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Thoracic Trauma: a Combat and Military Perspective

John Kuckelman[1] · Daniel Cuadrado[1] · Matthew Martin[1,2]

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Abstract

Purpose of Review This article reviews the finer points of thoracic trauma seen during combat and provides parallels to the civilian sector for potential implementation.

Recent Findings Lessons learned during recent conflicts in Iraq (Operation Iraqi Freedom), Afghanistan (Operation Enduring Freedom) as well as the ongoing military actions targeting the Islamic State (ISIS) have equipped combat surgeons with a breadth of knowledge concerning the management of complex thoracic trauma. The unique environment provided by war inherently fosters the development of innovation. Management of combat injuries has become more crucial to all trauma surgeons, as high-velocity weaponry and global terrorism can produce similar injury patterns in the civilian trauma setting.

Summary This review focuses on unique injuries seen in austere war-time environments with focus on thoracic trauma. Applications to civilian trauma are highlighted throughout the article with the hope that the experience gained by combat surgeons may aide in the advancement of trauma care.

Keywords Thoracic trauma · Combat trauma · Austere environments · Thoracic blast injury · High velocity injury · Operational medicine

Introduction

Times of war historically lead to progress in the surgical management of traumatic injuries and follow on care. Translating these lessons to the civilian sector for the advancement of trauma care is essential lest these advancements and lessons learned be forgotten [1, 2]. A wealth of knowledge has been gained in the arena of thoracic trauma during the most recent conflicts in the Global War on Terror [3, 4]. Injuries sustained to the thorax can be immediately life-threatening, but with a systematic approach and swift decision making life-saving intervention is possible. This chapter will focus on the unique circumstances, injures, and the necessary interventions seen in the thorax during combat with the hope that the transfer of this information will be applicable in the civilian sector [1, 5].

This article is part of the Topical Collection on *The Military Perspective*

✉ Matthew Martin
matthew.j.martin16.mil@mail.mil; traumadoc22@gmail.com

1 Department of Surgery, Madigan Army Medical Center, 9040 Fitzsimmons Drive, Tacoma, WA 98431, USA

2 Trauma and Emergency Surgery Service, Legacy Emanuel Medical Center, Portland, OR, USA

Incidence, Etiology, Mechanisms, and Presentation

The austere environments in which combat trauma is seen rarely lend itself to robust and comprehensive data collection; thus, the true incidence of thoracic trauma is difficult to ascertain. Furthermore, the data that is collected often excludes civilian wounded as well as local national forces. The Department of Defense Trauma Registry (DODTR) provides the best approximation citing an incidence of 6% for thoracic trauma requiring treatment [6, 7]. This represents a decline of over 8% when comparing incidence of thoracic trauma in World War II and the Vietnam War [6]. A decline in incidence may seem counterintuitive in the age of advanced weaponry; however, significant advancements have also been seen in the areas of body and vehicle armor [8]. This protection is not universally worn among all involved in war which underscores a higher incidence with potentially increased severity amongst civilian populations or other unprotected combatants such as local military forces and civilian bystanders.

The mortality of a thoracic injury remains high with 80% of preventable deaths being due to combat injuries consisting of non-compressible torso (abdominal and thoracic) hemorrhage (NCTH) [7, 9]. Injures to the thorax, abdomen, pelvis or the appendage junctions thereof are not amendable to the rapid, prehospital intervention of tourniquet placement that has seen so much success in controlling vascular injury in peripheral limbs [10]. Morrison and colleagues helped to better define the problem by evaluating specific etiologies of NCTH. They found that 2% of all battlefield injuries consist of NCTH with the majority of those being thoracic (32%). By calculating odds ratios for mortality the reported that injuries to the thoracic cavity have the second highest chance for mortality (OR 1.9) when compared to solid organ injury (OR 1.0) and pelvic injuries (OR .80). Not surprisingly, named vessel injury carried the highest risk of mortality with an odds ratio of 3.4, which would include many injuries to the chest (see *Major Vascular Injury* below) [11]. Similar lethality is seen in the civilian sector (40–85%) however the variable range may be at least partially attributable to the exceptional high energy mechanisms of injury seen during warfare not commonly seen by civilian trauma centers [12, 13].

