

Anaesthetic and Critical Care Management of Thoracic Injuries

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Abstract

Thoracic wounding has been a relatively common presentation of military wounds throughout modern conflict. When civilian casualties are included the incidence has remained constant at around 10%, although the frequency and severity of wounds to combatants has been altered by modern body armour. Whilst thoracic injury has a high initial mortality on the battlefield, those surviving to reach hospital frequently have injuries that only require simple management. In addition to penetrating ballistic injury, blunt chest trauma frequently occurs on operations as a result of road traffic collisions or tertiary blast injury. The physiological impact of thoracic wounds, however, is often great and survivors often require intensive care management and, where available, complex strategies to ensure oxygenation and carbon dioxide removal. This review examines the incidence and patterns of thoracic trauma and looks at therapeutic options for managing these complex cases.

Introduction

Thoracic wounding remains common on current military operations. This is predominantly ballistic penetrating trauma but there is also a background incidence of blunt injury from tertiary blast injury and road traffic collisions.

Previous editions have discussed penetrating cardiac injury [1], non-cardiac thoracic trauma [2] and emergency department thoracotomy [3]. This review discusses the incidence and pathophysiology of chest injury with particular emphasis on the anaesthetic and critical care considerations from point of wounding through the resuscitation room, operating theatre and later phases of care in the intensive care unit.

Background

Penetrating wounds to the thorax occur frequently during war fighting operations and these injuries are often fatal before the casualty reaches medical care. However, those casualties that do enter the medical chain usually only require conservative management and have good outcomes. Throughout the history of conflict, chest trauma has carried a high probability of death. This changed little from World War I where the mortality from all penetrating thoracic injuries was 74% through to Vietnam where a single assault rifle gunshot wound to the chest had an 80% mortality [4]. Throughout that period thoracic wounding rates remained relatively static at around 10% of casualties. Data from recent conflicts shows that despite improvements in protection for troops such as Combat Body Armour (CBA), chest injuries still occur. Wounding rates for US forces during Op Iraqi Freedom in 2003 were 5% [5], but the rate of thoracic injury amongst all presentations during the conflict, when civilians were included, was higher at 12.7% [6]. Thoracic injury remains common during the conflict in Afghanistan with approximately 13% of ballistic injuries requiring a thoracic intervention (chest drain, soft tissue

debridement or thoracotomy) [7] and contributing to 30% of combat deaths [8].

Pathophysiology and Specific Injuries

The thorax is a semi-rigid structure which affords protection to the lungs, heart and great vessels. Injury to these structures therefore typically requires a significant magnitude of force. The injury may be either blunt or penetrating. Blunt injuries tend to be managed conservatively or with the placement of an intercostal drain, whereas penetrating injuries frequently necessitate thoracotomy during initial resuscitation and often require operative intervention [9].

Chest injury leads to hypovolaemia secondary to major organ or vessel injury which is usually rapidly fatal, or hypoxia as a result of disruption of the mechanics of ventilation (Figure 1). A combination of hypoxia and reduced cardiac output can occur as a result of cardiac tamponade or tension pneumothorax. This is a far more common problem following penetrating trauma. Both of these conditions are potentially reversible but rapidly fatal if unrecognised.

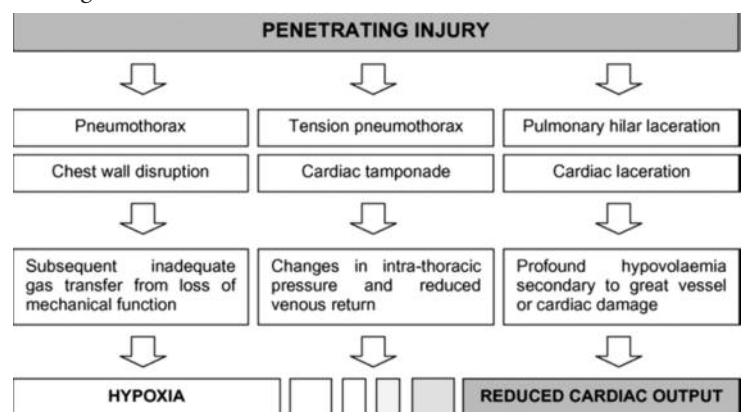


Figure 1. Pathophysiology of penetrating thoracic injury. Reprinted from *Injury Vol 37 (1)*. Hunt P, Owens A, Greaves I. Emergency thoracotomy in thoracic trauma – a review. Pages 1-19. Copyright (2006) with permission from Elsevier

