Thoracic Trauma

A. B. (Sebastian) van As, Haiko K. Jahn, and Benedict C. Nwomeh

Contents

E.A. Ameh et al. (eds.), *Pediatric Surgery*, https://doi.org/10.1007/978-3-030-41724-6_28

28.1 Introduction

Chest injuries occur commonly in children and include damage to the chest wall, lungs, mediastinal structures and diaphragm. They can be classified by mechanism, anatomical site and severity (immediately or potentially life-threatening). Due to the difference in physiological constitution of children and adults, pediatric chest trauma has features that are specific and unique to children compared to adults [1–3].

Approximately one million children die annually as a result of trauma globally. The vast majority of thoracic injuries result from blunt trauma, usually inflicted to a child pedestrian by a motor vehicle. Less than 5% are attributable to penetrating injuries [4–7].

Penetrating chest trauma in children, as in adults, is often the result of knife, other sharp objects and gunshot wounds. These include BBs or pellets fired from recreational air guns that can produce life-threatening injuries. Other unusual causes of penetrating trauma seen in children 12 years old or younger include impalement onto shards of broken glass or metal rods [7].

The severity of chest trauma in children ranges from minor to rapidly fatal. In children because of their smaller size, thorax injuries are often associated with head and abdominal injuries. It is these associated injuries that expose these children to a high mortality. It is therefore crucial to assess the whole patient in the case of a chest injury and to promptly diagnose and appropriately treat these injuries to ensure an optimal outcome. The association of chest and head injuries is the leading cause of childhood trauma death [8]. Therefore pediatric trauma scores may help to identify patients most at risk of death early in this patient population and facilitate and expedite treatment [9].

28.2 Anatomic Considerations

The chest wall in children is thinner and extremely compliant compared to adults because of greater cartilage content and incomplete ossification of the ribs. This makes rib fractures rare and allowing substantial energy transmission to underlying intrathoracic and abdominal organs without necessarily breaking the protective cage ribs. Children's thoracic volume is smaller and the arrangement of vital structures is more compact than in adults. This results in unusual injuries such as traumatic asphyxia and *commotio cordis*. Severe injury, e.g. pulmonary contusion or injuries to intra-abdominal organs (liver and spleen), can occur in the absence of overlying rib fractures. Whilst rib fractures and mediastinal injuries are distinctly uncommon in children, their presence usually indicates the transfer of a massive amount of energy, and multiple serious organ injuries should be suspected. The mediastinum is highly mobile in children, allowing for visceral shift, and a tension pneumothorax can develop rapidly [10–13].

28.3 Clinical Presentations

28.3.1 Initial Approach and Resuscitation

Initial assessment and resuscitations should strictly follow the principals of Basic and Advanced Trauma Life Support pattern, as discussed in ► Chap. 27 [11–13].

The presence of chest injury often portends involvement of other organs, reflecting the transmission of substantial force to the child's compact body [6]. The underlying thoracic injuries are often disproportionately severe compared with the visible surface injury. Therefore it is important to have an understanding of the mechanism of injury. Photography from the scene by pre-hospital personnel can predict injury pattern and guide detailed assessment of suspected injuries.

Signs and symptoms associated with blunt chest injuries include chest crepitation, subcutaneous emphysema, nasal flaring, chest retractions, diminished or absent breath sounds, tachypnoea, dyspnoea and low oxygen saturation.

Physical examination is highly unreliable; therefore, one should have a high index of suspicion for underlying injuries [14–16].

At the same time, concomitant extrathoracic injuries may obscure the presence of serious chest injuries. Intrathoracic injuries such as pulmonary contusions, great vessel injuries, oesophageal perforation, thoracic duct rupture leading to chylothorax and diaphragmatic ruptures may not present with immediate symptoms making prompt diagnosis difficult.

Thoracic injuries, also known as the deadly dozen can be classified into six lethal (life-threatening) injuries that need excluding in the primary survey and six hidden (potentially life-threatening) injuries that must be considered in the secondary survey and non-life-threatening injuries [14, 15].

Classification of thoracic injuries according to their risk to life [14, 15, 17].

Life-threatening	Potentially life-threatening	Non-life-threatening
Airway obstruction	Pulmonary contusion	Rib fractures
Tension pneumothorax	Diaphragmatic rupture	Simple pneumothorax
Open pneumothorax	Myocardial contusion	Simple haemothorax
Massive haemothorax	Oesophageal rupture	Chest wall contusion
Flail chest	Tracheobronchial injuries	
Cardiac tamponade	Great vessel injuries (thoracic aortic disruption)	

The aim of the primary survey with regard to is to identify and treat the six life-threatening thoracic injuries and the six potential life-threatening injuries during the secondary survey as outlined in ► Chap. 27.

Consideration during initial assessment should also be given to children who may benefit from *resuscitative thoracotomy*; however this is generally futile.

This is also reflected in two case series from the United States. Survival rate in a 40-year review of emergency department thoracotomy in children under the age of 15 years in a single centre was 3.4% [18]. In another case series, survival rate was 10.2% for penetrating chest trauma and 1.6% in arrest due to blunt chest trauma, with no survivors under the age 14 years with blunt chest trauma [19]. However, even when myocardial function is restored, survival ultimately requires additional operative procedures and intensive care, which are generally not available in resource-poor settings.

Therefore resuscitative thoracotomy is only indicated for penetrating trauma with signs of life within 10–15 minutes of arrival to find the correctable surgical cause of the arrest.

In summary full traumatic cardiac arrest is uncommon in children and is mostly due to blunt chest trauma. Blunt chest trauma in children with no signs of life is generally unsalvageable. In these cases, consideration should be given to halt resuscitative efforts because of their futility [4, 7, 11, 12, 18–20].

Children with physical findings suggestive of chest injury or who have sustained a high-energy deceleration mechanism of trauma require chest imaging.

