Emergency Management Of Blunt Chest Trauma In Children: An Evidence-Based Approach

Abstract

Pediatric trauma is commonly encountered in the emergency department, and trauma to the head, chest, and abdomen may be a source of significant morbidity and mortality. As children have unique thoracic anatomical and physiological properties, they may present with diagnostic challenges that the emergency clinician must be aware of. This review examines the effects of blunt trauma to the pediatric chest, as well as its relevant etiologies and associated mortality. Diagnostic and treatment options for commonly encountered injuries such as pulmonary contusions, rib fractures, and pneumothoraces are examined. Additionally, this review discusses rarely encountered—yet highly lethal—chest wall injuries such as blunt cardiac injuries, commotio cordis, nonaccidental trauma, and aortic injuries.
**Case Presentations**

A 4-year-old boy is brought in via EMS after a high-speed motor vehicle crash where he was an unrestrained rear-seat passenger. His vitals are: blood pressure, 70/39 mm Hg; heart rate, 155 beats/min; respiratory rate, 40 breaths/min; and oxygen saturation, 94% on room air. He is pale and displays an altered mental status. He is maintaining his airway, has diminished bilateral breath sounds, and has weak peripheral pulses. He has contusions on his head and torso, with an obvious right femur deformity. After you place 2 IVs, a chest x-ray is performed, which reveals pulmonary opacification with bilateral contusions. After a 20-cc/kg saline bolus, his heart rate is 150 beats/min, but his blood pressure rises to 100/40 mm Hg. You send him for a CT scan that reveals small frontal contusions. CT scans of the neck, chest, abdomen, and pelvis are negative. As he returns from CT scan, his blood pressure drops to 68/30 mm Hg and he remains tachycardic with a heart rate of 150 beats/min.

Just as you’re managing the boy who was in the motor vehicle crash, EMS notifies you that they are bringing in a 12-year-old boy who was hit in the chest with a baseball. He collapsed and stopped breathing, and bystanders started CPR and called 911. His coach had an AED and it immediately identified ventricular fibrillation. The coach shocked him once, and the boy had return of spontaneous circulation just as paramedics arrived on the scene. What is the next step for this patient?

Your next case is a 6-month-old girl brought in by her mother with 1 day of respiratory distress. The mother states that the baby has a bad cold, with some coughing. In the ED, the girl is nontoxic and appears well. She is afebrile, with a normal respiratory rate and oxygen saturation. Her lungs are clear, and there is no evidence of labored breathing. She has a small bruise on her upper back, which her mother says is from a “pinch” from her older brother. The baby passes an oral challenge and is discharged to follow up with her pediatrician the next day. A simple and straightforward case, you say to yourself…

**Introduction**

“Serious thoracic and abdominal injuries in children often are reported as isolated instances of trauma of an unusual or dramatic type. Failure to recognize these injuries or inaccurate appraisal of damage may result in inadequate or tardy treatment.”

Dr. John L. Keeley, 1962

Trauma is the leading cause of death in toddlers, children, teenagers, and young adults. Worldwide, it is estimated that nearly 25% of deaths are attributed to some form of chest trauma. Children have unique anatomical and physiological characteristics that make them susceptible to specific injury patterns. Specifically, trauma to the pediatric thorax has several unique features that make it potentially lethal. Chest injuries account for approximately 14% of pediatric deaths from blunt trauma, and when found in association with other injuries (especially to the head, abdomen, and long bones), the mortality rate increases. Blunt trauma to the pediatric chest can present in a variety of ways, from the subtle and nonspecific to the dramatic and deadly. Therefore, early recognition and prompt diagnosis is paramount for the emergency clinician. This article focuses primarily on blunt chest trauma, as this is the most common form of chest injury that affects pediatric patients.

**Critical Appraisal Of The Literature**

A literature search was performed in the PubMed database using the following terms (and their combinations): pediatrics, children, thoracic trauma, chest injuries, chest trauma, commotio cordis, blunt cardiac injury, cardiac contusion, myocardial contusion, rib fractures, first-rib fractures, child abuse-thorax-rib fractures, echocardiography, emergency medicine, aortic injury, tracheobronchial injury, emergency ultrasound, chest CT scan, and radiation. Additionally, the bibliographies of articles were reviewed for additional relevant publications, and over 100 studies were cited in this review. A search of the Cochrane Database of Systematic Reviews for pediatric thoracic trauma and pediatric trauma did not yield any results.

Many of the articles included here are retrospective reviews. Due to the rarity of some aspects of pediatric chest trauma (such as commotio cordis, aortic and cardiac rupture, and tracheobronchial disruption), robust prospective trials have not been performed on these topics. For this review, we primarily examined articles focusing on blunt trauma in the pediatric patient, although some studies did include penetrating trauma as well as adult patients. Prospective studies are also included when possible, including Chest NEXUS, a prospective study of nearly 10,000 patients, although this is a study of older adolescents and adults, it has some relevance to the overall topic of blunt chest trauma.

**Etiology And Epidemiology**

Pediatric chest trauma has been described in the literature for over 50 years. One of the earliest case reports of pediatric chest trauma was from Lis and Frauenberger, who described a case of a 10-week-old infant with a subdural hematoma, long bone fractures, and multiple rib fractures. In 1962, Bickford was one of the first authors to specifically look at chest injuries in childhood, reviewing 26 cases. Since then, multiple case reports and retrospective publications on chest trauma in the pediatric patient have been described and published.

Today, trauma remains the leading cause of
death among children and adolescents. Injuries to the chest account for 25% of trauma-related mortality. Trauma to the pediatric chest represents a unique and important aspect of traumatic injuries. The vast majority of trauma to the pediatric chest is from blunt mechanisms of injury. Common causes of blunt chest trauma include motor vehicle crashes, pedestrian injuries, falls, and sports injuries. Although not as common, nonaccidental trauma is also an important and deadly cause. Penetrating injuries to the pediatric chest are much less common, and they are seen mostly in the adolescent population.

Etiology

Up to 80% of all thoracic traumatic injury in children is due to blunt trauma. Incidents with motor vehicles and falls from height make up the majority of instances. Infants, toddlers, and younger children are typically injured as a result of mechanisms such as motor vehicle crashes, falls, or abuse. The younger the child, the more likely it is that the injury was nonaccidental. School-aged children typically incur injuries due to bicycling, skateboarding, and other transport-related mechanisms. Older adolescents are more commonly injured through motor vehicle crashes, sports injuries, and attempted suicide. In the United States, penetrating injury occurs more frequently in the adolescent and adult population, and it is most commonly caused by gunshot wounds. Geographic variation is also important in determining injury patterns. Proximity to mountains, an ocean, or major highways, as well as the prevalence of local participation in hunting activities or extreme sports, plays a role in injury patterns.

Peterson et al retrospectively reviewed over 14,000 cases of adult and pediatric trauma, finding a total of 2415 cases of blunt and penetrating chest trauma; the 342 patients who died were not included, leaving 2073 patients for review. In the study, 79 of the patients were aged ≤ 12 years, with 137 adolescents and 1742 adults (aged 18-59 years). Causes of pediatric chest trauma included pedestrian injuries (35%), motor vehicle crashes (34%), bicycle accidents (14%), and falls. Penetrating injuries were reported in 58% of adolescents and adults. In another study, Hanafi et al looked specifically at blunt chest trauma in different age groups. This retrospective record review of 486 patients with blunt chest trauma found that motor vehicle crashes were responsible for 93% of cases. Nakayama et al looked at 105 cases of pediatric chest injuries and found that 97% were caused by blunt forces, with more than half caused by motor vehicle involvement.

Additional studies consistently find motor vehicle crashes, pedestrian accidents, and falls as the most common cause of pediatric chest inju-

Figure 1. Prevalence Of Thoracic Injuries

<table>
<thead>
<tr>
<th>Injury Type</th>
<th>Percentage</th>
</tr>
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<tbody>
<tr>
<td>Pulmonary contusion</td>
<td>71%</td>
</tr>
<tr>
<td>Pneumothorax, 25%</td>
<td></td>
</tr>
<tr>
<td>Pneumomediastinum, 8%</td>
<td></td>
</tr>
<tr>
<td>Hemopneumothorax, 6%</td>
<td></td>
</tr>
<tr>
<td>Cardiac, 6%</td>
<td></td>
</tr>
<tr>
<td>Aortic, 3%</td>
<td></td>
</tr>
<tr>
<td>Diaphragmatic injury, 1%</td>
<td></td>
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<tr>
<td>Sternal fracture, 1%</td>
<td></td>
</tr>
<tr>
<td>Isolated rib fracture, 11%</td>
<td></td>
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<tr>
<td>Rib fracture, 35%</td>
<td></td>
</tr>
<tr>
<td>Total is &gt; 100%, as 48% of the patients had multiple thoracic injuries.</td>
<td></td>
</tr>
</tbody>
</table>

Mortality
Chest trauma causes significant morbidity and mortality. When additional organ systems are involved, the mortality rate increases. Smyth found a mortality rate of 2% for isolated chest trauma, which increased to 6.6%, 58%, and 100% when 2, 3, and 4 major body systems, respectively, were involved. Black et al found an isolated mortality rate of 4.3%, which increased to 29% when an additional major organ was injured. Ismail et al reported an overall mortality rate of 7.2%, mostly related to additional injuries. The most common injury associated with chest trauma was head injury.