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Intrathoracic Airway Injuries

Tracheobronchial injuries are found in 0.8% of blunt thoracic trauma victims presenting for emergency surgery [10]. The vast majority of these injuries are found within 2.5 cm of the carina [11] and are associated with a high mortality due to difficulty in ventilation and maintenance of adequate oxygenation and delay in diagnosis [11,12].

The management of intrathoracic airway injuries should ideally involve a thoracic surgeon at an early stage as operative repair will usually be required [12]. This is often not the case on deployed operations; however there is evidence to suggest that conservative management can obtain good results in carefully selected stable patients. In a study of 20 patients with tracheobronchial injuries that were managed conservatively, four died. The authors concluded that surgery should be performed in cases of associated oesophageal injuries, progressive subcutaneous or mediastinal emphysema, severe dyspnoea 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 [13].

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 fibre-optic bronchoscope. Alternatively a rigid bronchoscope may be used to facilitate this.

Cardiac Injury

Cardiac injury can occur secondary to blunt or penetrating trauma. Blunt cardiac injuries can present across a spectrum ranging from isolated ECG abnormalities to myocardial rupture, with the right ventricle and interventricular septum the most frequently involved [14]. 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 established. If haemodynamic instability is manifest, a trans-thoracic or trans-oesophageal echocardiogram (TOE) should be performed. Other imaging may include coronary angiography and nuclear medicine scans [15]. Measurement of troponin levels is probably of little benefit in management of blunt cardiac injury [16]. In the advent of cardiogenic shock, consideration should be given to the placement of an Intra-Aortic Balloon Pump (IABP) in order to off-load the left ventricle [17].

Behind armour blunt trauma (BABT) is a non-penetrating injury resulting from the deformation of body armour after sustaining a ballistic impact. Gryth et al have shown in animal models that apnoea occurring after BABT is a vagally-mediated reflex that results in severe hypoxia. They recommend that supportive ventilation should begin immediately in BABT casualties who are unconscious and apnoeic [18].

Penetrating cardiac injuries are typically fatal. Only 6% of patients with penetrating anterior chest wounds causing cardiac injury survive to reach hospital [19]. Presentation may frequently be the signs of cardiac tamponade which are classically Beck's triad of; hypotension muffled heart sounds and distended neck veins. Typically a globular heart is seen on chest x-ray although in practice this is a subtle sign (Figure 2). Cardiac tamponade has been reported with low energy ballistic wounds by Cooper et al [20]. Current practise of performing a rapid Focussed Abdominal Scan for Trauma (FAST) should include examination of the pericardium via the substernal window. Management is by needle pericardiocentesis or thoracotomy, with the latter being preferable and necessary for definitive treatment. Patients in extremis are candidates for emergency resuscitative thoracotomy. This has been defined in two reviews on the topic as those with vital signs absent for less than 10 to 15 minutes [3, 21]

