Chapter 110: Pediatric Trauma

Camilo E. Gutiérrez

FIGURE 110-1.

INTRODUCTION AND EPIDEMIOLOGY

Pediatric trauma is a leading cause of morbidity, mortality, and disability for children. More than 9143 children died in the United States due to trauma-related injuries in 2010. For each childhood death associated with injury, more than 1000 children received medical attention for nonfatal injuries. According to the American College of Surgeons National Databank 2013 Pediatric Report, 152,884 patients younger than 19 years of age were admitted to 803 facilities across the United States and Canada with 2834 fatalities. Trauma is the leading cause of death in children over age 1 and exceeds all other causes of death combined.

Unintentional injury death rates are high in some subgroups including newborns and infants less than 1 year of age and teenagers age 15 to 19 years old. Gun-related injuries in this population lead to 8.87 hospitalizations per 100,000 persons <20 years of age in 2009, with 6.1% dying in the hospital (35.1% fatality from suicide). In 2010, gun-related injuries accounted for 6570 deaths of children and young people (1 to 24 years of age).

BEHAVIORAL CONSIDERATIONS

In general, a child's developmental stage dictates the expected behavioral response to injury. An infant should be appropriately curious and interactive or afraid of strangers, while an older child should respond with fear to invasive procedures. Understanding normal child development helps identify alterations of the sensorium, which may be the result of traumatic brain injury, hypoperfusion, or hypoxemia.

Family presence during trauma care is extremely important, not only to help assess the child's mental status, but also to support the injured child. Studies repeatedly demonstrate that parental presence is beneficial for both the patient's and parent's psychological well-being, does not interfere with medical efforts or increase stress in the healthcare team for the most part, and does not result in increased medicolegal issues. Family presence during resuscitation is an important standard practice in pediatric care.

ED PREPAREDNESS

Children require age- and size-based medication and equipment, so EDs should prepare an appropriate pediatric resuscitation area, provide personnel with adequate training in the care of children, and stock appropriately sized pediatric resuscitation equipment. In 2013, the American Academy of Pediatrics, the American College of Emergency Physicians, the Emergency Nurses Association, and the Emergency Medical Services for Children
developed the Pediatric Readiness Project\textsuperscript{11} to improve care for children in the ED, to provide a quality improvement process following the Guidelines for Care of Children in the Emergency Department,\textsuperscript{12} and to measure ED improvements over time. Approximately 5000 EDs with a response rate of over 80\% were involved, resulting in one of the most successful assessments to date.\textsuperscript{13}

**PEDIATRIC ANATOMY**

The pediatric head has a larger surface area that is prone to significant bleeding either from open scalp wounds with brisk arterial bleeding or in the form of cephalohematomas or subgaleal hematomas that can cause hypovolemic shock in small infants. The cranium is thinner, transmits energy easily, and predisposes to skull fractures.\textsuperscript{14} Open sutures in infants can accommodate increases in intracranial pressure and delay the recognition of serious intracranial injuries. Infants have prominent extra-axial intracranial spaces through which bridging cortical vessels traverse and are prone to shear and acceleration-deceleration forces such as those sustained in aggressive shaking; this accounts for classic findings such as subdural hemorrhages in inflicted injury victims.\textsuperscript{15} Finally, the size of the head in young children is larger compared to the body, which predisposes to closed head injury when children fall and will also occlude the airway when placed supine without back support.

The facets in the pediatric cervical spine are more horizontal than in adults, with less calcified vertebral bodies, increased laxity of spinal ligaments, and weaker supporting musculature, all of which allow translational forces to cause spine injuries without bony abnormalities. Due to the weaker neck musculature and larger cranium, the fulcrum of force is more cephalad, predisposing children to higher cervical spine injuries compared to adults (see chapter 139, "Cervical Spine Injury in Infants and Children").\textsuperscript{16,17}

Significant anatomic differences between pediatric and adult airways are discussed in chapter 111, "Intubation and Ventilation in Infants and Children," as they relate to advanced airway management. The pediatric laryngeal cartilages are more pliable and therefore less prone to fracture than the firm ossified adult cartilages.\textsuperscript{18,19} Although the larynx is relatively protected, children have higher risk for airway compromise due to soft tissue swelling or expanding hematoma in relation to the smaller size of the pediatric airway and neck.

The chest wall in children is more compliant, its tracheobronchial structures are more vulnerable, and the heart is more anterior with mobile mediastinal structures, all of which predispose to intrathoracic injury such as pulmonary contusions with minimal thoracic wall injury. Delicate tracheobronchial structures are susceptible to barotrauma especially in situations of excessive volume ventilations during resuscitation generating iatrogenic pneumothorax. The diameter of the respiratory structures is much smaller than adults, and a change in the inner diameter (from aspirated fluids or secretions) has a four-fold impact on the resistance to air flow as stated by the Hagen-Poiseuille equation, predisposing to airway obstruction.

The child’s abdomen is relatively larger in size compared with the rest of the trunk, has underdeveloped musculature, and has relatively larger size intra-abdominal organs, which predisposes to solid organ injuries in blunt abdominal trauma and hollow viscus injuries in certain acceleration-deceleration mechanisms such as seat belt injuries.
The skeleton is incompletely calcified, which renders bones more pliable and leads to bowing and greenstick injuries; multiple active growth centers and weaker epiphysis explain certain fracture types specific to children such as supracondylar fractures of the elbow and epiphyseal injuries such as the ones described by the Salter-Harris classification (see chapter 140, "Musculoskeletal Disorders in Children").

The higher body surface area to overall body mass in children and thin epidermal and dermal layers of the skin along with a paucity of subcutaneous fat and immature thermoregulatory mechanisms lead to increased propensity for hypothermia in cold environments which must be considered when assessing an exposed child in the trauma bay.

**PHYSIOLOGY**

Table 110-1 shows the expected vital signs according to age. Be alert to abnormalities in heart rate, respiratory rate, and peripheral perfusion that can indicate acute deterioration in the setting of trauma.

**TABLE 110-1**

<table>
<thead>
<tr>
<th>Normal Pediatric Vital Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pulse (beats/min)</strong></td>
</tr>
<tr>
<td>Newborn</td>
</tr>
<tr>
<td>Infant</td>
</tr>
<tr>
<td>Toddler</td>
</tr>
<tr>
<td>Preschool</td>
</tr>
<tr>
<td>School age</td>
</tr>
<tr>
<td>Adolescent</td>
</tr>
</tbody>
</table>

*Abbreviation:* BP = blood pressure.