Peclet et al prospectively investigated the significance of thoracic trauma and its relationship to mortality. They looked at 2986 children (aged < 15 years) who were admitted with trauma. Nearly 50% of the children studied were aged ≤ 4 years, with 104 patients (4.4%) having thoracic trauma. In this prospective study, 90% of the injuries were from blunt forces, and children with isolated chest trauma had a mortality rate of 5%. There was a 20% mortality rate in children with chest and abdominal trauma and a 35% mortality rate for chest and head trauma. When all 3 organ systems were involved, the mortality rate was nearly 40%. Children with additional thoracic injuries also had increased mortality. The mortality rate was nearly 17% in children with only 1 thoracic injury, but it jumped to 41% and 50% when there were 3 or 4 additional thoracic injuries, respectively. They also found that chest wall injuries in abused children increased morbidity to 50%.

Anatomy And Physiology
The anatomic and physiologic properties of the thoracic region of children differ markedly from that of adults. The child who presents with chest trauma may have unique injury patterns and concerns. Children have incompletely ossified and mostly cartilaginous ribs, so the thoracic cage has greater compliance and flexibility. Due to this compliance, forces applied to the ribs are typically transferred and dissipated to underlying tissues and organs in the mediastinal cavity. As a result, external forces may be transmitted without significant external signs of trauma. This transferred force is responsible for causing fewer rib fractures but an increased number of pulmonary contusions in children. It is also responsible for the relatively rare pediatric injuries of traumatic asphyxia and commotio cordis.

The intrathoracic organs of children are also different from adults. Children have a smaller and more flexible trachea that is prone to compression. Due to its small radius, even small amounts of swelling and reduction in diameter may lead to significant changes in airway resistance, which can lead to increased work of breathing, potential rapid desaturation, and respiratory compromise. Displacement or disruption of the more mobile trachea may also cause respiratory issues. Total lung capacity, functional residual capacity, and, ultimately, oxygen reserves are also relatively reduced in children. Minimal reductions from pulmonary insult, causing increases in physiologic dead space, can lead to rapid deterioration from hypoxia.

Children’s increased metabolic demand leads to a higher oxygen consumption requirement and a subsequent higher baseline respiratory rate. Hypoxemia can occur rapidly with insult to this respiratory rate and may occur in head injury or altered level of consciousness. As a child approaches the age of 10 years, their metabolism and pulmonary capacity changes to one more similar to that of an adult.

Hypovolemia also presents differently in children than in adults, especially in its early stages. Children primarily compensate from hypovolemia with an increase in preload to the heart, as determined by heart rate. They are less able to compensate through stroke volume and contractility changes. Should bleeding occur, tachycardia will develop prior to changes in blood pressure. As hypotension may not occur until a child loses up to 40% of his blood volume, tachycardia may be the only finding of a child in significant shock. It has been hypothesized that the flexibility and mobility of the mediastinum may also contribute to diminished blood return to the heart should certain vessels be compromised. This may lead to diminished cardiac output due to decreased venous return.

Prehospital Care
Emergency medical services (EMS) personnel are commonly called upon to transport pediatric trauma patients. Prehospital delay of transport (especially from repeated intravenous line or intubation attempts) should be avoided as much as possible. Emphasis should be placed on oxygenation, ventilation, treatment of tension pneumothorax, intravenous and intraosseous access, and spinal motion restriction. Oxygenation and ventilation is the first priority, and this can usually be accomplished with manual airway maneuvers. Prehospital intubation may be needed in some pediatric patients. Prehospital providers should rule out tension pneumothorax, as this is a clinical entity that can be rapidly treated with needle decompression, which is quick, easy, and life-saving. All medications and fluids should be given in appropriate weight-based dosing, and a length-based resuscitation tape may be used for all patients receiving fluids or medications. Hypotension is an ominous sign, and immediate intravenous or intraosseous access is necessary. A “load and go” philosophy, when possible, should predominate.
**Emergency Department Evaluation**

In addition to having anatomical and physical attributes that put them at risk for early and rapid decompensation, children may not have the ability to communicate effectively. The younger the child, the greater the potential for underdeveloped language and interpersonal skills, lack of developed coping mechanisms, and fear of bodily harm. It is imperative to recognize age-specific variations in presentation and anticipate that many young children may not be able to cooperate with a proper history and physical examination.

**History**

While life-threatening blunt thoracic trauma in children is rare, serious causes must be diagnosed quickly and treated appropriately, as children can decompensate rapidly from unrecognized injury. Examples include cardiac tamponade and traumatic aortic injuries. The emergency clinician must have a high suspicion for these types of injuries. The first clue to significant thoracic injury may be a history of a very forceful mechanism, often resulting in abrupt acceleration or deceleration, such as a motor vehicle crash, motor-vehicle-versus-pedestrian accident, or fall from a significant height. Depending on the level of injury and the age and ability of the child, such history may only be available from EMS team members or parents. Additionally, in the situation of nonaccidental injury, the history may be unreliable or even fictitious.

**Physical Examination**

When conducting the physical examination of a child who has suffered thoracic trauma, it is important to recognize that certain injuries (such as pulmonary contusion or blunt cardiac injury) may not be clinically evident on initial presentation. While not uniformly present, the presence of contusions, the lack of breath sounds, an abnormal thoracic examination, bony tenderness, and crepitus may be indicative of underlying injury. While not uniformly present, the presence of contusions, the lack of breath sounds, an abnormal thoracic examination, bony tenderness, and crepitus may be indicative of underlying injury.

A seriously injured child may, initially, even have normal vital signs. In a retrospective series by Balci et al, 70% of children had normal vital signs upon arrival. Certainly, the presence of vital sign abnormalities should cause further consideration of significant injury.

**Emergent Stabilization**

As with all trauma, the initial focus is emergent stabilization for injuries that may compromise airway, breathing, or circulation. The smaller airway of a child may be compromised by bleeding, secretions, or anatomic positioning of the flexed neck. The pulmonary function of children may be compromised by contusion, pneumothorax, or blood in the airways. Pulmonary injuries (as well as bronchial and diaphragmatic injuries) may manifest as respiratory distress. Further evaluation and intervention should occur with the presence of subcutaneous emphysema, nasal flaring, retractions, lack of breath sounds, increased respiratory rate, and hypoxia.

If sufficiently compromised, children may require intubation, a chest tube thoracostomy, or ventilatory intervention.

Circulatory collapse may be due to hemorrhagic shock, vascular injury, tension pneumothorax, or other tamponade physiology. Vascular injury and pulmonary hemorrhage may cause hypovolemia, initially manifesting as tachycardia. Vessel injury may be represented by hypotension or diminished or absent pulse. Rhythm abnormalities and diminished pulses may also suggest cardiac injury. Widened pulse pressure with tachycardia may be indicative of cardiac tamponade physiology, requiring pericardiocentesis. Thoracic injury should also be considered in children with sufficient mechanism of injury and with associated injuries. In the study by Peclet et al, 82% of all children with chest trauma had associated injuries, most frequently head trauma. Extremity and abdominal injuries were also common. In addition, children may have more than 1 chest injury.

**A Clinical Decision Rule For Identifying Chest Trauma**

Holmes et al published one of the few prospective studies looking at children with thoracic injuries. The authors prospectively enrolled pediatric patients with blunt torso trauma who underwent a chest radiograph. In addition to looking at the prevalence of pediatric thoracic injuries, they sought to develop a clinical prediction rule to identify children with thoracic injuries. They found that 6 clinical findings helped to predict chest injuries. These included: (1) abnormal chest auscultation; (2) low systolic blood pressure; (3) Glasgow Coma Scale (GCS) score < 15; (4) abnormal thoracic examination; (5) elevated respiratory rate; and (6) femur fracture. Sensitivity, specificity, positive/negative predictive value, and likelihood ratios can be seen in Table 1, page 6.

**Diagnostic Studies**

Diagnostic studies are critical in the evaluation of suspected chest trauma in children. The following sections offer general guidelines regarding the use of various diagnostic studies. The “Specific Thoracic Injuries” section (beginning on page 8) discusses the evaluation and diagnostic studies of each type of thoracic injury in more detail.
Laboratory Studies
Labo ratory findings may be used to help evaluate the patient’s status. Hemoglobin evaluation and serial changes in hemoglobin can indicate blood loss. An elevated lactate may indicate hypoperfusion and early shock. Leukocytosis in trauma is fairly common and may indicate stress reaction.

Electrocardiogram
In cardiac injury evaluation, electrocardiogram (ECG) abnormalities such as sinus tachycardia, rhythm abnormalities, or ischemic changes, as well as troponin elevation, may be found.24-26 Children without ECG findings who have a normal troponin and unremarkable vital signs are unlikely to have clinically significant cardiac injury.24,26

Imaging Studies
Imaging options include conventional chest radiography, ultrasound evaluation, and computed tomography.

