CHAPTER 165

# Pediatric Trauma

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## PRINCIPLES

Trauma is the leading cause of death among children from 1 to 18 years old in the United States, with injuries accounting for more than 8 million annual emergency department (ED) visits.[1] Head injury is the most common cause of pediatric trauma deaths.[2] Motor vehicle collisions (MVCs) account for more than half of all pediatric trauma deaths, whereas nonfatal injuries are primarily due to falls.[1] Other nonfatal injuries vary by age. Young children (<4 years old) experience higher rates of animal bites and burns. School-age children (5 to 9 years old) are more likely to experience bicycle and pedestrian injuries. Older children (>9 years old) have high incidences of both fatal and nonfatal motor vehicle–related trauma and higher incidences of suicide and self-inflicted harm.

### Anatomy and Physiology

Children have distinctive anatomy and unique physiology that impacts the evaluation and management of the pediatric trauma patient (Box 165.1). Force is more widely distributed through the body of a child, making multi-system injuries more likely in children. The younger a patient is, the greater their surface area to weight ratio, resulting in a greater potential for heat loss. Even mild to moderate hypothermia contributes to metabolic acidemia and has direct negative effects on cardiac inotropy, chronotropy, catecholamine responsiveness, platelet function, and drug clearance through both renal and hepatic routes. Maintenance fluid requirements, oxygen extraction and consumption, and glucose utilization are much higher per kilogram in infants and small children than in adults.

A child's physiologic response to injury is different from an adult's, depending on the age and maturation of the child and the severity of the injury. Children have a great capacity to maintain blood pressure despite significant acute blood losses constituting up to 30% of total blood volume.[3] A child's cardiac output is primarily determined by the heart rate and systemic vascular resistance. Compensated shock should be considered and promptly addressed when a child's heart rate is elevated, especially if the capillary refill time is delayed. Changes in heart rate, blood pressure, and extremity perfusion commonly precede cardiorespiratory failure and should be recognized and resuscitation initiated.

## CLINICAL FEATURES

### Initial Assessment Priorities and Primary Survey

The highest priority is ruling out the presence of life- or limb-threatening injuries. Treatment of these injuries precedes continuation of the physical examination. This initial assessment and necessary initial resuscitation efforts occur simultaneously. In general, the assessment and resuscitation phase of the evaluation should be addressed within the first 5 to 10 minutes. Any child with a potentially serious or unstable injury should have continual reassessment. The elements of the primary survey for pediatric trauma patients can be remembered by *A, B, C, D, E,* and *F.*

#### A—Airway and Cervical Spine Stabilization

Chapter 161 describes anatomic considerations that have implications in the management of the pediatric airway. Possible airway obstruction or inability of the child to maintain his or her own airway should be assessed. Spinal motion restriction should be maintained with significant mechanisms, increased risk of spinal injury with trauma (eg, Down syndrome), or signs of neurological injury post trauma. (Evaluation of the cervical spine in children is discussed later in this chapter.) The airway can be opened with a jaw-thrust maneuver. Gurgling or stridor may indicate upper airway obstruction. Maxillofacial trauma, loose teeth, blood, swelling, or vomitus may obstruct the airway, and efforts should be made toward clearing the oropharynx of debris. If an open airway cannot be maintained by noninvasive means, endotracheal intubation (ETI) will be required.

Indications for ETI in a pediatric trauma patient may include (1) inability to ventilate with bag-mask ventilation (BMV) or the need for prolonged control of the airway, (2) Glasgow Coma Score (GCS) of less than 9, (3) respiratory failure from hypoxemia or hypoventilation, and (4) the presence of decompensated shock resistant to initial fluid administration. Box 165.2 lists airway equipment sizes.

#### B—Breathing and Ventilation

Breath sounds and adequacy of chest rise should be assessed. In a young child, this rise occurs in the lower chest and upper abdomen. Both the chest and the abdomen should move concordantly. Discordant motion is referred to as *paradoxical breathing* and is a sign of impending respiratory failure. Respiratory rates that are too fast or too slow can also indicate impending respiratory failure; treatment is assisted ventilation. If assisted ventilation is necessary, BMV should be initiated. Only the volume necessary to cause the chest to rise should be provided. Excessive volume or rate of ventilation can lead to gastric distention (increasing the risk of vomiting and aspiration), which may lead to respiratory embarrassment and potential hypotension caused by decreased venous return and impaired diaphragmatic function. Gastric decompression may be performed in children who are intubated with an orogastric or, when deemed appropriate, a nasogastric tube.

Many factors may compromise ventilatory function in an injured child. These include depressed sensorium, occlusion of the airway, painful restriction of lung expansion, diaphragmatic fatigue, and direct pulmonary injury. Adequate ventilation is dependent upon airway patency and sufficient air exchange. Pulse oximetry measures adequacy of oxygenation but not ventilation. Continuous end-tidal carbon dioxide capnography can better inform ventilatory status. Table 165.1 describes priorities in the assessment of breathing in pediatric trauma patients.

**BOX 165.1**

## Specific Anatomic Differences in Adults and Children: Implications for Pediatric Trauma Management

The child's head-to-body ratio is greater, the brain is less myelinated, and cranial bones are thinner, resulting in more serious head injury.
The child's internal organs are more susceptible to injury based on more anterior placement of liver and spleen, and less protective musculature and subcutaneous tissue mass.
The child's kidney is less well protected and more mobile, making it susceptible to deceleration injury.
The elasticity of the child's chest wall allows for pulmonary injury without skeletal injury.
Growth plates are not yet closed in pediatric patients, leading to Salter-type fractures with possible resultant limb-length abnormalities.
Children have a more tenuous spinal cord blood supply and a greater elasticity of the vertebral column, predisposing them to spinal cord injury without radiographic abnormality (SCIWORA).

**BOX 165.2**

## Equipment Size Estimates for Pediatric Trauma

### ENDOTRACHEAL TUBE SIZE ESTIMATES (SIZING IN MILLIMETERS INTERNAL DIAMETER) AND DEPTH

For children 1 to 10 years old, a length-based resuscitation tape may be used, or ETT size can be estimated by the following formulas:
Cuffed endotracheal tube size (mm) = (Age in years/4) + 3.5
Uncuffed endotracheal tube size (mm) = (Age in years/4) + 4
An ETT 0.5 mm larger and 0.5 mm smaller in internal diameter should also be ready at the bedside.
Depth of ETT (cm) = (tube size) × 3

### LARGEST CHEST TUBE SIZE

Largest chest tube diameter = 4 × the endotracheal tube size

### OROGASTRIC, NASOGASTRIC, OR FOLEY SIZE

Orogastric, nasogastric, or Foley diameter = 2 × ETT size

### FEMORAL LINE SIZING ESTIMATES (WEIGHT BASED)

≥3 kg = 3 F
3–10 kg = 4 F
10–20 kg = 5 F
>20 kg = 6 F

*ETT,* Endotracheal tube.

## C—Circulation and Hemorrhage Control

Shock is a state in which the body is unable to maintain adequate tissue perfusion. Maintenance of systolic blood pressure does not exclude the presence of shock. The pediatric vasculature has the ability to constrict, increasing systemic vascular resistance, in an attempt to maintain splanchnic perfusion. Signs of poor perfusion (cool distal extremities, decreases in peripheral versus central pulse quality, and delayed capillary refill time) are signs of pediatric shock, even when blood pressure is at normal levels. External hemorrhage should be sought and controlled with direct pressure. The assessment of circulation in pediatric trauma patients is described in Box 165.3.

**TABLE 165.1**

## Breathing: Assessment and Treatment

| ASSESSMENT PRIORITIES | INTERVENTIONS |
|---|---|
| Respiratory rate | Fast rates may indicate impending respiratory failure and need for intubation, shock and need for fluid resuscitation, or pain and need for analgesics.<br>Slow rates may indicate impending respiratory failure, head injury, or over-sedation. |
| Chest wall movements | Paradoxical breathing and flail segments may represent impending respiratory failure. 100% oxygen should be provided by non-rebreather mask, and intubation may be considered. |
| Percussion and breath sounds | Consider pneumothorax, hemothorax, or diaphragmatic rupture.<br>For significant pneumothorax or hemothorax, place chest tube. A small pneumothorax in a spontaneously breathing patient may require only close monitoring and oxygen.<br>For hemothorax, transfer to operating room if initial drainage >15 mL/kg or subsequent output >2 mL/kg/hr.<br>For open pneumothorax, seal with three-sided occlusive dressing followed by tube thoracostomy, then seal the remaining side of the occlusive dressing.<br>Diaphragmatic rupture requires surgical consultation. |
| Tracheal deviation | Tension pneumothorax: Needle decompression at second intercostal space, midclavicular line, followed by placement of chest tube; if a chest tube can be immediately placed, needle decompression is not needed. |

**BOX 165.3**

## Circulation Assessment and Treatment in Critical Pediatric Trauma Patients

### ASSESSMENT

Increased heart rate, slow capillary refill, decreased peripheral pulses, and altered sensorium may indicate poor circulation.
Vital signs should be monitored every 5 minutes during the initial assessment.
Continuous oximeter and cardiac monitor.