Cardiac output is mediated primarily by heart rate in children as opposed to stroke volume in adults. Children with significant blood loss develop tachycardia, which can be sustained for a variable period of time before cardiac output is compromised. In addition, the vasculature is quite sensitive to endogenous catecholamines, allowing children to modify vascular tone in response to hemodynamic changes and regulate perfusion to the core organs. These two parameters, capacity to increase heart rate and modulate peripheral vascular resistance, help children maintain normal blood and perfusion pressures in the face of significant hemorrhage (25% to 30%), and hypotension is a very late and ominous sign of cardiovascular compromise in children.
In children, pulmonary tidal volume is relatively fixed, so minute ventilation is maintained primarily by respiratory rate (tachypnea) rather than depth (hyperpnea). Small residual volumes contribute to atelectasis, and a smaller functional residual capacity contributes to rapid desaturation during apnea.  

Finally, the metabolic demands in children are higher than adults. Children have a much higher energy expenditure and caloric requirement at baseline. Although stress-induced hyperglycemia is common in the setting of polytrauma, hypoglycemia can occur and should be treated promptly.

**THE PRIMARY SURVEY**

**AIRWAY**

The most important step in trauma care for children is assessment and stabilization of the airway. Children experience desaturation sooner than adults, and desaturation is quickly followed by respiratory arrest, which can lead to full cardiac arrest. For this reason, the most experienced clinician should be in charge of airway management.

Assess the **patency** of the airway first; note a hoarse or muffled cry or voice, stridor or sonorous respirations, increased work of breathing, or poor chest rise with bag-valve mask ventilation. Evaluate the **maintainability of a protected airway** in the presence of facial or neck trauma or facial burns, or in patients with neurologic compromise that precludes them from having an organized breathing pattern.

Perform basic airway maneuvers such as jaw thrust and oropharyngeal suctioning and maintain a sniffing position to align the airway axes, often by placing a towel roll under the shoulders. Consider use of airway adjuncts such as nasal trumpets, oral airways, or supraglottic devices until a definitive airway through endotracheal intubation can be achieved (see chapter 111).

Maintain in-line cervical spine stabilization at all times. Rapid sequence intubation is the safest method of intubating a trauma patient with a full stomach. When possible, limit positive-pressure ventilation before intubation to avoid gastric insufflation and vomiting. Indications for endotracheal intubation in the trauma patient include:

1. Glasgow coma score <8 or inability to maintain or protect the airway
2. Inadequate oxygenation or ventilation
3. Inability to ventilate or oxygenate with bag-valve mask
4. Potential for clinical deterioration (e.g., facial burns, inhalation injury)
5. Flail chest
6. Decompensated shock resistant to fluid resuscitation
7. Anticipated surgical intervention or need for radiologic investigation outside of the ED in an unstable patient
**BREATHING**

Assess the adequacy of breathing, ventilation, and oxygenation through careful observation of the rate, depth, pattern, and work of breathing, including tracheal position and symmetry of chest wall rise and fall. Note that alterations in the mental status might signify hypoxia (agitation) or hypercarbia (somnolence) from inadequate breathing.

Remember that small children are predominantly diaphragmatic breathers, are highly sensitive to increased intra-abdominal pressure, and have mobile mediastinal structures that predispose to pneumothorax, hemothorax, or flail chest that can rapidly compromise respiration and ventilation.

When there is concern for tension pneumothorax, perform needle thoracostomy by placing a 14- to 18-gauge IV catheter in the midclavicular line at the second intercostal space attached via a three-way stopcock to a 10- to 20-mL syringe; do not wait for radiologic confirmation in the hemodynamically unstable child.

**CIRCULATION**

Recognize early signs of circulatory shock including tachycardia, mental status, and color and perfusion abnormalities, because hypotension is typically a terminal event in children. Estimate normal systolic blood pressure in children 1 to 10 years of age using the following formula: $90 + (2 \times \text{age})$ mm Hg; hypotension can be estimated as systolic blood pressure less than $70 + (2 \times \text{age})$ mm Hg.\(^{25}\)

Evaluate the heart rate, peripheral pulses, capillary refill time, skin color, body temperature, and mental status, which is an important surrogate for perfusion. Control external hemorrhage by applying direct pressure to limit ongoing blood loss; perform additional maneuvers such as scalp suturing, fracture reduction, and pelvic binding to limit ongoing hemorrhage.

Vascular access can be challenging in small children and is more difficult in shock. Ideally, place two proximal large-bore IV catheters, but limit attempts in the unstable child and proceed to intraosseous access if unsuccessful after 90 seconds (see chapter 112, "Intravenous and Intraosseous Access in Infants and Children").

For compensated or uncompensated shock, give a rapid infusion of crystalloid (20 mL/kg of normal saline or lactated Ringer’s solution). Give two to three boluses rapidly as needed, ideally within 5 minutes each using an automated "rapid infuser," a frequently monitored pressure bag, or the "hand push and pull method."\(^{26}\) After two to three crystalloid boluses, consider 10 mL/kg boluses of warmed O-negative blood.

Although techniques such as permissive hypotension and "damage control resuscitation" with goals to limit hemorrhage, hemodilution, and the disruption of the clotting process have been widely studied and practiced in adult trauma care,\(^{27}\) there are insufficient data to recommend routine use in pediatric trauma patients. Children may tolerate relative hypotensive states better than adults, but the current standard of care is to maintain tissue perfusion with crystalloid boluses and blood component replacement until definitive surgical control of hemorrhage is achieved.\(^{10}\)

Pediatric rapid or massive transfusion protocols, on the other hand, have been widely studied and used in pediatric trauma centers. Implement a massive transfusion protocol, if available, when the need for transfusion is
anticipated to equal one or more blood volumes within a 24-hour time frame or half of a blood volume in 12 hours is suspected. Massive transfusion protocols replace red blood cells, plasma, and platelets in specific amounts (usually 1:1:1) with the goal of minimizing the coagulopathy associated with significant hemorrhage and minimizing the effects of hypothermia and acidosis.  

DISABILITY

Assess mental status and neurologic deficits as part of the primary survey. Mental status can be assessed using the modified pediatric Glasgow coma scale, which mirrors the familiar adult Glasgow coma scale in assigning points for eye opening and motor response using the same scale, but defines verbal response in an age-appropriate way (Table 110-2).

TABLE 110-2

**Modified Pediatric Glasgow Coma Scale**

<table>
<thead>
<tr>
<th>Score</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Coos or babbles</td>
</tr>
<tr>
<td>4</td>
<td>Irritable cry</td>
</tr>
<tr>
<td>3</td>
<td>Cries to pain</td>
</tr>
<tr>
<td>2</td>
<td>Moans to pain</td>
</tr>
<tr>
<td>1</td>
<td>No response</td>
</tr>
</tbody>
</table>

However, the Glasgow coma scale lacks good interobserver reliability and reproducibility and does not accurately predict outcomes in individual patients. A simpler and validated method to assess mental status in children is by using the AVPU score, which is currently recommended by the pediatric advanced life support guidelines (Table 110-3).