Current combat brings with it advanced weaponry and patterns that are unique to the wartime environment (Fig. 1) [6, 8]. Military projectiles have inherently higher velocity resulting in more significant injury with larger areas of tissue damage when compared to the low velocity projectiles seen in civilian trauma. Figure 2a shows the massive soft-tissue injuries sustained to the right upper extremity from a high-powered rifle. The X-ray in Fig. 2b displays a blossoming pulmonary contusion related to the projectile force of this impressive weapon. The most prominent difference is in the blast injuries seen during combat. Historically, blast injury was mainly due to weapons such as rocket propelled grenade launchers (RPG) or land mines; however, in more recent conflicts, the use of improvised explosive devices (IED) placed alongside common military transport or ground patrol routes are the most common cause [14•]. Although the use of IEDs is often thought of as unique to combat zones, the rise of ISIS and other global terrorism has seen their increasing use in civilian arenas exemplified by the well-known recent attacks in Madrid, Spain, France, and Boston [15•, 16•, 17]. The devastation from blast injury stems from the multiplicity of concurrent mechanisms resulting in a combination of injuries [17]. These concomitant mechanisms may include penetrating injury from intentional or secondary fragments, blunt and /or thermal injury, and blunt trauma due to close proximity to the center of blast radius or subsequent to vehicle rollover. Blunt injury may also result from collision caused by the blast. A single patient may have multiple traumatic amputations with maxillofacial and cervical injury in addition to major thoracic trauma [11, 18]. Given the grave implications of these injuries and the increasing use of explosives outside the typical combat arena, civilian trauma centers and trauma surgeons alike, should be prepared to rapidly evaluate and treat potential victims of blast injury [18]. Again, the value of the implementation protective body armor as well as the use of vehicles engineered to resist IED blasts cannot be understated. Figure 3 displays the lifesaving power of this body armor after an encounter with an RPG. Not only has the incidence of thoracic injury been reduced by over 50% the severity of these injuries has also dramatically reduced even within the time the US has been at war in the Middle East [6, 11, 18].

Fig. 1 Result after an armored military vehicle was struck by an IED. Injuries included unsalvageable damage to the extremities, hollow viscus injury, pelvic fracture, brachial artery laceration, and pulmonary contusions. (Photo courtesy of COL Matthew Martin)

Initial Surveys

Identification and prioritization are key in all combat injuries. In mass casualty situations, appropriate triage prior to evaluation by the surgeon is crucial to effective management. It is typical for the military setting to be chaotic and a systematic approach focused on swift intervention of immediately life threatening issues is critical. Given that thoracic hemorrhage represents one of the largest reasons for preventable death, the primary survey should arguably begin with circulation assessment as shown in Figure 4, and then progress to evaluate the airway and breathing [18]. In reality, this is relative, as these components of the primary survey often happen simultaneously. To that point, the secondary survey should also begin within the first minutes of evaluation using physical exam and available rapid imaging such as chest X-ray and focused ultrasonography. For physicians in the deployed or austere setting, these types of imaging are often the only available [19]. Massive bleeding in the thorax, pericardium, or abdominal cavities should be easily identifiable with ultrasound when operated by physicians practiced in its use [19, 20]. This skill continues to aid physicians in less dire situations as it may also help diagnose pneumothorax, cardiac activity, as well as intravascular volume status which based on vena cava variation with respiration [19]. High-resolution imaging such as CT and MRI may not be a reality and in questionable or precarious circumstances exploratory surgery should be used in their

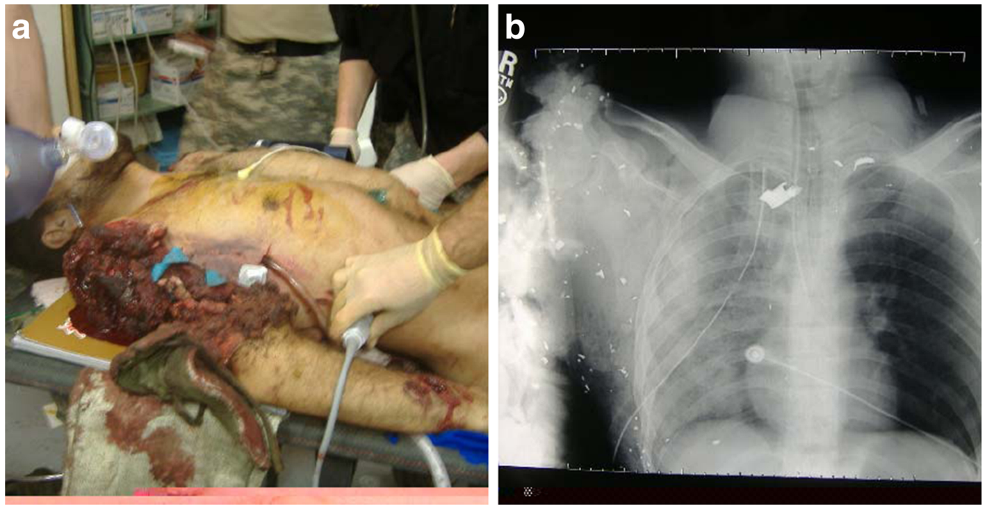


Fig. 2 High-powered gunshot wounds can result in devastating soft tissue injury as seen by here after this soldier sustained a gunshot wound to his right shoulder during combat (**a**). Corresponding X-ray demonstrates the effect of the impact on the lung parenchyma with development of pulmonary infiltrates due to pulmonary contusion (**b**). (Photos courtesy of COL Matthew Martin)

absence. Patient's triaged as immediate with an obvious need for surgical intervention may need to forego trauma bay evaluation and progress directly to the operating room [18, 21••].