A portable anteroposterior (AP) chest radiograph remains the most common first radiograph obtained in most trauma patients, although STATSCAN (Lodox Systems, Sandton, South Africa), a low-radiation dose, fan-beam digital radiography unit, is an alternative in the assessment of polytrauma. Standard anterior-posterior (AP) chest radiographs provide a low-cost screening tool and will be abnormal in 60–90% of children with significant injuries. It is important to have a systematic approach to trauma chest radiograph to detect injuries [11, 21].

Systematic initial review of chest radiograph [11]

1. Overview
2. Trachea and bronchi
3. Pleural spaces and lung parenchyma
4. Mediastinum
5. Diaphragm
6. Bony thorax
7. Soft tissues
8. Tubes and lines

However, not all thoracic injuries can be detected on plain radiography, and computed tomography (CT) of the chest may aid diagnosis where available. CT scan should be the standard imaging choice in penetrating chest trauma. In pediatric patients that are conscious and have normal vital signs and a normal chest radiograph, a CT scan of the chest is unlikely to change management [14, 15, 22–24].

Abdominal CT scans include sections of the lower thorax, which may also be of value in the diagnosis of intrathoracic injury, e.g. pneumothorax, pulmonary contusions, haemothorax, etc. [25]

Children rely on the diaphragm for ventilation because of their more compliant ribs and weak intercostal muscles. In the setting of trauma (even without abdominal injury), the majority of children hyperventilate and swallow air (aerophagia) leading to gastric distension. This results in elevation and splinting of the diaphragm leading to severe compromise of vital capacity and resulting in respiratory distress. Therefore, gastric decompression with a nasogastric or orogastric tube in the presence of head trauma is key to ensure adequate ventilation.

Most pediatric chest trauma can be managed with a tube thoracostomy (traditional thoracostomy tube size = 4 × endotracheal tube size) and supportive measures alone [14, 15] (◘ Table 28.1).

◘ **Table 28.1** Chest drain tube size by age-based guidelines [11–13, 26]

Age	Chest drain size (French gauge)
0–12 months	12–16
1–5 years	16–20
5–10 years	20–24
10–15 years	24–28

28.3.2 Airway Obstruction and Injuries

Children's airways are small. They have narrow nasal passages, large tongues and enlarged adenoids. As flow is inversely proportional to fourth power of the radius, even small changes in airway diameter can lead to rapid respiratory compromise. Due to their higher metabolic rate, they have a higher oxygen demand per kilogram of body weight.

Smoke inhalation and oropharyngeal trauma can lead to insidious soft tissue swelling and airway obstruction. Therefore, it is vital to closely monitor the child for deterioration and to consider securing the airway (intubation) early before the airway deteriorates.

Obstruction and surgical emphysema are the two hallmarks of airway obstruction. Inspiratory stridor would generally suggest an airway injury above or at the level of the vocal cords either due to foreign body inhalation or oropharyngeal trauma, whilst expiratory stridor is suggestive of trauma or foreign body obstruction below the vocal cords. Causes include blood, vomitus, mucous and aspirated foreign bodies, for example, teeth from a mouth injury. Signs of airway obstruction include agitation, sweating, chest wall retractions, asymmetrical breathing and cyanosis. This is a clinical diagnosis which requires urgent treatment. Management of airway obstruction follows standard resuscitation guidelines for obtaining and securing a patent airway (see also Difficult Airway Society ► www.das.uk.com) [11–13].

28.3.3 Chest Wall Injuries

The elasticity and flexibility of a child's chest cage often protect the child from a serious injury. If rib fractures do occur, however, this is usually a sign of a major energy transfer to the child's chest and often indicative of a high-velocity injury. The increased compliance of children's ribs allows the ribs to bend without fracturing. Rib fractures are usually a sign of a major energy transfer to the child's chest. In children under 3 years of age, it is estimated that 39–82% of rib fractures are the result of non-accidental injury. In the same age group, the positive predictive value of rib fractures for non-accidental injury is 95% and rises to 100% when other causes such as motor vehicle causes or predisposing medical conditions can be excluded [9, 27].

A flail segment is an unusual event in a child, and the underlying pulmonary contusion is much more important for the prognosis than the flail segment itself.

Anatomical position of rib fractures can predict potential underlying injuries. The commonest sites of rib fractures are posterolaterally from the 4th to the 10th rib. Greater force is required to fracture the upper four ribs as they are protected by the bony shoulder girdle, with the potential to injury the trachea, main stem bronchi and great vessels. Equally a greater force is needed to fracture the lowest three ribs as they are not attached to the sternum and may injure the underlying organs (liver, spleen or kidneys) [16].

In the setting of chest trauma, fractures of the clavicle, the first rib and the scapula raise the possibility of major intrathoracic and vascular injuries due to greater transmitted force and their anatomical relation to the great vessels [14, 15].

Rib fractures are extremely painful because immobilization is practically impossible. Therefore, adequate analgesia is of utmost importance to render the child pain-free and to ensure adequate breathing. Inefficient ventilation is much more serious with rib fractures of the lateral and posterior chest wall since they interfere more significantly with diaphragmatic movement, an essential part in pediatric respiration. It is important to pay attention to the underlying lung contusion that can easily be overlooked in the early stages of chest imaging.

Intravenous morphine is the drug of choice (as bolus, 0.1 mg/kg body weight). This should be titrated to effect. Patient-controlled analgesia (*PCA*) if available is a great way to keep the patient comfortable.

An alternative initially is intranasal diamorphine (0.1 mg/kg made up to maximal volume of 2 ml) or fentanyl in the absence of intravenous or intraosseous access. Oral analgesia is not often well tolerated, and intramuscular (IM) or subcutaneous drugs are often poorly absorbed and should be avoided. This ensures adequate breathing and prevents complications such as atelectasis and pneumonia, secondary to the inability to cough. Respiratory exercises are essential part of ongoing management. In cases of multiple rib fractures, admission to a specialized trauma unit with the availability of continuous chest physiotherapy is preferred.

