

Management of the crushed chest

Laszlo Kiraly, MD; Martin Schreiber, MD

Thoracic injuries are very common among trauma victims. This article reviews the current literature on the management of multiple aspects of the care of the patient with severe chest injury. The mechanics of chest injury are complex and varied. Chest wall injuries are the most common and noticeable manifestation of thoracic trauma. Overall morbidity and mortality are primarily determined by associated injuries. New ventilatory strategies permit oxygenation of the severely hypoxic patient. Acute pain management modalities offer the potential of decreasing associ-

ated pulmonary complications. Surgical chest wall fixation is clearly indicated in extreme cases of pulmonary herniation and chest wall disruption. There are potential benefits of surgical fixation in other settings, although further trials are needed. (Crit Care Med 2010; 38[Suppl.]:S469–S477)

KEY WORDS: rib fracture; trauma; flail chest; pulmonary contusion; acute respiratory distress syndrome; airway pressure release ventilation; high-frequency oscillatory ventilation

Severe chest injuries and their management have been described for millennia. The management of chest injuries was first described by the Egyptians. The Edwin Smith papyrus, which is estimated to have been written from 1700–3000 BC, contains the first descriptions of the management of chest trauma. The papyrus, thought to have multiple authors, describes the treatment of open chest wounds and rib fractures. It comments on the futility of treating open rib fractures with crepitus. These descriptions represent open chest wounds and flail chest, conditions carrying a high mortality at the time. Living roughly in the eighth century BC, Homer described 26 separate chest injuries in the *Iliad* (1). A majority of the injuries described were penetrating and fatal. The specific treatments are not very detailed in the epic poem and mostly consist of excising arrows, washing wounds, and treating with topical herbs. Four hundred years later, Hippocrates described the treatment of rib fractures and advocated the wrapping of uncomplicated rib fractures and those with underlying pulmonary injuries.

Hippocrates proceeds to recommend prolonged binding of the chest and strict dietary restrictions for the more severe cases. The current belief was that bowel function would result in increased pain and injury. Devastating chest injuries were also described during the early Olympic Games. Violent sports did result in fatal injuries. One particular account (2) describes a blunt chest wound with lung herniation and death.

Further advancements in the management of severe chest injuries primarily arose during military campaigns. The Romans advocated chest drainage with metal tubes (3). Roman surgeons also advocated for resection of depressed rib fractures. Closed reduction of unstable chest wall segments was later advocated by Ambrose Pare. Further management of chest injuries did not advance significantly until the 20th century. Penetrating chest injuries carried an approximately 60% mortality rate until World War I. Early surgery and closed drainage systems gained popularity. Treatment approaches continued to vary significantly through World War II. The first use of local and general anesthesia, bronchoscopy, effective transfusion practices, and antibiotics all helped to improve mortality rates. The Korean War experience brought about a standardization of care. Rapid evacuation, liberal use of tube thoracostomy, and early surgery decreased infectious complications and improved mortality rates. Vietnam further solidified the lessons learned in Korea. The incidence and mortality from empyema were markedly decreased. Vietnam saw

the first descriptions of the acute respiratory distress syndrome (ARDS) and prolonged ventilatory support.

Epidemiology

In victims of blunt trauma, chest injuries are exceedingly common. Approximately 33% of blunt trauma patients have a thoracic injury. It is estimated that 25% of traumatic deaths are secondary to chest trauma (4). Motor vehicle collisions represent the most common cause of thoracic trauma. In 2006, there were >45,000 deaths related to motor vehicle collisions (5). Unrestrained drivers are at particular risk with half of them presenting with thoracic injuries. Catastrophic chest injuries are more difficult to quantify. Injuries with chest wall disruption and lung herniation are rare with approximately 300 reported in the literature to date. Chest wall disruptions and their associated injuries have the potential to cause rapid death and their incidence may be underreported.

Injury Mechanics

Severe blunt chest injuries carry risks of devastating early mortality. Several early mechanisms are usually fatal, if untreated. Direct airway trauma can result in hemorrhage, obstruction, and rapid death. Untreated tension pneumothorax can result in venous return obstruction and death. Cardiac tamponade can similarly cause sudden death. Hemorrhage from the great vessels, chest wall, pulmonary parenchyma, or the heart may result in exsanguination. Direct cardiac trauma

From the Division of Trauma, Critical Care and Acute Care Surgery, Oregon Health & Science University, Portland, OR.

