Chapter 11

THORACIC INJURY

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INTRODUCTION

Thoracic injuries remain a common presentation to medical facilities during current military operations. These cases are predominantly ballistic penetrating trauma, but also include blunt trauma from tertiary blast injury and road traffic collisions, as well as behind-armor blunt trauma (BABT).

This chapter discusses the incidence and pathophysiology of chest injury with particular emphasis on the anesthetic and surgical considerations from point of wounding through the emergency room to the operating room.

BACKGROUND

Penetrating wounds to the thorax frequently occur during military conflict. These injuries are often fatal before the casualty reaches medical care. This high probability of death has changed little from World War I, when the mortality from all penetrating thoracic injuries was 74%, through to Vietnam, when a single assault rifle gunshot wound to the chest resulted in an 80% mortality rate.[1] Thoracic wounds remain common during the conflict in Afghanistan, where approximately 13% of ballistic injuries require a thoracic intervention (chest drain, tissue debridement, or thoracotomy),[2] and thoracic injuries contribute to 30% of combat deaths.[3]

PATHOPHYSIOLOGY AND SPECIFIC INJURIES

The thorax is a semirigid structure that affords protection to the lungs, heart, and great vessels. Injury to these structures therefore typically requires a significant magnitude of force delivered by either penetrating or blunt injury. Penetrating injuries (Figure 11-1) frequently necessitate thoracotomy during initial resuscitation and will often require a surgical intervention, whereas blunt injuries (Figure 11-2) tend to be managed conservatively or with the placement of an intercostal drain.

Chest injury leads to hypovolemia secondary to major organ or vessel injury, or to hypoxia as a result of disruption to the mechanics of ventilation. A combination of hypoxia and reduced cardiac output can occur as a result of cardiac tamponade or tension pneumothorax (see Figures 12-1 and 12-2).

Intrathoracic Airway Injuries

Tracheobronchial injuries are found in 0.8% of blunt thoracic trauma victims presenting for emergency surgery.[4] The vast majority of these injuries are found within 2.5 cm of the carina[5] and are associated with a high mortality because of the difficulties in maintaining adequate ventilation and oxygenation, as well as delayed diagnosis.[5,6]

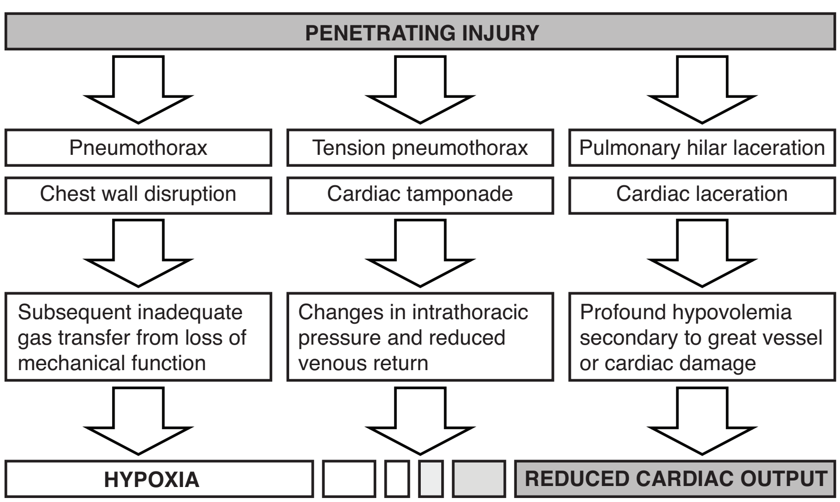

Figure 11-1. Effects of penetrating thoracic injury.
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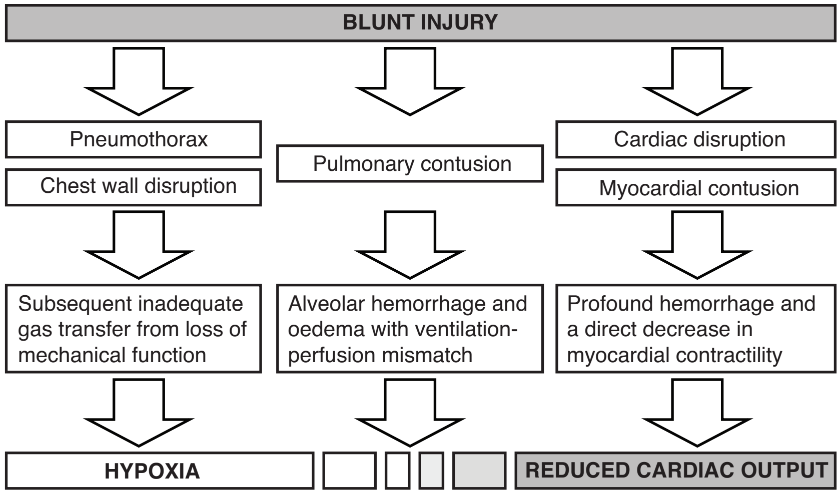