Thoracic Injury-Related Shock

Not every patient enduring thoracic injury will have a surgical problem in nature. Maintenance of solid critical care principles is crucial to the survival of patients enduring thoracic trauma and will also help ensure the success and survival of patients requiring surgery. Persistent hypotension and other evidence of instability that is present after hemorrhage has been decidedly excluded, should focus on causes related to the other common types of shock to include cardiogenic shock from contusion, penetrating injury or tamponade. When cardiogenic shock is present, intensive care is similar to any other setting with optimizing cardiac function and prompt treatment of lethal arrhythmias being the primary focus. High thoracic vertebral injury inducing neurogenic shock may present with the classic signs of hypotension and bradycardia. These patients require supportive care with aggressive fluid resuscitation and often vasopressor support. Blunt cardiac injury is an exclusionary diagnosis and should only be considered when all other causes of cardiogenic shock have been ruled out. When this is the case, patients should be managed with ionotropic medications and fluid resuscitation with continuous telemetry. Most patients will fully recover with supportive care but late complications such as fatal arrhythmias and ruptured cardiac aneurysms are possible and there should be a low threshold for further diagnostic evaluation when an otherwise improving patient worsen [22, 23].

Fig. 3 A soldier suffered no significant injury after being struck in his chest wall body armor by a rocket-propelled grenade. (Photo courtesy of COL Matthew Martin)

Respiratory distress can be due to a multitude of factors including pulmonary contusion from blast injury, exposure to biologic or chemical weapons such as phosgene or chlorine, as well as secondary effects stemming from high injury severity or prolonged ICU care. Victims subjected to blast injury in an enclosed space are at significant risk for pulmonary related injuries to include blast lung injury. The attacks in Madrid in 2004 revealed that the majority of injuries in this circumstance where intra-thoracic [15•]. Blast lung injury has been seen in over 10% of those injured during Operation Enduring Freedom (OEF-Afghanistan) [24]. The physiologic effect of blast injury and chemical injury is similar to Acute Respiratory Distress Syndrome (ARDS) but the presentation may be highly variable [24, 25]. Suspicion should be high in patients who have endured a blast injury who are reporting shortness of breath while appearing hemodynamically normal as complete respiratory collapse may be sudden. Rapid intubation and supportive care will usually suffice in patients without additional injuries as mortality is low. It is important to remember that when rapid intubation is required, the treating physician should be prepared for significant resuscitative efforts once the patient is induced as loss of sympathetic tone in these patients can result in profound hemodynamic instability [21••].

Patients being treated for ARDS require physician foresight in the wartime setting, as progression through the treatment algorithm may be significantly limited depending on the site's resources. There may be only a small window of time between when a patient with ARDS is stable enough for evacuation and advancement of disease beyond local capabilities. Evacuation capabilities were improved during both Operation Iraqi Freedom (OIF) and OEF with the use US Air Force Critical Care Air Transport Teams (CCATT) who are able to provide rescue ventilation maneuvers such as inhaled nitrous oxide and/or settings such as airway pressure release ventilation (APRV) [26, 27]. Transport was further improved with the advent of the Acute Lung Rescue Team (ALeRT) which was able to provide and sustain extracorporeal membrane oxygenation (ECMO) during transport to higher echelons of care (Fig. 5) [28].

Specific Injuries and Surgical Intervention

Combat Surgical Principles

While the basic steps and techniques of operative intervention for thoracic trauma to not stray from those practiced in civilian centers, there are some key differences in the basic tenets applied to the combat setting. Primarily, the decision to transfer to the operating room should be made within the first few minutes. Combat injured patients who are hypotensive with obvious extensive injuries will likely need operative intervention and prompt movement to the operating room should not be delayed [18]. Principles of rapid induction and intubation have been cited above and should be considered again here when preparing a patient for emergency surgery.

Patients should be supine and the whole body should be prepped and draped for operative access. Supine positioning allows for quick access to injuries in the neck, bilateral thoracic cavities, mediastinum, abdominal and pelvic cavities. An experienced combat surgeon will be flexible in their approach, maximizing a versatile incision over an incision focused on ease of exposure. Lateral decubitus positioning can be a potentially fatal mistake in cases when suspected unilateral thoracic injuries are realized to be on the contralateral side or within the abdomen. Anterolateral thoracotomies may be extended medially up to 10 cm or fully converted to a clamshell if needed giving all the exposure granted by median sternotomies or classic posterolateral thoracotomies [21••, 29].