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For information regarding this article, E-mail: kiralyi@ohsu.edu

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may also result in dysrhythmia, valve dysfunction, coronary artery injury, and heart failure.

Massive forces are often required to cause severe chest injuries. The more common forces involved in blunt chest trauma are compression and shear forces. Compressive forces exert on a fixed point on the chest wall. If these forces exceed the combined strength of the thoracic structure, compressive injuries—such as rib fractures—occur. Cadaveric studies (6) have demonstrated that the amount of rib deflection is the primary determinant of the number of fractures. Therefore, the degree of rib deformity, rather than its rate, is the more important determinant of chest wall injury. Further cadaver studies determined that a 20% deformation of the chest wall is required to produce a rib fracture. According to Kroell and colleagues (7), 40% is required to produce multiple fractures and flail chest. The shape of the impacting object also factors into the fracture pattern. A small focal point of contact can cause a local injury at any area of the chest. A broader contact area more often results in posterior or contralateral injury (8). If enough force is involved, multiple fractures can occur at the same level or even on the contralateral side. Anterior-posterior compression results in several fracture patterns. The lateral portions of ribs have less muscular soft tissue support and less curvature and, therefore, are more commonly injured. Ribs can also become separated from the sternum anteriorly. Posterior ribs can lever against the transverse process of the spine, producing a second fracture (9). The ribs themselves can protrude into the thoracic or abdominal cavity, causing visceral injury.

Shear forces are caused by sudden deceleration or acceleration. This phenomenon primarily causes injury to the viscera and internal structures, rather than the chest wall. All structures in the thorax are tethered to different degrees. Sudden changes in velocity result in shear injury of these structures. Aortic transection commonly occurs distal to the attachment to the ligamentum arteriosum. Movement of the heart in relation to the great vessels may also play a role (8, 10). The trachea is relatively fixed proximally above the carina and untethered distally. Shear forces can result in tracheal transection distal to the carina. The energy wave is transmitted through the chest wall to the lung parenchyma. This results

in alveolar hemorrhage, pulmonary contusion, and laceration. This injury to the lung tissue is the most common manifestation of internal chest trauma.

Blast injury is a third potential mechanism for thoracic injuries. Immediate pressure changes in relation to atmospheric pressure are thought to be responsible for a majority of these injuries. These are a heterogeneous group of injuries. The primary determinants are distance from the source and intensity of the blast. Indoor blasts create reflections, resulting in a second wave of pressure changes. An animal model suggests that blast effects have more potent physiologic effects on the thorax compared with other body cavities (11). Hypotension, bradycardia, and apnea occurred immediately in thoracic blasts, but not abdominal blasts in a rat model (11, 12). Pulmonary hemorrhage, contusion, pneumothorax, hemothorax, and air embolism can occur immediately (13). These injuries are similar to conventional blunt injuries, but their onset can be much more rapid.

Initial Evaluation and Treatment

A crushed chest can result immediately in life-threatening injuries. Initial efforts in the care of the patient with severe chest injuries follow basic Advanced Trauma Life Support guidelines (14). Patients in obvious respiratory distress or those unable to protect their airway should be managed with prompt endotracheal intubation. Common thoracic injuries, such as rib fractures and pulmonary contusion, are not likely to improve in the short term and, if required, positive-pressure ventilation should be initiated early. Breathing is simultaneously evaluated. The chest wall is palpated for stability and inspected for any signs of injury. Evidence of a pneumothorax on examination should prompt tube thoracostomy. Given the potential for ongoing blood loss, large-bore intravenous access should be secured.

Patients with severe chest injuries often have an inability to communicate either from respiratory compromise or concomitant neurologic injury. Much of the information must be obtained from focused physical examination. If the patient is hemodynamically unstable or hypoxic and has signs of chest injury, bilateral tube thoracostomy should be considered. Massive hemothorax and hemodynamic instability prompt exploratory thoracotomy. Emergency department thoracotomy should be considered

for patients who become pulseless during the initial resuscitation. Patients undergoing thoracotomy in this setting have a poor prognosis (15). Open sucking chest wounds can be managed temporarily and sometimes definitively with a simple dressing and chest tube thoracostomy. Unless life-threatening hemorrhage is noted, further intervention can be delayed until the patient is stabilized. After the initial evaluation and resuscitation, severely injured patients should be treated in the intensive care unit.