Figure 11-2. Effects of blunt thoracic injury.
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The management of intrathoracic airway injuries should ideally involve a thoracic surgeon at an early stage because operative repair will usually be required.[6] However, most trauma surgeons are not cardiothoracic specialists; therefore, adequate risk assessment must be done before embarking any operative procedure. In the deployed environment, conservative management frequently becomes the best course of action in carefully selected stable patients. There is evidence to support this view: in a study of 20 patients with tracheobronchial injuries who were managed conservatively, four died. The authors concluded that surgery should be performed in cases of associated esophageal injuries, progressive subcutaneous or mediastinal emphysema, severe dyspnea requiring intubation, difficulty with mechanical ventilation, pneumothorax with air leak through chest drains, or mediastinitis. The remaining cases are likely to do well with conservative medical management.[7]

The aim of initial management should be to improve ventilation and reduce air leak. This can be achieved by placing a cuffed airway device distal to the site of injury typically with the use of a fiberoptic bronchoscope, although this instrument may not be available in the field setting.

Cardiac Injury

Cardiac injury can occur secondary to blunt or penetrating trauma. Blunt cardiac injuries can present as a spectrum ranging from isolated electrocardiogram (ECG) abnormalities to myocardial rupture, with the right ventricle and interventricular septum the most frequently involved.[8] Cardiogenic shock may ensue as a result of arrhythmias, structural damage, or impaired ventricular contractility.

ECG abnormalities that may indicate cardiac injury include ST segment changes and arrhythmias. These patients should have continuous ECG monitoring. If hemodynamic instability is manifest, a transthoracic or transesophageal echocardiogram should be performed. Measuring troponin levels is probably of little benefit in management of blunt cardiac injury.[9] In the advent of cardiogenic shock, consideration should be given to placing an intraaortic balloon pump to off-load the left ventricle (although this procedure is unlikely to be possible in the deployed field hospital).[10]

BABT is a nonpenetrating injury resulting from the deformation of body armor after ballistic impact. It has been shown in animal models that apnea occurring after BABT is a vagally mediated reflex that results in severe hypoxia. Supportive ventilation should begin immediately in BABT casualties who are unconscious and apneic.[11]

Penetrating cardiac injuries are typically fatal. Only 6% of patients with penetrating anterior chest wounds causing cardiac injury survive to reach hospital care.[12] Presentation frequently includes the signs of cardiac tamponade, which are classically the Beck triad of hypotension, muffled heart sounds, and distended neck veins. Typically a globular heart is seen on chest radiograph, although in practice this is a subtle sign (Figure 11-3). Cardiac tamponade has also been reported with low-energy ballistic wounds.[13] The current practice of performing a rapid focused abdominal scan for trauma should include examination of the pericar-

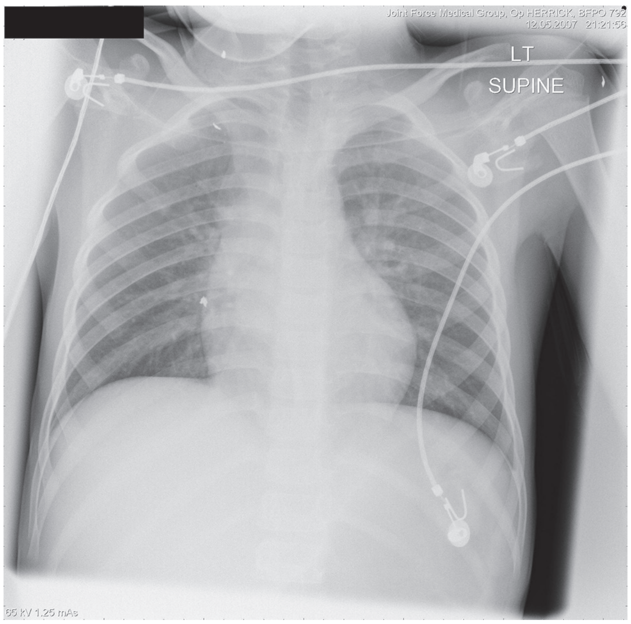

Figure 11-3. Chest x-ray showing cardiac tamponade.