At least two staff surgeons should be working simultaneously to control hemorrhage whenever possible and multiple teams may be required when several areas of hemorrhage

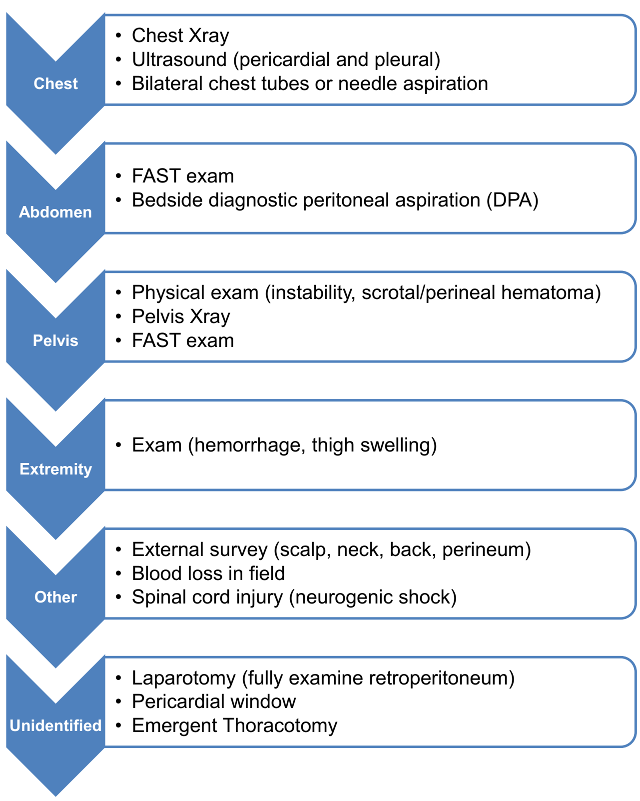


Fig. 4 Approach for rapid identification of hemorrhage in the unstable trauma patient. (Reprinted with permission from Martin M, Beekley A, eds. Front Line Surgery: A Practical Approach. 1st edition: Springer Publishing, New York, NY, 2010)

need to be addressed. In mass casualty scenarios, consideration of expectant victims and site resources should truncate interventions whenever necessary. The subsequent sections will provide examples of specific situations and interventions by increasing acuity [21••].

Emergent Thoracotomy

Guidelines for emergent thoracotomy (ET) continue to be somewhat debated. Their utility in civilian traumas situations does not differ greatly from combat scenarios. Patients who have lost pulses in transport or during resuscitation with continued evidence of cardiac activity on ultrasound should undergo ET [30, 31•]. A survival rate of 11% has been reported in appropriately selected patients injured during combat compared to rates as low as 1% reported in civilian literature [30, 32, 33•, 34]. Decision to progress to ET should also consider the total number of wounded how they are triaged and the resources and time available.

ET in the combat setting may effectively act as a damage control operation in the chest. Although damage control laparotomy may be common practice for a general and trauma surgeon, this comfort does not inherently translate to the chest. This is primarily because hemorrhage is the singular cause of acute death from abdominal injuries. Injuries in the chest can also be fatal due to loss of cardiac output from arrhythmia, tamponade, or tension pneumothorax as well as lung or airway injury resulting in terminal hypoxia. Further, vascular injuries can be more severe with a greater ratio of large vessels present and the potential for deadly air embolus. When bleeding is present, the removal of clot should be followed by manual control, sponge-stick tamponade or vascular clamping. Packing of the chest may lead to a false sense of security with on-going uncontrolled hemorrhage. When there is continuation between the thorax and the abdomen via diaphragmatic disruption, bleeding can be better localized if these compartments are separated by a temporary diaphragmatic closure. Just as in damage control laparotomy, once control is obtained, the surgeon should coordinate resuscitation and potential repair with the anesthesia team. Leaving an open chest with or without single lung ventilation may be necessary to avoid progression to severe metabolic and/or respiratory acidosis. Contrary to an open abdomen, the “open chest” should include placement of 2–3 chest tubes to prevent tension or tamponade physiology with a temporary closure of the thoracotomy using a running suture that includes all layers of the thoracic wall [21••].