28.3.4 Traumatic Asphyxia

Traumatic asphyxia is also known as Perthes' syndrome. In the presence of a closed glottis, the sudden increase from the air trapped in the chest results in increased intrathoracic pressure, i.e. a Valsalva manoeuver. This causes venous back-flow through the right heart, the superior vena cava to the neck, head and brain, with subsequent rupture of the superficial blood vessels. Usually, the child presents tachypnoeic with petechiae over the face including the conjunctivae, neck and chest. The face might be cyanosed and swollen with jugular venous distension, and retinoscopy might reveal retinal haemorrhages.

Because of the massive compressive force to the chest needed to cause traumatic asphyxia, the affected child should be carefully examined for any underlying and concomitant chest and abdominal injuries. Treatment is supportive. As these children are likely to develop respiratory insufficiency, they should be managed in a pediatric intensive care unit (PICU). Long-term follow-up of isolated traumatic asphyxia has proved to have an excellent prognosis [28–30].

28.3.5 Tracheobronchial Injuries

Tracheobronchial injuries are rare and usually occur at fixed points of the tracheobronchial tree such as the carina or segmental branches of the bronchus. Rupture of the trachea or bronchus is usually complete and associated with vascular and oesophageal injuries. This commonly occurs within 2.5 cm from the carina. Proper airway management takes priority; the injuries can usually be repaired primarily via a thoracotomy. In injuries that involve less than a third of the airway circumference can be considered for non-operative management, especially short longitudinal tears of a single airway. However, this should not be attempted in the case of ventilation difficulty and massive air leak. The approach to the cervical trachea is via a transverse neck incision. Injury to the distal trachea or right main stem bronchus is via a right thoracotomy, whilst localized injury to the left main stem bronchus is approached via the left chest. The repair should be reinforced with a vascularized tissue flap of pleura, pericardium or muscle. This is especially important in tracheo-oesophageal injury to prevent fistula formation.

28.3.6 Pulmonary Injuries

Blunt pulmonary parenchymal injuries include pulmonary contusions, traumatic pneumatoceles and pulmonary lacerations. The pliable thorax in children allows the transmission of energy through the chest wall to the underlying parenchyma. Nearly one half of children with pulmonary injury have no evidence of external chest wall trauma [4, 14, 15, 31, 32].

28.3.7 Lung Contusions

Lung contusion is one of the most common childhood chest injuries, followed by infection and haematoma. It occurs in approximately two-thirds of all cases of chest trauma. Usually, it results from a rapid acceleration/deceleration injury (primarily motor vehicle collisions). Contusions occur within minutes after the injury, are mostly localized to a (lower) segment or lobe of the lung and can be diagnosed on the initial chest radiograph. Typical findings are multiple opacifications corresponding to the sites of intraparenchymal haemorrhage. CT does not usually aid management [33]; however, the contusions might be visible on the chest slices of the abdominal CT as usually the lower segments are affected. Hypoxia results from shunting and ventilation perfusion mismatch.

Management is symptomatic, but intensive care is often required in the initial phase, where there is danger of respiratory collapse and ventilation might be indicated for adequate oxygenation. The prognosis is good if infection does not occur; healing can be expected within 1–2 weeks.

Serious complications associated with lung contusion include pneumonia (20%), acute respiratory distress syndrome (ARDS, 5–20%) and death (15–20%) and are similar in all age groups. Post-traumatic pseudocysts are another complication.

The risk of acute respiratory distress syndrome is high in the first 24 hours and low after 72 hours. Unfortunately, infection occurs due to the extravasation of fluid and blood in the interstitium and alveoli, which creates an excellent microbial culture medium. Ventilation efforts are often poor due to pain, and without active and passive chest physiotherapy, the prognosis is poor [31, 32].

Pulmonary haematoma is rare. It is usually caused by an injury to a major blood vessel within the lung, creating a so-called coin-lesion in the lung tissue. Management is non-operatively, except in massive bleeds.

28.3.8 Simple Pneumothorax

Pneumothorax is a common occurrence in childhood chest injury. Collapse of the lung might be caused by a penetrating injury, a rupture of lung parenchyma or a tear in the oesophagus or tracheobronchial tree.

Physical signs are diminished breath sounds, poor motion of the haemithorax, hyperresonance to percussion, subcutaneous emphysema and deviation of the trachea to the ipsilateral site. Diagnosis is confirmed with an erect expiratory chest radiograph.

Treatment consists of a tube thoracostomy in the 4th intercostal space, in the triangle of safety (anterior to mid-axillary line, posterior to pectoral groove, above the fifth intercostal space), under adequate analgesia. Care should be taken not to cause injury to the lung parenchyma or diaphragm during the insertion of the tube. An underwater seal should be connected immediately to the drain following insertion. In the asymptomatic child with a pneumothorax, management options may also include aspiration or observation alone; however, the resources to rapidly insert a chest tube must be available in the event of any deterioration [11–13].

28.3.9 Tension Pneumothorax

Progressive accumulation of air under pressure in the pleural space is usually due to a valve-effect tear in the lung parenchyma. It may lead to ipsilateral collapse of the lung and mediastinal shift, thereby compressing the (only properly ventilating) contralateral lung. This might result in severe impairment of ventilation as well as compromise the venous return to the heart and is often a lethal condition if not acted upon rapidly.

Diagnosis should be made clinically. Decreased breath sounds, a hyperinflated ipsilateral haemithorax, tracheal deviation to the contralateral side and a severely distressed patient all indicate that rapid needle decompression of the anterior chest (second intercostal space, midclavicular line) will be life-saving. The needle has to be replaced by a proper tube thoracostomy as soon as possible because blockage occurs frequently, and the excursions of an inflated lung will damage its visceral pleural surface against the sharp tip of the needle [11–13].