dium via the substernal window. Management is by needle pericardiocentesis or thoracotomy; the latter is preferable and necessary for definitive treatment. Patients in extremis are candidates for emergency resuscitative thoracotomy (defined as thoracotomy in casualties with vital signs absent for less than 10 to 15 minutes).[14,15] In the civilian setting most chest wounds are caused by low-energy mechanisms (stab wounds or low-energy ballistics). In these circumstances, thoracotomy performed at the roadside on patients with a penetrating chest injury observed to lose their cardiac output has a survival rate of about 7%.[16] Military trauma is different and tends to produce complex injuries that require complex surgery; for this reason, thoracotomy should not be undertaken forward of a hospital with a surgical facility and blood products available to handle such cases.[2]

Aortic Injuries

Blunt aortic dissection is the second most common cause of death (after head injury) in blunt trauma.[17] However, diagnosis can be difficult and a high index of suspicion should be maintained. Computerized tomography and transesophageal echocardiogram are invaluable in establishing the diagnosis. Early decision-making and prompt thoracotomy with proximal control of the aorta is essential. Resuscitation with permissive hypotension (approximately 90 mm Hg) should be instituted until control is established, with correction of coagulopathy, acidosis, and hypothermia. It is essential to maintain good blood pressure control perioperatively. Glyceryl trinitrate and beta blockers should be used to keep the systolic pressure less than 140 mm Hg to minimize further aortic dissection.

Increasingly, endovascular stent grafting is being used rather than the conventional open aortic repair.[15] Neither of these options are likely to be available in forward surgical locations, however.

Lung Injury

The pathophysiology of lung injury, whether blunt or penetrating, can be seen as a 2-fold process with direct injury to the lung parenchyma followed by a systemic inflammatory response causing alveolar-capillary changes. This leads to acute lung injury (ALI) or acute respiratory distress syndrome (ARDS). ALI is defined by the following features: acute onset, bilateral infiltrates on chest radiograph, pulmonary artery occlusion pressure less than 18 mm Hg, PaO_2 to FiO_2 ratio less than 40 kPa. ARDS is defined by the same criteria except the PaO_2 to FiO_2 ratio is less than 27 kPa. These conditions represent a spectrum of increasing severity of lung dysfunction. Excessive bronchial secretions predispose the patient to lobar collapse and a further decrease in lung compliance, with pneumonia ensuing in approximately 50% of cases. The end result is a significant ventilation/perfusion mismatch with the additional effect of decreased oxygen delivery to vital organs.[18]

Blast lung results in an extreme form of pulmonary contusion. Shock waves from the blast cause both intraalveolar and intrabronchial hemorrhages with a sudden increase in lung weight.[19,20] The hemorrhage decreases lung compliance and leads to severe impairment of alveolar gas exchange and a rapidly worsening ventilation/perfusion mismatch. Typically these casualties present with dyspnea, cough, hemoptysis, and chest pain following blast exposure. The onset of hypoxia can occur as quickly as 1 to 2 hours after the blast exposure, in contrast to the 24 to 48 hours that has traditionally been described in this type of injury.[21] Theoretically, the administration of recombinant factor VIIa (rFVIIa) may rapidly control the pulmonary hemorrhage associated with blast lung. Prompt control of lung hemorrhage may improve the ALI/ARDS picture and prevent the need for mechanical ventilation. In an Israeli case series, full recovery in soldiers with life-threatening blast lung treated with rFVIIa was reported.[22] This indication for rFVIIa remains controversial and off-license. More studies are required to prove its efficacy in this situation.

Management of traumatic lung injury is supportive.

It should aim to minimize the systemic inflammatory response syndrome and its progression to ALI/ARDS. This is achieved by using hemodynamic monitoring to avoid excessive fluid overload or profound hypovolemia. The treatments indicated may include the use mechanical ventilation with lung-protective strategies (as discussed later in this chapter), crystalloids (in restricted volumes), colloids, diuretics, and inotropes.