Chest X-Ray
After physical examination, the chest x-ray remains the most important initial diagnostic modality for identifying thoracic trauma. This test is an easy and efficient way of rapidly identifying pediatric thoracic trauma with minimal radiation exposure. Unfortunately, the chest x-ray may not be sensitive enough for identifying some thoracic pathologies, including aortic injury, pulmonary laceration, and tracheobronchial pathology. Chest radiographs may be abnormal in 60% to 90% of all children with significant injuries.4,6,14 Additionally, rib fractures, occult pneumothoraces, and early pulmonary contusions may be missed on conventional chest x-ray. Chest films may not be required in the setting of a minor mechanism, and in children with normal vital signs and a completely normal thoracic examination.4

Ultrasound
Ultrasound is being utilized more frequently in the pediatric population. Thoracic ultrasound is fast, informative, and not associated with an increase in radiation. In addition, it can be performed at the bedside. For thoracic trauma, ultrasound use consists of evaluation for significant pericardial effusion, pneumothorax, hemothorax, and pulmonary contusion. In a prospective study in 2004, Kirkpatrick et al looked at the extended focused assessment with sonography in trauma (eFAST) examination, which includes evaluation of the lung for pneumothoraces.27 They found eFAST to be more sensitive than anteroposterior supine chest x-ray in the detection of pneumothoraces after trauma.

In a review of 4 prospective observational studies (totaling 606 patients), thoracic ultrasound was found to be more sensitive than anteroposterior chest radiography for identifying pneumothorax in blunt chest trauma.29 Additionally, a prospective study of 119 adult patients found that thoracic ultrasound was better at detecting pneumothoraces and contusions than clinical examination and x-ray.29

Chest Computed Tomography
The computed tomography (CT) scan is also helpful in the evaluation of chest trauma; however, its routine use has been questioned in light of the low incidence of significant injuries as well as the radiation dose delivered to the child. CT does have the potential to find additional injuries that may not be clinically or radiographically evident on plain film (such as pulmonary contusion and fractures).14,30,31 A high suspicion for vascular or tracheobronchial injury or an abnormal chest film that is concerning for significant injury should prompt CT use to distinguish these injuries from other surgical (or even benign) findings.14

Debate continues over the role and clear indications for chest CT in pediatric trauma, weighing the radiation risks and the fear of misdiagnosis with the benefits of increased sensitivity of diagnosis (see the “Controversies” section, page 16). Chest CT is a much more sensitive diagnostic modality than chest x-ray and ultrasound, but when does this matter? How can emergency clinicians limit unnecessary pediatric exposure to radiation? Do all acutely injured pediatric trauma patients need to be “pan scanned?” How do we balance these risks against a CT scan that is quick, easily accessible, and able to offer incredibly sensitive diagnostic options? Some of the

<table>
<thead>
<tr>
<th>Examination</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
<th>LR+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormal chest auscultation findings</td>
<td>14</td>
<td>99</td>
<td>55</td>
<td>93</td>
<td>14</td>
</tr>
<tr>
<td>Hypotension</td>
<td>14</td>
<td>98</td>
<td>44</td>
<td>93</td>
<td>7</td>
</tr>
<tr>
<td>GCS score &lt; 15</td>
<td>61</td>
<td>74</td>
<td>17</td>
<td>96</td>
<td>2.3</td>
</tr>
<tr>
<td>Abnormal thoracic examination</td>
<td>68</td>
<td>64</td>
<td>14</td>
<td>96</td>
<td>1.9</td>
</tr>
<tr>
<td>High respiratory rate</td>
<td>51</td>
<td>84</td>
<td>22</td>
<td>95</td>
<td>3.2</td>
</tr>
<tr>
<td>Femur fracture</td>
<td>13</td>
<td>37</td>
<td>12</td>
<td>99</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Holscher et al retrospectively reviewed trauma registry data on 57 pediatric patients who underwent a chest CT (nearly 70% of whom were admitted to the pediatric intensive care unit). They found chest CT did not change patient management, and chest x-rays were adequate in identifying patients needing urgent interventions. The authors recommended "selective use of chest CT, particularly in the presence of an abnormal mediastinal silhouette on chest x-ray after a significant deceleration injury."  

Barrios et al reviewed the combination of a chest x-ray and abdominal CT scan to predict thoracic injury (all age groups) and found that chest x-ray and abdominal CT scan identified most occult thoracic injuries, and that occult pneumothoraces that were only seen on chest CT did not require any intervention.  

In another study, Pinette et al prospectively compared thoracic CT and abdominal CT to assess thoracic injury prevalence in 444 trauma patients with an average age of 38 years. Highlights of their study can be found in Table 2.  

While CT may provide very useful information to the emergency clinician with an undifferentiated pediatric trauma patient (especially with an abnormal chest film), its use as a routine screening tool has been debated. Findings of significant injury are rare in children, and even as CT use has increased, outcomes have essentially been the same. A study by Renton et al looking at the increase in routine CT use showed no benefit in overall cost-effectiveness to such an approach. Kea et al compared chest CT results in 791 blunt trauma patients aged > 14 years with a normal chest x-ray. They found 18% of injuries were only seen on chest CT, although most of these were minor or insignificant. The chest x-ray was abnormal in 84% of patients with a major thoracic injury. They concluded that in patients with a normal chest x-ray, chest CT rarely detected a clinically significant injury.  

Debate exists as to whether plain radiography can adequately screen for children who require a CT. At issue is what clinical situation exists to suggest CT use when there are no findings on chest x-ray. Provider gestalt, in addition to plain chest radiography, may be adequate to avoid routine CT, though it is unclear to what extent. Currently, validated evidence-based pediatric protocols to direct the emergency clinician are lacking. However, both Holscher et al and Barrios et al identify a high-risk mechanism (deceleration injury, crush torso injury) or an abnormal chest x-ray (wide mediastinum) as potential indications for chest CT scan, looking for an aortic injury or, potentially, a tracheobronchial disruption. Additionally, validated protocols for older adolescents and adult patients have been recently published.  

NEXUS Chest, a prospective observational study, set out to validate a tool for the need of chest imaging in blunt trauma patients (aged > 14 years). This multicenter study, published in 2013, enrolled nearly 10,000 patients. The NEXUS Chest decision criteria were: (1) age > 60 years, (2) rapid deceleration mechanism, (3) chest pain, (4) intoxication, (5) decreased level of consciousness, (6) distracting injury, and (7) chest wall tenderness. The authors hypothesized that the NEXUS Chest criteria would be able to predict chest injuries that would be seen on chest x-ray and chest CT. If patients did not have any of the above 7 criteria points, than chest imaging was not needed. Their decision criteria had a 98.8% sensitivity and a negative predictive value of 98.5%. It should be noted that this study did not look at the younger pediatric patient. The authors stated, “…this decision instrument should not direct imaging in younger patients.”  

### Echocardiography  

Echocardiography should be utilized in cases where cardiac tamponade or cardiac injury is suspected. Bedside cardiac ultrasound, sometimes referred to as focused cardiac ultrasound (FOCUS), point-of-care echocardiography (POCE), or focused transthoracic echocardiography (F-TTE), is an important lifesaving tool for emergency clinicians. FOCUS is a noninvasive, fast, and immediate bedside tool that allows for real-time diagnostic capabilities. This is especially important in the critically ill patient and when evaluating for blunt cardiac injury. The physical examination (as well as radiographic imaging with chest x-ray and chest CT scan) may miss important cardiac injuries.  

Bedside cardiac ultrasound assessment allows the emergency clinician to rapidly assess for pericardial effusion, cardiac preload, ventricular size, and global ventricular function, thus allowing for rapid treatment decisions. Plummer et al retrospectively compared thoracic CT and abdominal CT and found the following:

**Table 2. Abdominal Computed Tomography And Chest X-Ray To Identify Significant Blunt Chest Trauma**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Finding on CT</th>
<th>Finding on Abdominal CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age &gt; 60 years</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Rapid deceleration mechanism</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Chest pain</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Intoxication</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Decreased level of consciousness</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Distracting injury</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Chest wall tenderness</td>
<td>Yes</td>
<td>Yes</td>
</tr>
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</table>

In a prospective study by Pinette et al of 444 patients, the authors examined the utility of chest x-ray and abdominal CT and found the following:

- 8 out of 444 patients had findings on chest CT that were not diagnosed via abdominal CT or chest x-ray that resulted in different treatment decisions.
- Rib fractures and lung contusions missed on abdominal CT and chest x-ray were less significant and mostly occult.
- Nearly 90% of pulmonary contusions were occult.
- There were 15 pneumothoraces that needed a chest tube, all of which were diagnosed on the abdominal CT.

The authors concluded that clinically significant chest injuries can be identified on abdominal CT and chest x-ray.