TABLE 110-3

**AVPU Score**

<table>
<thead>
<tr>
<th>Score</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Awake</td>
</tr>
<tr>
<td>V</td>
<td>Responds to verbal stimuli</td>
</tr>
<tr>
<td>P</td>
<td>Responds to pain</td>
</tr>
<tr>
<td>U</td>
<td>Unresponsive</td>
</tr>
</tbody>
</table>

In addition to assessing mental status, perform a pupillary examination and focused assessment of tone and strength.

EXPOSURE

To identify all potential injuries and perform life-saving procedures, disrobe and expose the child; however, children are particularly susceptible to hypothermia when exposed to cold environments or receiving room
temperature fluids. To avoid iatrogenic hypothermia, maintain a warm resuscitation environment, remove wet clothing, and place warm blankets underneath the child. Additional measures to maintain euthermia include use of radiant warmers and infusion of warmed intravenous fluids. Monitor and record temperature carefully throughout assessment and resuscitation.

THE SECONDARY SURVEY

Begin the secondary survey after the primary survey is complete and resuscitative measures have been initiated. For the secondary survey, perform a complete head-to-toe physical examination, cervical spine evaluation, and clearance. Ancillary tools such as pulse oximetry, blood gas measurement, and quantitative end-tidal carbon dioxide (CO₂) monitoring help guide therapy. Initiate laboratory evaluation, bedside ultrasonography, and radiographic imaging. During the secondary survey, perform nonemergent procedures such as placing a nasogastric or orogastric tube and Foley catheter (minimum urine output should be 0.5 mL/kg/h). A nasogastric tube will decompress the stomach, as a full stomach can restrict functional residual capacity.

In this phase, stabilize the child's condition sufficiently to allow transfer to the radiology suite or inpatient unit or a facility that can provide a higher level of care. Reassess the airway, breathing, circulation, and neurologic status continually because some injuries may manifest over time and complications from therapeutic interventions can occur. Consider endotracheal tube dislodgment, equipment failure, pneumothorax, regurgitation and aspiration of stomach contents, occult hemorrhage, and progression of intracranial hypertension as causes for deterioration. Carefully monitor fluid administration to prevent inadvertent overhydration. Provide appropriate analgesics and sedatives because pain treatment is often neglected in children.

REFERRAL TO A PEDIATRIC CENTER

Pediatric trauma center designation in the United States is conferred by governmental authority, and requirements vary from state to state. Guidelines have been created by American College of Emergency Physicians and American College of Surgeons to delineate the capabilities of a pediatric trauma center. The receiving institution should have a dedicated pediatric trauma service; comprehensive pediatric services should be available from scene care to rehabilitation and reintegration into the family and society. The trauma team should be immediately available at all times and capable of treating at least two patients simultaneously. Additional pediatric specialists should be on site or immediately available, including specialists in pediatric emergency medicine, anesthesiology, neurosurgery, radiology, orthopedics, critical care, and nursing. A pediatric intensive care unit is an essential component of a designated pediatric trauma center.

Use of trauma triage scores can help identify a child with more severe injuries, increase awareness of the need for higher level of care and monitoring, and predict outcomes. Two of the most commonly used systems are the Pediatric Trauma Score (Table 110-4) and the Revised Trauma Score (Table 110-5). Their advantages over other systems include use of physiologic variables instead of reliance solely on anatomic factors. Lower scores are associated with greater mortality and thus a need for pediatric trauma center care: a Revised Trauma Score of <12 or a Pediatric Trauma Score of <8 should prompt transfer to a pediatric trauma center.
TABLE 110-4

Pediatric Trauma Score

<table>
<thead>
<tr>
<th></th>
<th>-1</th>
<th>+1</th>
<th>+2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (kg)</td>
<td>&lt;10</td>
<td>10–20</td>
<td>&gt;20</td>
</tr>
<tr>
<td>Airway</td>
<td>Unmaintained</td>
<td>Maintained</td>
<td>Normal</td>
</tr>
<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>&lt;50</td>
<td>50–90</td>
<td>&gt;90</td>
</tr>
<tr>
<td>Level of consciousness</td>
<td>Comatose</td>
<td>Altered</td>
<td>Awake</td>
</tr>
<tr>
<td>Wounds</td>
<td>Major open</td>
<td>Minor open</td>
<td>None</td>
</tr>
<tr>
<td>Skeletal trauma</td>
<td>Open/multiple</td>
<td>Closed</td>
<td>None</td>
</tr>
</tbody>
</table>

*Total score is calculated by adding the score corresponding to the appropriate value from each column.

TABLE 110-5

Revised Trauma Score

<table>
<thead>
<tr>
<th>Number</th>
<th>Glasgow Coma Scale Score</th>
<th>Systolic Blood Pressure (mm Hg)</th>
<th>Respiratory Rate (breaths/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>13–15</td>
<td>&gt;89</td>
<td>10–29</td>
</tr>
<tr>
<td>3</td>
<td>9–12</td>
<td>76–89</td>
<td>&gt;29</td>
</tr>
<tr>
<td>2</td>
<td>6–8</td>
<td>50–75</td>
<td>6–9</td>
</tr>
<tr>
<td>1</td>
<td>4–5</td>
<td>1–49</td>
<td>1–5</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Total score is calculated by adding the score corresponding to the appropriate value from each column.

Additional indications for transfer to a pediatric trauma center are listed in Table 110-6. Anatomic and physiologic parameters are most useful in determining which children should be transported to a trauma center.
TABLE 110-6

Indications for Transfer to a Pediatric Trauma Center

<table>
<thead>
<tr>
<th>Mechanism of injury</th>
<th>Anatomic injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ejection from motor vehicle</td>
<td>Multiple severe trauma</td>
</tr>
<tr>
<td>Fall from a significant height</td>
<td>More than three long-bone fractures</td>
</tr>
<tr>
<td>Motor vehicle collision with prolonged extrication</td>
<td>Spinal fractures or spinal cord injury</td>
</tr>
<tr>
<td>Motor vehicle collision with death of another vehicle occupant</td>
<td>Amputations</td>
</tr>
<tr>
<td></td>
<td>Severe head or facial trauma</td>
</tr>
<tr>
<td></td>
<td>Penetrating head, chest, or abdominal trauma</td>
</tr>
</tbody>
</table>


Care of seriously injured children at a pediatric trauma center is associated with improved survival. In a study of 53,702 pediatric traumas comparing children treated at adult or pediatric trauma centers, the adjusted odds of mortality was 20% lower for children seen at trauma centers with pediatric qualifications.\(^{33}\) If not available, transport to a designated trauma center, adult or pediatric, is still associated with improved outcomes.\(^{34,35}\) Interfacility transfer of critically injured children is best done by a specialized pediatric transport team or a critical care transport team with pediatric experience when available (see chapter 107, "Neonatal and Pediatric Transport").