OPERATIVE INTERVENTION

Although the majority of trauma cases with thoracic involvement can be managed without thoracotomy, a significant proportion do require thoracotomy, particularly with penetrating trauma. Following the principles of damage control resuscitation may further lower the threshold for operative intervention to control hemorrhage.

For those unfamiliar with thoracic surgery, the prospect of performing a thoracotomy may be daunting. The most common concerns are about the indications and timing of such intervention. Resuscitative thoracotomies—those performed for a patient in cardiac arrest—have been the subject of much debate and study (albeit retrospectively). It is generally accepted that resuscitative thoracotomies are most likely to be successful in the context of cardiac tamponade, when the patient has lost vital signs during the resuscitative process, and the period of cardiopulmonary resuscitation was limited. Those who sustained blunt trauma or had no vital signs for some time are less likely to survive. In certain polytrauma victims with a blunt thoracic injury in cardiac arrest, it is much more likely that cardiac arrest is secondary to hypovolemia from the nonthoracic injury, for example, a traumatic limb amputation. In these cases a thoracotomy would in all likelihood delay fluid resuscitation and hence worsen outcome.

It must be borne in mind that there is a limit to what can be achieved rapidly through a left anterior thoracotomy during resuscitation. Relief of tamponade or undiagnosed tension pneumothorax may lead to the restoration of a cardiac output; however, identifying and controlling a source of hemorrhage can be challenging, and cross-clamping the aorta may not be as straightforward as expected. Better exposure is almost always required, typically through conversion to a bilateral anterior thoracotomy (clamshell) incision, enabling a better assessment of the injuries and actions required to address them. In a series of traumatic cardiac arrest cases from the conflict in Afghanistan, all of the survivors (4 survivors out of 52 cardiac arrest patients) had a thoracotomy, although only one had an intrathoracic injury.[23] Whether or not thoracotomy, in itself, is beneficial in these cases is unknown.

Once the chest is opened, rapid assessment of cardiac filling and function can be made, the aorta cross-clamped, transfusion lines inserted under direct vision, and internal cardiac massage started. Deciding whether or not to perform an early thoracotomy in a patient in extremis is challenging and will, to a large extent, depend on the personalities involved. In the military setting, prehospital thoracotomy is unlikely to be a life-saving procedure due to the complex injury pattern associated with high-energy ballistic trauma and should arguably be avoided.[2] That said, prehospital thoracotomy has been found not to be an independent predictor of mortality (albeit in the civilian setting), leading to the conclusion that this intervention applied early, to a well-selected group of patients, may be of benefit.[24]

The more common scenario, and arguably more challenging in terms of decision-making, is the patient who does not require an immediate resuscitative thoracotomy, but has thoracic trauma that is not being adequately managed with simple maneuvers such as chest drain placement and volume resuscitation. The danger for patients such as this is to delay thoracotomy and persist with fluid resuscitation without controlling hemorrhage (and often air leak), which may allow the acidotic, hypothermic, and coagulopathic triad that damage control resuscitation seeks to prevent. The challenge is in identifying which patients are likely to need a thoracotomy and making the decision to proceed. Using absolute volumes of chest drainage as a trigger point for thoracotomy may be tempting, but this approach ignores the effects of air leaks and trauma elsewhere in the body. Instead, the logical and well-defined Advanced Trauma Life Support physiological principles should be used to guide the decision-making process, by identifying “transient” or “non-responders”’ to fluid resuscitation: patients who have either partial or no improvement in circulatory status in response to fluid resuscitation.[25] Current resuscitative strategies have moved away from initial resuscitation with crystalloids in favor of early use of blood products, but distinguishing those responding to volume replacement from those with ongoing massive hemorrhage is pivotal in the decision-making process. Other indications for early thoracotomy include massive air leaks affecting the ability to ventilate or oxygenate, and more obvious conditions such as foreign body transfixion.

Once the decision to perform a thoracotomy has been made, the next dilemma is the surgical approach to be taken. The classical posterolateral thoracotomy used for elective pulmonary surgery is arguably the least useful incision in the trauma setting. This technique relies on effective one-lung ventilation, and access to other parts of the chest cavity is limited. Establishing one-lung ventilation represents a challenge in a field hospital environment for a variety of reasons including lack of equipment or expertise, the need to rapidly establish a secure airway, and the lack of bronchoscopes to optimally position a double-lumen tube.