Tension Pneumothorax

Tension pneumothorax or a progressive build-up of air in the pleural space, usually from an air leak in the lung parenchymal, creates a pressure in the thoracic cavity that is greater than the mean venous pressure causing decreased return of blood to the heart and ultimately leading to pulseless electric activity (PEA) cardiac arrest. This issue has been identified as one of the leading causes of preventable death of soldiers on the battlefield [35]. Current Tactical Combat Casualty Care (T-CCC) guidelines recommend needle thoracostomy with 14Ga, 3.25-in needle/catheter as first-line in decompression of tension pneumothorax in the field [36, 37]. Unfortunately, needle thoracostomy has been shown to be unreliable and ineffective in decompressing a tension pneumothorax with failure rates up to 58% with needle decompression [38]. One human posthumous review study under even controlled circumstances observed a failure rate of 41%. Furthermore, conventional chest tube insertion, although more reliable clinically, is currently discouraged by T-CCC guidelines for field care due to technical skill needed and size of wound created [37]. Deployed surgeons should take the time to teach their medics the pitfalls of needle decompression and encourage repeat needle decompression when signs and symptoms of reaccumulated tension pneumothorax exist. This data underscores the importance of realizing that even when interventions are deployed in the field, tension pneumothorax should be excluded in the initial evaluation and treated promptly when identified. Finger thoracostomy and or chest tube placement should give near immediate relief with spontaneous return of pulses. In cases where a large air leak is present, exploratory surgery and repair should be pursued.

Massive Hemothorax

Massive hemothorax is classically defined as a rapid accumulation of > 1000 mL of blood in a unilateral thoracic cavity typically associated with shock from both loss of blood volume and possibly mass effect within the chest. In reality and in the combat setting, it may be difficult to accurately quantify the amount of blood in the chest, however rapid assessment and chest x-ray should allow for speedy diagnosis and intervention. Placement of two large bore IVs and implementation of a massive transfusion protocol is the first line of care in coordination with an appropriately placed chest tube. In recent conflicts, the use of whole blood from walking blood banks has proven to be one advantage of the wartime setting for patient’s requiring large volume blood resuscitation [39–41]. The data published touting the benefits seen from whole blood resuscitation have in many ways be the impetus for studies such as the PROMMTT trial [42].

Once patients have been appropriately resuscitated and bleeding controlled (see above sections), the next area of concern should be the high risk of empyema and the development of a fibrothorax. Even large hemothoraces that are seen on plain film but otherwise asymptomatic should be addressed as early as possible. After a chest tube has been placed, residual fluid seen chest x-ray has a reported 33% chance of becoming infected [43]. An infected retained hemothorax and development of empyema only becomes more difficult to treat surgically over time. As the fluid organizes a thick fibrotic capsule can form and may even lead to a 'trapped' portion of the lung that unable to expand [44]. This can be avoided with early intervention and evacuation of fluid and clot. In austere environments, this is best accomplished by making a small (2–3 cm) thoracostomy at the time of chest tube placement, suctioning out any free fluid with a standard Yankauer suction tip and using copious lavage to break up any existing clot. When ongoing bleeding is encountered during this procedure, progression to an antero-lateral thoracotomy is easily accomplished. If empyema later develops, a larger debridement may be necessary. There is currently no consensus of the use of prophylactic antibiotics for retained hemothorax and the decision for their use in the combat setting should be individually assessed with consideration of the patient and available resources [45].

Major Vessel Injury

The vast majority of patients subjected to great vessel injury in the thorax will not survive to treatment. However, for exposure, proximal, and distal control are crucial to successful management. As previously discussed, an antero-lateral thoracotomy should afford access in nearly all cases and extension to complete clamshell exposure providing visualization to remaining contralateral and mediastinal vessels. Proximal control on the aorta should avoid clamping of the aortic arch. Clamped segments should remain as short as possible and minimized to < 30 min to avoid major spinal cord ischemia. Partial occlusion and repair may be possible using a side biting Satinsky clamp in some circumstances [46•].

The subclavian artery is the most commonly injured great vessel and as such multiple incision choices are available if this is the suspected injury; however, the simplest first step may be insertion of a foley balloon directly into a neck or superior chest wound to temporarily control the hemorrhage [47, 48]. Sponge stick compression apically can control this injury if a thoracotomy has been used, preferable entering in the 3rd or 4th interspace. Described complex incisions should be avoided in the deployed setting as focused incisions rarely allow for access to additional injured areas [21••].

Suture ligation may be necessary and can be utilized even for control of larger vessels such as the innominate artery and veins. Superior or inferior vena cava ligation is incompatible with life as well as aortic arch clamping even for temporary control. Major reconstruction is typically not feasible in combat settings. Rapid injury bypass and shunting using immediately available tubing (with consideration to comparable diameter) can be a durable temporary repair of a major vascular injury after clearance of inflow and outflow tracts [49].

It is worth mentioning that new products such as the resuscitative endovascular balloon occlusion of the aorta (REBOA) device have no role in the initial control of great vessel injury in the chest and if placed erroneously, may worsen hemorrhage. Once the vessel and full extent of the injury is identified, it may be determined that an appropriate landing zone proximal to the injury may allow for temporary use of the REBOA to aide in primary repair [50, 51].

