscuring the costophrenic angle may be at risk of retained hemothorax. These patients should receive a contrasted chest CT scan to evaluate for retained hemothorax because chest radiographs alone are insufficient to determine the presence of retained hemothorax.[79] Chest CT scanning should be used for volumetric analysis of the retained blood within the hemithorax. A validated formula, $v = d^2l$, is used to calculate the fluid volume, where d represents the greatest depth (in cm) of the hemothorax on a single axial CT slice and l represents the greatest length (in cm) of the hemothorax in craniocaudal direction.[80] Dubose and colleagues[81] showed that retained hemothoraces of greater than 300 mL were unlikely to be resolve with observation and required intervention to drain. Patients with chest radiographs that showed clearing of the costophrenic angle or those with retained hemothorax volume 300 mL or less, observation and management of the initial chest alone is adequate treatment.[71,81] Chest tubes should remain in place until the air leak subsides and drainage is 200 mL or less per day.[82]

For those patients with retained hemothorax volumes of greater than 300 mL on volumetric analysis, surgical intervention is required to evacuate hematoma. Meyer and associates[83] demonstrated that video-assisted thoracoscopic surgery (VATS) drainage is more effective than placing a second chest tube for drainage of retained hemothorax. The goal of surgical intervention for retained hemothorax is 2-fold: (1) evacuate the retained blood and (2) free any entrapped lung to allow maximal expansion. Whether VATS or open approach is used, the same goals apply.

Although open thoracotomy would be considered the gold standard therapy for retained hemothorax, VATS is a much more common initial approach to operative drainage.[81] A prospective observational study by Dubose and colleagues[81] showed that 79% of patients undergoing open thoracotomy required no further intervention. The minimally invasive approach of VATS was shown to require no further intervention in 70% of cases.[81] The benefit of VATS lies in its minimally invasive, yet effective nature. The ability to remain minimally invasive is important in limiting postoperative pain, improving pulmonary function, reducing postoperative infectious complications, and shortening the recovery period, making it the recommended treatment of choice for retained hemothorax.[71] Timing correlates with the success of the minimally invasive approach. Early VATS has shown to be more effective in evacuating hemothorax and limiting conversion to open thoracotomy, considered to be before hospital day 7.[71,83–86] However, for interventions after day 7, it is still appropriate to first attempt a VATS and convert to open if ineffective.[71]

Other approaches to evacuation of retained hemothorax include image-guided catheters and intrapleural thrombolytics. In the study from Dubose and associates,[81] 41% of patients who received image-guided catheters for retained hemothorax failed this treatment and required an additional treatment. Intrapleural thrombolytics have shown promise as an alternative for patients not able to undergo VATS. In observational studies, thrombolytics were successful in clearing traumatic hemothoraces in 92% of cases.[87,88] Unfortunately, there are no prospective, randomized studies comparing thrombolytics to surgical intervention. The only retrospective study to compare these 2 approaches evaluated streptokinase as compared with VATS. The thrombolytic group had a failure rate of 29%, compared with 6% for the VATS group (P<.02). Hospital duration of stay was longer for the thrombolytic group also (mean 14.5 days vs 9.8 days; P<.0001).[89] In light of these data, thrombolytic therapy and image-guided catheters are considered to be a second-line therapies for retained hemothorax and reserved for patients who are not considered surgical candidates.[90]

Tracheobronchial Injury

Injury to the tracheobronchial tree is a rare, but potentially life-threatening event. Penetrating mechanisms are more common than blunt, but still quite rare. The proposed mechanisms in blunt tracheobronchial injury include rapid deceleration in which the airway is lacerated near a fixed point, often the carina or cricoid cartilage; airway rupture from high airway pressures owing to compressive forces generated by the blunt trauma; and airway disruption owing to traction injuries created by the lateral displacement of intrathoracic organs during chest wall compression.[91] Stab wounds result in lacerations of the trachea that typically appear as a puncture wound or a linear slash-type wound. Gunshot wounds create larger wounds that frequently have some element of tracheal tissue loss, depending on the ballistic caliber, muzzle velocity, and associated cavitary effect.