Box 28.1: Performing a Needle Thoracocentesis

- ***Needle Thoracocentesis* [11–13]**

This procedure can be life-saving and has to be performed quickly with minimum equipment. It should be followed by chest drain placement.

Minimum equipment

- Alcohol swabs
- Large over-the-needle intravenous cannula (gauge 16 or larger)
- 20 ml syringe

Procedure

1. Identify the second intercostal space in the midclavicular line on the side of the pneumothorax.
2. Swab the chest wall with surgical preparation solution or an alcohol swab.
3. Attach the syringe to the cannula. Fluid in the cannula will assist in the identification of air bubbles.
4. Insert the cannula vertically into the chest wall, just above the rib below, aspirating all the time.
5. If air is aspirated, remove the needle, leaving the plastic cannula in place.
6. Tape the cannula in place and proceed to chest drain insertion as soon as possible.

If needle thoracocentesis is attempted, and the patient does not have a tension pneumothorax, the risk of causing a pneumothorax is 10–20%. Patients who have had this procedure must have a chest radiograph and will require chest drainage if ventilated.

28.3.10 Haemothorax

Haemothorax is the accumulation of blood in the pleural space. Up to 40% of the blood volume can easily be lost in one pleural cavity. The blood loss usually arises from injury to a major artery, either from the chest wall or the lung, although this is not always the case. Persistent bleeding from an intercostal artery or a tear in the lung parenchyma can also produce major blood loss.

The diagnosis is made clinically and confirmed with an erect chest radiograph. Blood in the lower part of the pleural cavity often causes referred pain in the upper abdomen. Once the haemothorax is drained, the abdominal symptoms disappear.

Treatment consists of wide bore tube thoracostomy to drain the haemothorax; a thoracotomy is rarely indicated. When diagnosed blood should be promptly evacuated from the pleural space with tube thoracostomy, since:

1. Blood left in the pleural space can produce fibrous scar tissue, causing restrictive lung disease.
2. Blood acts as a perfect culture media promoting sepsis and pneumonia. (Empyema)
3. Drainage allows accurate measurements of the blood loss for replacement determining further treatment.

Intrathoracic blood should be evacuated within 1 week of injury by either thoracotomy or thoracoscopy. The indication for open thoracotomy is ongoing, and active bleeding with an intercostal drain is in place. This should be considered if the initial blood loss is greater than 15 ml/kg, or there is continued drainage of more than 2–3mls/kg/hr of blood for 3 hours. The inability to drain the chest adequately or re-expand the lung is an additional criterion for open thoracotomy. Video-assisted thoracic surgery (VATS) if available is a helpful diagnostic tool in the haemodynamically stable patient with a large initial drainage or continuing blood loss.

It allows visualization of a nonbleeding injury, evacuation of a haematoma, tamponade by fully expanding the lung or cauterization or ligating of a bleeding vessel avoiding open thoracotomy.

VATS or open thoracotomy is also used to drain the empyema from infected haemothorax and remove any organizing peel from the lung, which usually occurs 5–7 days after injury [34].

On rare occasions, a massive haemothorax may lead to a tension haemothorax with deviation of the heart and mediastinum to the opposite side (◘ Fig. 28.1) [11–13].

Box 28.2: Inserting a Chest Drain

- ***Chest Drain Placement*** [11–13]

Chest drain placement should be performed using the open technique described here. This minimizes lung damage. In general, the largest size drain that will pass between the ribs should be used.

Minimum equipment

- Skin preparation and surgical drapes
- Scalpel
- Large clamps • 2
- Suture
- (Local anaesthetic)
- Scissors
- Chest drain tube

Procedure

1. Decide on the insertion site (usually the fifth intercostal space in the mid-axillary line) on the side with the pneumothorax (▶ Fig. 22.2).
2. Swab the chest wall with surgical preparation or an alcohol swab.
3. Use local anaesthetic if necessary.
4. Make a 2–3 cm skin incision along the line of the intercostal space, just above the rib below.
5. Bluntly dissect through the subcutaneous tissues just over the top of the rib below, and puncture the parietal pleura with the tip of the clamp.
6. Put a gloved finger into the incision and clear the path into the pleura (▶ Fig. 22.3). This will not be possible in small children.
7. Advance the chest drain tube into the pleural space during expiration.
8. Ensure the tube is in the pleural space by listening for air movement and by looking for fogging of the tube during expiration.
9. Connect the chest drain tube to an underwater seal.
10. Suture the drain in place, and secure with tape.
11. Obtain a chest radiograph.

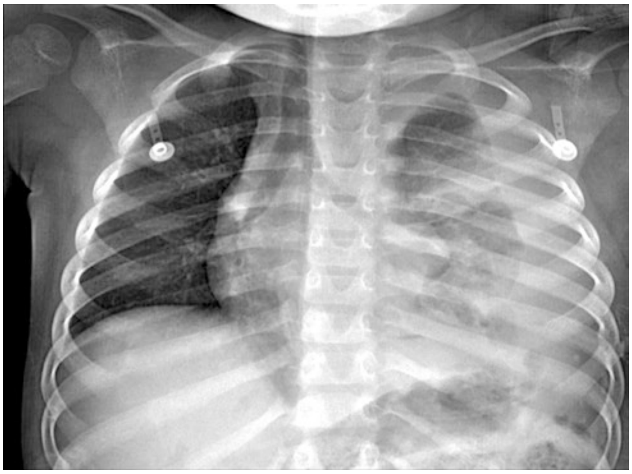

Fig. 28.1 Chest radiograph of a left side tension pneumothorax with displacement of heart and mediastinum to the right. This is a clinical diagnosis and requires immediate decompression

28.3.11 Pneumomediastinum

In blunt chest injury in children, pneumomediastinum is a sign of potential injury to the tracheobronchial tree or oesophagus or vascular injury. It gives a streaky appearance on the radiograph, and it often extends beyond the pleural space into the neck or the abdomen. Pneumomediastinum in the absence of radiographic or clinical evidence of other thoracic injuries does not routinely require further investigations and resolves with no intervention [11–13, 31, 32].