Blunt vascular injury or deceleration injury resulting in aortic dissection should be treated conservatively with blood pressure control using beta blockade as the first line of care. If patients are stable repair can be delayed, patients should be transferred to a higher level of care and endovascular techniques should be used if available [52, 53].

Penetrating Cardiac Injury

Cardiac injury may be seen from fragmentation or gunshot wounds. Evidence can often be seen rapidly during the initial evaluation with the pericardial window of the FAST ultrasound exam [19]. Pericardial tamponade physiology may have a sudden onset. Evacuation of clot via pericardotomy through a thoracotomy or sub-xiphoid cardiac window is the first step. Once the clot is cleared and a myocardial defect is visualized, digital control should be utilized. Temporary control with a foley balloon or stapling may be used if more pressing matters are at hand [21••]. If cardiac arrest is present, these temporary methods should be employed while ACLS maneuvers are attempted. ACLS adjuncts should include manual ventricle compression using palms and open cardioversion using low voltage (10–30 J) if a shockable rhythm is present [54]. Once repair is possible it should be carried out using a nonabsorbable monofilament suture (typically Prolene) on a large needle. These should be pledgeted with felt or the patient's pericardium and repaired using horizontal mattress techniques. Visualization may be improved by maintaining digital occlusion with the non-dominant hand or temporary right atrial occlusion. Care should be taken to take large purchases of myocardium while avoiding ligation of the epicardial vessels. Placement of moistened laparotomy sponges under the heart facilitates exposure while limiting hemodynamic compromise by maintaining ventricular geometry. Complex or multiple injuries should be either temporarily controlled using whatever means necessary until a cardiothoracic surgeon is available.

Chest Wall

Complex damage to the chest wall is more common in the combat setting when compared to civilian trauma [32, 33•, 55]. Whereas open chest wounds, flail chest, and traumatic rib cage hernias are relatively rare in civilian trauma centers, these injuries occur with some frequency in the solider that has sustained an injury to their chest from a blast injury or high velocity rifle. The primary management should focus on restoring chest wall mechanics to facilitate breathing and control of life threatening hemorrhage with chest wall reconstruction and hernia repair delayed until the patient has stabilized. Initial management of chest wall defects includes debridement of devitalized tissue to include bone fragments, foreign materials, and missile or blast debris [21••].

Open chest wounds are defined as chest wall defects that are larger than the largest diameter of the patient's trachea (usually the size of a quarter) communicating the atmosphere to the pleural spacing and creating a 'sucking' chest wound with potential for tension physiology. Open pneumothoracies are often collateral damage from blast injury commonly present with associated simultaneous injury within the chest. T-CCC guidelines teach placement of a partially occluding 3-sided dressing and with placement of tube thoracostomy to treat and prevent development of tension pneumothorax [37]. This temporizing solution is adequate while associated injuries are addressed prior to definitive closure of the defect. Early intubation should be utilized as the positive pressure ventilation negates the effects of the natural inspiration and thus the development of tension pneumothorax.

Large volumes of blood can be lost from injuries to the chest wall and requires surgical attention early in the absence of other major intrathoracic bleeding. Transections of intercostal vessels are the main culprit of chest wall hemorrhage and can usually be controlled with suture ligation. This may prove easier stated than accomplished as the intercostal space can be narrow and making accurate suture placement challenging. Taking throws parallel to the ribs within the space in a horizontal mattress fashion is a helpful technique for adequate ligation. Alternatively, full thickness encircling of the rib and vascular bundle will suffice for quick and effective hemorrhage control [21••].

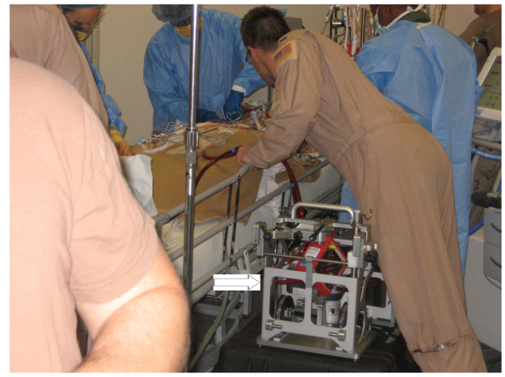
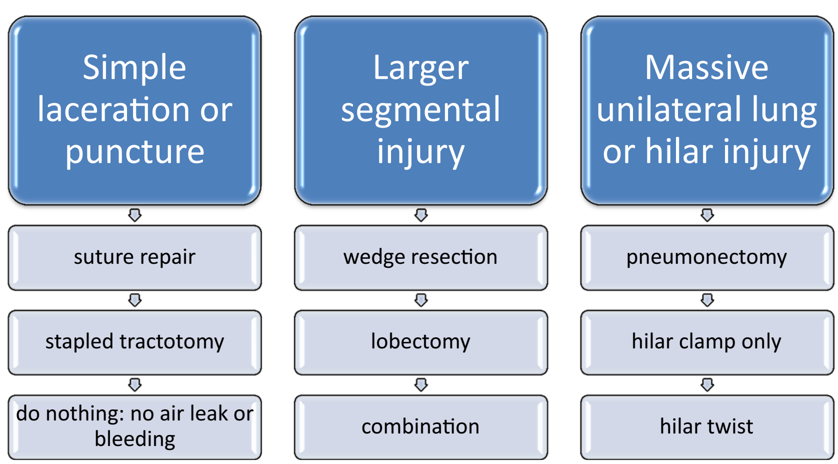