Prior Advanced Trauma Life Support guidelines have recommended chest radiograph for the evaluation of all trauma patients (Fig. 1). Chest radiographs can be performed rapidly and can diagnose potentially life-threatening injuries. Computed tomography (CT) scans have consistently been shown to be more sensitive and specific for multiple injuries in thoracic trauma. Multiple studies have demonstrated significant management changes as a result of CT imaging compared with conventional radiographs (16–18). These series demonstrate significant findings on CT scan even in the setting of a normal chest radiograph. More recent series question the liberal use of CT scan especially without signs of injury or findings on plain radiographs (19). The differences seen in these studies are largely attributable to patient selection. Patients with the “crushed chest” often have severe mechanisms and obvious injuries. Severely injured patients are likely to have more significant findings on CT scan. If the patient is hemodynamically stable, a CT scan can yield valuable information. Recent epidemiologic studies (20) have noted a marked increase in malignancies attributable to CT scans. Such studies further highlight the need for sound judgment, especially in patients with low-risk mechanisms and negative radiographs.

Specific Injuries

Pulmonary contusion and ventilator management

Pulmonary contusion represents the most common internal injury after blunt thoracic trauma. Pulmonary contusion results from direct compressive and shear forces. Animal models have elegantly described the many associated derangements (21). The overall effect results in increased localized and systemic inflammation. Interstitial and alveolar tissues



Figure 1. This patient presented after a motor vehicle collision. Note the multiple left lateral rib fractures and unilateral pulmonary contusion.



Figure 2. Elderly man struck by automobile while in a wheelchair. The figure demonstrates the admission chest radiograph and corresponding chest computed tomography (CT) scan. Note the extensive right-sided rib fractures. On CT scan, there is evidence of significant contusion and collapse.

are traumatized, resulting in hemorrhage and later edema. This injury results in increased permeability of the alveoli and associated capillaries. The quantity and quality of surfactant are significantly reduced in the setting of pulmonary contusion (22–24). These localized insults result in ventilation/perfusion mismatch. Compliance is also adversely affected, resulting in higher airway pressures. Aspiration is also common in the setting of severe trauma. Aspiration combined with bleeding into larger airways causes further difficulties with plugging and effectively increases intrapulmonary shunt. Pain from rib fractures and associated injuries results in splinting, which can exacerbate atelectasis.

Pulmonary contusions are often not evident on initial chest radiograph. This phenomenon can lead to underestimation of injury and delay in treatment of the patient. The contusion can evolve over several days on a radiograph. A CT scan has been demonstrated to have su-

perior sensitivity and specificity for the diagnosis of pulmonary contusion (Fig. 2). Series have demonstrated that the extent of pulmonary contusion predicts the need for ventilatory support (25). Clinical course, rather than radiologic appearance, however, should drive further treatment decisions.

In relatively stable patients, the early goals of therapy should include maintaining lung volume and preventing further collapse and atelectasis. Incentive spirometry has been utilized to counter the collapse associated with blunt chest trauma. Underlying reactive airway disease should be optimized as well. Another treatment option involves patient initiated positive airway pressure therapy. With the use of a valve, patients can induce periods of positive airway pressure in an effort to recruit the collapsed lung. This method has been utilized at various institutions as part of a clinical pathway. A prospective cohort study recently investigated the use of a multidisciplinary

pathway, including positive airway pressure therapy. This trial (26) demonstrated reduced intensive care unit length of stay, pneumonia, and mortality in patients with rib fractures. These therapeutic modalities are often limited secondary to the requirement of an awake, cooperative patient. The use of any method of positive airway pressure does carry a theoretical risk of increasing the size of a pneumothorax or even creating a tension pneumothorax. Few data exist on the potential risks in this setting. Positive-pressure therapy (invasive or noninvasive), however, is often essential for maintaining adequate oxygenation and should not be withheld for this concern alone. If concern exists, the patients should be followed closely clinically and radiographically.