28.3.12 Oesophageal Injuries

Fortunately, due to the location of the oesophagus, injuries to it are rare. Transmitted pressure from the stomach may cause either Mallory-Weiss bleeding (if the lower oesophageal sphincter is closed) or the more sinister Boerhaave syndrome, characterized by perforation of the lower oesophagus into the left chest cavity (if the upper oesophageal sphincter is closed).

Penetrating injuries may cause oesophageal injuries if they are *transthoracic*. Radiographic contrast studies and/or endoscopies are strongly advocated in these cases. A non-ionic contrast material should be used.

The management of the oesophageal injuries depends on the nature of the injury, the timing of presentation and the location. With the exception of major (high-velocity) gunshot injuries, the majority can be repaired primarily within 24 hours of the injury. Beyond the first 24 hours, the operative strategy may include oesophageal diversion, exclusion, T-tube drainage or even total oesophagectomy.

28

28.3.12.1 Cervical Oesophageal Injuries

Cervical oesophageal injuries rarely represent a large problem because leakage from a repair produces localized tissue infection or abscess, which can be drained externally.

28.3.12.2 Thoracic Oesophageal Injuries

Thoracic oesophageal injuries are notorious for the fast spread of saliva, food and acid from the stomach through the injury into the chest, able to cause a rampant and usual lethal mediastinitis. Oesophageal diversion might be indicated in these cases.

28.3.12.3 Abdominal Oesophageal Injuries

Abdominal oesophageal injuries will usually present as an acute abdomen and will require a laparotomy for repair.

28.3.13 Diaphragmatic Injuries

Traumatic disruption of the diaphragm is usually caused by blunt trauma. It involves the left side in the majority of cases. The injury is high velocity in nature, such as from motor vehicle collisions and falls from a height. Because the force required to damage the diaphragm is considerable, associated injuries are common (about 80%) and include intrathoracic, intra-abdominal as well as extratruncal injuries.

The clinical presentation varies according to the associated injuries; an isolated diaphragmatic rupture can easily be misdiagnosed. In children, the mechanism of injury might be slightly different from that in adults. Whereas in adults the typical injury involves the dome of the diaphragm (as a blow-out), in children rupture seems to take place more often along the periphery of the diaphragm (probably due to the increased elasticity of the chest wall).

Diagnosis is made on an erect radiograph, which typically shows the nasogastric tube in the stomach above the diaphragm (Fig. 28.2). However, herniation can involve nearly any intra-abdominal organ, and the appearance of the stomach below the diaphragm does not exclude a diaphragmatic rupture.

Penetrating injuries in the lower half of the chest as well as the upper part of the abdomen can involve the diaphragm. In these cases, herniation will rarely occur in the acute phase, but an undiagnosed hole in the diaphragm can lead to complications on the long term. Repair should be performed via a laparotomy, during which the state of the intra-abdominal organs also can be assessed.

Fig. 28.2 Chest radiograph of a ruptured left haemidiaphragm, with displacement of the heart and mediastinum to the right

28.3.14 Widened Mediastinum and Great Vessel Injuries

Blunt injuries to the thoracic aorta and great vessels are rare in children but are lethal if missed, as the mediastinum in children is more flexible and mobile.

The majority of blunt aortic injuries die at the scene of the injury or during transport. About a third of those who reach hospital die within 6 hours making expedient evaluation mandatory. The abdominal aorta rather than the thoracic aorta is more commonly involved in restrained as compared to unrestrained children. The typical location of the injury is at the aortic isthmus distal to the left subclavian artery at the ligamentum arteriosum.

Clinical findings suggestive of aortic injury include first rib and sternal fractures, paraplegia, upper extremity hypertension and/or lower extremity pulse deficits.

Signs suggestive of mediastinal pathology on initial chest radiograph include straightening of the mediastinal borders, with loss of the anteroposterior (AP) window, mediastinal diameter greater than that of the haemithorax and right shift of an oro- or nasogastric tube off the vertebral column. Radiographic signs that would lead on to suspect disruption of the aorta are a widened mediastinum, left pleural effusion, apical capping and depression of the left main bronchus [35].

CT scan when available greatly aids diagnosis. In the stable child, aortography is the diagnostic procedure of choice.

Operative repair remains the standard therapy with aggressive preoperative blood pressure control with beta-blockers to reduce shear on the aortic wall in order to decrease the risk of free rupture. In children with minimal aortic injuries (small intimal flaps) or in situations, in which the child has a limited life expectancy due to other injuries, non-operative management has been used.

Other great vessel injuries (pulmonary vessels, superior and inferior vena cava, proximal carotid, subclavian, innominate arteries) are extremely rare [14, 15, 26, 36].