### TREATMENT AND INTERVENTIONS FOR HYPOVOLEMIC SHOCK FROM TRAUMA

Place two large-bore IV lines (above and below diaphragm when indicated).
Consider central line or intraosseous line placement if peripheral venous access is difficult.
Bolus with 20 mL/kg of warmed normal saline, and repeat if necessary.
Consider intubation and ventilation to decrease work of breathing.
Transfuse 10 to 20 mL/kg PRBC for decompensated shock secondary to blood loss.

*IV,* Intravenous; *PRBC,* packed red blood cells.

## D—Disability Assessment

For assessment of patient disability, a rapid neurologic and mental status evaluation is needed. The assessment of disability in pediatric trauma patients is described in Box 165.4. The alert, verbal,

**BOX 165.4**

### Disability: Neurologic Assessment and Treatment

**ASSESSMENT**

Level of consciousness: Use AVPU scale and age-appropriate Glasgow Coma Scale
Pupil size and reactivity
Extremity movement and tone
Posturing and reflexes

**TREATMENT AND INTERVENTIONS**

Stabilize spinal column with spinal motion restriction techniques.
If GCS <9: RSI.
If altered mental status, obtain a head CT scan and neurosurgical consultation as needed.
With signs of herniation, consider 3% hypertonic saline 6.5–10 mL/kg IV (or mannitol 0.25 to 0.5 g/kg IV), if possible elevate the head of the bed, keep the facing forward, and hyperventilate to a $P_{CO_2}$ of 30 to 35 mm Hg.
Maintain CPP of at least 50 mm Hg in children and 70 mm Hg in adults.
Assess for signs of spinal injury, including respiratory failure and bulbocavernosus reflex or presence of anal wink.

*AVPU,* Alert, verbal, painful, unresponsive; *CPP,* cerebral perfusion pressure; *CT,* computed tomography; *GCS,* Glasgow Coma Score; IV, intravenous; $P_{CO_2}$, partial pressure of carbon dioxide, *RSI,* rapid sequence intubation.

painful, unresponsive (AVPU) system (Box 165.5) and the modified pediatric GCS (Table 165.2) are useful to the emergency clinician to assess level of consciousness as well as motor strength.

### E—Events, Exposure, and Thorough Examination

The historical details of the trauma as well as initial response to the event are key to estimation of risk of injury. Type of force applied, secondary impacts, such as being struck and then ejected from a vehicle or thrown onto the ground, response to the trauma (ie, loss of consciousness, seizure, altered level of consciousness), and initial interventions by emergency medical service (EMS) personnel as applicable.

The trauma patient should be fully undressed to assess for hidden trauma. However, patients should also be kept normothermic, because metabolic needs are greatly increased by hypothermia. The environment of care for pediatric trauma patients should

**BOX 165.5**

### AVPU System

*A*—*A*lert
*V*—Responds to *v*erbal stimuli
*P*—Responds to *p*ainful stimuli
*U*—*U*nresponsive

**TABLE 165.2**

### Glasgow Coma Scale Modified for Pediatric Patients*

| | | | |
|---|---|---|---|
| | EYE OPENING RESPONSE | | |
| **SCORE** | **>1 YEAR OLD** | **<1 YEAR OLD** | |
| 4 | Spontaneous | Spontaneous | |
| 3 | To verbal command | To shout | |
| 2 | To pain | To pain | |
| 1 | None | None | |
| | MOTOR RESPONSE | | |
| **SCORE** | **>1 YEAR OLD** | **<1 YEAR OLD** | |
| 6 | Obeys commands | Spontaneous | |
| 5 | Localizes pain | Localizes pain | |
| 4 | Withdraws to pain | Withdraws to pain | |
| 3 | Abnormal flexion to pain (decorticate) | Abnormal flexion to pain (decorticate) | |
| 2 | Abnormal extension to pain (decerebrate) | Abnormal extension to pain (decerebrate) | |
| 1 | None | None | |
| | VERBAL RESPONSE | | |
| **SCORE** | **>5 YEARS OLD** | **2 TO 5 YEARS OLD** | **0 TO 2 YEARS OLD** |
| 5 | Oriented and converses | Appropriate words and phrases | Babbles, coos appropriately |
| 4 | Confused conversation | Inappropriate words | Cries but is consolable |
| 3 | Inappropriate words | Persistent crying or screaming to pain | Persistent crying or screaming to pain |
| 2 | Incomprehensible sounds | Grunts or moans to pain | Grunts or moans to pain |
| 1 | None | None | None |

*Total score key: severe, <9; moderate, 9-13; mild, 14-15.

**TABLE 165.3**

### Exposure: Assessment and Treatment

| ASSESSMENT PRIORITIES | INTERVENTIONS |
|---|---|
| Full examination | Fully undress.<br>Look under collar and splints.<br>Log roll and examine back.<br>Perform rectal examination if indicated. |
| Imaging | Consider chest and pelvis radiographs.<br>Consider additional imaging of any area of pain or trauma.<br>Perform a bedside FAST examination. |
| Laboratory | Complete blood cell count, type and crossmatch, urinalysis, urine pregnancy test, urine drug screen. |
| Supportive interventions | For pelvic fracture, consider binding to decrease pelvic volume and aid hemostasis.<br>For extremity fractures, consider reduction and splinting.<br>Place urinary catheter and nasogastric or orogastric tube as indicated. |
| Medications | Provide analgesia with IV medications.<br>Tetanus vaccine and tetanus immune globulin for appropriate cases.<br>Antibiotics when indicated. |

*FAST,* Focused assessment with sonography in trauma; *IV,* intravenous.

have an increased ambient temperature, and warmed humidified oxygen, warmed fluids, and warmed blood should be used to avoid heat loss as is possible. Head wraps, and convective warmers or radiant heat sources should be used as soon as possible in newborns and infants, as well as older children when their temperature is 95°F (35°C) or lower. The exposure phase of the survey is often the appropriate time to concurrently begin imaging and further diagnostic testing (Table 165.3).

### F—FAST and Family

The focused assessment with sonography in trauma (FAST) evaluates for traumatic free fluid in the peritoneum and pericardial space and has proved to be useful in children.[4,5] In hemodynamically unstable children, a FAST may point to hemorrhage in the abdomen or the pericardial space and the need for intervention. In hemodynamically stable children, the FAST examination may indicate the need for computed tomography (CT) imaging, closer observation, repeat abdominal examinations, or repeat ultrasound examinations. The extended FAST (eFAST) examination incorporates the addition of lung views to evaluate for pneumothorax or hemothorax.

In the management of children, the family (caregivers) may be added to the primary survey, to remind emergency clinicians to rapidly inform the family of the evaluation and progress and address their concerns. Allowing family members to be present during resuscitations is acceptable and often preferred by families. Some family members choose not to be present, but they should have the choice. We recommend having a staff member dedicated to the family during the resuscitation: to explain treatments, answer questions, and provide emotional support.

## Secondary Survey

After completion of the primary survey and requisite procedures, the secondary survey is performed. The secondary survey is an organized, complete assessment to detect additional injury. A more complete history and examination are obtained. Features of the history that need to be obtained can be remembered by the mnemonic *AMPLE* (Box 165.6). Ongoing assessment of the patient occurs after the secondary survey, and key points are summarized in Box 165.7.

**BOX 165.6**

### AMPLE History

*A*—*A*llergies
*M*—*M*edications
*P*—*P*ast medical history
*L*—*L*ast meal
*E*—*E*vents and *E*nvironment

**BOX 165.7**

### Tasks to Be Completed After the Secondary Survey

- Continuous monitoring of vital signs
- Provision of analgesia, and continuous reassessment of pain
- Antibiotics and tetanus as appropriate
- Ensure urine output of 1 mL/kg/hr
- If patient is intubated, ensure adequate sedation and analgesia
- If head injury is present, frequent neurologic assessment

## MANAGEMENT AND DIAGNOSTIC TESTING

### General Management Principles

In most cases of pediatric trauma, the child is stable and evaluation can proceed without need for intravenous (IV) access or laboratory evaluation. In pediatric patients who have sustained *major* trauma, they should be placed on cardiac and pulse oximetry monitoring, receive supplemental oxygen, and have continuous reassessment of vital signs. Vascular access is best obtained by accessing the upper extremity for the establishment of two large-bore IV lines. In the absence of available upper extremity peripheral sites, lower extremity sites may be used. Many emergency clinicians favor the femoral vein as a safe site for insertion of a central line; preferably under ultrasound guidance (see Box 165.2).