Patients with pulmonary contusion present with hypoxia, hypercarbia, and increased work of breathing. By the time the trauma victim has respiratory distress, his/her pulmonary reserve is exceedingly low. Noninvasive ventilation is a reasonable option in select patients with thoracic injuries. A small randomized trial (27) examined the utility of noninvasive ventilation in the treatment of trauma patients with acute lung injury. In selected patients, noninvasive ventilation was found to reduce the intubation rate and hospital stay significantly. No determinants on mortality could be made. Patients with frank shock or head injuries do not make good candidates for noninvasive ventilation and are at high risk for aspiration. In severe chest injuries, adequate pain control may be exceedingly difficult. Patients with high narcotic requirements are also poor candidates for noninvasive ventilation. These patients with severe injuries have the potential to dramatically worsen in the hours after admission. If noninvasive ventilation is attempted, close follow-up is essential as many patients will fail and require endotracheal intubation.

During rapid sequence intubation, delays in endotracheal tube placement quickly result in severe hypoxemia. Positive-pressure ventilation usually rapidly improves respiratory function. Increasing the positive end-expiratory pressure (PEEP) can aid in recruitment of previously collapsed alveoli. PEEP does have numerous physiologic effects relevant to the traumatized patient. Most notably, PEEP can significantly reduce venous return in the hypovolemic patient. This can worsen hemodynamics in the setting of

hemorrhagic shock. PEEP can also exacerbate ventilation/perfusion mismatch in patients with asymmetric pulmonary contusion. The increased pressure is distributed to the more compliant normal lung, which redistributes blood flow from the normal lung to the abnormal lung.

Patients with severe pulmonary contusion have a high risk for developing ARDS. A randomized controlled trial (28) has demonstrated improved mortality with low-volume ventilation in the setting of ARDS. Many centers now use low-volume strategies in traumatized patients at risk for ARDS. This strategy, although not clearly proven in the setting of pulmonary contusion, is aimed at reducing further ventilator trauma. Commonly, patients with severe injuries progress to a clinical picture consistent with ARDS. These patients may have predominantly unilateral injuries and, therefore, may not meet the criteria for ARDS. However, management strategies are often similar.

As in ARDS, patients with significant pulmonary contusions can have severe difficulties with oxygenation and ventilation. No randomized trials have demonstrated a mortality benefit to a particular mode of ventilation in the setting of pulmonary contusion. Several newer modes of ventilation have been utilized with the goal of improving physiology in the setting of injury. ARDS is theorized to be exacerbated or even caused by ventilator-induced lung injury. This phenomenon is thought to be secondary to alveolar collapse and reopening, or "atelectrauma." Injury secondary to high pressures in the alveoli or "barotrauma" also plays a role. The newer methods of ventilation are similar in that they attempt to minimize both of these phenomena. High-frequency oscillatory ventilation (HFOV) was initially described in a small series of neonates but has gained wider acceptance recently (29). HFOV achieves oxygenation and ventilation through atypical air transfer. Most of the air movement is not dependent on bulk flow. Multiple combinations of convection and diffusion are theoretically responsible for air movement (30). As a result of this atypical air flow, higher airway pressures are maintained consistently without cyclic alveolar collapse. More recently, a randomized trial demonstrated a more rapid improvement in oxygenation with HFOV compared with conventional ventilation (31). The difference in oxygenation and other outcome measures were not durable. Smaller series (32) have been published