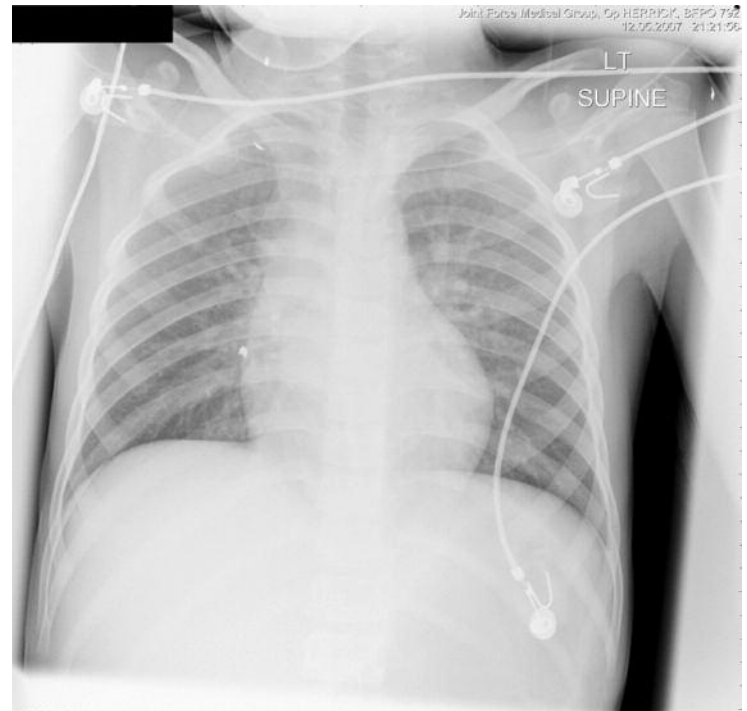


Figure 2. Chest x-ray showing fragments of land mine at right sternal edge and the globular heart of cardiac tamponade

Aortic Injuries

Blunt aortic dissection is the second most common cause of death after head injury in blunt trauma [22]. Diagnosis can be difficult and a high index of suspicion should be maintained. Computerised Tomography (CT) and TOE are invaluable in establishing the diagnosis. Increasingly Endovascular Stent Grafting (EVSG) is being used as opposed to the conventional open aortic repair [21]. Neither of these options are likely to be available in forward surgical locations. Intra-operatively it is essential to maintain good blood pressure control. Glyceryl Trinitrate and Beta Blockers should be used to keep the systolic pressure less than 140 mmHg in order to minimise further aortic dissection.

Penetrating aortic injuries are often rapidly fatal. Early decision making and prompt thoracotomy with proximal control of the aorta is essential. Resuscitation with permissive hypotension should be instituted until control is established, with correction of coagulopathy, acidosis and hypothermia.

Lung Injury

The pathophysiology of lung injury whether blunt or penetrating, can be seen as a two-fold process with direct injury to the lung parenchyma and 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 following features: an acute onset, bilateral infiltrates on chest radiograph, pulmonary artery occlusion pressure <18 mmHg, PaO₂:FiO₂ <40 kPa. ARDS is defined by the same criteria except PaO₂:FiO₂ is <27 kPa. These conditions represent a spectrum of increasing severity of lung dysfunction. Excessive bronchial secretions predispose to lobar collapse and decreased lung compliance with pneumonia ensuing in approximately 50% of cases. The end result is a significant ventilation/perfusion mismatch with the knock-on effect of decreased oxygen delivery to vital organs [23].

Blast lung results in an extreme form of pulmonary contusion. Shock waves from the blast cause both intra-alveolar and intra-bronchial haemorrhages with a sudden increase in lung weight [24, 25]. The haemorrhage decreases lung compliance and leads to severely impaired alveolar gas exchange and a rapidly worsening ventilation/perfusion mismatch.

Management of traumatic lung injury is supportive. It should aim to minimise the Systemic Inflammatory Response Syndrome (SIRS) and its progression to ALI/ARDS. This is achieved by utilising haemodynamic monitoring to avoid excessive fluid overload or profound hypovolaemia. The treatments indicated may include the use mechanical ventilation, crystalloids and colloids, diuretics and inotropes [26].

Principles of Anaesthesia

The patient should be initially assessed and managed in accordance with Advanced Trauma Life Support or Battlefield Advanced Trauma Life Support in the deployed UK military setting.

Broadly speaking, the principles of thoracic trauma anaesthesia involve the restoration of circulating volume, maintenance of adequate oxygenation and correction of hypothermia and coagulopathy.