Fig. 5 Soldier being placed on portable ECMO for transfer to Germany. (Photos courtesy of CDR Rodd Benfield and CAPT Eric Elster)

Greater than three ribs broken in more than one location on each rib is classified as a flail segment of chest, allowing paradoxical motion which hinders basic breathing mechanics. Although the current body armor protects against lethal penetrating injury, the high velocity impact now results in a flail segment. Treatment with early rib plating is crucial for improved inspiration, prevention of hypoxia, and pain control. Nearly 100% of flail chest victims suffer from some degree of pulmonary contusion. Pulmonary contusion is the primary cause of hypoxia in patients with flail chest [32]. Judicious resuscitation, early rib plating, and pulmonary hygiene are key to the prevention of ARDS and/or pneumonia. A low threshold should be kept for intubation and respiratory optimization using the ventilator in these patients. Patients with flail segments with very small or occult pneumothorax should have early placement of tube thoracostomy as they are at high risk increasing pneumothorax over time in the battlefield setting due to limited ability to monitor during transport and air evacuation [21••].

Large defects created by chest wall trauma can result in traumatic rib cage hernias with protrusion of lung or

Fig. 6 Operative intervention based on lung injury type. (Reprinted with permission from Martin M, Beekley A, eds. Front Line Surgery: A Practical Approach. 1st edition: Springer Publishing, New York, NY, 2010)



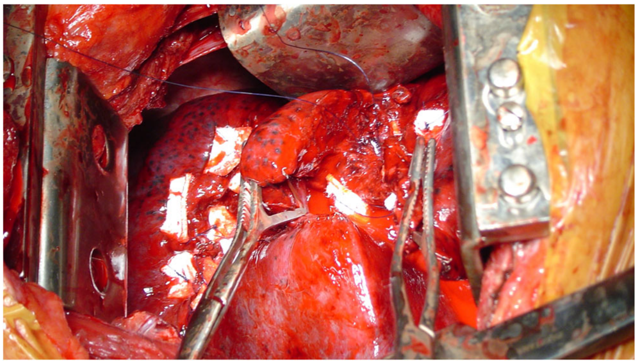


Fig. 7 Patient undergoing primary repair of lung laceration to control bleeding and air leak with areas of destruction requiring wedge resection. (Photo courtesy of LTC Daniel Cuadrado)

intraabdominal organs through the defect. Initial management includes reduction of the herniated tissue and primary closure if possible. Biologic mesh may be used at the outset in contaminated wounds to attempt recreation of the chest wall to facilitate breathing. More complex reconstruction using rib plating and prosthetic mesh may be ultimately required once the patient has progressed out of the acute setting.

Lung Injury

Injury to the lung parenchyma requiring operative intervention accounts for over one third of all combat related thoracic trauma. Location and the extent of the injury largely determine specific intervention (Fig. 6). As previously discussed, most of combat injuries are from high velocity or blast type injuries. These mechanisms often result in large areas of tissue disruption requiring more extensive operations. Time and resources should again be considered in this setting, as extensive reconstructions are almost never feasible in austere environments. Damage control principles previously discussed should be employed whenever appropriate in conjunction with use of the ALeRT and CCAT systems.

Most small lacerations or peripheral parenchymal damage, like that seen in the overwhelming majority of civilian trauma, can be managed conservatively with a chest tube. Persistent air leak or large air leaks from these types of injuries can be managed with primary suture closure or wedge resection. Larger injuries involving a segment of the lobe will require surgical attention with wedge resection, segmentectomy or formal lobectomy (Fig. 7) [33•]. Through and through injuries seen with low velocity penetrating injuries are rare in the war-setting. However, in these cases, lung parenchyma sparing operations should be utilized whenever possible. This can be accomplished by performing a stapled or sutured tractotomy [56, 57]. This technique should be avoided if there are large areas of tissue destruction.