The two incisions most frequently employed for access to the thoracic cavity in trauma are therefore the bilateral anterolateral thoracotomy (the clamshell incision) and the median sternotomy, as shown in Figure 11-4. Both provide good access to the pericardial cavity without creating any of the additional anesthetic or physiological stresses associated with one-lung ventilation. The median sternotomy provides excellent access to the great vessels and, in the case of junctional trauma, is easily extended superiorly into the root of the neck or inferiorly into a laparotomy incision. Disadvantages include the need for a sternal saw or a Gigli saw to perform the incision; the former is not always readily available and the latter is slower and can be harder to keep in the midline. The other disadvantage of this approach is the relatively limited access to the lungs and pleural cavities, which may be particularly important in penetrating trauma associated with projectile injuries.

The clamshell incision is easily performed with scalpel and scissors. The sternum can usually be divided across the midline to join the anterior thoracotomies with bone shears or a Gigli saw. These thoracotomies should be performed in the fifth intercostal space, because making the incision too low can restrict access, particularly to the great vessels. The advantages of the incision are immediately apparent on retracting the thoracotomies: excellent exposure of both pleural cavities and the pericardial cavity. It is also the logical method of opening the chest following a resuscitative left anterior thoracotomy by simply extending the incision across the midline. It is important that bleeding from the transected internal thoracic arteries should be addressed early in the procedure, preferably when identified. A transected vessel overlooked at this stage may not be apparent until the casualty is resuscitated to more normal physiological values, leading to significant delayed hemorrhage.

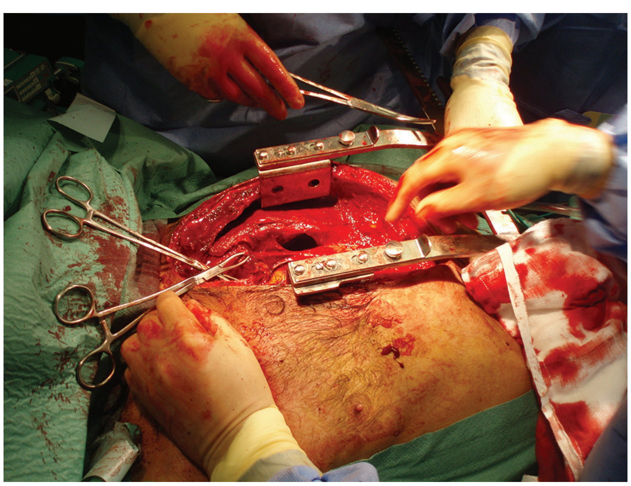

Figure 11-4. Median sternotomy.

Once the thorax is opened, the typical next step is to open the pericardial cavity. This should initially be done longitudinally, then making an inverted-T incision, avoiding the phrenic nerves, particularly on the left where is it most vulnerable to iatrogenic damage. Subsequent surgical maneuvers depend on the pathology found, but the main principles of any trauma surgery apply: first control hemorrhage. Bleeding from the heart or great vessels is initially controlled with digital pressure, possibly with the subsequent application of side-biting clamps to enable direct suture repair. Massive pulmonary hemorrhage or air leak can be controlled by temporarily clamping the lung at the hilum. A pneumonectomy is occasionally necessary but is associated with a high mortality of around 75%.[26,27] The high incidence of mortality is related to exsanguination, right heart failure, and pulmonary edema in the remaining lung. Oversewing pulmonary lesions, or performing a tractotomy with standard stapling devices for deeper lacerations, is often adequate to achieve permanent control; wedge resections may also be required. Inevitably thoracotomies performed for blunt or blast trauma will be more challenging, typically due to the magnitude of soft tissue and chest wall injury, and there are no easy ways to deal with these.

Junctional trauma is a well-recognized issue; traumatic injuries do not respect anatomical boundaries and chest injuries are not infrequently associated with abdominal, neck, and spine injuries. As discussed, a median sternotomy is easily extended into a laparotomy, or vice versa, and the clamshell incision can also be combined with a midline extension. Extending the operative field from the chest into the abdomen is something that most trauma surgeons should be comfortable with, but the root of the neck can prove more challenging. Access to the subclavian vessels, particularly on the left, can be difficult, and often necessitates a trap-door incision with division or removal of part of the clavicle. Definitively dealing with great vessel trauma in this challenging region requires good exposure, which initially can seem daunting.