It is highly likely that a definitive airway will need to be secured at an early stage. Usual practice to achieve a definitive airway is a rapid sequence intubation (RSI) of the trachea with cricoid pressure applied and the cervical spine controlled with manual in-line stabilisation. This can increase the likelihood of difficult intubation occurring. Difficult intubation should be dealt with in accordance with the Difficult Airway Society (DAS) algorithms [27]. 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 these. They concluded that tension pneumothorax was the cause of death in 3 - 4% of fatally wounded combat casualties [28].

Emergency thoracotomy may be indicated and anaesthesia for this may include one-lung ventilation (OLV). OLV is most frequently achieved by means of a Double Lumen Endobronchial Tube (DLEBT). Alternatives to the DLEBT in providing OLV include bronchial blockers and the Univent tube [29]. It is recognised that DLEBT can be difficult to place by those not regularly undertaking routine thoracic anaesthesia and the tubes are commonly associated with malposition and a high complication rate. This can be compounded in the RSI situation [30]. In the authors' experience, most emergency thoracotomies carried out as part of damage control resuscitation can be managed on a single lumen tube and two lung ventilation. One lung ventilation (at least for surgery on the left lung) can be easily established by advancing a single lumen tube beyond the carina and into the right main bronchus.

In the shocked patient Ketamine is the induction agent of choice due to its preservation of blood pressure and cardiac output [31]. Hypotension immediately post-induction should be anticipated and treated with further intravenous fluid resuscitation (usually blood products) or sympathomimetic drugs in a euvoalaemic patient. Anaesthesia is usually maintained with a low dose volatile agent and non-depolarising muscle relaxation. The use of nitrous oxide should generally be avoided as 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.

Principles of Analgesia

The ongoing management of these casualties hinges on providing excellent analgesia; this will allow weaning from mechanical ventilation and hence restoration of normal respiratory mechanics. Local anaesthetic techniques have the benefit of avoiding 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 in that they have no unwanted effects on the uninjured side, are safe to perform, relatively easy to learn and provide analgesia comparable to that of epidural analgesia [32].

Paravertebral blocks can also be placed under direct vision, by the surgeon at thoracotomy, as described by Sabanathan [33]. Thoracic epidurals however are likely to be the technique of choice for most anaesthetists. These blocks provide bilateral analgesia but also muscle weakness, however the improvements in respiratory mechanics resulting from excellent analgesia more than offset this [34].

Critical Care Management

A significant number of these patients will need critical care, including mechanical ventilation, after the initial resuscitative phase and/or post surgical intervention. Sputum retention is a major issue leading to pulmonary collapse with the increased risk of infection. Early pneumonia, within the first few days, may well be a result of aspiration. Chest injury, shock, emergency intubation and blood transfusion are all risk factors for development of later ventilator associated pneumonia (VAP) and sepsis [35]. Good intensive care nursing and the application of ventilator care bundles - specifically adopting a 30° head up posture for the patient and daily sedation breaks - can reduce the incidence of VAP [36, 37]. Sepsis remains the major cause of late deaths in the victims of trauma.

Ventilation Strategies

The concept of ventilator - associated lung injury has changed the way that mechanical ventilation is delivered. The Acute Respiratory Distress Syndrome Network study 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 30cm H₂O. However these protective ventilation strategies frequently result in hypercapnia and respiratory acidosis [38]. When conventional methods of mechanical ventilation fail in those with an asymmetric lung injury, it is likely that the intensive care doctor will resort to methods such as independent lung ventilation to maintain oxygenation.

One lung independent ventilation (OL-ILV) is a technique which allows ventilation of one lung while the other main bronchus is artificially blocked in order to isolate fluid such as 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 and/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 (PEEP) are set separately. Asynchronous TL-ILV must use two separate ventilators to deliver different modes as well as different ventilator settings.

Other Strategies

There are occasions when clinical deterioration continues despite standard intensive care therapies. There are numerous other techniques with a limited evidence base that may be employed.