**Abbreviation:** CT, computed tomography.
studied 49 patients with penetrating cardiac injury; 28 patients had an immediate echocardiogram, while 21 did not. Not surprisingly, patients who had an immediate echocardiogram had a shorter time until diagnosis, an increased survival rate, and better neurologic outcome.40

Pearson et al retrospectively reviewed charts from approximately 500 children who were diagnosed with blunt chest trauma via transesophageal echocardiography (TEE). Patients with cardiac contusion were excluded from this study. They diagnosed 10 children with injury to the aorta or cardiac valves and found that rapid diagnosis of these unusual cardiac injuries supports improved outcome.41

Differential Diagnosis

There is a wide differential diagnosis when dealing with trauma to the chest. The chest wall encompasses structures from the trachea to the diaphragm. Common injuries will be pulmonary contusion, rib fractures, pneumothorax, and hemothorax. The emergency clinician should also be aware of less common and rarely encountered injuries such as blunt cardiac trauma, first-rib fractures, tracheobronchial disruption, and aortic rupture, which are described in greater detail in the “Specific Thoracic Injuries” section.

Chest wall injuries may not be initially obvious, and they may have subtle presentations. For example, infants with nonaccidental chest trauma may present with coughing and difficulty breathing. Patients with blunt cardiac injury may present solely with tachycardia and may lack external clinical findings. Findings for a pulmonary contusion may be delayed several hours. While emergency clinicians must recognize significant and obvious injuries to the head, abdomen, and extremities, they must also maintain a high index of suspicion for the subtle and nonobvious aspects of pediatric chest wall injuries. Examples include a pulmonary contusion or rib fractures without external bruising or crepitus.

Specific Thoracic Injuries

Tracheobronchial Injury

Tracheobronchial injury is a rare, but life-threatening form of major thoracic trauma.14,23,42 As is the case with aortic injury, many of these patients will die prior to hospital arrival.14 Tracheobronchial injury is most commonly associated with penetrating trauma, though it may also occur with significant high-mechanism blunt trauma due, in part, to the mobility of the pediatric mediastinum.6 Most injuries occur at the distal trachea and proximal bronchi.20,43,44

Clinical presentation may vary from mild respiratory symptoms to death, which is often thought to occur at the scene of injury.42,43 Clinical and radiographic findings of this injury may include elevated hyoid bone, subcutaneous air in soft tissues and near airway structures, and bronchial obstruction.6 Mediastinal air seen on plain film is common, though if the injury is more distal, air may leak into the pleural space where tension pneumothorax becomes more likely.6,40 Complete tracheal transection may present with respiratory collapse and it should be suspected if there is a persistent air leak after chest tube placement.47

Due to the severity of force necessary to cause this injury, associated injuries (such as rib fractures) are common.14,42 CT examination is warranted if a tracheal injury is suspected. Bronchoscopy should typically be done as well, looking for the exact area and extent of tracheobronchial injury. In a stable patient requiring endotracheal intubation with a suspicion of tracheobronchial injury, intubation should generally be performed in the operating room using fiberoptic visualization. Misplaced or forceful endotracheal tube placement may worsen partial tears or even transect the trachea altogether.6

Subsequent issues and challenges in management include stenosis, fistulas, and infection.6,14 Unrecognized injury may lead to further scarring and obscuration of an already small airway, leading to diminished respiratory function.58,49 Prospective studies on treatment are limited. If the tear is small, nonoperative intervention may be utilized. For re-anastomosis, operative intervention and primary repair is indicated.50

Pulmonary Contusions And Lacerations

Pulmonary contusions are common in children who have suffered traumatic thoracic injury, and in many series of children with chest trauma, they are the most common manifestation of injury.6,13,14,18,23 In a series by Cooper et al of children who incurred thoracic trauma, 49% had pulmonary contusions.55 Pulmonary contusions occur from significant force to the lung parenchyma. As force is applied and then transmitted to the thoracic cavity, parenchymal damage and hemorrhage may occur, resulting in alveolar collapse and swelling. These contusions are commonly visualized on chest x-ray as opacities.6 Chest film may underestimate the size of the contusion, perhaps by as much as 60%.51,55 Small or very recently created contusions may only be visible on CT.

The significance of contusions lies in their ability to create a ventilation/perfusion mismatch.6 If this mismatch is large enough, it can create significant respiratory distress due to the diminished pulmonary reserve and increased metabolic requirements present in children.6,51 Early manifestations include respiratory distress. Wagner et al suggested that when approximately 25% of the parenchyma is involved, mechanical ventilation may be warranted.54
Respiratory distress syndrome can occur in up to 20% of cases if the contusion is severe enough. Later in the course of disease, up to 20% of children may develop pneumonia. In severe cases, mortality can reach 10% to 20%.

When the manifestations of contusions do not require mechanical ventilation, they often respond to conservative treatment, such as incentive spirometry, pain control, and maintenance of activity levels. Most children with pulmonary contusions improve without significant complications. Resolution typically occurs in 2 to 7 days, depending on the extent of pulmonary parenchymal involvement and associated complications.

Kwon et al reported that children whose contusions were found by initial chest film required more respiratory support (including intubation), longer intensive care unit stays, and longer hospital stays than children whose contusions were only diagnosed by CT. Children diagnosed with CT typically had a shorter hospital stay, likely due to the smaller size of the contusions and lesser effect on pulmonary parenchyma. CT scan has shown some benefit in diagnosing some pneumothoraces and hemothoraces that were not initially visible on chest film. Therefore, while CT may improve diagnosis and delineate pulmonary and other concomitant injuries, diagnosing isolated contusions not seen on chest film is of questionable benefit in directing the clinical course of the child (especially in the well-ventilated and well-oxygenated child who appears comfortable). Ultrasound may also play a role in the diagnosis of pulmonary contusion.

Pulmonary lacerations and parenchymal tears occur much less frequently than contusions, with an incidence < 2% of all significant thoracic injuries. The resultant bleeding can be significant, however, and can lead to significant blood loss, pulmonary parenchyma obscuring, respiratory distress, and hypovolemic shock. These diagnoses may carry a mortality rate of up to 55%. If hemothorax occurs, treatment is chest tube placement. In the event of serious bleeding from the chest tube, the emergency clinician should be prepared for rapid replacement of blood products.

**Pneumothorax And Hemothorax**

Pneumothorax may be seen in the pediatric population as a result of blunt and penetrating injury. It commonly occurs in association with other injuries, but it may also occur in isolation. Traumatic pneumothorax commonly results in chest pain, shortness of breath, and diminished respiratory sounds. The initial presentation may be subtle and may include only mild chest pain, with a normal respiratory rate and oxygen saturation. In more severe cases, the child may exhibit absent breath sounds, significant respiratory distress, and circulatory compromise.

Tension pneumothorax is classically characterized by the unilateral absence of breath sounds, tracheal deviation, muffled heart tones, and jugular venous distension. Tension pneumothorax is relatively uncommon in children, though it is emergently life threatening and requires immediate decompression. The procedure for decompression includes insertion of a 14-gauge angiocatheter into the second intercostal space in the midclavicular line or the fifth intercostal space in the midaxillary line. This should be followed by chest tube thoracostomy.

Hemothorax is frequently seen in patients with penetrating injury. According to a retrospective study of > 23,000 pediatric patients with penetrating injury, 64% had a pneumothorax or hemothorax, 14% had pulmonary contusion, and 10% had blood vessel injury. Hemothorax results from parenchymal damage or intrathoracic vessel injury from great vessels or intercostal arteries. A full hemothorax can contain a significant percentage of a child’s entire blood volume.

In cases where observation is not appropriate, the treatment for pneumothoraces and hemothoraces is chest tube insertion, which allows reexpansion of the lung and removal of blood. In a study of 36 patients, Kulvatunyou et al found that 14-French pigtail catheters drained blood as well as large chest tubes in stable chest trauma patients.

**Aortic Injury**

Traumatic aortic injury is a rare, yet devastating complication of pediatric thoracic trauma. Studies estimate its incidence to be between 0.1% and 3%. However, the incidence of this injury may be underrepresented, as many of these children are thought to die at the scene of the trauma. The initial survival rate to the hospital may be as low as 7%, though accurate numbers are difficult to discern. If a child survives transport to the hospital with this type of injury, survival rates improve; however, there is significant disparity between studies in the rates of mortality, ranging from 33% to 90%.

A high-energy mechanism is typically required to cause aortic injury. Motor vehicle crashes with an unrestrained driver and passenger, other motor vehicle incidents, or falls from significant height are consistently found to be the most common mechanisms for these types of injury. Patients who do survive through admission to the ED may be severely ill. Common results of injury include hypotension, diminished pulses, and, potentially, lower-extremity neurologic deficits. Hemodynamics may play an important role in survivability, though this was not found in the cohort reviewed by Anderson. Paraplegia remains a significant morbidity in this population, and may occur in up to 17% of patients.

Due to the force of mechanism required to create a great vessel injury, children will often have associ-
ated injuries, commonly involving the head, abdomen and extremity. Pabon-Ramos et al found that solid-organ abdominal injury was the most common concurrent injury. Anderson et al also found bowel, spine, and extremity fractures were commonly associated injuries. Despite the severity of underlying injury, there are some children who will have no external signs of thoracic trauma.

**Radiographic Findings In Aortic Injuries**

Most aortic injuries show chest film abnormalities. Some studies suggest that chest radiography may be 96% to 98% sensitive for aortic injury. Findings on chest film may include apical capping, widened mediastinum, widened paratracheal stripe, esophageal deviation, loss of contour of the aortic knob, first- or second-rib fractures, and hemothorax. Thymic prominence in younger children can make this determination on plain chest film difficult.