If vascular access is unobtainable or delayed, intraosseous access is a safe, quick, and reliable procedure to access the vascular space. Although most commonly started in the proximal medial tibia just below the growth plate, intraosseous access can be obtained in the proximal humerus, the flattened area of the anterior distal femur, the distal tibia, or even the sternum. Once intraosseous access is obtained, it should be stabilized and secured to ensure it is not accidentally displaced. More than one intraosseous needle may need to be placed (in separate bones), and IV access may be more easily inserted once fluids have been given. Intraosseous placement in a fractured extremity is contraindicated. Medications and blood products can be administered through an intraosseous line.

Other less commonly used vascular access techniques for trauma include venous cut-down and umbilical vein cannulation for neonates. Venous cutdown is a skill not often performed by emergency clinicians and is rarely needed to obtain vascular access in the pediatric trauma patient. If performed, the greater saphenous vein at the ankle is the preferred site. Umbilical vein cannulation can be achieved in infants up to approximately 7 to 10 days old, as long as there is enough of an umbilical stump to perform the procedure.

Most hypovolemic pediatric trauma patients respond to 20 mL/kg boluses of isotonic crystalloid solutions. If 40 mL/kg has not reversed systemic signs of hypoperfusion, an additional 20 mL/kg bolus of crystalloid may be given, and an infusion of packed red blood cells (PRBCs) at 10 mL/kg should be given while investigating for potential sources of shock. In patients in decompensated hemorrhagic shock or cardiopulmonary failure secondary to hemorrhage, crystalloid and blood products should be administered simultaneously. With massive transfusion (blood product volume of ≥40 mL/kg), it is important to add platelets to correct coagulopathy.[6] We recommend plasma, platelets, and PRBCs given in a near 1:1:1 ratio if massive transfusion is expected. This is based predominantly on adult studies.[7-9]

In trauma, shock is most likely hemorrhagic in nature. Cardiogenic shock is rare. However, chest trauma associated with shock should alert the emergency clinician to the possibility of concomitant tension pneumothorax, myocardial injury, or pericardial tamponade. Neurogenic and spinal shock can also occur in traumatic injury and are discussed later in this chapter.

### Physical Examination

After the primary survey, a head-to-toe examination is carefully performed. Specifics of the head examination include inspection and palpation of the skull and facial bones, assessment of pupil size and reactivity, and evaluation of extraocular movements. A funduscopic examination may be considered in cases of possible nonaccidental trauma. A fluorescein examination may reveal occult eye injury. Eye shields (not patches) should be used to protect eyes with possible globe rupture.

Assessment of the cervical spine is done carefully. The patient should be removed from the backboard with spinal motion restriction maintained if not clinically cleared or if at high risk for cervical spine injury. Backboards cause pain and with time skin breakdown at pressure points and should be removed as quickly as possible. There are no common indications to justify leaving children on backboards after their initial evaluation. When the patient is rolled to remove the backboard, palpation of the rest of the spine can take place with an emphasis on evaluating for ecchymosis, tenderness, and step-offs. Obtunded patients and those with signs or symptoms of thoracic or lumbar spine injuries should be carefully moved and positioned to protect them from possible further injury until imaging or return of consciousness allows more definitive assessment.

Assessment of the chest and internal structures involves inspection for wounds and flail segments; palpation for tenderness, crepitus, and point of maximal cardiac impulse; and auscultation for asymmetry or abnormal breath sounds.

The abdominal examination consists of inspection, palpation, and a FAST examination. A "seat belt sign" across the abdomen is a sign of potential serious traumatic injury. Palpation is best done on a cooperative patient but is an insensitive screening test for the presence of an injury.

A digital rectal examination should only be performed when its result has a reasonable chance of changing the patient's treatment.[10] It may provide information on sphincter tone in possible spinal injury and the presence of blood in penetrating trauma but otherwise we recommend it not be done routinely.

Although urethral injury is rare in children, all trauma patients should be assessed for perineal, scrotal, penile, or lower abdominal hematoma and blood at the urethral meatus. If there is concern for urethral injury, a retrograde urethrogram should be completed before the insertion of a urinary catheter.

Extremity examination evaluates for deformities, penetrations, neurologic deficits, and interruptions of perfusion. Fractures may be stabilized with splinting prior to definitive management. Careful and recurrent (especially after interventions such as splinting or reduction) vascular and neurologic examinations should be performed in all cases of extremity injury.

Reexamination of trauma patients throughout their time in the ED is important to ensure that their condition has not changed, that their pain is controlled, and that no injuries are overlooked. Ambulation as appropriate prior to discharge is helpful in uncovering additional injuries identified with previous examinations. Up to 70% of injuries with delayed diagnosis in pediatric trauma are orthopedic in nature.[6]

### Pain Control

Pain control is an essential part of any trauma patient's management. Analgesic medications, immobilization of injured extremities, and nonpharmacologic techniques should all be considered. Please refer to Chapter 162.

## Diagnostic Testing

### Laboratory Studies

Blood sampling for a pediatric trauma patient is no different than that for an adult trauma patient; however, use of smaller blood collection tubes may be necessary in infants and small children.

In hypovolemic shock, hemoglobin alone is unreliable because equilibration will not have occurred at the time of presentation to the ED. Serial hemoglobin measurements may be useful to assess the possibility of ongoing bleeding.[11]

Children's glucose utilization and metabolic rate per kilogram are much greater than those of adults. Any child with a change in mental status after trauma should have a point of care glucose level checked immediately. Any child requiring dextrose owing to hypoglycemia will likely need an ongoing dextrose supply to prevent recurrence of hypoglycemia.

Older pediatric trauma patients should be assessed for substance abuse and depression as contributing factors to the traumatic event. Post-pubertal females or those girls Tanner stage 3 or greater should be tested for pregnancy.

### Radiology

Chest and pelvic radiographs can assess for causes of respiratory failure, sites of blood loss, and causes of shock. In stable, alert children without distracting injuries, the pelvic film may be eliminated if no suggestion of sacral or pelvic fracture is found on thorough clinical examination.[12] Plain pelvic films have been shown to have limited sensitivity in children after blunt trauma.[13] In children with pelvic or sacral tenderness and negative plain radiographs, a CT scan should be strongly considered.

Other imaging is obtained based on the physical examination. For patients sustaining minor trauma, no imaging may be needed. Evaluation of suspected nonaccidental trauma is discussed in detail in Chapter 177.

# SPECIFIC DISORDERS AND INJURIES

## Head Injury

### Principles

Traumatic brain injury is the leading cause of death and disability in children older than 1 year old in the United States.[14-16] Infants and toddlers are more prone to falls from their own height, school-age children are involved in sports injuries and MVCs, and children of all ages are subject to the sequelae of abuse.

Important anatomic variations lead to differences in pediatric and adult head trauma. The cranial vault of a child is larger and heavier in proportion to the total body mass. This predisposes young children to high degrees of torque that are generated by forces along the cervical spine axis. Sutures within the pediatric skull are both protective and detrimental to the outcome of head injury. Although the cranium may be more pliable relative to traumatic insult, forces are generated internally that predispose the pediatric patient to parenchymal injury in the absence of skull fractures. The pediatric brain is less myelinated, with higher water content, predisposing it to shearing forces, further injury, and post-traumatic seizures.

## Clinical Features

The mechanism of the head injury relates to the severity of injury. The height of the fall and the quality of the surface at the point of impact are particularly important with regard to the development of associated injury. Most children fall from their own height, and impact with an object increases the localized force even after a short fall. In MVCs, the type of restraint that was present at the time of the collision should be evaluated because unrestrained and improperly restrained children are more prone to serious injury.