**GENERAL ASSESSMENT**

The goals of evaluation in a trauma victim are to determine the extent and severity of injury, what interventions, if any, are needed, and the level of monitoring required if admission is indicated. The mechanism of injury, history, and initial physical examination influence the degree of suspicion for intra-abdominal injury and guide subsequent radiographic and laboratory evaluation. Persistent emesis (especially bilious or bloody), abdominal distention, abdominal pain or any signs of peritoneal irritation, gross hematuria, and blood on rectal examination are indications for further investigation.

Carefully inspect the abdomen for signs of trauma including distention, abrasions, seat belt marks, or ecchymosis. Palpate for abdominal tenderness, which has a high positive predictive value for intra-abdominal injury. In high-mechanism injuries, maintain a high index of suspicion because pancreatic and hollow viscus injuries can present with delayed symptoms such as pain or emesis. Clinical evaluation of patients with altered mental status or distracting or associated injuries is difficult, and in this setting, a normal abdominal examination does not rule out the possibility of injury.
Routine laboratory "trauma panels" are frequently obtained in the evaluation of injured children, but individual laboratory abnormalities, while common, are seldom useful to dictate therapy, and no single laboratory test has acceptable sensitivity or negative predictive value to safely and effectively screen patients with abdominal trauma when used alone.\textsuperscript{36} Even organ-specific chemistries predicted injury poorly in children, are of little value, and alter acute management in only 5% to 6% of trauma patients.\textsuperscript{37} Although elevated liver function tests, particularly alanine aminotransferase, are suggestive of liver injury, no consensus exists as to the cut point for determining risk. Alanine aminotransferase levels >80 to 125 units/L have a sensitivity of 77\%, specificity of 82\%, but a positive predictive value of only 16\%.\textsuperscript{38,39} An exception to the generally poor utility of liver function tests is in the setting of suspected inflicted injury in infants and young children, for whom liver function tests are recommended as a screening tool to detect occult blunt intra-abdominal injury.\textsuperscript{40}

Amylase is not sensitive for acute pancreatic or other intra-abdominal organ injury, but lipase levels are fairly specific for pancreatic injury and can be used to serially monitor children for the development of complications such as pseudocyst formation or small bowel injury.\textsuperscript{41} In the seriously injured child, a base deficit >8 on blood gas analysis and lactate >4.0 mg/dL correlate with severe intra-abdominal injury and prognosis.\textsuperscript{42,43,44}

Urinalysis is frequently obtained in trauma patients, but microhematuria alone is poorly predictive of either genitourinary or intra-abdominal injury across a range of cut points for number of red blood cells per high-power field; gross hematuria and mechanism of injury, rather than microhematuria, should guide imaging studies.\textsuperscript{45}

**IMAGING**

**Plain Radiography** Plain radiography is still advocated as part of the trauma series in which the cervical spine, chest, and pelvis are imaged. Plain radiography has a low sensitivity for detecting intra-abdominal injury.

**US** Bedside ultrasonography is an extension of the physical examination of adult trauma patients. The FAST and extended FAST are used to evaluate for fluid in the peritoneal, pericardial, or pleural spaces. The utility of FAST is predicated upon its ability to identify free fluid (hemoperitoneum) and the assumption that the presence of free fluid is an indication of serious intra-abdominal injury requiring further evaluation. FAST is an appealing test due to its rapid bedside acquisition, relatively low cost, and lack of radiation, but there are a number of limitations in pediatric use. **Due to anatomic and physiologic differences between children and adults, up to 30\% of children with solid organ injury have no demonstrable free fluid on FAST, decreasing the sensitivity of this exam for solid organ injuries and limiting its negative predictive value, particularly in hemodynamically stable patients.** Moreover, unlike adults in whom free fluid (hemoperitoneum) usually requires laparotomy, the vast majority of children with hemoperitoneum are successfully managed nonoperatively, so a positive FAST does not always change management. On the other hand, in the hemodynamically unstable patient with multiple trauma, FAST can provide valuable information as to the source of instability and help to focus resuscitative and surgical efforts when positive.\textsuperscript{46,47,48} As in adults, FAST poorly detects retroperitoneal and hollow viscus injury.

**CT** CT scan is the study of choice for the evaluation of blunt pediatric abdominal trauma. Advantages of CT include its speed, excellent depiction of solid organs, and widespread availability. Reformatted images in the coronal and
sagittal planes allow good depiction of anatomy, and CT angiography can provide additional detail. Disadvantages include the need to remove the patient from the controlled and monitored setting of the trauma bay, radiation exposure, and potential complications related to the use of contrast materials. The main limitation to CT use is persistent hemodynamic instability despite adequate fluid resuscitation.

Common indications for CT include intubated children with multisystem trauma; altered mental status in the setting of trauma; spinal cord injuries resulting in loss of abdominal sensation; gross hematuria; abdominal pain and tenderness on examination; free fluid on FAST examination; abdominal or flank bruising or seat belt mark above the iliac crests; suspected inflicted trauma to the abdomen with elevated liver function tests; and direct blow to the abdomen from bicycle handlebars.49,50

**PEDIATRIC HEAD TRAUMA**

Minor head injury (Glasgow coma scale >13) and concussion, including pathophysiology and clinical decision rules to decide which children require neuroimaging, is discussed in chapter 138, "Head Injury in Infants and Children." Inflicted head injuries are discussed in more detail in chapter 148, "Child Abuse and Neglect". This section focuses on more severe traumatic brain injury (Glasgow coma scale <14).

**IMAGING**

**Plain Films** Plain films of the skull have limited use in the evaluation of pediatric head trauma except in children less than 2 years old in whom they are an acceptable screening tool for fractures when there is a large, usually boggy scalp hematoma noted on physical examination. However, if a skull fracture is identified by plain film, obtain a CT scan to rule out an intracranial injury, as there is a four- to six-fold risk of intracranial pathology associated with skull fracture.51 A four-view series is recommended and consists of anteroposterior, right and left lateral, and Towne (30-degree caudal angulation) views.52 Plain films can be difficult to interpret due to normal cranial sutures and may miss as many as 25% of skull fractures, and plain films have a low sensitivity for intracranial injuries.53,54

**US** A number of studies suggest an emerging role for bedside ultrasonography to detect skull fractures in children, with a sensitivity ranging from 94% to 100% and a specificity up to 96%,55,56 and US may be more sensitive than plain films for certain types of fractures.57 Brain US can be used in infants with open anterior fontanel to assess for intraventricular hemorrhage and is commonly used in preterm neonates, but its use has not been validated in trauma, and there is a risk that it might miss peripheral or extra-axial hemorrhages. US interpretation is highly dependent on sonographer skill, however, and when compared to CT scan, has limited ability to detect traumatic brain injury in the absence of skull fractures. US is not yet a reliable tool to determine if CT can be avoided in children with a single isolated risk factor for intracranial injury and no evidence of fracture by US.