In a study by Lowe et al from 1987 to 1996, 7 patients with traumatic aortic injuries were found. In 6 out of the 7 children, chest radiographic findings were seen. One 6-year-old child with an intimal tear had no abnormal findings on plain radiography. Pabon-Ramos et al’s review of aortic injury in chest radiography showed that the most frequent finding on x-ray was an indistinct aortic knob. They found that 94% of the children with aortic injury had an abnormal aortic knob on plain film and suggested that lack of findings on chest film and lack of other “compelling reason” may obviate the need for further studies (CT or angiography) for aortic evaluation.

Should concerning x-ray findings exist along with clinical suspicion for aortic or great vessel injury, further imaging is necessary. With the evolution of multislice computed tomography angiography (CTA), evaluation for suspected injury has shifted from thoracic angiography to CT scanning. CTA is, typically, readily available and adequate to evaluate for great vessel injury without the invasive, resource-intensive, and time-consuming nature of traditional aortography. Dyer found that CTA was 100% sensitive and had a 100% negative predictive value for aortic injury. Anderson found that CT was able to see aortic transections as well as intimal flap tears and pseudoaneurysm. True sensitivity for a minor intimal tear is difficult to ascertain if not found, and no adverse events occur in proximity to the injury.

Due to the rarity of the disease, much of the data regarding treatment and outcome of aortic injury in the pediatric population come from case series. Children limited to intimal flap tears have been treated successfully by nonoperative management. Treatment for significant injuries (such as transection) is operative, though technique and options may be debated. Aortic endografts may be placed by the surgeon, and grafts may be used. It is possible that the child may eventually outgrow the graft, potentially leading to pseudocoarctation of the aorta.

**Nonaccidental Injury**

Nonaccidental injury in the pediatric patient represents a unique population. In 2011, United States Child Protective Services agencies fielded over 3 million referrals for suspected abuse. Sadly, in the same year, over 1500 children died secondary to abuse. Abusive head trauma was the most common cause of death. Abusive head trauma and rib fractures may present with respiratory complaints such as apnea or labored breathing.

Injuries from nonaccidental trauma to the chest are a serious concern, as a significant amount of force must be present to break the compliant rib of an infant. Rib fractures are generally uncommon in the infant or young toddler, yet they are the most common thoracic injury from abuse and are observed at almost triple the rate of the general pediatric population. (See Figure 2.) Bulloch and colleagues retrospectively looked at infants with rib fractures who were aged ≤ 12 months. They identified 39 infant patients, of whom 32 had rib fractures caused from abuse. Three infants had rib fractures from “fragility” (osteogenesis imperfecta, rickets, and prematurity), while another 3 infants had rib fractures from nonintentional injuries (such as a fall or motor vehicle crash).

Cadzow and Armstrong looked at children aged < 2 years with rib fractures, and found that in 15 of 18 patients, nonaccidental injury was the cause of the fracture. In 4 of the 15 patients studied, rib

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**Figure 2. Multiple Rib Fractures In An Infant With Nonaccidental Trauma**

Image courtesy of Denis Pauzé, MD.
fractures were found incidentally, as abuse was not initially considered. Barsness et al also reviewed the positive predictive value of rib fractures in children < 3 years of age for inflicted trauma. They found a 95% positive predictive value of rib fractures caused by abuse in this age group. Additionally, rib fractures were the only bony sign of abuse in 29% of patients reviewed.

The emergency clinician must have an elevated index of suspicion for nonaccidental trauma when treating a young patient with rib fractures. Unless there is a witnessed fall or high-speed motor vehicle crash, virtually all infants (aged < 12 months) with rib fractures should be evaluated for nonaccidental trauma until proven otherwise. In infants, fracture of the first rib is especially concerning for abuse.

**First-Rib Fracture**

Though uncommon, children may present with a fracture of the first rib. In infants, this type of fracture is highly suspicious for nonaccidental injury. In children and teenagers, first-rib fractures can be seen in high-energy blunt trauma, such as high-speed motor vehicle crashes. Because of concern for associated vascular injuries, especially to the aorta, the question arises: Do children with first-rib fractures need a chest CT to evaluate for associated vascular injuries? Certainly, unnecessary radiation in the pediatric patient is of significant concern, and the risk-benefit ratio of chest CT scan radiation needs to be addressed. In 1997, Gupta et al looked at the available medical literature (case reports and series) and found 730 cases of first-rib fractures. They found that 3% of patients with an isolated first-rib fracture had a major vascular injury. If the rib fracture was associated with additional injuries to the head, thorax, or abdomen, then vascular injuries were found in 24% of cases. They concluded that specific indications for vascular evaluation are: (1) pulse deficit, (2) wide mediastinum on chest x-ray, (3) posteriorly displaced rib, (4) brachial plexus injury, and (5) expanding hematoma. This meta-analysis included both adult and pediatric patients.

Hamilton et al looked at first-rib fractures found in the pediatric patient. Over a 10-year study period, they retrospectively reviewed 12,603 injured children to assess the correlation between first-rib fractures and thoracic injuries. Only 0.027% of the children with blunt chest trauma had either a first-rib fracture or a thoracic vascular injury. The authors concluded that a fractured first rib does not indicate a higher likelihood of a vascular injury, and it is not an indication for further testing. Rather, they found that mediastinal abnormalities on the chest x-ray were a more important indication to perform further testing to evaluate for aortic injury.

**Blunt Cardiac Injury**

Blunt cardiac injury represents an important and potentially lethal aspect of blunt chest trauma. Blunt cardiac injury may lead to cardiac contusion, cardiac rupture, and injuries to the valvular and papillary muscles, coronary arteries, and pericardium. Comotio cordis is also a unique form of blunt cardiac injury, in that it solely and specifically affects the electrical conduction system of the heart. Although some patients may present with an isolated cardiac injury, most cases of blunt cardiac injury occur as a multisystem injury. The exact incidence of blunt cardiac injury remains unknown, as many cases may be mild and go undetected. In addition, there is no gold standard test to make this sometimes-elusive diagnosis. Estimates ranging from 20% to 76% have been reported in patients with blunt thoracic trauma.

The clinical presentation of blunt cardiac injury varies. Mild injuries may present without objective findings, while some patients may have minor dysrhythmias. Other cases of significant cardiac injury will present more dramatically, with malignant dysrhythmias, hypotension, cardiogenic shock, or even death. It is imperative that clinicians have a high index of suspicion for blunt cardiac injury when treating patients with multisystem injuries.

Data concerning pediatric cardiac trauma usually come from retrospective chart reviews, case reports, or autopsy reviews. In a multicenter study, Dowd et al retrospectively reviewed pediatric patients diagnosed with blunt cardiac injury. Of the 184 pediatric patients (median age 7.4 years) diagnosed with blunt cardiac trauma, 85% were secondary to motor vehicle involvement. The vast majority (94.5% of injuries) were myocardial contusions. Nearly 9 out of 10 patients with blunt cardiac injury had multisystem trauma, with associated injuries to the extremities, brain, abdomen, and lungs. Only 12.5% of children had an isolated injury to the heart.

Autopsy reviews for cardiac trauma also reveal useful information. In 1958, Parmley reviewed 546 autopsy cases of blunt cardiac injury for the Armed Forces Institute of Pathology. Cardiovascular rupture was the cause of death in half of the patients, while 19% had some type of cardiac contusion or laceration. Turk looked at cardiac injuries in fatal motor vehicle crashes. Of 380 motor vehicle crash fatalities reviewed in patients aged 19 months to 86 years of age, 80 (21.1%) had cardiac injuries. Thirty of the patients had isolated cardiac injuries. Scorpio and colleagues looked at the autopsies of 282 pediatric patients who died from blunt trauma and found blunt cardiac injury in 41 patients, with 25 patients having a cardiac contusion and 16 with a cardiac rupture. Blunt cardiac injury represented approximately 15% of pediatric blunt trauma fatalities. Surprisingly, 22 of 41 patients (54%), arrived to the ED alive. This is important, as rapid diagnosis and
Clinical Pathway For Management Of The Pediatric Patient With Suspected Blunt Chest Trauma

Patient presents with suspected blunt chest trauma

Signs/symptoms of tension pneumothorax?

YES

Perform needle decompression, insert chest tube (Class I)

Check:
• Blood pressure
• Heart rate
• Heart rhythm

NORMAL

ABNORMAL

Significant blunt chest trauma unlikely (Class II)

NO

Perform chest x-ray

If there is significant mechanism of injury, consider delayed pulmonary contusion.
Abbreviations: FAST, focused assessment for sonography in trauma.

Perform:
• FAST examination (may be done at any point) (Class I)
• Telemetry monitoring
• Serial troponin (Class III)
• Formal echocardiography (Class III)
• Admit for observation (Class II)

Go to abnormal chest x-ray pathway (page 13)

Class Of Evidence Definitions

Each action in the clinical pathway section of Pediatric Emergency Medicine Practice receives a score based on the following definitions.