It is also important to establish if alteration of consciousness occurred at the time of the injury event.[17] The behavior of a child after a traumatic event should be assessed with questions related to the presence or absence of irritability, lethargy, personality change, or other alterations in behavior. The prognostic significance of vomiting after pediatric head trauma is unclear. Recurrent vomiting is commonly seen in patients with significant head injury and is often considered in the decision to obtain a CT study; however, in the case of isolated vomiting without other clinical signs, a period of observation is an option.[18]

A brief seizure that occurs immediately after an insult (with rapid return to normal level of consciousness) is commonly called an *impact seizure.* The decision to scan should take into account the mechanism of injury and current neurologic status of the

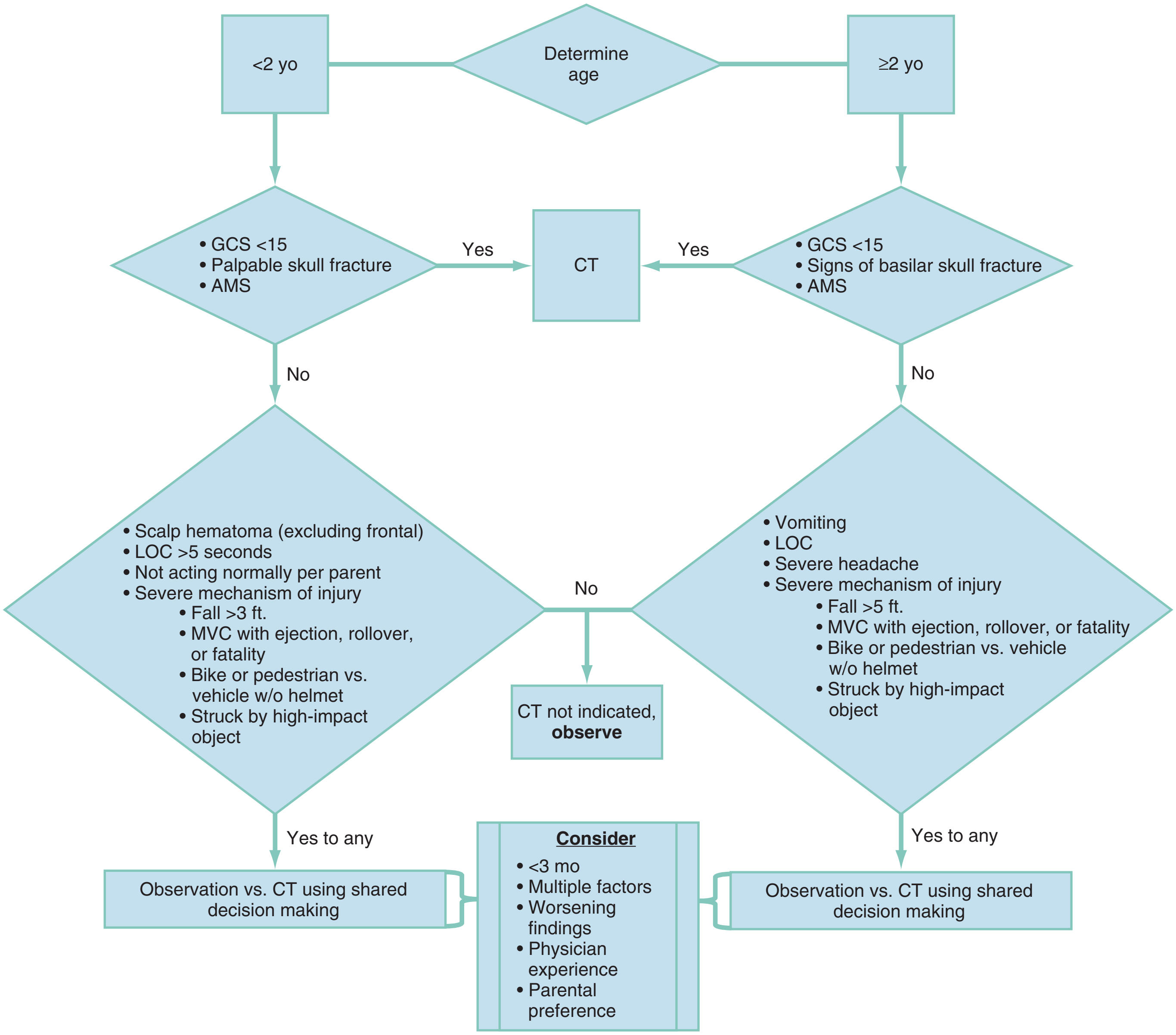


**Fig. 165.1.** Head injury rule chart. AMS, Altered mental status; CT, computed tomography; GCS, Glasgow Coma Score; LOC, loss of consciousness; MVA, motor vehicle collision.

child, but in most cases a CT scan is performed for post-traumatic seizure.[19] If a CT scan is not performed, a period of observation for at least 2 hours in the ED is prudent. Seizures that occur later (more than 20 minutes after the insult) herald a greater possibility of traumatic brain injury and the development of seizures at a later date. A CT scan is indicated for these later post-traumatic seizures. These patients may benefit from treatment with anticonvulsants as having one later seizure (nonimpact) raises the risk of subsequent additional seizures. Seizures also raise ICP, while often decreasing oxygenation and ventilation.

The examination of a head-injured child includes strict attention to the ABCs (airway, breathing, and circulation). Because the pediatric brain is sensitive to decreases in oxygen, perfusion, and glucose, their maintenance reduces further brain insult and optimizes the chances of good recovery. Cerebral perfusion pressure (CPP) is adequate only in the face of a normal mean arterial pressure (MAP). Conceptually, CPP is equal to MAP minus ICP:

$$CPP = MAP - ICP$$

As MAP is reduced, so is CPP. Localized CPP at the site of injury and in the areas surrounding it may vary greatly from this formula's approximations. Pediatric patients with any form of head injury should have an evaluation of their cervical spine for injury.

Several methods are available for evaluating the mental status of head-injured patients, including the AVPU system and the GCS.[20,21] A commonly used modification of the GCS for children is shown in Table 165.2. A child with a head injury should have cranial nerve, motor, sensory, cerebellar, reflex, and memory testing. The most important aspect of motor and cranial nerve evaluation involves ruling out the presence of increased ICP. Common symptoms and signs of increased ICP in infants and children should be sought (Boxes 165.8 and 165.9).

**BOX 165.8**

### Symptoms and Signs of Increased Intracranial Pressure in Infants

- Full fontanel
- Split sutures
- Altered level of consciousness
- Paradoxical irritability
- Persistent emesis
- "Setting sun" sign (bilateral downward gaze of the eyes with apparent inability to elevate the eyes superiorly in a normal manner leading to an area of sclera being seen between the iris and the upper palpebra)

**BOX 165.9**

### Symptoms and Signs of Increased Intracranial Pressure in Infants and Children

- Headache
- Stiff neck
- Photophobia
- Altered state of consciousness
- Persistent emesis
- Cranial nerve involvement
- Papilledema
- Hypertension, bradycardia, and hypoventilation
- Decorticate or decerebrate posturing

## Differential Diagnoses

**Concussion.** A *concussion* is a functional brain injury seen after a blow to the head or body, a fall, or another injury that shakes the brain within the skull.[22] Radiographic studies should be obtained if there are symptoms suggestive of intracranial hemorrhage. In concussions, structural radiographic studies are normal. Patients who sustain concussive insults may have somatic, cognitive, affective, and sleep symptoms. All children with concussive symptoms should be monitored for progression of symptoms by their primary care physician or a concussion recovery specialist. They should undergo both physical and cognitive rest until symptoms have resolved, then return slowly to their baseline activities.

**Scalp Injuries.** Bleeding from scalp wounds is often profuse and can lead to hemodynamic compromise in infants and small children if not quickly controlled. Scalp injuries in infants and children may also involve the development of three injury complexes. For these injury complexes to be better understood, the layers of the *s*kin, *c*onnective tissue, *a*poneurosis, *l*oose areolar tissue, and *p*eriosteum (SCALP) should be considered (Fig. 165.2). *Caput succedaneum* refers to a hematoma in the connective tissue layer. This is freely mobile and crosses suture lines. A *subgaleal hematoma* refers to a hematoma that is subgaleal within the loose areolar tissue above the periosteum. Lastly, *cephalohematoma* refers to a collection of blood under the periosteum. Because the periosteum adheres tightly to the various suture lines, the cephalohematoma does not cross them.

**Skull Fractures.** In children, skull fractures occur in many different configurations. Simple linear non-depressed fractures rarely require therapy and often are associated with good outcomes. Factors associated with poor outcomes include the presence of a fracture overlying a vascular channel (especially the middle meningeal artery), a depressed fracture, or a diastatic fracture. Diastatic fractures, or defects extending through suture lines, are different from simple linear fractures in that leptomeningeal cysts ("growing fractures") may develop at these sites.[23] Leptomeningeal cysts are more common in children younger than 3 years old and are the result of a dural tear and skull fracture. In "growing fractures," the leptomeninges herniate through the dural tear, causing bony erosion around the fracture site.

The presence of cerebrospinal fluid rhinorrhea and otorrhea has been associated with fractures of the skull base. Signs of basilar skull fractures in children are similar to signs in adults and include the presence of periorbital subcutaneous hematoma (raccoon eyes) and posterior auricular ecchymosis (Battle sign). It should be noted that these signs can take hours to days to develop, and therefore absence of these signs cannot rule out basilar skull fractures.