Surgical Strategies for Heart and Great Vessel Injury [36]:

Cardiac tamponade: left anterior or anterolateral thoracotomy (fifth intercostal space)
Heart, great vessels or pulmonary hilum: median sternotomy and extension into the neck
Descending thoracic aorta: left posterolateral thoracotomy (fourth and fifth intercostal spaces)
Ascending aorta: median sternotomy (cardiopulmonary bypass is usually required to repair a blunt injury; penetrating injuries can be repaired without bypass)
Aortic arch: median sternotomy with extension into the neck for great vessel exposure
Innominate artery: median sternotomy with right cervical extension if necessary
Subclavian artery: cervical extension of median sternotomy for right subclavian artery injury or a supraclavicular approach for left subclavian artery injury (proximal control of either vessel is best via an anterolateral thoracotomy above the nipple)
Carotid artery injury: right cervical incision for right carotid artery injury or, as in innominate artery injury, median sternotomy with left cervical extension for left carotid artery injury
Pulmonary artery: respective side thoracotomy for hilar control

28.3.15 Heart and Pericardium

Blunt chest trauma can produce several types of cardiac injuries including contusions; concussions; frank rupture of the myocardium, a valve and a septum; and – very rarely – laceration and thrombosis of a coronary artery. Pericardial tears leading to herniation of the heart often lead to diminished cardiac function and a low-output state. Occult structural cardiac injuries (i.e. atrial or ventricular septal defects, valvular insufficiency and ventricular aneurysm formation) may also occur and present without physiologic signs of injury. Often, these injuries are identified only after a new murmur is noted or a change in the electrocardiogram (ECG) occurs. Echocardiography, where available, can assist to confirm the diagnosis. The same is the case with cardiac catheterization in suspected coronary vessel injury.

28.3.15.1 Myocardial Contusion

The most common type of blunt cardiac injury is the myocardial contusion. Unlike myocardial concussions, myocardial contusions produce focal damage to the heart that can be demonstrated histologically. Patients with myocardial contusions often have an associated chest wall injury. Many diagnostic tests have been proposed to diagnose a contusion (e.g. echocardiography, electrocardiography, enzyme determinations and nuclear imaging), but still no definitive diagnostic test exists. A 12-lead ECG is the simplest test and may show reversible changes in the ST and T waves. Symptomatic myocardial contusions are diagnosed by echocardiography based on finding a reduced ejection fraction, localized systolic wall motion abnormalities and an area of increased end-diastolic wall thickness and echogenicity.

Myocardial contusions may be silent and asymptomatic, can present with cardiovascular collapse from reduced cardiac output or cause arrhythmias that may be life-threatening.

The treatment of myocardial contusions remains supportive, with 12- to 24-hour electrocardiographic monitoring and inotropic support as needed. Most authors recommend cardiac monitoring in an intensive care unit to identify arrhythmias. Patients with arrhythmias and obvious thoracic injuries should be monitored with ECG, serum cardiac enzymes and echocardiogram as needed.

28.3.15.2 Myocardial Rupture and Valve Injury

Traumatic rupture of any chamber of the heart usually results in rapid death. The most common cause of death from thoracic injury is myocardial rupture. The majority of these are due to high-energy impacts such as motor vehicle collisions or falls from great heights. The majority of these patients die at the scene. The right ventricle is the most commonly ruptured cardiac chamber. Children with myocardial rupture present in extremis with pericardial tamponade. Patients with traumatic atrial or ventricular septal defects may be clinically stable, with the only finding being that of a new murmur. Early diagnosis and repair is mandatory for survival from these lethal injuries.

Valvular injuries may occur following severe blunt chest trauma, but these are rare. The atrioventricular valves are most susceptible to injury, and the damage often occurs to the valve apparatus (i.e. annulus, ruptured chordae tendineae or papillary muscle). These injuries in clinically stable patients may be repaired electively.

28.3.16 Penetrating Cardiac Injuries

Generally penetrating injuries to the heart result in either leakage of blood in the pleural space causing haemothorax, generally with haemorrhagic shock or persistent bleeding from the chest drain.

The second pathology is due to the accumulation of blood in the pericardial space causing cardiac tamponade. Often the pressure in the pericardial space causes occlusion of the wound preventing frank exsanguination.

Whilst any of the four chambers of the heart can be involved, penetrating trauma usually involves the right ventricle as it is the most anterior. Haemopericardium on echocardiography requires urgent sternotomy or thoracotomy for repair of cardiac injury. Sternotomy is preferred as it allows access to all four chambers of the heart. Repair is with non-absorbable sutures with atraumatic needles and pledgets. This is to prevent sutures from pulling through the myocardium [35].

Rupture of the pericardium can occur in the absence of cardiac injury.

28.3.16.1 Pericardial Tamponade

The accumulation of blood within the pericardial sac from blunt or penetrating trauma can produce pericardial tamponade. Although a range of clinical signs may be seen, the most common presentations are tachycardia, peripheral vasoconstriction, Beck's triad of jugular venous distention, persistent hypotension unresponsive to aggressive fluid resuscitation and muffled heart sounds. In resource-poor environments, tools needed to establish an accurate diagnosis, such as an ECG or focused abdominal sonography for trauma (FAST), often are not available. Although pericardiocentesis can be life-saving, it should not be done by those without the proper training and skill [11–13].

Box 28.3: Performing Pericardiocentesis

- ***Pericardiocentesis* [11–13]**

The removal of a small amount of fluid from the pericardial sac can be life-saving. The procedure is not without risks and the ECG should be closely monitored throughout. An acute injury pattern (ST segment changes or a widened QRS) indicates ventricular damage by the needle.

Minimum equipment

- ECG monitor
- Local anaesthetic
- 20 ml syringe
- Skin preparation and surgical drapes
- 6-inch over-the-needle cannula (gauge 16 or 18)

Procedure

1. Swab the xiphoid and subxiphoid areas with surgical preparation or an alcohol swab.
2. Use local anaesthetic if necessary.
3. Assess the patient for any significant mediastinal shift if possible.
4. Attach the syringe to the needle.
5. Puncture the skin 1–2 cm inferior to the left side of the xiphoid junction at a 45° angle.
6. Advance the needle towards the tip of the left scapula, aspirating all the time.
7. Watch the ECG monitor for signs of myocardial injury.
8. Once fluid is withdrawn, aspirate as much as possible (unless it is possible to withdraw limitless amounts of blood, in which case a ventricle has probably been entered).
9. If the procedure is successful, remove the needle, leaving the cannula in the pericardial sac. Secure in place and seal with a three-way tap. This allows later repeat aspirations should tamponade recur.