**CT** CT is the gold standard in the diagnosis of traumatic brain injury and has 100% sensitivity and 100% specificity for significant intracranial lesions.58 In the setting of significant trauma, CT of the head is typically performed without contrast, and sedation is rarely required. See chapter 138 for further discussion of CT imaging decision rules in pediatric head injury.
MRI MRI is not widely available, scan times are lengthy, and MRI is not appropriate in unstable patients. MRI is an option once the patient has been stabilized and additional information is needed regarding extent of injury and prognosis. MRI may be useful when there are inconsistencies between the clinical picture and the CT findings, for dating of extra-axial hemorrhage, and for detecting diffuse axonal injury.

**TREATMENT**

Emergent treatment for serious traumatic brain injury is listed in Table 110-7.
**TABLE 110-7**

Management of Serious Traumatic Brain Injury in Children

<table>
<thead>
<tr>
<th>Considerations</th>
<th>Primary Goal</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical spine</td>
<td>Maintain spinal precautions</td>
<td></td>
</tr>
<tr>
<td>Airway</td>
<td>Maintain airway, intubate for GCS &lt;8 or as needed for oxygenation and ventilation</td>
<td></td>
</tr>
<tr>
<td>Oxygenation and ventilation</td>
<td>Oxygen saturation &gt;90%; $P_{CO_2}$ 35–40 mm Hg</td>
<td>No prophylactic hyperventilation</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>SBP &gt; 70 + (2 × age)</td>
<td>No permissive hypotension</td>
</tr>
<tr>
<td>Cerebral perfusion pressure (CPP)</td>
<td>CPP = 40–65 mm Hg (ref)</td>
<td></td>
</tr>
<tr>
<td>Intracranial pressure (ICP) monitoring</td>
<td>ICP ≤20 mm Hg</td>
<td>Consultation with neurosurgean</td>
</tr>
<tr>
<td>GCS</td>
<td>GCS before paralytics if possible</td>
<td>Serial GCS to document changes</td>
</tr>
<tr>
<td>Sedation and pain management</td>
<td>Midazolam</td>
<td>Consider paralytics once thorough neurologic examination is completed</td>
</tr>
<tr>
<td></td>
<td>Fentanyl</td>
<td></td>
</tr>
<tr>
<td>Neuroimaging (noncontrast head CT and cervical spine CT when indicated)</td>
<td>Identify intracranial injury and signs of increased intracranial pressure or herniation</td>
<td>Transcranial Doppler$^{108}$ may be useful in infants with open fontanelles but requires an experienced pediatric radiologist</td>
</tr>
<tr>
<td>Glucose</td>
<td>Treat hypoglycemia and hyperglycemia</td>
<td>Maintain normal blood glucose</td>
</tr>
<tr>
<td>Increased ICP/impending herniation</td>
<td>Elevate head of bed 30 degrees</td>
<td>3% normal saline 5 mL/kg bolus over 10 minutes followed by infusion of 0.1 mL/kg/h to maintain serum Na within 155–165 mEq/L or Mannitol 0.5–1 gram/kg if normotensive (response is not dose-dependent)</td>
</tr>
<tr>
<td>Considerations</td>
<td>Primary Goal</td>
<td>Comments</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Core temperature</td>
<td>Maintain temperature 36–38°C</td>
<td>Hypothermia in children not recommended(^{109}); avoid hyperthermia</td>
</tr>
<tr>
<td>Seizure prophylaxis</td>
<td>Optional: consider for children with witnessed posttraumatic seizures and intracranial blood</td>
<td>Phenytoin 20 milligrams/kg (or fosphenytoin 20 PE/kg) or Levetiracetam 10–20 milligrams/kg (maximum, 500 milligrams/dose)(^{111}) for first week following severe traumatic brain injury</td>
</tr>
<tr>
<td>Anemia</td>
<td>Transfuse for hemoglobin &lt;7 grams/dL(^{110})</td>
<td></td>
</tr>
<tr>
<td>Neursurgery/transfer</td>
<td>ICP monitoring, evacuation of intracranial blood, or cerebrospinal fluid shunt for refractory intracranial hypertension</td>
<td></td>
</tr>
</tbody>
</table>

*Abbreviations: GCS = Glasgow coma scale; \(P_{\text{CO}_2}\) = partial pressure of carbon dioxide; PE = phenytoin equivalent; SBP = systolic blood pressure.*

**PALATAL INJURIES**

Children commonly place objects in their mouth and may trip and fall leading to penetrating injuries of the oropharynx. It is estimated that around 1% of children suffer such injuries.\(^{59}\) Such injuries present a diagnostic challenge for several reasons: soft palate injuries can heal rapidly leaving few visible clues; the size of the lacerations does not relate to the depth of the wound; most of these injuries are caused by long, thin, sharp objects (i.e., pencils) that can penetrate deeply; and the potential for severe complications related to vascular injury is high. Well-known complications based on observational studies\(^{60}\) include compression, thrombosis or laceration of the carotid artery, deep soft tissue infections and mediastinitis, and stroke.\(^{61,62}\)

Wounds longer than 2 cm or with evidence of flaps require repair, while smaller ones usually heal by primary intention.\(^{63}\) The location of the wound is most important, as lateral wounds (over tonsillar pillars) have a greater risk of vascular injury than wounds near the midline where the hard palate is located. Obtain CT when a foreign body is noted or suspected.
The imaging modality of choice for lateral palatal injuries or those associated with focal neurologic injury, the presence of a bruit, persistent bleeding, or concern for significant mechanism of injury is CT or MRI angiography or digital subtraction carotid angiography. There are differences in the sensitivity and specificity of the various imaging modalities, and a balance needs to be established between radiation exposure, the need for sedation, and the length of time required to complete the study. Admit patients with lateral palatal penetrating injury for observation and serial neurologic exams unless vascular injury has been excluded by angiography. In patients with midline hard palate lacerations, minor trauma, or trivial injuries, no imaging is necessary. Provide clear discharge instructions with signs and symptoms of complications for which to seek prompt medical care, including fever, dysphagia, persistent bleeding, or symptoms of stroke. The use of empiric antibiotics such as clindamycin, ampicillin, or amoxicillin with clavulanic acid is recommended, although evidence is lacking. Provide tetanus prophylaxis as appropriate.