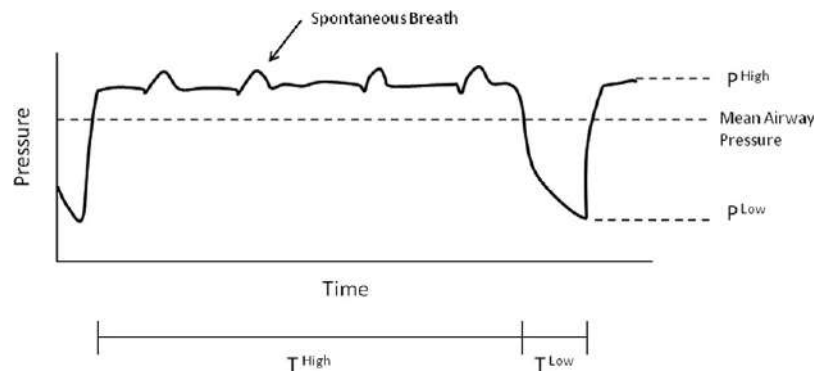


Figure 3. Airway pressure release ventilation. The set variables include Time High (T^{High}), Time Low (T^{Low}), Pressure High (P^{High}), and Pressure Low (P^{Low}). Note the extended period of time spent at higher pressures and the resulting elevated mean airway pressure. The patient can perform spontaneous breaths throughout the pressure curve.

on the utility and safety of HFOV in the setting of pulmonary contusion.

Airway pressure release ventilation (APRV) is another ventilator strategy that has been recently popularized in the treatment of ARDS. APRV was originally described in the 1980s by Stock et al (33). In APRV, patients are exposed to periods of positive pressure during relatively long inspiratory phases (Fig. 3). Brief expiratory releases occur during each cycle. Spontaneous breathing can occur during any phase of the cycle; this is a major advantage of this mode. Spontaneous ventilation provides more active diaphragm movement and may help prevent dependent atelectasis improving ventilation/perfusion matching. Furthermore, APRV requires fewer sedative medications than aggressive conventional ventilation. The decreased narcotic and sedation requirement was demonstrated in a large observational series (34).

Patients with multitrauma often require significant fluid resuscitation. Inadequate initial resuscitation may result in hypotension and inadequate perfusion, and may contribute to multiple organ failure. In the setting of hemorrhage and shock, resuscitation should not be withheld for the risk of worsening the respiratory status of patients with pulmonary contusion. However, overzealous use of fluids can contribute to worsening edema, especially in patients with cardiac dysfunction. No human randomized trials exist that demonstrate a clear benefit to fluid restriction in the setting of pulmonary contusion and other chest injuries. A subgroup of surgical patients with acute lung injury did have fewer ventilator and intensive care unit days with a conservative fluid strategy (35).

Special circumstances in thoracic trauma can have significant implications for ventilator management. Unilateral injuries can result in a severely dysfunctional lung on the affected side and relatively normal lung on the contralateral side. Methods of high-pressure recruitment that are successful in acute lung injury and ARDS can be counterproductive in this setting. The two lungs can have markedly different compliances. The uniformly applied higher pressure will not reach the collapsed injured alveoli. Instead, the pressure is applied to normal, healthy uninjured alveoli. This can lead to overinflation and barotrauma. Furthermore, the higher pressures can cause decreased blood flow to the healthy lung. This increases perfusion to the poorly ventilated lung and, thereby, increases the total shunt. Applying ever higher pressures can lead to worsening oxygenation. In patients with little reserve, each lung can be independently ventilated with synchronized ventilators. With this system, higher pressure is applied to the injured lung. This redistributes blood flow from the injured lung to the healthy lung, improving ventilation/perfusion matching. Small series (36) have demonstrated safety and improvement in oxygenation in patients suffering thoracic trauma, using dual lung ventilation. This method does have serious logistic drawbacks. Patients require a dual lumen endotracheal tube and two synchronized ventilators. These patients require significant sedation and often neuromuscular blockade. Separate monitoring must be performed on each individual lung. No randomized trials exist, demonstrating a clear benefit in mortality. A simple temporizing method to achieve the same goal is to place

the patient in the decubitus position with the normal lung down. This improves perfusion of the healthy lung.

Patients presenting with severe thoracic trauma are at risk for bronchopleural fistulas. With proper drainage, smaller fistula may be asymptomatic. The clinical picture can change remarkably in the setting of positive-pressure ventilation. Traditional bulk flow ventilation can result in loss of significant tidal volume through the fistula. Furthermore, the path of least resistance through the fistula may create difficulties with oxygenation and ventilation. A great majority of blunt trauma-induced bronchopleural fistulas heal spontaneously. Conservative management of the patient on positive-pressure ventilation is aimed at minimizing airway pressures. An animal model of bronchopleural fistulas has demonstrated that increased PEEP results in increased leak rate (37). In the same model, HFOV was more successful in ventilating the animals, at the same time minimizing the leak rate. Case reports (38) have demonstrated success in the treatment of HFOV after the failure of conventional ventilation. Failure of conservative management resulting in a persistent leak or inability to ventilate may prompt surgical intervention.