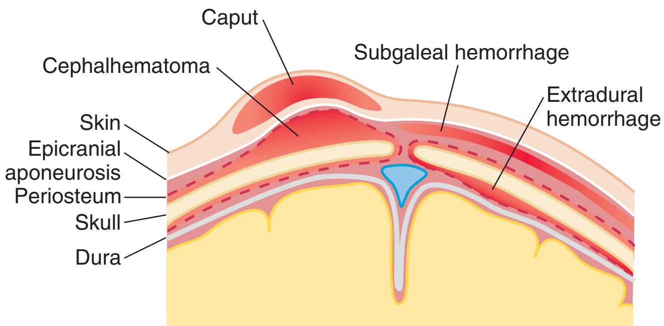


**Fig. 165.2.** Sites of extracranial hemorrhages in the infant. (From Volpe JJ: Neurology of the newborn, ed 4, Philadelphia, 2001, WB Saunders.)

**Cerebral Contusions.** Cerebral contusions are often the result of coup and contrecoup forces. Cerebral contusions may not be associated with any loss of consciousness at the time of insult. Patients often have associated symptoms, such as altered level of consciousness, severe headache, vomiting, or focal deficits on neurologic assessment. Contusions are clearly demonstrable on CT.

**Epidural Hematoma.** Epidural hematomas are typically caused by bleeding from the meningeal vessels and often associated with overlying fractures. Traditional teaching regarding the development of epidural hematomas involves the typical triad of head injury followed by a lucid interval, followed by rapid deterioration as intracranial hemorrhage worsens. After head trauma, guardians are informed of the delayed signs and symptoms that should prompt immediate reassessment.

**Subdural Hematoma.** Subdural hematomas are often secondary to the rupture of bridging veins. Less than half of pediatric cases have overlying fractures. Subdural hematomas most commonly occur in patients younger than 2 years old. Chronic subdural hematomas are associated with "shaken baby syndrome." This clinical complex involves forcible shaking of the child with accelerating and decelerating forces affecting the cranial vault. This syndrome is most often a result of nonaccidental trauma. Subdural hematomas at multiple sites, over areas other than the convexities, in the posterior fossa, or in the posterior interhemispheric fissure should suggest the possibility of nonaccidental trauma. These patients have nonspecific findings, such as vomiting, failure to thrive, change in level of consciousness, or seizures. See Chapter 177 for a more in-depth discussion on nonaccidental trauma.

## Diagnostic Testing and Management

Serial examinations are the most reliable indicators of clinical deterioration. The presence of focal findings on neurological examination is a reliable indicator of a localized insult, whereas the absence of focality may be misleading. The classic Cushing response (bradycardia and hypertension) does not always occur in children; but when it occurs, it is often an ominous sign. If ICP elevation is suspected, emergency intervention and neurosurgical consultation are immediately warranted (Table 165.4).

The contents of the skull are composed of three main compartments: brain, cerebrospinal fluid, and blood. Because the cranial vault is a fixed volume, the Monroe-Kellie doctrine suggests the effects that changes within each compartment may have on the others. For example, in the presence of an intracerebral hemorrhage of significant volume, either cerebral spinal fluid or brain must leave the cranial vault. Similarly, if the brain swells, cerebral spinal fluid, blood, or both must leave the cranial vault. When this balance is disrupted and the autoregulatory system's capacity to adapt is exceeded, the ICP rapidly increases. ICP can quickly reach a level that is not conducive to localized brain survival or continued blood flow to the brain. If the condition is left untreated, herniation may occur.

**TABLE 165.4**

### Emergent Management of Increased Intracranial Pressure

| THERAPY | DOSAGE | MECHANISM OF ACTION |
|---|---|---|
| Head elevation (30 degrees) | | Lowers intracranial venous pressure. |
| Head in midline | | Prevents jugular vein compression. |
| Hyperventilation | Maintenance $Pa{CO_2}$ 38 to 42 mm Hg<br>If acute increase in ICP, then reduce $Pa{CO_2}$ to 30 to 35 mm Hg | Promptly but temporarily decreases cerebral blood volume and thus intracranial pressure.<br>Recommended only for short-term treatment of acute ICP elevation. |
| **HYPEROSMOLAR AGENTS** | | |
| Mannitol (20% solution)<br>Hypertonic saline (HTS) 3% | 0.25 to 0.5 g/kg IV<br>6.5–10 mL/kg IV | Both agents effect rapid osmotic diuresis.<br>Diuresis may decrease BP and CPP.<br>Mannitol should be given through filter.<br>Effect from osmotic and rheologic effects.<br>Avoid dehydration. |
| Pentobarbital | 5 to 10 mg/kg over 30 minutes, then 5 mg/kg/hr for 3 hours, then 1 mg/kg/hr<br>Rarely indicated or started in ED | Thought to lower cerebral metabolism; also may have some effect on free radical formation.<br>Other barbiturates (phenobarbital) have also been used.<br>May decrease BP and CPP. |
| Decompressive craniotomy | | Allows more space for swelling and decreases ICP. |
| Maintain euvolemia | Clinically or invasive monitoring | Maintenance of MAP. |
| Pressors if needed to maintain CBF | Depends on agent used | Maintain CBF and CPP by increasing MAP. |
| Neuromuscular blockade | Depends on agent used | Helps maintain lower ICP. |
| Sedation | Depends on agent used | Do not assume patient is completely incapable of response to noxious stimuli or situation. |
| Prevent fever | Acetaminophen 15 mg/kg orogastrically | Fever raises ICP and metabolic demand. |
| Treat seizure aggressively | Depends on agent used | Prophylactic treatment controversial. Treatment of seizure is not controversial and is aggressive to prevent increased ICP, hypoxia, hyperpyrexia, and hypercarbia. |

*BP,* Blood pressure; *CBF,* cerebral blood flow; *CPP,* cerebral perfusion pressure; *ED,* emergency department; *ICP,* intracranial pressure; *IV,* intravenously; *MAP,* mean arterial pressure; $Pa{CO_2}$, arterial carbon dioxide partial pressure.

Most emergency clinicians favor early and controlled intubation in pediatric trauma patients with GCSs that are deteriorating or are less than 9. For the out-of-hospital phase of care, BMV ventilation is recommended over intubation for support of ventilation and oxygenation.[24] Isolated head injury is uncommon; a careful search for other injuries should be made.

The use of anticonvulsants after moderate to severe head injury in children is controversial. Early prophylaxis does not decrease the incidence of late seizures and is not recommended for this purpose. However, because early seizures after trauma are discordant with the management principles of acute brain injury, some guidelines suggest the use of prophylactic anticonvulsants (most often phenytoin or levetiracetam).[25,26] These decisions should be made in consultation with the neurosurgical service. If a seizure does occur, aggressive management is necessary.

Herniation syndromes in children are similar to those in adults. These are described in Chapter 34. Management of suspected acute herniation begins with immediate controlled hyperventilation.[26] Clinical endpoints of hyperventilation are improved patient status or constriction of dilated pupils. Subsequent management of herniation includes hyperosmolar agents, (mannitol or hypertonic saline) followed by other specific interventions in the intensive care unit (ICU).[26,27]

### Radiology

**Skull Radiographs.** Possible indications for skull radiographs include the skeletal survey involved with the evaluation of child abuse, establishment of a functioning ventricular peritoneal shunt, some penetrating wounds of the scalp, or the suspicion of foreign bodies underlying scalp lacerations. In children requiring neuroimaging because of concern for intracranial injury, a noncontrast CT scan is the recommended test, because plain skull radiography lacks sufficient sensitivity to be used as a screening tool.[28] A recent retrospective cross-sectional study calls into the question the necessity of admission for otherwise neurologically normal children with isolated skull fractures and no concern for nonintentional trauma, because the cost is high and the incidence of neurosurgical intervention in these patients seems very low. In selected cases after neurosurgical consultation, discharge with close outpatient follow-up and return precautions may be acceptable.