**NECK TRAUMA**

Although adult penetrating neck trauma accounts for 5% to 10% of trauma visits and carries an overall mortality of 3% to 10%, penetrating neck trauma is rare in children, comprising only 0.5% of trauma admissions. Blunt neck injuries are more common than penetrating injuries in children and are a result of falls into stationary objects, direct impact during sports, "clothesline injuries," and intentional hanging injuries. Hanging can result in laryngeal fractures or separation injuries. For a complete discussion of neck injuries, see chapter 260, "Trauma to the Neck" in the adult section.

An approach to the evaluation of pediatric blunt neck trauma is shown in Figure 110-1. Assess children with neck injuries in a position of comfort to avoid airway compromise; avoid forcing a patient into recumbence when the physiology dictates tripoding and neck hyperextension in order to maintain airway patency.

**Figure 110-1.**
THORACIC TRAUMA

Thoracic injuries occur infrequently in children, accounting for 5% to 12% of pediatric trauma admissions, but are the second leading cause of death from trauma after closed head injury. Isolated chest trauma in children carries a 4% to 12% mortality rate in isolation, but when associated with closed head injuries and abdominal trauma, mortality increases to 40%.68

Blunt forces account for 80% to 85% of pediatric thoracic injuries. Motor vehicle crashes, pedestrian accidents, and inflicted injury are more common in younger children, whereas falls, sports-related injuries, and high-speed crashes are more common in older children and teenagers.69 Penetrating trauma is rare in children and most commonly the result of impaling injuries; accidental gunshot wounds in younger children have become increasingly common as the number of firearm injuries steadily increases in the United States.

Pulmonary contusions are the most common injury in blunt chest trauma in children and may present with minimal or no external signs of trauma.70 Anatomic changes in pulmonary contusion include interstitial edema.
and alveolar hemorrhage with subsequent consolidation. Areas of ventilation/perfusion mismatch reflect poor lung compliance and are associated with disordered ventilation and oxygenation.\(^7^1\)

Pneumothoraces are common and present in up to 33% of trauma victims; they should alert the clinician to the possibility of associated injuries. Tension pneumothorax is of special concern in younger children due to the relatively easier compromise of cardiopulmonary physiology and detrimental effect on right side heart-filling pressures. Signs like jugular venous distention are less prominent in children than in adults, and their absence can be falsely reassuring. Treat tension pneumothorax emergently with needle decompression and closed chest thoracostomy without waiting for confirmatory chest x-ray in the child with unstable vital signs and asymmetric breath sounds.

Hemothorax is relatively less common in children than adults. No clear guidelines exist with regard to initial output volume or continuous blood drainage from a closed chest thoracostomy to indicate the need for surgical intervention. A child's hemithorax can contain up to 40% of the effective blood volume, and intrathoracic bleeding can lead to hemorrhagic shock. Hemothorax is associated with morbidity from infection, lung scarring, and chronic atelectasis.\(^7^2\)

Rib fractures are uncommon in children as a result of the elasticity of the rib cage. When present, however, rib fractures are often associated with severe injuries due to the high force required to cause them, and mortality increases with an increasing number of ribs fractured.\(^7^3\) In the absence of a witnessed high-energy mechanism, rib fractures, especially posterior, are highly suggestive of inflicted injury in infants. Obtain a chest x-ray to assess for acute or healing rib fractures when abuse is suspected.

Cardiac contusions are uncommon in infants and children but may be seen in sports-related blunt chest trauma in school-age children and teenagers. They can manifest as sudden death, commotio cordis, or arrhythmias with ECG changes and elevation of cardiac enzymes.\(^7^4\)

**ASSESSMENT**

Begin the evaluation of the thorax with careful inspection for bruising or laceration. Observe chest rise and fall, noting paradoxical chest movement suggestive of flail chest or pneumothorax. Palpate for bony defects and crepitus associated with subcutaneous emphysema, and auscultate for symmetry of breath sounds.

Plain chest x-ray can identify rib fractures and most pneumothoraces (a small pneumothorax can layer anteriorly in the supine patient and be missed by an anteroposterior view of the chest). Point-of-care US has better specificity and sensitivity to detect small pneumothoraces than x-ray. Pulmonary contusions may not be visible on initial radiographs, and serial imaging may be required to reliably determine the progression of parenchymal lung injuries. Evolving contusions can be exacerbated by overhydration and might not be present until well into the first hours of the hospital course.

Plain radiography is a screening tool for significant injury in children, and CT scan is an adjunct to the clinical evaluation and initial plain radiography.\(^7^5,^7^6\) Although thoracic CT is more sensitive than chest x-ray at recognizing intrathoracic injuries, CT seldom results in significant changes in patient management and is not routinely indicated for the emergent evaluation of chest trauma.\(^7^7,^7^8\) CT is indicated in blunt thoracic injury when suspicion
of aortic disruption is high and has a sensitivity of 95% to 100% and negative predictive value of 99% to 100% for this aortic injury. Surgical intervention is the standard of care for these patients.\textsuperscript{79,80}

Tracheobronchial injuries are difficult to detect with radiography and are best evaluated by bronchoscopy. Consider tracheobronchial disruption in the setting of persistent air leak, pneumothorax, or pneumomediastinum, although presentation can be subtle.\textsuperscript{81}

**TREATMENT**

The management of injuries such as flail chest, pneumothorax, hemothorax, and pulmonary contusions is similar to that in adults (see chapters 261, "Pulmonary Trauma" and 262, "Cardiac Trauma" in the adult section). Emergency thoracotomy is rarely indicated in pediatric patients and has no role in blunt traumatic arrest in children. Thoracotomy should be considered for children with penetrating chest injuries who lose vital signs during transport or in the trauma bay. Overall, emergency thoracotomy yields minimal improvement in patient survival, poses substantial risk of injury to staff, and carries significant financial impact.\textsuperscript{82,83}

**ABDOMINAL TRAUMA**

Abdominal trauma is the third most commonly injured anatomic region in children but the most common site of initially unrecognized fatal injury and the third leading cause of injury-related mortality in the pediatric population of all ages in the United States after head injuries and thoracic trauma.\textsuperscript{1,84,85} Blunt abdominal trauma accounts for approximately 10% of all trauma admissions to pediatric hospitals and usually results from motor vehicle collisions, pedestrian injuries, falls, or direct trauma (bicycle handlebar), although blunt abdominal trauma is also common in inflicted injuries (see chapter 148).\textsuperscript{86} Penetrating abdominal injuries are less common in children and account for 10% of abdominal injuries, mostly from firearms in adolescents (87% of all pediatric firearm injuries),\textsuperscript{2} although children of all ages suffer firearm-related injuries.\textsuperscript{87} The abdomen is injured in 25% of children with gunshot wounds, and 14% of these injuries are fatal.\textsuperscript{2} Other causes of penetrating injuries in this age group include impalement, animal bites, and stab wounds.