A range of other related injuries and structures are not addressed here, thoracic duct and esophageal injuries for example. The need to understand the anatomy of the thoracic cavity and neighboring areas cannot be over emphasized.

PRINCIPLES OF ANESTHESIA

The patient should be initially assessed and managed in accordance with Battlefield Advanced Trauma Life Support guidelines in the deployed military setting. Broadly speaking, the principles of thoracic trauma anesthesia involve the restoration of circulating volume, maintenance of adequate oxygenation, and correction of hypothermia and coagulopathy (ie, the goals of damage control resuscitation).

It is highly likely that a definitive airway will need to be secured at an early stage. The usual practice to achieve a definitive airway is a rapid sequence intubation of the trachea, with cricoid pressure applied and the cervical spine controlled with manual in-line stabilization. However, this practice can increase the likelihood of difficult intubations. Difficult intubation should be dealt with in accordance with local guidelines. Any unexplained hypotension and difficulty in ventilation should arouse suspicion of a tension pneumothorax. A retrospective analysis of 978 penetrating chest trauma casualties during the Vietnam War found radiographic evidence of tension pneumothorax in 198 of the cases. The researchers concluded that tension pneumothorax was the cause of death in 3% to 4% of fatally wounded combat casualties.[28]

Anesthesia for an emergency thoracotomy may include one-lung ventilation. In the shocked patient, ketamine is considered by some to be the induction agent of choice because it preserves blood pressure and cardiac output.[29] Alternative strategies involve a significantly reduced dose of other induction agents or opioid-based anesthesia. Hypotension immediately postinduction should be anticipated and treated with further intravenous fluid resuscitation (usually blood products) or sympathomimetic drugs in a euvolemic patient. Anesthesia is usually maintained with a low-dose volatile agent and nondepolarizing muscle relaxation. Using nitrous oxide should generally be avoided because it has a propensity to increase the size of gas-filled cavities including air emboli and pneumothoraces. Monitoring should include invasive arterial blood pressure measurement as well as placement of a central venous catheter.

PRACTICAL CONDUCT OF ANESTHESIA

The common theme in all cardiothoracic procedures is the close communication required between surgeon and anesthetist. This is true through the decision to operate, surgical approach, lung isolation, and problem solving. Only by paying close attention to the progress of the surgery and understanding the implication of surgical maneuvers can the anesthetist interpret changes in airway pressure, blood pressure, or heart rhythm correctly.

The choice of surgical approach can obliviate the need for lung isolation, and a clamshell or median sternotomy are optimal approaches for intrathoracic procedures for this reason. Lung isolation with a double-lumen endobronchial tube (DLEBT), standard for elective thoracic work, allows the surgeon to operate on a nonventilating lung. Alternatives to the DLEBT in providing one-lung ventilation include bronchial blockers and the Univent (Fuji Systems Corp, Tokyo, Japan) tube.[30] Fiberoptic scopes are used to facilitate and confirm placement. Some or all of this equipment may not be available in a deployed field hospital. The DLEBT can be difficult to place by those not regularly undertaking routine thoracic anesthesia, and the tubes are commonly associated with malposition and a high complication rate, which can be compounded in the rapid sequence intubation situation.[31]

Several simple strategies are available to a nonthoracic anesthetist providing anesthetic for emergency intrathoracic surgery to facilitate surgery on the lung or chest cavity. Most emergency thoracotomies carried out as part of damage control resuscitation can be managed with a single-lumen tube and two-lung ventilation. Typically a single-lumen tube passed beyond the carina will rest in the right main bronchus (which is in a straighter line from the larynx than the left main bronchus). A single-lumen tube can readily be used to isolate the left lung and preferentially ventilate the right. Simply advancing (an uncut) tube should provide lung isolation with this technique. Single-lumen tube design will then almost inevitably occlude the take-off of the right upper-lobe bronchus, which may worsen hypoxemia. Rotation of the patient's head to the right on insertion can sometimes allow the tube to pass into the left main bronchus and allow ventilation of the left lung.

Lung movement can be minimized by periods of relative hypoventilation or even disconnection from ventilation for brief periods to allow a specific surgical maneuver to be performed. Combined with gentle surgical retraction of the lungs, this technique will allow most emergency procedures to be undertaken.