Class I
• Always acceptable, safe
• Definitely useful
• Proven in both efficacy and effectiveness

Level of Evidence:
• One or more large prospective studies are present (with rare exceptions)
• High-quality meta-analyses
• Study results consistently positive and compelling

Class II
• Safe, acceptable
• Probably useful

Level of Evidence:
• Generally higher levels of evidence
• Non-randomized or retrospective studies: historic, cohort, or case control studies
• Less robust randomized controlled trials
• Results consistently positive

Class III
• May be acceptable
• Possibly useful

Level of Evidence:
• Generally lower or intermediate levels of evidence
• Case series, animal studies, consensus panels
• Occasionally positive results

Indeterminate
• Continuing area of research
• No recommendations until further research

Level of Evidence:
• Evidence not available
• Higher studies in progress
• Results inconsistent, contradictory
• Results not compelling

This clinical pathway is intended to supplement, rather than substitute for, professional judgment and may be changed depending upon a patient’s individual needs. Failure to comply with this pathway does not represent a breach of the standard of care.

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Clinical Pathway For Management Of The Pediatric Patient With Blunt Chest Trauma And Abnormal Chest X-Ray

Abnormal findings on x-ray

- Aortic knob abnormality
- Apical capping
- Wide mediastinum

- First-rib fracture
- Pneumomediastinum
- Pulmonary contusion

- Hemothorax
- Pneumothorax

Clinical concern for aortic disaster, pulmonary laceration, or tracheobronchial disruption based on following signs?
- Significant deceleration injury
- Crushed torso
- Multisystem trauma patient
- Diminished or unequal pulses
- Respiratory distress
- Air leak after chest tube placement

Yes

- Chest CT (Class II)*
  And/or
  - Consider transfer to trauma center (Class II)

No

- Admit for observation (Class II)
  And/or
  - Consider transfer to trauma center (Class II)

*CT scans should be performed at regional trauma center except in situations where transfer will not be delayed by compatible-quality imaging and direct link to radiography images exists.
Abbreviation: CT, computed tomography.
See Class of Evidence definitions on page 12.
treatment of some forms of blunt cardiac injury will, indeed, save lives.

Kaptein and colleagues looked at traumatic pediatric cardiac injuries derived from the National Trauma Data Bank, a data registry review of nearly 2 million medical records as submitted by approximately 900 trauma centers over a 4-year period (2002-2006). This article deserves special mention, as it may be the largest review of pediatric cardiac injuries reported in the English literature. There were 626 pediatric patients (<18 years of age) with blunt cardiac injury, which represented only 0.03% of all charts reviewed. Pediatric patients with cardiac trauma had an overall mortality rate of 40% (with a 76% result of death when a firearm was involved). Blunt injury was seen in 402 of the patients. Mortality rates from blunt trauma were nearly equal when comparing motor vehicle crashes (31%), auto versus pedestrian accidents (27%), and falls (25%). Nearly 90% of the patients with blunt cardiac injury were diagnosed with a cardiac contusion.85

There have been few prospective studies on pediatric cardiac trauma. Ildstad et al prospectively evaluated pediatric patients with blunt thoracic trauma. Any child with blunt thoracic trauma (defined as a pulmonary contusion and/or rib fracture) was prospectively enrolled to determine how many had associated cardiac contusion. Of the 7 patients enrolled with a pulmonary contusion or rib fracture, 3 of the patients had a cardiac contusion.86 Tellez looked at pediatric patients admitted to the intensive care unit with blunt trauma, and found 11 of the 39 patients admitted had blunt cardiac injury.87

Diagnosing Blunt Cardiac Injury

For some patients, making the diagnosis of blunt cardiac injury can be challenging, as some minor cardiac injuries may be clinically silent and go undetected. Other patients may present more dramatically with hypotension, arrhythmias, heart murmur, or heart failure. The key is being aware of the potential diagnosis and having a high index of suspicion. As there is no gold standard for the diagnosis of some cardiac injuries (eg, myocardial contusion), ECG, telemetry, troponin, FAST, and echocardiography are useful tools to assist in the diagnosis.

Pediatric patients with a normal sinus rhythm and a normal blood pressure can be safely ruled out for clinically significant blunt cardiac injury. Velmahos et al prospectively looked at 333 patients with “major” blunt thoracic trauma. They looked at performing serial ECGs and troponin I to evaluate for significant blunt cardiac injury (defined as arrhythmias, low cardiac index, abnormalities on echo, and hypotension). They found a normal ECG and troponin I during the first 8 hours of hospital stay rules out blunt cardiac injury, and the negative predictive value of combining these 2 simple tests was 100%.84

Rajan and Zellweger looked at patients with blunt thoracic injury and the association between troponin I and the risk of arrhythmia. They evaluated 187 patients, 34% of whom were diagnosed with a myocardial contusion. The study concluded that patients without symptoms who had a troponin I < 1.05 mcg/L within 6 hours of admission did not have a myocardial contusion. Interestingly, patients with elevated troponin I levels had an increased risk of arrhythmia. The risk of arrhythmia was increased by 1.9% for every 1 mcg/L increase of troponin I. Additionally, increased troponin levels correlated with decreased ejection fraction.85

Patients with significant cardiac injury will commonly present with hypotension or arrhythmia. Dowd’s review of patients with blunt cardiac injury found that patients with significant cardiac injuries were in shock or had ECG abnormalities upon initial presentation.83 Patients with arrhythmias, ECG changes, or hemodynamic instability should be admitted for serial ECGs, serial troponin measurements, and echocardiography. Echocardiography evaluates for tamponade, wall or valve rupture, wall motion function, and ejection fraction.

Isolated injuries to the heart are less common and most are described as isolated case reports. These injuries can often be fatal. Roland describes a 4-year-old girl who drove a go-kart into a fence and was later found to have an isolated right atrial appendage rupture. Despite several hours of tachycardia and hypotension from an unrecognized cardiac tamponade, her injury was successfully repaired.86 (See Figure 3.) Scolan reported a ruptured left ventricle in a 5-year-old boy who suffered a lethal blunt injury when 2 concrete fountain basins fell on him.87

Figure 3. Cardiac Tamponade In A 4-Year-Old Girl

Arrow points to blood surrounding the heart. Image courtesy of Denis Pauze, MD.
Commotio Cordis

Commotio cordis is a unique and often deadly form of blunt chest trauma. It is a common cause of sudden death in young athletes.90 Commotio cordis occurs when a blunt blow to the chest triggers a lethal dysrhythmia, commonly ventricular fibrillation. It is hypothesized that this blow to the chest, when directed solely at the precordium, occurs during repolarization of the ventricle, which is the upstroke of the T wave, and that it subsequently induces a life-threatening dysrhythmogenic event. (See Figure 4.) While histopathological damage (such as necrosis to the heart) occurs with cardiac contusions, commotio cordis differs in that there is no resultant structural damage to the heart or thorax. Commotio cordis cases are seen predominantly as a result of injuries occurring in sports.90,91 Commotio cordis has also been reported in nonaccidental injury,92-94 fights,95 motorbike crashes,96,97 and steering wheel injuries.98 The premier source of data comes from the Commotio Cordis National Registry.

Since the creation of the National Commotio Cordis Registry in 1995, over 220 cases have been registered.90 Results from the registry reveal that most patients are young (<15 years of age), with 26% of cases in patients aged ≤10 years, and 91% in those aged <24 years. In addition, commotio cordis affects males 95% of the time.90 Seventy-five percent of the patients are involved in a sporting activity such as baseball, softball, soccer, lacrosse, hockey, boxing, and rugby.90 Many cases involve pediatric patients who sustain minor blows to the chest such as being hit by a plastic saucer, hitting the chest on bicycle handlebars, being hit by a playground swing, and being hit by a plastic bat. These are seemingly innocuous injuries, and one might not consider that these mild mechanisms would be deadly in the pediatric patient.

As these blunt blows to the chest wall are often fatal, commotio cordis used to be an entity once virtually reserved for pathologists’ study. Fortunately, recent trends show an increasing survival rate from commotio cordis.99 This lethal entity now becomes extremely relevant for EMS providers and emergency clinicians. As the majority of commotio cordis cases occur among young patients, and with survival rates increasing, emergency clinicians are more apt to encounter a surviving patient with commotio cordis in the ED.

Treatment

Treatment of the injured pediatric patient involves following the ABCs (airway, breathing, and circulation) and subsequently completing a secondary survey. Patients presenting with airway emergencies (blood or vomitus in the airway, tracheal injury, obstructing tongue, etc) should be immediately stabilized with proper positioning, suctioning, and potential intubation.

Patients with respiratory distress should be closely evaluated for tension pneumothorax, pneumothorax, and hemothorax. Rapid needle decompression and/or emergent chest tube thoracostomy may be needed. Thoracostomy by pigtail catheter (as opposed to large-bore stiff chest tube) may be an acceptable alternative in pneumothoraces.100-102 Dull and Fleischer found that children undergoing pigtail catheterization for pneumothorax under Seldinger technique had a similar length of stay and required less opioid use compared to children who had large-bore chest tube.100 Roberts et al found that younger children with pneumothoraces (specifically, patients <10 kg in weight) achieved successful removal of air with pigtail placement. They found that pigtails were 81% successful in the evacuation of hemothorax.101

Next, the pediatric circulatory system may be compromised with injuries to the heart or vascular system. Resuscitative fluids are weight-based in the pediatric patient, and intravenous saline in 20 cc/kg boluses and blood (10 cc/kg) should be rapidly administered as indicated. The emergency clinician should start with a rapid administration of a 20-cc/kg bolus of normal saline (or Ringer’s lactate), followed by another one or two 20-cc/kg boluses if there is still hemodynamic instability. If there is no improvement after aggressive fluid resuscita-
tion, packed red blood cells (10 cc/kg) should be given. Ultrasound-guided pericardiocentesis may be needed for cardiac tamponade and impending arrest. Very rarely, pediatric ED thoracotomy may need to be performed.