More central injuries will often be associated with an unstable physiology requiring emergent intervention [33•, 57]. Disruption the hilum not only subjects the victim to massive blood loss but also carries a significant risk of air embolism. Hilar clamping or a hilar twist maneuver with temporary closure may be needed to stabilize these patients (Fig.8). Total pneumonectomy should be considered when patients are too unstable—and resources too thin—for extensive reconstruction. Although, pneumonectomy may be generally better tolerated in the young active duty military community, dramatic changes to cardiac and respiratory physiology will occur within the first 24–72 h after pneumonectomy and planning for early transport to higher echelons of care using the ALeRT and CCAT teams is recommended [26, 28, 58].

Diaphragm Injury

Due to the complexity of injuries to the chest and abdomen, diaphragmatic injuries are usually occult and associated with other intrathoracic or intra-abdominal injuries. Civilian incidence and laterality of diaphragmatic injury in blunt and penetrating circumstances do not strictly translate to the deployed setting due to previously discussed mechanisms however the protective nature of the liver does result in the majority of diaphragm injuries occurring on the left side. Fragment wounds may transverse the diaphragm and result in small diaphragm wounds that can be difficult to identify. Missed diaphragmatic injury will result in bowel or lung hernia in 90% of people by 3 years and thus should be repaired to prevent potential obstruction leading to incarceration [59]. If injury is on the right, devastating pleural or broncho-biliary fistula may develop [60]. If diaphragmatic injuries are identified during exploratory surgery then extension of the exploration to either thoracic or abdominal cavities should be completed as risk for associated injury such as small bowel perforation is high (Fig. 7).

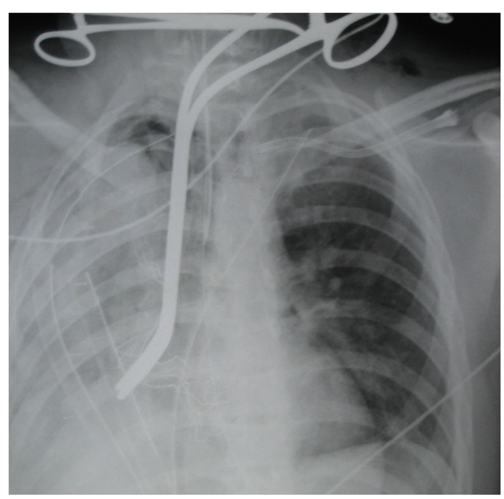


Fig.8 Hilar clamp placed during damage control thoracotomy. Patient ultimately underwent emergent pneumonectomy. (Photo courtesy of COL(retired) Brian Eastridge)

Small defects (< 2 cm) may be repaired primarily with pledgeted suture. Complex injuries with large defects, sometimes involving attachments to the chest wall are more commonly seen in war than in civilian populations and may require creative complex repairs. Use of biologic mesh or temporary placement of vicryl mesh may be necessary when there is related contamination either due to bowel injury or communicating atmospheric defects [61]. Thoracostomy tube drainage should be used to ensure removal of air, blood, and reactive fluid from the pleural space [21••] (Fig. 8).

Airway Disruption

Disruption of the tracheobronchial tree is relatively rare even from combat injuries. The presentation can be quite dramatic with severe respiratory distress, subcutaneous emphysema or a pneumothorax that does not resolve after chest tube placement. Suspicion should be high in patients with penetrating neck injuries and those exposed to high velocity or deceleration injury. In austere environments, temporizing measures with an endotracheal tube passed distal to the defect should be the primary focus. In the deployed setting, intubation aides such as fiberoptic visualization are rarely available. As such a low threshold should be kept for obtaining a definitive airway with the creation of a surgical airway if there is any difficulty passing on oral ET tube [62]. This is because false passages can be created with oral intubation worsen the injury creating a larger defect. Reconstruction and ultimate repair should be completed by a qualified specialist after stabilization [63].

Esophageal Injury

In the setting of multiple injuries and in the austere environment, the solution to esophageal injury is stabilize the patient, widely drain, and place a nasogastric tube distal to the injury. If the defect is large place a large bore drain or T-tube and sew around the tube to create a controlled fistula. After this is completed, the pleural space should also be drained with separate thoracostomy drains. Primary repair should only be considered in the stable patient who will be able to advance to a higher level of care. When primarily repairing the esophagus, debridement of the wound to fully realize the extent of the injury is key. A layered repair of mucosa followed by muscle and a protecting vascularized tissue flap (intercostal, diaphrapm etc.) should be used [64].

Conclusions

Combat trauma with injuries sustain in the thorax can be rapidly lethal and complex. The development of protective equipment has aided in quelling the effect of high velocity weaponry and blast injury but unique and severe injuries persist. Lessons learned from recent and ongoing conflicts have come with a more complete realization of bail out operations, temporizing procedures and the development of definitive reconstructions in the chest. These advancements may be applied to civilian centers as similar injury pattern become more common amongst trauma patients in the general population.

Compliance with Ethical Standards

Conflict of Interest The authors declare no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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