Pediatric anatomy differs from adults and accounts for the different response to abdominal trauma: the abdominal wall and ribs in children are more compliant than in adults, providing less effective protection of intra-abdominal and thoracic structures. The relative size of solid organs is comparatively larger in the child than in the adult, which further increases the potential risk for injury, and a thick capsule limits hemoperitoneum in solid organ injury in children, decreasing the sensitivity of FAST to detect significant injury. The lower intra-abdominal fat content and elastic ligamentous attachments in children (i.e., perinephric fat, sigmoid and ascending colon peritoneal attachments) contribute to increased vulnerability to injury from acceleration-deceleration or abdominal compression. In infants and younger children, the bladder boundaries extend cephalad to just below the umbilicus and the bladder is vulnerable to direct blows to the lower abdomen.

Blunt abdominal trauma can be divided according to the different structures that are involved. Abdominal wall contusions are frequent in children secondary to minor accidents, often sports related. Solid organs are more commonly injured in high-energy mechanisms. The spleen is the most commonly injured solid organ (25% to 39%), followed by the liver (15% to 37%) and kidney (19% to 25%). Hollow viscous injuries involve the jejunum,
duodenum, colon, and stomach (15%) in decreasing order of frequency. Pancreas injuries are less commonly seen in pediatric abdominal trauma (7%).

**CLINICAL DECISION RULES FOR BLUNT ABDOMINAL TRAUMA**

A number of clinical decision rules have been developed to risk stratify children with blunt abdominal trauma. The largest study to date was conducted by the Pediatric Emergency Care Applied Research Network group, in which 20 EDs enrolled 12,044 children with blunt abdominal trauma in a prospective observational study, and an algorithm was used to identify patients at very low risk for intra-abdominal injury requiring intervention (surgery, embolization, transfusion for abdominal bleeding, IV fluid requirement >48 hours). Children are classified as very low risk if they meet the following criteria:

1. No evidence of abdominal wall trauma/seat belt sign or Glasgow coma scale <14 with blunt abdominal trauma
2. No abdominal tenderness on examination
3. No thoracic wall trauma, and no complaints of abdominal pain, decreased bowel sounds, or vomiting

Forty-two percent of the study population met these very low risk criteria, among whom the risk of intra-abdominal injury requiring intervention was 0.1%. The Pediatric Emergency Care Applied Research Network rule has a sensitivity of 97% and negative predictive value of 99.9%.

**SPLENIC INJURIES**

Splenic injury may present with diffuse abdominal pain or localized tenderness in the left upper quadrant. Pain can be referred to the left shoulder from accumulation of blood in subphrenic spaces. Concomitant injuries include left lower rib fractures and pulmonary contusion. The American Association for the Surgery of Trauma grades splenic injuries from 1 to 5 according to the size of the subcapsular hematoma and degree of parenchymal or vascular involvement on CT.

The management of acute splenic injury in children is often nonoperative and is based on observation with serial abdominal examinations and laboratory values (hemoglobin/hematocrit) or imaging; this conservative approach has led to a decreased incidence of postsplenectomy sepsis syndrome. Prognosis is excellent, with full recovery from splenic injury in 90% to 98% of children. Emergent laparotomy is indicated for splenic injury causing hemodynamic instability, massive organ disruption, or continuing transfusion requirements. Surgical options include partial or total splenectomy or splenic autotransplantation (revascularization of splenic tissue in other intra-abdominal locations such as the omental pocket). Children who require splenectomy should receive vaccination against encapsulated bacteria (meningococcal and streptococcal pneumonia) as well as common antibiotic prophylaxis.

**HEPATIC INJURY**

Blunt hepatic trauma is the most common cause of fatal intra-abdominal injury in children. Localized tenderness to the right upper quadrant and diffuse abdominal tenderness are the most common physical findings. The
American Association for the Surgery of Trauma classifies hepatic injuries as grades 1 to 6 according to the size of the subcapsular hematoma and degree of parenchymal and vascular injury. As with splenic injury, conservative management is the rule, dictated by the hemodynamic stability of the patient, and can be achieved in over 90% of traumas. Close monitoring, serial exams, and occasional follow-up imaging are the cornerstones of management. Success rates for nonoperative management are between 85% and 90%.

KIDNEY INJURY

Renal injury is seen with high-energy mechanisms such as motor vehicle and pedestrian collisions, falls, and occasionally sport injuries. Urologic injuries usually accompany other injuries and rarely are the cause of death. The Organ Injury Scaling Committee of the American Association for the Surgery of Trauma grades renal injury from 1 to 5 based on degree of contusion, laceration, subcapsular or retroperitoneal hematomas, and involvement of the vascular hilar structures or collecting system. Contusions and hematomas comprise 60% to 90% of renal injuries, whereas lacerations comprise only 10% of injuries.

Clinical findings include localized flank tenderness, ecchymosis, or a palpable flank mass. Microscopic hematuria is common after blunt trauma and does not require further investigation as an isolated finding; the pediatric trauma victim with microscopic hematuria can be followed clinically and with serial urinalysis and does not require imaging unless indicated for other injuries. Although gross hematuria indicates potential serious injury, up to 50% of patients with vascular hilar injuries have no hematuria. Obtain imaging in patients with history of significant force trauma or with gross hematuria. Approximately 95% of renal injuries can be treated conservatively, although surgical or radiologic intervention is indicated for expanding retroperitoneal hematoma, vascular pedicle injury, or urinomas, and total nephrectomy may be required for major renal vascular injury.

PANCREATIC INJURY

Pancreatic injury is uncommon in children and usually due to focal upper abdomen trauma, often from bicycle handlebar injuries. Pancreatic injuries are difficult to diagnose due to their nonspecific and indolent clinical presentation. When present, the combination of epigastric pain, a palpable abdominal mass, and elevated liver and pancreatic enzymes suggests pancreatic pseudocyst, although this classic triad is rarely seen in children. Pancreatic enzymes are neither sensitive nor specific for pancreatic injury in pediatric blunt abdominal trauma: they can be elevated without otherwise demonstrable pancreatic injury, and are normal in up to 30% of patients with complete pancreatic transection.

Most patients with pancreatic injury respond to conservative supportive management. Severe injuries with parenchymal disruption may lead to pancreatitis and pancreatic pseudocyst formation. Treat traumatic pancreatitis conservatively with close monitoring, often initially in an intensive care setting. Pseudocysts often require surgical or percutaneous drainage, although spontaneous resolution occurs in up to one fourth of children specially with cysts <5 cm. Patients with pancreatic duct injury or transaction more often require surgical exploration and repair.