28.3.16.2 Commotio Cordis

This is caused by the induction of arrhythmias through a moderate precordial impact. The four influencing factors for the development of commotio cordis are the type, the location, the force of the impact with regard to the heart and the timing of the impact in relation to cardiac cycle. Children and young adults are especially susceptible due to their pliable chest walls.

The typical scenario is of a child or young fit adult collapsing following sustaining a blow to the chest during a sporting event.

Management is immediate defibrillation and advanced life support. Increased awareness of the condition and availability of automatic external defibrillators in the community should improve outcomes [12, 13].

28.4 Pitfalls in the Management of Pediatric Thoracic Trauma

Several pitfalls exist in the management of pediatric thoracic trauma, as outlined here.

- Underestimating the degree of chest injury at the initial survey because of little external evidence and performing only a supine chest radiograph.
- Administration of excess intravenous fluid during resuscitation, aggravating pulmonary contusion and oedema. (Major haemorrhage protocols should be used to manage ongoing bleeding.)
- Inadequate analgesia and inadequate chest physiotherapy promoting the retention of secretions, which lead to pulmonary infection.

- Iatrogenic damage through emergency (and faulty) procedures during endotracheal intubation, chest drain insertion and central line insertion.

28.5 Conclusion

Thoracic trauma is the second most common cause of trauma mortality in children. It generally occurs as part of multisystem trauma in the pediatric population with increasing frequency owing to high-speed travel and violence. In multisystem trauma, chest trauma usually is a marker of increased injury severity and resulting in increased mortality. Most of the chest trauma can be managed conservatively or by tube thoracotomy. Early diagnosis and management is key to improve outcome [16].

28.6 Prevention of Thoracic Trauma

The top three causes of child mortality from unintentional injury are road traffic collisions (32%), drowning (17%) and burns (9%) [5]. All of these causes are highly preventable [2].

Factors that influence injuries are supervision, particularly of small children, single caregiver, home with multiple siblings and substance abuse either by the caregiver or within the larger family.

Risk factors for child abuse include the demographic characteristics of the child (e.g. younger age), caregiver characteristics (e.g. prior history of abuse), family structure and resources and community factors (e.g. increased poverty, decreased social capital).

Although these risk factors are located within particular households, the wider context in which they operate cannot be ignored. Child safety is ultimately a matter of concern for society at large. Studies have demonstrated the feasibility of interventions to reduce child mortality and morbidity from unintentional injury [6, 9]. Any child protection concerns must be reported in line with local guidelines and protocols.

It is the responsibility of anyone involved in the care of children to be an advocate for children's safety and injury prevention.

28.7 Evidence-Based Research (Table 28.2)

Table 28.2 Evidence-based research

Title	Treatment of Thoracic Trauma in Children: Literature Review, Red Cross War Memorial Children's Hospital Data Analysis, and Guidelines for Management [16]
Author	van As AB, Manganyi B, Brooks A
Institution	Department of Pediatric Surgery, University of Cape Town, Red Cross Children's Hospital, Rondebosch, Cape Town, Western Cape, South Africa
Reference	Eur J Pediatr Surg 2013;23:434–443
Problem	Incidence, aetiology and management of thoracic trauma in the pediatric population with reference to the recent experience at our institution in a developing country
Methods	Retrospective review of children with thoracic injury presenting to the institution and literature review
Outcomes	378 pediatric patients under the age of 13 with thoracic injury were treated from 2008 to 2012 (a 5-year period). Blunt chest trauma was the main cause in 90.5% and penetrating trauma in 9.5% of the injuries The majority was due to road traffic accidents 74% presented with injuries of the thoracic cage; rib fractures occurred in 13%, chest wall contusions in 40% and abrasions in 31% Respiratory system injuries occurred in 22%, haemothoraces in 23%, pneumothoraces in 45% and haemopneumothoraces in 29%. Management was non-operative in 79.4%, tube thoracotomy in 17.2% and open surgery in 3.4%. The mortality rate was 1.3%, all a result of firearm-related injuries and polytrauma
Comments	The majority of cases were managed non-operatively with tube thoracotomy Road traffic accidents were the main cause

Key Summary Points

1. The majority of thoracic injuries can be diagnosed by a good clinical exam and plain chest x-ray.
2. The majority of chest trauma in children can be treated non-operatively, often with a well-placed chest tube.
3. Life-threatening injuries from thoracic trauma are relatively uncommon in children, and when they occur, they are related to associated head and abdominal injuries.
4. Optimum treatment and outcomes can be achieved only by having a thorough understanding of the unique anatomy and physiology of children.
5. Even the most severe of injuries requiring operative therapy can, if recognized early, be managed successfully.