Occasionally, after blunt chest trauma, patients develop cavitary lesions of the chest. The exact pathophysiology of this process is unclear but involves air leakage from pulmonary parenchyma combined with large-scale tissue disruption. The process has been described as posttraumatic pulmonary pseudocyst but is also referred to as traumatic pneumatocele. The current literature only consists of small case series (39). A proposed mechanism for a recent increased incidence is the higher utilization of CT scans. These lesions can be managed conservatively if the patient is stable and not demonstrating signs of infection. Antibiotics and CT-guided drainage can be utilized if infection is suspected. Complicated cases are more likely to occur in severely injured patients. If conservative and minimally invasive methods fail, thoracotomy and lobectomy may be required.

Rib fractures and flail chest

Rib fractures are a very common traumatic injury. In a review of 7,000 consecutive trauma patients, 10% had rib fractures (40). This rate has been confirmed in epidemiologic studies, using the National Trauma Data Bank (41). The sen-

sitivity of a chest radiograph for rib fractures is low, and fractures are thought to be significantly underreported. Rib fractures have a high association with more severe underlying injuries. Conversely, given the low sensitivity of chest radiographs, the absence of rib fractures does not rule out significant underlying injuries (42). This is especially true in the pediatric population. Due to their high chest wall compliance, pediatric patients can have massive compression of their chest wall without developing fractures (43). Significant internal injuries can occur despite a lack of bony injury. Therefore, rib fractures in the pediatric population are a marker of tremendous force and are markers of morbidity and mortality.

At the other end of the age spectrum, elderly patients are at higher risk for poor outcomes in the setting of rib fractures. Holcomb et al (44) found that age >45 yrs and greater than four rib fractures were predictors of morbidity. Bulger et al (45) found that patients >65 yrs had twice the mortality with rib fractures and that each additional rib fracture carried additional risk of death and pneumonia. These elderly patients have more comorbidities and less pulmonary reserve. Any insult can have magnified effects in this patient population.

The overall mortality of patients presenting with rib fractures has been reported to be >10% (40, 45). The major determinants of mortality seem to be related to associated injuries. In a recent review (46) of patients with rib fractures, extremity, pelvic, hepatic, splenic, diaphragmatic, cardiac, and head injuries were all independent predictors of death. Furthermore, a study (44) of patients with rib fracture, excluding severe abdominal and head trauma, found that the mortality rate was only 2% to 4%. Age, number of rib fractures, and underlying injuries should all be determinants of admission level of care.

Flail chest occurs when multiple ribs are fractured in multiple places, creating a section which moves independently from the remainder of the chest wall. On spontaneous inspiration, the affected segment is pulled inward by the negative intrathoracic pressure. This theoretically can lead to recirculation of inspired air to the contralateral lung, although the actual clinical implications are unclear. The displacement of the chest wall during breathing is reduced. Therefore, the force of inspiration and expiration is also re-

duced. Multiple definitions have been put forward for the term *flail chest* involving specific numbers of ribs. However, this is a clinical diagnosis, and a variety of fracture patterns can result in flail. The production of a flail segment is dependent on a number of factors, including the extent of adjacent soft tissue support. Ribs can separate from their cartilaginous attachments to the sternum, causing a sternal flail. Two adjacent fractures laterally can cause a lateral flail segment. Flail chest is a clinical diagnosis made by carefully observing the patients' chest. Occasionally, muscle splinting can mask the flail early. Once patients begin having respiratory compromise, the flail segment becomes more evident (47).

The mortality of flail chest is significantly higher than that of simple rib fractures. Compared with patients with simple rib fractures, flail chest is an independent predictor for the requirement of mechanical ventilation and respiratory complications (48). Borman et al (49) demonstrated that the mortality of patients with flail chest is 20%, which is nearly double the rate of simple rib fractures. When taking into account isolated unilateral flail, the mortality decreased to 6%. This evidence suggests that, like rib fractures, most of the mortality with flail chest is secondary to associated injuries.