In the pediatric blunt trauma patient, thoracotomy is rarely indicated. Specific indications for pediatric thoracotomy remain unclear and poorly studied, but may include a child with penetrating thoracic injury who loses pulses in the ED or while being transported by EMS. Sartorelli and Vane advise that return of 20% to 30% of the child’s blood volume (including a 1- to 1.5-liter loss in an older adolescent) or continued bleeding of 2 to 3 mL/kg/hour in a child over 4 hours are indications for thoracotomy.14 Thoracotomy should not be performed if trauma surgery or pediatric cardiac surgery backup is not immediately available.

Children who present to a community ED with significant thoracic trauma should be stabilized to the extent of capability at the institution. Children with significant pneumothoraces should have tube thoracostomy in place prior to transport, if possible. Large-bore intravenous access should be obtained as well. External thoracic bleeding should be tamponaded. Chest x-ray should be obtained prior to transport, which should occur as soon as possible to the nearest pediatric trauma center.

Upon arrival at the trauma center, institutional protocols typically drive who will provide initial care for the presenting child. Among ED providers and trauma surgeons, roles for procedures and care should be identified prior to patient arrival. If indication for admission exists after evaluation, these children should be admitted to the pediatric trauma service with appropriate specialty consultation.

**Controversies And Cutting Edge**

**Chest Computed Tomography Scans And Radiation Exposure**

CT use has increased dramatically over the past several years. In a series review by Markel, from 2002 to 2005, CT usage jumped from 5.5% to 10.5% in blunt trauma cases.36 Newer iterations of CT scanners as well as ease of CT angiography have delivered increasingly detailed images of the vascular, parenchymal, and bony structures of the thorax. CT scanners are also readily available and are commonly located within the physical structure of the ED. With such readily available technology, the malpractice environment may also play a role in an emergency clinician’s fear of missing a potentially life-altering diagnosis that could be easily seen by CT.

Radiation exposure in the pediatric patient is involved in much debate. Children are more sensitive to radiation, and repeated exposure may potentially lead to increased cancer risk. The significant radiation dose imparted to a child from a CT scan must be considered when deciding whether or not to order a chest CT, as the CT radiation dose may be 100 times greater than that of x-ray.103 Brody et al stated that a 5-year-old child typically receives a 3-mSv dose from a chest CT, which is the equivalent to 150 chest x-rays.104 This ionizing radiation may, theoretically, lead to adverse effects such as an increase in cancer. Earlier lifetime exposure can, theoretically, increase such risk. Frush et al claim that 1 out of every 1000 patients to get a CT scan will develop cancer.103 Pearce found that CT use in children might triple the risk of brain tumors and leukemia.105

Ultimately, despite these claims, the risk from ionizing radiation remains unclear. Prospective population-based studies are sparse in the literature. Such risk is often derived from expert panel consensus and extrapolation from populations that received significant radiation doses (> 500 mSv) from nuclear radiation exposure.104 Consideration of such radiation exposure from a potential CT scan with a cogent risk-benefit analysis is important in the care of each child. Fortunately, new technology will soon offer low-radiation CT scans.

The ALARA (as low as reasonably achievable) approach supports the notion that radiation should be limited unless otherwise necessary, thus limiting numbers of routine CT scans. In the future, as newer CT scanners with significant reductions in radiation become available, risk-benefit ratios may change.

**Low-Radiation Computed Tomography Scans**

One of the major drawbacks of CT scans for pediatric patients is the high-dose radiation involved. Fortunately, new low-dose radiation CT technology has been developed. One new CT scanner offers > 80% less radiation.106,107 This is important for the multi-injured pediatric patient who needs to be pan-scanned, as it promises high-resolution images without the significant radiation. It is the authors’ opinion that within 25 years, this technology will be widespread and CT scans will have a 99% radiation reduction compared to today’s typical total radiation dosage.

**Negative Pressure Ventilation**

Pulmonary complications from trauma can lead to increased morbidity and mortality. Peclet found that one-third of children with pulmonary contusions died.13 Battle showed the development of pneumonia to be a risk factor for increased mortality.108 Ismail found 0.8% acute respiratory distress syndrome complication.10 If emergency clinicians could decrease lung involvement, survivability may improve. Current treatment modalities for improved oxygenation and ventilation include invasive mechanical ventilati-
tion, which involves positive pressure ventilation. Unfortunately, there are many possible complications associated with positive pressure mechanical ventilation, including barotraumas, laryngeal injury, swallowing impairment, and tracheal stenosis, to name a few. But there may be a “new” solution, whereby an old treatment regimen may be a new solution when it comes to mechanical ventilation: The old “iron lung” used to treat polio and tuberculosis was a technology that used negative pressure ventilation. Picture an iron lung with 21st-century technology.

**Experimental Treatments**

A cuirass biphasic ventilator is a flexible piece of plastic that fits around the chest wall. It applies negative pressure ventilation, and can be used in neonatal patients up to patients weighing 180 kg. It has numerous advantages in that it is noninvasive, controls both phases of the respiratory cycle, improves cardiac output, decreases work of breathing, and does not have any risk of barotrauma. Patients do not have to be sedated for its use. There are many indications for its potential use, including cystic fibrosis, chronic obstructive pulmonary disease, neuromuscular disease, and patients with respiratory failure. Negative pressure can also be used in the trauma patient.

In a review of 15 patients with head trauma, Torrelli and colleagues found negative pressure ventilation increased cardiac index and oxygen delivery. It should be noted, however, that a recent Cochrane review failed to find an adequate number of studies that supported the use of continuous negative extrathoracic pressure in children.

**Disposition**

The disposition of children with chest trauma depends on the mechanism and significance of injury as well as the capabilities of the caring institution. When considering observation, reliability of caregivers and follow-up also plays a role. Children with a minor mechanism of trauma, no external evidence of injury, and no other significant clinical findings are likely able to be safely discharged home. Children with a more serious injury, including pneumothorax; hemothorax; pulmonary contusion; and tracheobronchial, cardiac, and aortic injury require admission to the hospital and may require further invasive intervention. Children with cardiac injuries require admission to a floor with telemetry monitoring. Emergency clinicians in hospitals without capability to care for pediatric patients with chest trauma should consider transfer to a facility with more extensive pediatric trauma capabilities.

**Summary**

Emergency clinicians must be prepared for a variety of presentations of pediatric trauma, especially when the thorax is involved. Common thoracic injuries include pulmonary contusions, rib fractures, and pneumothoraces. Additionally, blunt cardiac injury, tracheobronchial injury, diaphragmatic injury, and commotio cordis are unusual injuries that are encountered. Due to unique anatomical and physiological characteristics, pediatric patients may arrive to the ED with subtle, atypical, or dramatic presentations; therefore, a close evaluation for abnormal chest auscultation and/or thoracic examination, low systolic blood pressure, GCS score < 15, elevated respiratory rate, and femur fracture may prove helpful for diagnosing chest injuries. After physical examination, chest x-ray remains the initial test of choice.

**Case Conclusions**

For the 4-year-old patient whose blood pressure was dropping following the motor vehicle crash, you performed a FAST exam with particular emphasis on point-of-care cardiac ultrasound. You found that he had a large pericardial effusion with resultant cardiac tamponade. Given his hemodynamic instability, you performed an ultrasound-guided pericardiocentesis. His blood pressure returned to 105/60 mm Hg, and you admitted him to the hospital for further observation.

The 12-year-old boy who was hit in the chest with a baseball arrived awake and alert to the ED after his coach AED defibrillated him out of ventricular fibrillation into sinus tachycardia. You ordered him to be observed overnight in the PICU and he was subsequently discharged. Rapid placement of an AED saved this child’s life.

The 6-month-old girl who came in with a cold last week (and a pinch mark on her back) arrived again, via EMS, with apnea and bruises on her face and neck. You emergently intubated her and ordered imaging studies. Stat chest x-ray revealed many rib fractures of various ages. Her head CT scan revealed a large parietal skull fracture, frontal contusions, and a subacute subdural bleed. You looked through her records and found that, not only was she seen in the ED last week, she had also had several recent visits her primary care provider. This was a case of missed nonaccidental injury...missed by providers several times. She died several days later.

**References**

Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.
To help the reader judge the strength of each reference, pertinent information about the study, such as the type of study and the number of patients in the study will be included in bold type following the references, where available. The most informative references cited in this paper, as determined by the author, will be noted by an asterisk (*) next to the number of the reference.