Nitric Oxide

Nitric oxide induces pulmonary vasodilatation in un-injured areas of the lung, thus favourably altering the ventilation/perfusion ratio. Johannigman et al demonstrated the greatest improvement in pulmonary function when nitric oxide was delivered to either normal lung or to both lungs (injured plus un-injured) [39]. The use of inhaled nitric oxide may also be useful in patients with bilateral lung injury consisting of multiple patchy contusions and acute respiratory failure.

Prone Positioning

Prone positioning has been extensively used in ALI/ARDS patients. The postulated mechanism is one of change in regional distribution of ventilation and perfusion in the lung [40]. Despite the improvement in oxygenation seen in the majority of patients, there is no proven improvement in mortality.

High Frequency Oscillatory Ventilation

High Frequency Oscillatory Ventilation (HFOV) was initially used to treat neonates suffering from respiratory failure. It has been used in adults to treat refractory hypoxaemia. It delivers low-amplitude proximal airway vibrations that result in sub-dead space tidal exchanges. The airway pressure, inspired oxygen fraction and oscillatory frequency are titrated to achieve adequate oxygenation and ventilation.

Extracorporeal Membrane Oxygenation (ECMO)

ECMO may be used as a temporary replacement for the lungs in those situations where the lungs catastrophically fail to provide ventilation and oxygenation, after all other treatment strategies have failed. The aim of ECMO is to give the lung increased time to recover. It employs veno-venous or veno-arterial large bore cannulation (usually only veno-venous for oxygenation purposes) and a pump mechanism with a membrane oxygenator. The CESAR trial compared ECMO with conventional ventilatory strategies in patients with ARDS. They found a significant improvement in survival in the ECMO group but a longer hospital and intensive care stay [41]. There were, however, several problems with this study – all the patients in the ECMO group went to one centre whereas the standard group stayed in a specialist ICU. There was no set ventilatory strategy used in the non-ECMO group and a number of patients did not receive optimal ventilatory management, whereas most of those in the ECMO group did. ECMO remains a highly specialised technique that is only available in a few centres; there is just one adult ECMO centre in the United Kingdom.

Extracorporeal Carbon Dioxide Removal

Lung protective ventilation strategies frequently lead to hypercarbia and acidosis. This often limits the ability to apply strict low volume, low pressure strategies. One technique that has shown promise in military casualties is extracorporeal carbon dioxide removal [42]. These devices use heparin bonded circuits, negating the need for anticoagulation, and arterio-venous cannulation, rather than needing a pump. The use of this device has also been reported in the retrieval of patients with ARDS [43].

Partial Liquid Ventilation

The use of a perfluorocarbon solution to ventilate and oxygenate the lung has been postulated. There is limited evidence to support its efficacy. One small scale study comparing ECMO plus partial liquid ventilation to ECMO alone showed a greater improvement in lung compliance and reduction of physiological shunt in the liquid ventilation group [44]. The theoretical benefits of partial liquid ventilation stem from the perfluorocarbon allowing free diffusion of O₂ and CO₂ as well as acting like surfactant and increasing alveolar surface tension [23]. The benefits of perfluorocarbon liquid ventilation remain theoretical. Trials in respiratory failure patients have not demonstrated a significant improvement.

Recombinant Factor VIIa (rFVIIa)

The use of recombinant activated factor seven in overcoming complex trauma-related coagulopathy and as an adjunct to surgical haemostasis has been described both anecdotally and in several studies [45, 46]. Theoretically, the administration of rFVIIa may rapidly control the pulmonary haemorrhage associated with blast lung. Prompt control of this haemorrhage may improve the

ALI/ARDS picture and avoid the need for mechanical ventilation. The Israeli military has reported full recovery in soldiers with life-threatening blast lung treated with rFVIIa [47]. This indication for rFVIIa remains controversial and off-licence, more studies are required to prove its efficacy in this situation.

Conclusion

Thoracic injuries and especially those sustained in the military setting, present a major challenge to the surgeon, anaesthetist and intensivist. To compound this challenge, the initial management of these wounds in the deployed military setting will usually be carried out by non-thoracic surgeons and anaesthetists in an austere environment.

The essentials for dealing with these injuries are:

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

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