Pain is the primary symptom suffered by those with rib fractures. Splinting from pain contributes to further respiratory decline and dysfunction. Traditionally, intravenous narcotic pain medications are used in an attempt to control the pain of rib fractures. Narcotic medications are effective for pain but have numerous side effects. Oversedation can result in hypoventilation, atelectasis, and aspiration. Furthermore, patients on heavy doses of narcotics are not able to participate in active lung expansion exercises. These drawbacks have prompted investigations into alternate therapies for the pain of rib fractures.

Early therapies for management of rib fractures included chest wall fixation with belts. The rib belts would theoretically decrease motion and therefore pain. Two small studies (50, 51) were conducted on the use of such devices. Both studies found an increase in complications in groups using the belt, whereas only one study demonstrated a benefit in terms of pain relief. External fixation and binding of ribs have generally fallen out of favor as a treatment for rib fractures.

Multiple studies have been published, examining the use of localized pain strategies in the management of rib fractures. These techniques are varied and include intrapleural blocks, intercostal blocks, paravertebral blocks, epidural blocks, and transdermal local anesthetics. Two small studies (52, 53) with a total of 36 patients compared epidural catheters with intrapleural catheters for patients with chest wall trauma. The findings were not conclusive due to small numbers. Carrier et al (54) performed a recent meta-analysis of studies on epidural catheters for thoracic trauma; they concluded that there was no overall benefit based on the current literature. This meta-analysis, however, included multiple very small trials with varied study designs. A benefit in duration of mechanical ventilation was noted with the use of epidural catheters dosed with local anesthetics. The largest randomized trial of epidural catheters vs. intravenous opioids enrolled 46 patients and did demonstrate a significant decrease in pneumonia rates and ventilator days in the epidural group (55). With the proper patient selection, there is a probable benefit to the use of epidural catheters. Associated injuries of the traumatized patient present hurdles to their use. Coagulopathy can prevent their safe placement. Vertebral fractures, which can be quite common in the setting of thoracic trauma, can also prevent catheter placement. Most published studies do note a prevalence of hypotension in patients with local anesthetic epidurals.

These complications and contraindications limit the number of eligible patients.

Smaller observational studies have demonstrated the safety and efficacy of paravertebral and more distal intercostals blocks in the treatment of thoracic trauma patients (56, 57). A more recent randomized study (58) compared epidural and paravertebral catheters. The authors found equivalent outcomes in the two groups, although there were fewer hypotensive episodes in the paravertebral group. The paravertebral block can be administered through a catheter and left in place for days. More study is needed in this area as the potential benefits for patients with thoracic trauma are great.

Surgical repair of chest wall injury

The mainstay of treatment of chest wall lesions causing respiratory compromise involves prolonged positive-pressure ventilation. Historically, there has been varying enthusiasm for the surgical fixation of rib fractures and flail chest. External binding hardware was promoted in the early part of the century but eventually abandoned. Rib fixation theoretically can aid in a patient's recovery by allowing them to mobilize and ventilate comfortably. Associated injuries are the primary cause of morbidity and mortality in patients with rib fractures and flail chest. Therefore, to provide a theoretical

benefit, patients need to be chosen very selectively. This was demonstrated in a retrospective review by Voggenreiter et al (59). In this study, patients undergoing operative stabilization for flail chest were compared with patients managed without surgery. In terms of ventilator weaning, the surgical group only benefited if no pulmonary contusions were present. A trial by Tanaka et al (60) randomized a small group of patients between mechanical ventilation and surgical stabilization. The surgical group demonstrated a decreased rate of pneumonia, intensive care unit days, and ventilator days. These results have not been duplicated in a larger trial, however.

Multiple encouraging case reports do exist regarding surgical fixation and rapid improvement in select patients. Figure 4 demonstrates a chest radiograph of a trauma patient presenting after a fall from a horse. The patient could not mobilize 10 days after injury and operative repair was performed. Figure 5 demonstrates his postoperative chest radiograph. The patient mobilized well postoperatively and was discharged after surgery. Nirula et al (61) commented on potential indications for rib fracture repair. These indications include flail chest with failure to wean from the ventilator, painful and mobile ribs, chest wall deformity, symptomatic nonunion, and incidental repair when performing thoracotomy for another reason. More serious life-threatening injuries are a clear contraindication. Larger multicenter trials are required to investigate the specific indications and the overall benefit of these operations.