HOLLOW VISCUS INJURY
Intestinal trauma is less common than solid organ injury and is usually associated with motor vehicle versus pedestrian trauma, seat belt injuries, or inflicted injury. Injury can result from a direct blow producing visceral compression or acceleration-deceleration forces at anatomic points of fixation, resulting in visceral and mesenteric tears. Visceral injuries include bowel perforation, bowel wall hematoma, and mesenteric tears. Acute symptoms are nonspecific and sometimes mild, making the diagnosis difficult. Imaging is less reliable than with solid organ injury due to the minimal and often nonspecific findings. Persistent or worsening abdominal pain, vomiting (particularly bilious), or the development of peritonitis or fever should alert the clinician to the possibility of hollow viscus injury. Surgical exploration is often required for definitive diagnosis.

Duodenal injuries are often associated with handlebar injuries and classically present in a delayed manner 48 to 72 hours after the injury, as expansion of the hematoma causes partial or complete obstruction. Abdominal pain and bilious vomiting are the most common symptoms.95

The seat belt injury complex is a pattern of blunt abdominal injury seen in children who are inappropriately restrained with a lap belt positioned over the abdomen instead of the pelvic girdle. Acceleration-deceleration forces crush the bowel between the seat belt and the spine. Classic findings include a "seat belt sign" (abdominal wall contusion in the distribution of the lap belt), with small bowel injury and Chance fractures of the lumbar spine. Seat belt sign may be present in up to 10% of motor vehicle collisions and, when present, confers a risk of intra-abdominal injury around 80%; the presence of a Chance fracture is associated with a 50% incidence of associated intra-abdominal injury.96,97,98 Small bowel injuries are difficult to diagnose with CT and require a high index of suspicion and serial physical examination and monitoring of labs (lipase, lactate, complete blood cell count).99

**PEDIATRIC SPINE AND SPINAL CORD INJURY**

**PEDIATRIC CERVICAL SPINE TRAUMA**

Any pediatric patient involved in significant trauma has the potential for a cervical spine injury; therefore, immobilize the patient until injury is ruled out either clinically or radiologically to avoid significant morbidity and mortality.100 Guidelines for immobilization and imaging as well as specific injuries are discussed in chapter 139, "Cervical Spine Injury in Infants and Children."

**PEDIATRIC THORACIC AND LUMBAR SPINE TRAUMA**

Children account for only 2% to 5% of all spine injuries, and only 5% of pediatric fractures occur in the spine.101 Twenty to 60% of pediatric spine fractures occur in the thoracic or lumbar spine, with older children experiencing more lumbar fractures and younger children more prone to cervical and thoracic fractures.102 There is a bimodal age distribution in pediatric spine injuries, with one peak in children <5 and another in children >10 years of age. Falls and motor vehicle accidents account for the first peak; motor vehicle accidents account for the majority of spine injuries in older children; and sports-related mechanisms account for the majority of injuries in adolescents.102
The pediatric spine differs from that of adults in that children have greater ligamentous elasticity and flexibility, more horizontal facets, and relatively weak musculature, particularly before the age of 8, with a transition toward adult anatomy and physiology after this age. Distraction forces can result in Salter-type fractures of the thoracolumbar spine in children, and anatomic differences make multilevel injuries more common in children than adults in the setting of compression forces.  

Evaluate the pediatric spine during the secondary survey with careful palpation of the entire spine and paraspinous region for tenderness, step-offs, crepitus, bruising, or open injuries. Physical examination is 87% sensitive and 75% specific for thoracolumbar injuries. In one prospective study, the sensation of "breath arrest" (a feeling of breathlessness in the few seconds immediately following the injury) had a sensitivity of 87%, specificity of 67%, positive predictive value of 69%, and negative predictive value of 86% for predicting thoracolumbar spine fractures.

Obtain anteroposterior and lateral x-rays of the entire spine in all children with symptoms or signs of spinal injury during physical exam, because up to one third of children with spine injury have multilevel imaging. CT scan, although commonly used in adults, exposes children to significant ionizing radiation and should be limited to those with neurologic deficits or significant concern for intra-abdominal or intrathoracic injuries requiring cross-sectional imaging for other reasons. Stable children with thoracolumbar spine injury associated with neurologic deficits should be imaged with MRI.

Thoracolumbar injuries can be classified using the Thoracolumbar Injury Classification and Severity Score System, which appears to be valid in children as well as adults. This scoring system, based on morphology (compression, burst, rotation/translation, or distraction), integrity of posterior ligaments (intact, suspected disruption, confirmed disruption), and neurologic status (intact, nerve root deficits, cord and conus medullaris, and cauda equina function), helps to guide surgical versus nonsurgical management. Generally speaking, most stable fractures are treated conservatively with the use of braces such as the thoracolumbosacral orthosis.

Compression fractures are the most common fracture in the thoracolumbar spine and are usually stable and managed with bracing. Fractures of the spinous or transverse processes are often associated with blunt trauma and carry low risk for associated visceral injury; most of these fractures are managed with analgesics and rest, often without immobilization. The flexion-distraction injury known as the Chance fracture (see Table 258-1) deserves special consideration. This injury typically results from inappropriate restraint of children with a lap belt and is a high-energy flexion injury; this fracture is associated with intra-abdominal injury in up to 40% of children and should prompt a thorough search for such injuries.

**PEDIATRIC SPINAL CORD INJURY AND SPINAL CORD INJURY WITHOUT RADIOGRAPHIC ABNORMALITY**

Pediatric spinal cord injury is uncommon, occurring in 1.99 of 100,000 children. Children <15 years old account for only 10% of spinal cord injuries, which are often related to motor vehicle accidents and involve the cervical spine in 60% to 80% of identified injuries in this age group. Adolescent spine injuries are more often caused by sports-related mechanisms. The mortality rate for children <5 years of age is 18.5%, and most deaths were associated with injuries to the upper cervical spine.
Overall, neurologic recovery is better among children than adults with traumatic spinal cord injury, with incomplete injuries associated with better outcomes. A unique pediatric feature of spinal cord injury is spinal cord injury without radiographic abnormality, which is reported to occur in 4.5% to 35% of children with spinal cord injury and 0.2% of all pediatric traumas. Scoliosis can be a sequel to spinal cord injury, particularly among younger children. Spinal injuries are often associated with other injuries, with rates ranging from 42% to 65% and most commonly involving thoracic structures (pulmonary contusion, pneumothorax, rib fractures) or other contiguous or noncontiguous fractures of the appendicular skeleton or spine.

The clinical evaluation and presentation of spinal cord injury and syndromes as well as the principles of physical examination and stabilization are similar to that of adults (see chapter 258, "Spine Trauma"). As with adults, hypotension with relative bradycardia and flaccid paralysis suggests spinal shock that may require administration of vasopressors, because aggressive fluid administration may worsen spinal cord edema. Corticosteroids are not recommended to treat acute spinal cord injury in children. Steroids increase the risk of infection and do not result in significant neurologic improvements in children.

REFERENCES