Hypoxemia is common during single-lung ventilation and may also be "permissive" due to hypoventilation during particular surgical maneuvers such as lung retraction. Inspired oxygen percentage can be increased and acceptable arterial oxygenation monitored with arterial blood gases. Lung injury from contusion or blast lung is common in military trauma, and every effort should be made to keep tidal volumes and ventilator pressures low intraoperatively. Airway pressures can be affected by mechanical retraction of the airway, as can hypotension.

Hypotension is frequently caused by surgical retraction around the mediastinum or great vessels. Periods of hypotension should first be addressed by ensuring there is no mechanical cause. Surgical stimulation around the mediastinum is a potent cause of arrhythmias, which are usually self-limiting once the surgical stimulus is withdrawn. Turning a patient with a massive hemothorax to the lateral position can provoke profound hypotension both through redistribution of blood volume and also from the contained blood's pressure on the mediastinum. For this reason it is recommended that the supine position be used wherever possible (with incision via clamshell or median sternotomy).

Fluid management for major lung resections is challenging, as reflected in the high mortality associated with traumatic pneumonectomy.[26,27] It seems reasonable to adopt a more cautious approach to transfusion than in non-chest-related trauma. Resuscitation should aim to correct initial acidosis and hypotension with blood and blood products, which will maintain a normal plasma oncotic pressure. Over-transfusion and increasing right ventricular load should be avoided at all costs with major lung resection.

VENTILATION STRATEGIES

The incidence of ventilator–associated lung injury has changed the way that mechanical ventilation is delivered. The Acute Respiratory Distress Syndrome Network study[32] used tidal volumes of 6 and 12 mL/kg to ventilate patients with ARDS. A significant absolute reduction in mortality was achieved using the lower tidal volumes and maintaining inspiratory plateau pressures less than 30 cm H_2O. However, these protective ventilation strategies frequently result in hypercapnia and respiratory acidosis.[32] When conventional methods of mechanical ventilation fail in patients with an asymmetric lung injury, intensivists may resort to methods such as independent lung ventilation to maintain oxygenation.

One-lung independent ventilation (OL-ILV) is a technique that allows ventilation of one lung while the other main bronchus is artificially blocked to isolate fluid (ie, blood) or secretions, avoiding contamination of normal lung alveoli and improving gas exchange. OL-ILV can be facilitated by deliberate left or right main bronchus intubation with a normal endotracheal tube, the use of a DLEBT, or placement of a bronchial blocker.

Two-lung independent lung ventilation (TL-ILV) allows different ventilatory parameters or ventilatory modes to be applied to each lung. Separate ventilator circuits are used for each lung. TL-ILV can be applied synchronously or asynchronously. Synchronous TL-ILV maintains the same respiratory rate for both lungs but the flow rates, tidal volumes, and positive end-expiratory pressure are set separately. Asynchronous TL-ILV must use two separate ventilators to deliver different modes as well as different ventilator settings.

PRINCIPLES OF ANALGESIA

The ongoing management of thoracic casualties hinges on providing excellent analgesia, which allows weaning from mechanical ventilation and hence restoration of normal respiratory mechanics. Using local anesthetic techniques avoids the respiratory depressant side effects of opiates. However, regional techniques to provide adequate analgesia for significant thoracic injuries are relatively complex. Thoracic paravertebral blocks are attractive because they have no unwanted effects on the uninjured side, are safe to perform and relatively easy to learn, and provide analgesia comparable to that of epidural analgesia.[33] Paravertebral blocks can also be placed under direct vision by the surgeon during thoracotomy.[34] Thoracic epidurals, however, are likely to be the technique of choice for most anesthetists. These blocks provide bilateral analgesia but also cause muscle weakness; however, improvements in respiratory mechanics resulting from excellent analgesia more than offset this side effect.[35]

CONCLUSION

The majority of combat thoracic injuries can be managed with simple interventions, such as placement of an intercostal drain or soft tissue debridement. It is the minority of cases, when thoracotomy is indicated, that pose the greatest challenge for the military anesthetist and surgeon.

The essential principles for dealing with these injuries are:

1. Recognize life-threatening problems and intervene accordingly.
2. Understand the prevailing pathophysiology.
3. Adopt a multidisciplinary approach to provide care from point of wounding though resuscitation and surgery to intensive care.

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