**Computed Tomography of the Head.** There has been a considerable amount of research on the indications and relative value of CT scanning in pediatric head-injured patients. CT of the head when appropriately used can be lifesaving and of small individual risk even to children who generally have higher risk than adults due to higher radiation sensitivity, higher likelihood of future imaging studies, longer life expectancy, and the still prevalent higher than necessary radiation dose used for pediatric studies. Although based on extrapolations of data from atomic bomb related cancers, it is generally accepted that the lifetime risk of cancer to an individual due to a CT scan is on the order of one in 500 to 1000. Studies have shown various combinations of characteristics that make significant intracranial injury very unlikely but have provided less guidance in the selection of which patients actually need a head CT scan (high negative predictive value but low positive predictive value).[21,29-31]

As children of different ages manifest intracranial trauma differently, guidelines on CT imaging are age-based. In infants, suspicion of abuse should trigger strong consideration for head CT imaging if signs and symptoms warrant it. For children younger than 2 years old, head CT imaging should be performed in the presence of altered mental status, GCS of 14 or lower, or a palpable skull fracture. In the same age group, occipital, parietal or temporal scalp hematomas, a history of loss of consciousness 5 seconds or more, not acting normally per parent, or a severe mechanism of injury should lead to a period of observation in the ED or head CT. Children older than 2 years old with GCS of 14 or lower, altered mental status, or signs of basilar skull fracture should undergo head CT imaging. A history of loss of consciousness, vomiting, severe headache or severe mechanism of injury should prompt observation or a head CT.[29]

All children who sustain head injury, with or without diagnostic imaging, should be monitored closely for any signs of deterioration. Those with intracranial injury should be admitted to the hospital and seen by the neurosurgery service. Most patients with normal brain CTs or with isolated linear skull fractures in the setting of minor blunt head trauma who have a normal GCS, a stable examination, and no focal neurologic signs may be discharged home.[30] Reliable caretakers should be given specific return precautions for any focal deficit, lethargy, worsening of symptoms, or alteration of consciousness.

## Spinal Injury

### Principles

Spinal cord injury patterns vary with the age of the patient. Although cervical spinal injuries are less common in children than in adults, higher cord level injuries are more common in children and can lead to devastating outcomes. Fractures above the C3 level account for the majority of cervical spinal lesions in children younger than 8 years old, which differs dramatically from the patterns seen in older children and adults.[31,32] Anatomic features of the cervical spine approach adult patterns between 8 and 10 years old (Box 165.10). However, injury patterns identical to those of adults often do not fully manifest until 15 years old.

**BOX 165.10**

**Anatomic Differences in the Pediatric Cervical Spine**

- Cervical spine fulcrum changes from C2 to C3 in toddlers to C5 to C6 by 8 to 12 years old.
- Relatively larger head size, resulting in greater flexion and extension injuries.
- Relatively large occiput in children younger than 2 years old leads to flexion of cervical spine if they are laid flat on standard backboard without support under their scapula and pelvis.
- Smaller neck muscle mass with ligamentous injuries more common than fractures.
- Anterior wedge appearance of cervical vertebral bodies is common.
- Increased flexibility of interspinous ligaments.
- Flatter facet joints with a more horizontal orientation.
- Incomplete ossification, making interpretation of bony alignment difficult (synchondrosis).
- Uncinate processes do not calcify until approximately 7 years old.
- Basilar odontoid synchondrosis fuses at 3 to 7 years old.
- Apical odontoid epiphyses radiographically apparent at 7 years old but may not fuse until approximately 12 years old.
- Posterior arch of C1 fuses at 4 years old.
- Anterior C1 arch may not be visible until 1 year old and fuses at 7 to 10 years old.
- Neural arches fuse to body by approximately 7 years old.
- Posterior arches fuse by 3 to 5 years old.
- Epiphyses of spinous process tips may mimic fractures.
- Predental space 4 to 5 mm in those <8 years old and <3 mm in those ≥8 years old.
- Pseudosubluxation of C2 on C3 seen in 40% of children 8 to 12 years old.
- Prevertebral space size varies with phase of respiration.

The pediatric spine has greater elasticity of the supporting ligamentous structures than the adult spine. The joint capsules of the child have greater elastic properties, and the cartilaginous structures are less calcified than in adults. In the spine, there is a relatively horizontal orientation of the facet joints and uncinate processes, and the anterior surfaces of the vertebral bodies have a more wedge-shaped appearance. Compared with the adult, the child has relatively underdeveloped neck musculature and a disproportionately large and heavy head. These differences lead to an anatomic fulcrum of the spine in children that is at the level of the C2 and C3 vertebrae versus the lower cervical vertebrae as found in adults. These combined anatomic features lead to higher cervical cord injuries and an increased incidence of cord injury without bone injury.[31,32] Thus *s*pinal *c*ord *i*njury *w*ithout *o*bvious *r*adiographic *a*bnormality (SCIWORA) is more common in children. SCIWORA may be a misnomer in the era of magnetic resonance imaging (MRI), because most injuries traditionally described as SCIWORA are seen immediately on MRI, albeit not plain radiographs. Treatment and prognosis are based upon neurologic presentation and MRI findings.[33] Whenever a spinal injury is noted or suspected, careful attention should be paid to the entire spine as multilevel injuries are common.[34]

## Clinical Features

Any patient with severe multiple injuries should be evaluated for spinal cord injury. Likewise, significant head, neck, or back trauma, trauma associated with high-speed MVCs or falls from a height onto the head should raise suspicions for spinal cord injury. The evaluation of a pediatric patient should begin with a primary survey to assess airway patency, ventilatory status, and perfusion. After initial evaluation and stabilization, the cervical region can be examined. Palpation of the neck for pain and bony deformity should be performed. Closely watching the patient's facial expression will often indicate more than asking, "Do you have pain?"

Tenderness or pain with palpation may be underappreciated in a child who is not yet old enough to talk. Similarly, patients with head injury, decreased level of consciousness, or distracting injury, and those who are intoxicated may not reliably localize pain; therefore, spinal motion restriction should be maintained to avoid potential additional injury.

The neurologic examination in a pediatric patient can be difficult, but several factors should be evaluated in a patient with suspected spinal cord injury. Paralysis, perceived paresthesias, ptosis, torticollis, and priapism are neurologic signs highly correlated with spinal cord injuries. Complaints of paralysis or paresthesias, even if completely resolved at the time of examination, should be considered an indication of possible spinal injury. Symptoms that resolve in the ED may be an indication of spinal cord injury from SCIWORA; deficits from an initial stretching of the cord with a rapid deceleration mechanism resolve, only to resurface (even days later) from subsequent cord edema.

Several characteristic spinal cord injury syndromes can be diagnosed on initial ED evaluation. Pediatric presentations of these syndromes are similar to adults and are detailed in Chapter 36. Spinal cord injuries are generally described as either complete or incomplete, depending on the presence or absence of sensory or motor function. Incomplete lesions have some preservation, even if slight, of sensory or motor function below the area of SCI. Incomplete SCI has a better prognosis for recovery of some motor function after spinal shock resolves. The determination of complete or incomplete lesions is not a one-time assessment and cannot be reliably made until after spinal shock has resolved, manifested by return of spinal cord reflexes.

## Diagnostic Testing

Some pediatric trauma patients can safely avoid cervical spine imaging. Patients older than 3 years old do not require imaging if they are alert, have no midline tenderness, neurological deficit, painful distracting injury, unexplained hypotension, or intoxication. In addition to the aforementioned criteria, children younger than 3 years old generally do not require cervical spine imaging if their mechanism of injury is not a MVC, suspected nonaccidental trauma, or a fall from a height of more than 10 feet. Cervical spine imaging should be performed for children not meeting the aforementioned criteria.[35-37]

We recommend cervical spine CT for children with high clinical pretest likelihood for cervical fracture. In young children (<3 years old) at risk for cervical spine injury who are receiving a head CT scan for head injury, emergency clinicians should obtain a C-spine CT to the top of C3. In lower risk populations, plain radiographs should be performed.[37,38] When obtained, plain radiographic evaluation should routinely consist of a cross-table lateral and an anteroposterior view. In children older than 8 years old, an open-mouth odontoid view should also be performed.[36,37] The sensitivity of cervical spine plain radiographs is highly variable. Interpretation of plain cervical spine radiographs in children may be especially challenging because of the anatomic changes that occur with growth (see Box 165.10). In addition, pseudosubluxation of C2 on C3 is common on non-extended cervical spine radiographs in children up to adolescence, occurring in approximately 40% of patients. Pseudosubluxation and true subluxation on non-extended cervical spine radiographs can be distinguished through use of the posterior cervical line and the relationship of the spinolaminar line (also called the *line of Swischuk*) to the anterior cortical margin of the spinous process at C2 (Fig. 165.3). This line should maintain its integrity with no more than 1.5 mm of deviation. Exceptions to this guideline do occur, and the clinical scenario is taken into account before it is applied. Pseudosubluxation may be seen less commonly at C3 to C4.