References

1. Buntain WL, Buntain WL. Management of pediatric trauma. Philadelphia: W.B. Saunders Company; 1995. p. 788.
2. Eichelberger M, Eichelberger M. Pediatric trauma. Beijing: Pmph Bc Decker; 1993. p. 708.
3. Mayer TA, Mayer TA. Emergency management of pediatric trauma. Philadelphia: W.B. Saunders Company; 1985. p. 552.
4. Abdessalam SF, Keller A, Groner J, Kable R, Krishnaswami S. An analysis of children receiving cardiopulmonary resuscitation (CPR) following cardiac arrest with blunt trauma. J Am Coll Surg. 2004;199(3):53.
5. Peden M, Oyebite K, Ozanne-Smith J, Hyder AA, Branche C, Rahman FA, et al. World report on child injury prevention. World Health Organisation, Geneva, 2008.
6. Peden M, Hyder AA. Time to keep African kids safer. S Afr Med J Suid-Afrikaanse tydskrif vir geneeskunde. 2009;99(1):36–7.
7. Coley E, Roach P, Macmillan AI, West AT, Johnston AM. Penetrating pediatric thoracic injury. J R Army Med Corps. 2011;157(3):243–5.
8. Cooper A. Thoracic injuries. Semin Pediatr Surg. 1995;4(2):109–15.
9. Naidoo S, As SV. Pediatric trauma and child abuse. Cape Town: Oxford University Press; 2008. p. 352.
10. Nwomeh BC. Peculiarities of the injured child. In: Ameh EA, Nwomeh BC, editors. Pediatric trauma care in Africa: a practical guide. Ibadan: Spectrum Books; 2006. p. 12–24. SRC – BaiduScholar.
11. American College of Surgeons Committee on Trauma. Advanced trauma life support for doctors. 8th ed; 2008.
12. Council UK, Skellett S, Hampshire S, Bingham R, Maconochie I, Mitchell S. European pediatric advanced life support 2016. 154 p.
13. Group ALS. Advanced life support G. Advanced pediatric life support: Wiley; 2016. p. 384.
14. Kerr M, Maconochie I. Pediatric chest trauma (part 2) -- hidden injuries. Trauma. 2008;10(3):195–210.
15. Maya K, Ian M. Pediatric chest trauma (part 1) — initial lethal injuries. Trauma. 2008;10:183–94.
16. van As AB, Manganyi R, Brooks A. Treatment of thoracic trauma in children: literature review, Red Cross War Memorial Children's Hospital data analysis, and guidelines for management. Eur J Pediatr Surg Zeitschrift fur Kinderchirurgie. 2013;23(6):434–43.
17. Tovar JA. The lung and pediatric trauma. Semin Pediatr Surg. 2008;17(1):53–9.
18. Moore HB, Moore EE, Bensard DD. Pediatric emergency department thoracotomy: a 40-year review. J Pediatr Surg. 2016;51(2):315–8.
19. Allen CJ, Valle EJ, Thorson CM, Hogan AR, Perez EA, Namias N, et al. Pediatric emergency department thoracotomy: a large case series and systematic review. J Pediatr Surg. 2015;50(1):177–81.
20. Fallat ME, Trauma ACoSCo, Committee ACoEPPEM, Physicians NAoE, Medicine AAoPCoPE. Withholding or termination of resuscitation in pediatric out-of-hospital traumatic cardiopulmonary arrest. Pediatrics. 2014;133(4):e1104–16.
21. Bell D, Ryu Y. Chest radiograph assessment using ABCDEFGHI. Available from: https://radiopaedia.org/articles/chest-radiograph-assessment-using-abcdefghi.
22. Renton J, Kincaid S, Ehrlich PF. Should helical CT scanning of the thoracic cavity replace the conventional chest x-ray as a primary assessment tool in pediatric trauma? An efficacy and cost analysis. J Pediatr Surg. 2003;38(5):793–7.
23. Moore MA, Wallace EC, Westra SJ. The imaging of pediatric thoracic trauma. Pediatr Radiol. 2009;39(5):485–96.
24. Patel RP, Hernanz-Schulman M, Hilmes MA, Yu C, Ray J, Kan JH. Pediatric chest CT after trauma: impact on surgical and clinical management. Pediatr Radiol. 2010;40(7):1246–53.
25. Holmes JF, Brant WE, Bogren HG, London KL, Kuppermann N. Prevalence and importance of pneumothoraces visualized on abdominal computed tomographic scan in children with blunt trauma. J Trauma. 2001;50(3):516–20.
26. Karmy-Jones R, Hoffer E, Meissner M, Bloch RD. Management of traumatic rupture of the thoracic aorta in pediatric patients. Ann Thorac Surg. 2003;75(5):1513–7.
27. Barsness KA, Cha E-S, Bensard DD, Calkins CM, Partrick DA, Karrer FM, et al. The positive predictive value of rib fractures as an indicator of nonaccidental trauma in children. J Trauma. 2003;54(6):1107–10.
28. Barakat M, Belkhadir ZH, Belkrezia R, Faroudy M, Ababou A, Lazreq C, et al. Traumatic asphyxia or Perthe's syndrome. Six cas reports. Ann Fr Anesth Reanim. 2004;23(1):59–62.
29. Berkeley RP, Bledsoe BE, Markus T. Rare but serious. Recognizing the signs and symptoms of traumatic asphyxia. JEMS. 2010;35(9):30, 2, 4.
30. Eken C, Yigit O. Traumatic asphyxia: a rare syndrome in trauma patients. Int J Emerg Med. 2009;2(4):255–6.
31. Allen GS, Cox CS, Moore FA, Duke JH, Andrassy RJ. Pulmonary contusion: are children different? J Am Coll Surg. 1997;185(3):229–33.
32. Allen GS, Cox CS. Pulmonary contusion in children: diagnosis and management. South Med J. 1998;91(12):1099–106.
33. Holscher CM, Faulk LW, Moore EE, Cothren Burlew C, Moore HB, Stewart CL, et al. Chest computed tomography imaging for blunt pediatric trauma: not worth the radiation risk. J Surg Res. 2013;184(1):352–7.
34. Tsao K, St Peter SD, Sharp SW, Nair A, Andrews WS, Sharp RJ, et al. Current application of thoracoscopy in children. J Laparoendosc Adv Surg Tech A. 2008;18(1):131–5.
35. Sharma M, Kupferschmid J. Pediatric thoracic trauma https://emedicine.medscape.com. Available from: https://emedicine.medscape.com/article/905863-overview#a7.
36. Hormuth D, Cefali D, Rouse T, Cutshaw J, Turner W, Rodman G. Traumatic disruption of the thoracic aorta in children. Arch Surg (Chicago, Ill: 1960). 1999;134(7):759–63.