Risk Management Pitfalls For Chest Trauma In Children (Continued on page 19)

1. “The infant presented with shortness of breath. There was no fever, the oxygen saturation was normal, and the lungs were clear. I thought it was respiratory syncytial virus. I didn’t think it could be from abusive chest trauma.” Infants with abusive head trauma and/or abusive chest trauma can present with nonspecific signs and symptoms, including respiratory complaints. These patients may present similarly to infants with bronchiolitis. Emergency clinicians should look for the presence of upper respiratory symptoms, runny nose, fevers, etc, that may indicate an upper respiratory infection or bronchiolitis. Absence of these symptoms should generate a high index of suspicion to evaluate for potential nonaccidental trauma.

2. “The 7-year-old presented with confusion and a femur fracture. His CT scan showed a splenic laceration. I didn’t think his persistent hypotension was caused by a cardiac tamponade.” Blunt cardiac injury is usually seen in a patient with multisystem injuries. Emergency clinicians may be distracted when seeing additional injuries (such as intra-abdominal pathology or extremity fractures). It is important to consider blunt cardiac injury when assessing the child with multisystem injury.

3. “The 4-year-old boy came in after a high-speed car accident. He was not belted and was thrown into the windshield. His chest x-ray revealed multiple rib fractures and a pneumothorax. He was admitted to the pediatric intensive care unit, where they subsequently found a traumatic aortic dissection. I can’t believe I forgot to look at his mediastinum on the chest x-ray! It was definitely widened. I didn’t think children could have this injury.” Emergency clinicians should carefully examine the chest x-ray for abnormalities such as widened mediastinum or abnormal apical knob. Although aortic injuries are uncommon in the pediatric patient, they do occur.

4. “The 8-year-old was riding her bike when she was struck by a car. Her initial heart rate was 140 beats/min with a blood pressure of 70/30 mm Hg. She presented with a GCS score of 10 and was immediately intubated. Chest x-ray revealed rib fractures. Her FAST exam was negative, and CT of chest and abdomen was negative for acute injury. She remained tachycardic and intermittently hypotensive. What injury am I missing with a negative pan scan?” This young girl was later diagnosed with a cardiac contusion, the most common form of blunt cardiac injury. Clues to her diagnosis were tachycardia, rhythm abnormalities, and hypotension. An ECG and troponin may have helped with the diagnosis.

5. “The 5-year-old girl presented after a large TV fell on her chest. She arrived tachycardic with a blood pressure of 100/65 mm Hg. Her initial oxygen saturation was 99% and her chest x-ray revealed only 2 rib fractures. Three hours later, she developed respiratory distress and became hypoxic, with an oxygen saturation of 82%. I had to intubate her. Repeat chest x-rays revealed a large pulmonary contusion. How did I miss it?” Findings of pulmonary contusion may be delayed for several hours in the pediatric patient. Respiratory distress and hypoxia may develop after an initial chest x-ray that is normal. The emergency clinician should be aware of delayed clinical findings from a developing pulmonary contusion. Initial findings to suggest a developing pulmonary contusion includes relative hypoxia, with saturations in the 93% to 95% range.

6. “We came to the scene of a 7-year-old with head, chest, and abdominal trauma. She was breathing OK with a saturation of 97%. Looking back at the record, I can’t believe we spent 44 minutes on the scene. We should have transported faster.” Prehospital delay of transport should be avoided as much as possible, especially if the delay is from repeated intravenous or intubation attempts. Emphasis should be placed on oxygenation, ventilation, treatment of tension pneumothorax,
9. “The 9-year-old boy presented after a fall from a height of 20 feet. He arrived with a blood pressure of 70/30 mm Hg and a heart rate of 140 beats/min. He was awake and alert. We did a CT scan of his head, neck, chest, abdomen, and pelvis, all of which were negative. He remained tachycardic and hypotensive. I can’t believe I missed a severe myocardial contusion. I didn’t even think of the heart.”

This is a perfect example of a patient with a negative pan scan who still has a severe undiagnosed injury. Patients with significant cardiac injury will commonly present with hypotension or arrhythmia. They may be nonresponsive to fluid resuscitation. Dowd’s review of patients with blunt cardiac injury found that patients with significant cardiac injuries were in shock or had ECG abnormalities upon initial presentation. Patients with hemodynamic instability should also be evaluated for a blunt cardiac injury such as myocardial contusion. Serial ECGs, serial troponin measurements, and echocardiography are available diagnostic tools. Echocardiography evaluates for tamponade, wall or valve rupture, wall motion function, and ejection fraction.

10. “A 13-year-old presented after falling off his bicycle. He complained of chest pain. He had normal vital signs and significant abrasions to his head and trunk. Chest x-ray revealed a large pneumothorax, not under tension. We placed a 32-French chest tube in him. It was painful. I completely forgot I could have placed a small pigtail catheter, which would have saved him a lot of pain and discomfort.”

Thoracostomy by pigtail (as opposed to large-bore stiff chest tube) is an acceptable alternative in pneumothoraces. Dull and Fleischer found that children undergoing pigtail catheterization for pneumothorax under Seldinger technique had a similar length of stay and required less opioid use compared to children who had large-bore chest tube.


23. Rajan GP, Zellweger R. Cardiac troponin I as a predictor of arrhythmia and ventricular dysfunction in trauma patients with myocardial contusion. J Trauma. 2004;57(4):801-808. (Retrospective comparative review; 187 patients)


1. The most common cause of chest trauma in children is:
   a. Falls
   b. Nonaccidental injury
   c. Guns and knives
   d. Motor vehicle crashes and pedestrian accidents

2. The most common injury seen in pediatric blunt chest trauma is:
   a. Blunt cardiac injury
   b. Tracheobronchial rupture
   c. Rib fractures
   d. Pulmonary contusion

3. Mortality for pediatric trauma
   a. Is around 78% for isolated chest trauma.
   b. Increases when additional organ systems (head, abdomen, extremities, etc) are involved.
   c. Is very rare.
   d. Is most commonly associated with extremity trauma.

CME Questions

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4. When dealing with a multitrauma pediatric patient, prehospital providers should concentrate their efforts on:
   a. Immunization status
   b. Forearm or extremity splint application
   c. Intubation
   d. Oxygenation, ventilation, intravenous/intraosseous access, “load and go”

5. There are many clinical signs that predict thoracic trauma in the pediatric patient. The clinical signs and symptoms that would best predict thoracic trauma include:
   a. GCS score < 15, upper extremity fracture, splenic laceration
   b. GCS score < 15, hypotension, femur fracture, abnormal thoracic examination
   c. GCS score of 15, Liver laceration, femur fracture, normal blood pressure
   d. GCS score of 15, spleen and liver laceration, femur fracture, normal blood pressure

6. When evaluating a child with blunt chest trauma, which of the following is the best indicator to perform a chest CT scan to rule out a thoracic vascular injury?
   a. First-rib fracture
   b. Strong radial pulses
   c. Pulmonary contusion
   d. Mediastinal abnormality on chest x-ray

7. Which of the following statements concerning pediatric trauma is TRUE?
   a. The most common injuries found are blunt cardiac injury and aortic transection.
   b. External injuries of the chest are always present, making the diagnosis relatively easy and straightforward.
   c. Findings for pulmonary contusion may be delayed several hours.
   d. Any rib fracture will need an immediate chest CT scan regardless of physical examination findings.

8. A 5-month-old child presents with cough and labored breathing. Her oxygen saturation is normal. Chest x-ray reveals no evidence of pneumonia, but it does reveal old rib fractures. The parents state the child fell down some stairs yesterday. With regard to the rib fractures, the physician should know:
   a. Rib fractures in the infant are uncommon, and should be a red flag for nonaccidental injury (especially old, healing, or different-aged rib fractures).
   b. Rib fractures in the infant are common from coughing.
   c. Mild trauma can cause rib fractures in infants.
   d. Abused children with rib fractures will usually also have fractures of the extremities.

9. The most common blunt cardiac injury is:
   a. Myocardial rupture
   b. Cardiac tamponade
   c. Cardiac contusion
   d. Coronary artery laceration

10. Commotio cordis is most commonly seen in:
    a. Motor vehicle collisions
    b. Sporting activities
    c. Penetrating injury
    d. Falls

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**This Month In EM Practice Guidelines Update: Guidelines For The Evaluation And Management Of Concussion In Sports**

As a pediatric emergency clinician, no doubt you are frequently called upon to answer questions from colleagues, parents, and coaches about concussion and mild traumatic brain injury in the young athlete. Are there any useful diagnostic tools? Is neuroimaging indicated? What about return to the classroom or the sports field? The November/December 2013 issue of *EM Practice Guidelines Update* reviews the practice guidelines for the evaluation and management of sports-related concussions that were released in March 2013 by the American Academy of Neurology. Authors Amish M. Shah, MD and Natasha Desai, MD from the Icahn School of Medicine at Mount Sinai in New York, NY discuss the new guidelines, and Andy S. Jagoda, MD, Guest Editor, offers some comments on the guidelines. Subscribers to *Emergency Medicine Practice* can get free access to this online publication at www.ebmedicine.net/Concussion. Subscribers to *Pediatric Emergency Medicine Practice* can access this single issue at no charge by visiting the link above, logging in, and then clicking “Download Full Topic PDF.”