An important criterion for radiographic clearing of the cervical spine is complete visualization of all seven cervical vertebral bodies on plain film down to and including the C7 to T1 interface. The predental space should be less than 5 mm in children younger than 6 years old, and the prevertebral soft tissue space should not be greater than normal (variable but generally one-third to one-half the vertebral body width through C4, and <14 mm at C6). The four cervical radiographic lines should be evaluated, and the atlanto-occipital alignment should be assessed for dislocation in this region. If there is any question of injury, thin-section CT and MRI can be used to delineate injury. If the dens cannot be adequately assessed by the open-mouth odontoid view, then a transforaminal view or CT scan should be used. Patients with high clinical suspicion for fracture but negative plain radiographs should be considered candidates for CT or MRI radiographic evaluation and specialist consultation.

The pretest likelihood of fracture is considered when decisions are being made regarding the removal of cervical immobilization in children with apparently normal imaging. Patients with continued neck pain despite negative radiographs or CT may require MRI evaluation.[39] Rare cases may necessitate evaluation by neurosurgery under fluoroscopy. The use of flexion-extension views in the ED is rarely indicated nor helpful. If ligamentous injury is suspected, a MRI should be obtained; and if MRI is not available, consider CT in consultation with neurosurgery.

Young children are at greater risk for upper cervical spine injury. Many occipital cervical junction injuries are immediately fatal. However, survival is possible in some cases. Early detection and immobilization is crucial. Occipital cervical junction injuries should be suspected in any pediatric pedestrian versus vehicle

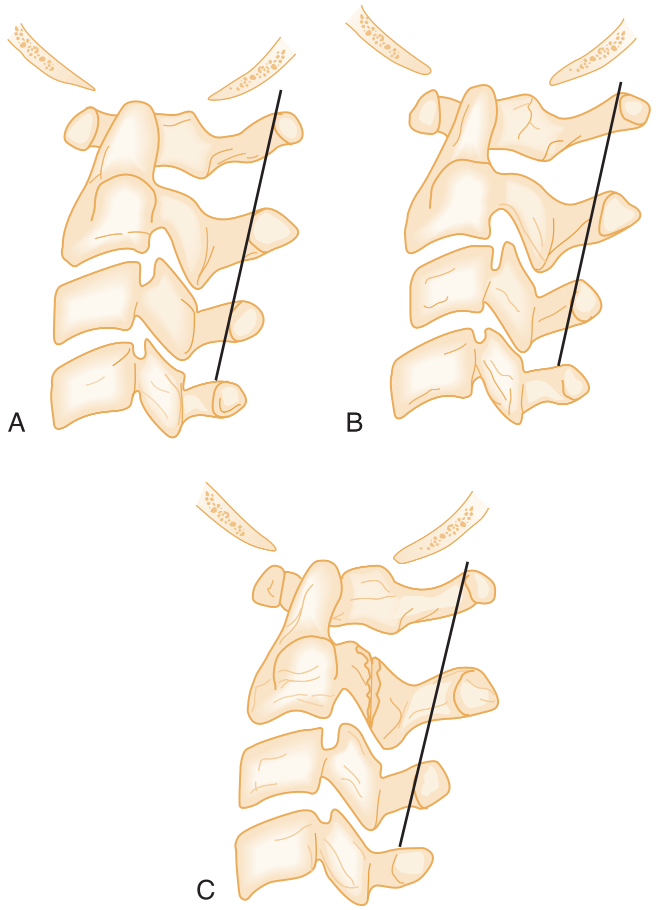


**Fig. 165.3.** Spinolaminar line. Use only to access anterior displacement of C2 on C3. A line is drawn from the cortex of the spinous process of C1 to the cortex of the spinous process of C3, and the relationship of the spinous process of C2 is noted. **A,** Normal line passing through the cortex of C2. **B,** Normal line passing within 1.5 mm of the cortex of C2. **C,** Abnormal line passing more than 1.5 mm anterior to the cortex of C2, suggesting underlying fracture of posterior elements of C2. (From American Academy of Pediatrics and American College of Emergency Physicians: APLS: the pediatric emergency medicine resource, ed 4, Sudbury, MA, 2004, Jones and Bartlett Publishers.)

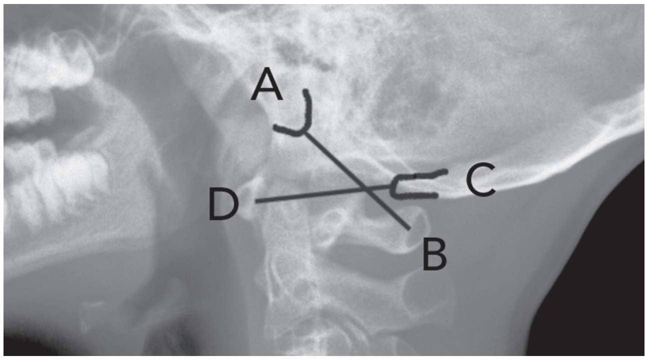


**Fig. 165.4.** Power's ratio is calculated as the ratio of the distance from the basion (midpoint of the anterior margin of the foramen magnum) *(A)* to the anterior cortex of the posterior arch of the atlas *(B)* divided by the distance from the opisthion (median (midline) point of the posterior margin of the foramen magnum) *(C)* to the posterior cortex of the anterior arch of the atlas *(D)*. A ratio of AB:CD greater than 1 indicates an atlanto-occipital dislocation. The figure shows a normal Power's ratio.

accident, especially if the child has a laceration under the chin from a forward fall. In many fatal cases, distraction and displacement are obvious. However, in nonfatal cases, they can be subtle. A Power's ratio greater than 1 indicates an atlanto-occipital dislocation until proven otherwise (normal, approximately 0.77). Power's ratio is shown in Figure 165.4.

A traumatic or even sometimes nontraumatic atlantoaxial rotatory subluxation should be suspected in a child with a fixed rotatory cervical abnormality. Classically, this can be differentiated from a muscular torticollis in nontraumatic cases by the history, the time course, and the presence of palpable spasm of the sternocleidomastoid muscle on the side contralateral to the direction in which the chin is pointing in the case of torticollis. When atlantoaxial rotatory subluxation cannot be confidently ruled out clinically, plain radiographs or CT should be used.

In children with upper cervical spine tenderness, it is prudent to consider a fracture of the synchondrosis between the odontoid and C2. This can be difficult to diagnose on plain radiographs, but it is often recognized as a subtle anterior tilt to the odontoid on C2. A CT scan with sagittal reconstructions will clarify this entity.[40]

## Management

There are two phases of spinal cord injury. Direct injury (initial phase) results in largely irreversible injury to the spinal cord. Indirect injury results from preventable or reversible injury to the spinal cord secondary to ischemia, hypoxemia, and tissue toxicity. Resuscitation of a patient with injury to the cervical spine should focus on prevention or minimization of the indirect causes of injury to the cervical spine. Management of possible spinal cord or column injury should begin in the out-of-hospital phase of emergency care. Most injured children arrive at the ED with adequate immobilization. For transport, the child who requires spinal motion restriction should be immobilized with a stiff cervical collar, a rigid backboard, and external fixation by means of head blocks, cloth tape, or straps to provide adequate precautions. Appropriate padding should be placed under the shoulder blades of the patient to approximate neutral alignment of the cervical spine and help prevent pressure-related injury. Some out-of-hospital protocols call for small children to be immobilized in their car seats. In the hospital, spinal immobilization should be maintained throughout the evaluation. However, even when thoracic or lumbar fractures exist, patients should be expeditiously removed from the backboard to prevent discomfort and morbidity. Sliding boards (smooth movers) can be used to move patients onto scanner tables and back to their trauma beds.

Breathing should be assessed to determine the presence of hypoventilation. Patients with spinal cord injury may hypoventilate because of diminished diaphragmatic activity or intercostal muscle paralysis. Supplemental oxygen should be given routinely, and ventilatory assistance by BMV or definitive airway management should be considered in the presence of clinically significant hypoventilation.

Circulatory status should also be addressed early to prevent end-organ perfusion deficits. Hypotension can result from hypovolemia, neurogenic shock, spinal shock, or other less common causes. Spinal shock usually results from injury above the level of T1. It manifests with lower extremity findings of spinal cord injury, with flaccid paralysis of skeletal and smooth muscle leading to the appearance of a relative hypovolemia caused by diminished systemic vascular resistance. Spinal shock generally resolves in hours to approximately 1 day once some spinal level reflexes return below the site of injury. Neurogenic shock typically occurs after injury to the spinal cord above the level of approximately T6. Patients with neurogenic shock lose their sympathetic tone and demonstrate hypotension in the face of unopposed parasympathetic action, such as bradycardia. In each case, fluid administration, parasympathetic receptor blocking agents (such as, atropine or glycopyrrolate) and vasopressors with chronotropic, vasoactive, and inotropic characteristics (eg, dopamine) are used. If spinal shock with normal chronotropy and inotropy is found, then fluids and agents with more peripheral vascular vasoconstrictive properties may be preferable, such as phenylephrine or norepinephrine. Spinal and neurogenic shock remain diagnoses of exclusion once hemorrhagic shock has been definitively eliminated.