In terms of anatomic location, 75% to 80% of penetrating airway injuries occur in the cervical trachea.[92] Blunt tracheobronchial injuries occur much more commonly in the thoracic trachea and proximal mainstem bronchi, with 75% of blunt airway injuries occurring within 2 cm of the carina, lending credence to the deceleration injury mechanism theory.[93,94]

Clinical symptoms vary somewhat based on the anatomic location and mechanism of injury. In general, though, subcutaneous emphysema, dyspnea, and respiratory distress are common findings.[95] Persistent air leak after chest tube placement for pneumothorax should raise suspicion for a tracheobronchial injury. For patients with penetrating cervical injuries, air escaping from the wound is common and is considered pathognomonic for tracheal injury.[96]

Radiographic imaging studies can identify findings suggestive of possible tracheobronchial injury. Subcutaneous emphysema, pneumothorax, and pneumomediastinum are the most common findings in patients with intrathoracic airway injuries. Cervical tracheal injuries are less commonly associated with pneumothorax, but may show deep cervical emphysema.[95] CT imaging often shows similar findings and occasionally visualize defects in the tracheal wall suggesting disruption.

A definitive diagnosis is made by bronchoscopy. Fiberoptic bronchoscopy is an easy and fast method to determine the location and extent of the injury. A disruption of the tracheobronchial tree is often easily identified and may be associated with blood in the airway or an inability to assess the airway distal to the injury.[97] In a review by Symbas and associates,[94] nearly 75% of blunt injuries resulted in transverse tears; only 18% were longitudinal.

Treatment consists of 2 components: securing the airway and injury management. Endotracheal intubation should be performed on all patients with suspected tracheobronchial injury. Fiberoptic intubation is an extremely useful method for intubating these patients.[95] The patient's neck remains in a neutral position, which prevents traction or stretching of the injured airway and addresses some of the technical challenges of intubating an 'uncleared' cervical spine. Without the need for direct laryngoscopy, fiberoptic intubation can be performed relatively easily without paralysis or sedation. This is useful in spontaneously breathing patients who are at risk of airway loss with rapid sequence induction.[98] Additionally, bronchoscopic intubation potentially allows for direct visualization of the injury. This can allow for both diagnostic and therapeutic interventions. Guiding the endotracheal tube beyond the injury can be safely accomplished with the aid of the bronchoscope. In patients with other significant injuries, this may potentially serve as a temporary, or occasionally a definitive, treatment until more concerning issues can be addressed. For injuries of the distal trachea, carina, or mainstem bronchi, single lung ventilation of the uninjured side is recommended, preferably under bronchoscopic guidance.[95,97] Distal airway injuries may require bronchial blockers to prevent ventilating injured segments.

Surgical repair is associated with a 10-fold improvement in survival odds and should be considered the management option of choice.[93] Definitive surgical management varies depending on the location and extent of the injury, as well as individual patient factors. Injuries to the proximal two-thirds of the trachea are most easily approached through the neck. Slash or stab wounds involving the cervical trachea often leave the injured segment of trachea exposed and provide a direct path to the injury, simple extension of the wound is usually adequate. For injuries without a large open wound, a collar incision is often the best approach for injuries in this area.[99] Occasionally, extending the collar incision inferiorly and splitting the manubrium may allow further exposure of the trachea to the aortic arch.[95] Injuries to the distal trachea, carina, right mainstem bronchus, and even the proximal left mainstem bronchus are best approached through a right thoracotomy.[94] Distal left mainstem bronchus injuries are best approached via a left thoracotomy incision. Sternotomy offers no advantages in exposure owing to overlying cardiac and vascular structures.

Suture repair should be performed whenever possible. For penetrating wounds or large tears, the wound edges may require debridement before suture closure. Some injuries may be too large for primary closure. For these wounds, the damaged area should be circumferentially resected and primary end-to-end anastomosis should be performed. Careful dissection is required to prevent devascularization of the anastomosis. In particular, excessive circumferential dissection beyond area of injury can result in damage to the blood supply to the tracheobronchial tree, which can threaten the healing and lead to stenosis or leak. If resection of a small portion of the trachea is required, the neck should be flexed during repair and maintained postoperatively by using a chin-to-chest stitch. If more mobility is needed, blunt dissection of the pretracheal plane anteriorly may provide additional tracheal mobility in this avascular space.[100] Almost any area of the tracheobronchial tree can be resected; the carina, however, is the exception to this rule. Resection of the carina should not be performed. To protect the repair, buttressing using pleural flaps has been described.[99] Flaps can also be used as tissue interposition in cases of combined tracheal and esophageal injuries.

Tracheostomy is seldom required for these injuries if successful endotracheal intubation is performed. For patients unable to be intubated orally, a tracheostomy may be necessary for airway control. Tracheostomy is also indicated for proximal airway injuries near the vocal cords, where airway obstruction owing to edema can occur. For relatively small anterior penetrating cervical tracheal injuries, tracheostomy via the tracheal injury defect may be an alternative to primary repair.[101]

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