Figure 4. This patient presented after falling off a horse while jumping. This chest radiograph demonstrates multiple posterior rib fractures and a left clavicle fracture. He had an unstable segment of chest wall, and his injuries prevented mobilization. After 10 days of conservative management, he underwent operative repair.

Chest wall hernia

Chest wall disruption with herniation is a rare injury that develops in the setting of massive forces. Automobile accidents are the most common cause of modern traumatic chest hernias. These injuries can present acutely or in a delayed fashion. High-energy motor vehicle collisions, particularly with the use of shoulder harnesses, may subject victims to particular forces responsible for chest wall disruption (62). With rib fracture and sternal disruption, sudden deceleration can cause lung tissue to herniate from the chest cavity. The acute condition can be temporized with chest tube thoracostomy. If the patient is not compromised by the chest wall mechanics, operative fixation can be delayed until the



Figure 5. The chest radiograph shows the patient after internal fixation of his rib fractures and left clavicle.

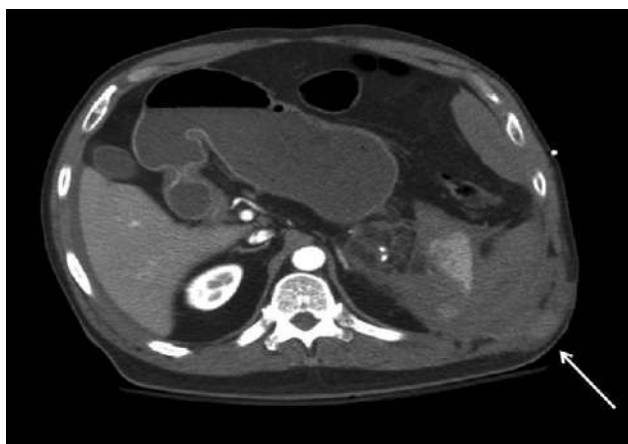


Figure 6. This patient presented after falling off a ladder. One month after his initial admission, he was noted to have a chest wall defect with herniation. The *arrow* points to the site of chest wall disruption and herniation of lung.

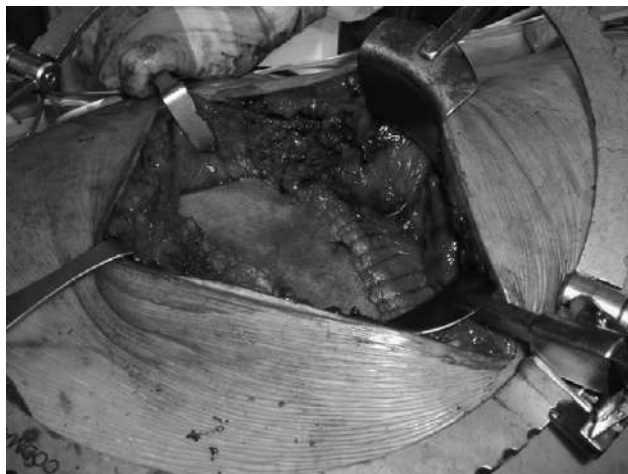


Figure 7. The patient underwent surgical repair of his chest wall hernia with biological mesh.

patient is more stable. The goal of surgery should be to restore physiologic pulmonary function and restore the volume of the chest cavity. Case reports (63–65) have described fixation with muscle flaps, plates, wire, and mesh. Pneumonia and empyema are not uncommon complications of severe chest trauma, and placement of implants should be considered carefully. Biological mesh can be considered in select cases, although long-term follow-up data do not exist. Figure 6 demonstrates a CT scan of a patient presenting 1 month after a fall from a ladder. He was repaired with a biological mesh in an elective fashion. His surgical repair is demonstrated in Figure 7.

CONCLUSION

The care of the patient with a “crushed chest” can be challenging. These victims have a high number of associated injuries, leading to a significant overall mortality rate. A systematic approach is crucial in order to treat the acute life-threatening complications of this process. These patients often require prolonged intensive care support and thus many resources. Further research is clearly warranted in the areas of ventilatory strategies, pain control, and operative fixation.

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