Immediate evaluation by a spinal cord specialist should be sought for all children with spinal cord injury. In the absence of such a specialist, the patient should be transported to a center with adequate facilities to care for spinal cord–injured patients.

## Cardiothoracic Injury

### Principles

Most serious chest injuries in children are caused by blunt trauma and result from MVCs, pedestrian accidents, and falls. Isolated chest injury is a relatively infrequent occurrence considering the typical mechanisms of blunt trauma in the pediatric patient. Pediatric trauma patients with thoracic injury have a twentyfold increase in mortality over pediatric trauma patients without thoracic trauma.[41] Sequelae of blunt injury include pulmonary contusion, pneumothorax, hemothorax, myocardial injury, pericardial injury, vascular injury, and rib fractures.

Children subjected to penetrating trauma, in contrast to the injuries associated with blunt trauma, often die from the primary insult. Nationwide misuse of firearms has resulted in an increasing incidence of penetrating trauma, often with children as victims.

Specific clinical patterns should alert the emergency clinician to the potential for concurrent abdominal and thoracic injury. Any patient with penetrating trauma at or below the level of the nipples falls into this category. Apparent isolated thoracic trauma does not exclude abdominal injury.

It is important to understand the physiology of pediatric respiration in considering the potential for early decompensation after chest injury; any impairment of diaphragmatic mobility compromises ventilation. The presence of gastric distention elevates the diaphragm and severely diminishes the vital capacity of a child. In addition, the particular types of muscle fibers involved in the diaphragm of infants and young children predispose them to the sudden development of apnea when these muscles become fatigued. Unlike adults, whose thoracic wall musculature can pull the ribs up anteriorly to give a larger circumference to the chest wall, children's chest wall circumference does not change drastically during respiration, because a child's chest is barrel-like throughout the respiratory cycle. This also decreases the ability of children to increase their vital capacity. For these reasons, children will increase ventilation typically by increasing their respiratory rate. Most important, the presence of adequate oxygenation in a pediatric patient does not always ensure sufficiency of ventilation, necessitating confirmatory auscultation. End-tidal carbon dioxide capnography can be very useful in this regard in both the intubated and the nonintubated trauma patient.

Infants and children are anatomically protected against blunt thoracic cage trauma because of the compliance of the rib cage. Compressibility of the rib cage dissipates the force of impact, which lessens the likelihood of bony injury. However, this protective mechanism may mask complex pediatric thoracic insults. The compliance of the rib cage allows significant injury to occur with little apparent external signs of trauma. Multiple rib fractures are a marker of serious injury in children. In addition, the pediatric mediastinum is mobile, which favors the development of rapid ventilatory and circulatory collapse in the presence of a tension pneumothorax.

### Specific Disorders

**Pneumothorax.** The development of a traumatic pneumothorax is commonly associated with significant pulmonary injury. In contrast to spontaneous pneumothoraces, these insults do not resolve spontaneously and often are associated with the presence of a hemothorax. Signs and symptoms include external evidence of chest trauma, such as abrasion, contusion, or ecchymoses; tachypnea; respiratory distress; hypoxemia; and chest pain. Decreased breath sounds may not be appreciated in children with pneumothoraces because of the wide transmission of breath sounds in the chest and upper abdomen. Emergency clinicians should listen to the chest from the axilla in children; this location helps with lateralization to distinguish decreased breath sounds on one side compared with the other. Extended FAST procedure performed by the emergency clinician during the initial trauma evaluation, utilizing B mode and M mode ultrasound, have high sensitivity and accuracy for diagnosing pneumothorax. Plain radiography should be performed, however ultrasound of the chest has high sensitivity in detecting pneumothorax in a child and should be performed when a pneumothorax is suspected but not present on plain radiography.

Management of a hemopneumothorax includes the placement of a large-caliber chest tube (largest tube that can fit between the ribs; or estimated as four times the endotracheal tube size) far enough posteriorly, near the mid-axillary line, to prevent encroaching on more anterior soft tissue that will later become part of the breast. Chest tube size for hemopneumothorax management can be found in Box 165.2 or on a length-based resuscitation tape. A chest tube should be considered for any patient with a pneumothorax who will be undergoing mechanical ventilation. Some small (<20%) simple pneumothoraces without tension may be managed with observation and 100% oxygen supplementation in a child not being mechanically ventilated. Reassessment can be accomplished by repeat chest radiographs at selected intervals, or a pigtail catheter can be placed percutaneously.

**Open Pneumothorax.** An open pneumothorax exists when the chest wall is injured sufficiently to allow bidirectional flow of air through the wound. The patient is unable to expand the lung because of equalization of pressures between the atmosphere and the chest cavity. Ventilation and oxygenation are severely impaired.

Management of an open pneumothorax is dictated by the size of the defect and the amount of respiratory compromise. A simple, small, open pneumothorax in a breathing patient may be treated by covering the chest wall defect with occlusive dressing, such as sterile petroleum gauze, and performing a separate incision for a thoracostomy tube. Defects that are too large to seal adequately and patients with ventilatory failure are candidates for intubation.

In the out-of-hospital setting, a bandage applied over an open pneumothorax wound and taped on three sides as a temporizing measure may allow air to escape during expiration but not to enter during inspiration.

**Tension Pneumothorax.** Pulmonary air leaks that occur in a one-way valve arrangement favor the development of a tension pneumothorax. Increasing amounts of free air within the pleural cavity cause the mediastinal structures to shift toward the opposite side, compromising cardiac output. The final common pathway involves hypoxia, hypotension, and refractory shock. Most patients with tension pneumothoraces have severe respiratory distress, decreased breath sounds (often bilaterally), and a shift in the point of maximal cardiac impulse. In the worst scenario, there is mediastinal shift, contralateral tracheal deviation, and distention of the neck veins with decreased venous return to the thorax. In pediatric patients, signs of tension pneumothorax are often subtle. A short neck and increased soft tissue may make detection of tracheal deviation difficult. The emergency clinician should consider the diagnosis of tension pneumothorax and, if it is detected or strongly suspected, should treat with needle thoracostomy or chest tube decompression.

Immediate treatment includes needle thoracostomy placed in the second intercostal space in the midclavicular line or in the fourth intercostal space just above the rib and anterior to the mid-axillary line. The needle should be placed above the rib margin to avoid injuring the intercostal vessels. In the ED, definitive treatment involves the use of a large-caliber thoracostomy tube that favors drainage of the tension pneumothorax and any accompanying hemothorax.

**Hemothorax.** Significant bleeding may occur as a result of injury to intercostal vessels, internal mammary vessels, or lung parenchyma. Without an upright chest radiograph, it is difficult to quantify the degree of bleeding on plain films. The only sign of hemothorax on a supine radiograph may be a slightly less radiolucent appearance on the affected side of the chest. Clinically, patients have decreased breath sounds and dullness to percussion on the affected side. A pneumothorax may coexist with a hemothorax.

The treatment of hemothorax includes a tube thoracostomy. The tube needs to be large enough to occupy most of the intercostal space and should be placed laterally and directed posteriorly. In the supine patient with simple pneumothorax, chest tubes are directed superiorly; in hemopneumothorax, they are directed posteromedially. Repeat chest radiographs should be obtained to confirm tube position and document improvement in lung expansion.

Development of a massive hemothorax is rare in children and is associated most often with severe impact, such as that seen in high-velocity MVCs, falls from extreme heights, or the use of high-powered firearms. Any alteration in cardiovascular sufficiency should be treated with rapid fluid replacement with isotonic crystalloid solutions. The emergency clinician should also prepare for transfusion with the institution of red blood cell (RBC) replacement as necessary. Patients with profound shock may receive either type-specific or O-negative blood; crossmatched blood may be used for more stable patients. Many centers have the capability to salvage blood from hemothoraces and to reinfuse it through use of an autotransfusor. The emergency clinician is often able to stabilize the patient with RBC replacement until surgical intervention is achieved.

Indications for thoracotomy in an operating room include evacuated blood volumes exceeding 15 mL of blood per kilogram immediately after the placement of the chest tube, persistent blood loss (exceeding 2 to 4 mL/kg/hr over 3 hours), or continued air leak.

ED thoracotomy is reserved for patients with thoracic trauma who deteriorate to cardiopulmonary arrest despite maximal resuscitation in the out-of-hospital setting or ED. For both children and adults, it has been shown to be more effective in cases of penetrating trauma.[42-44] In patients with penetrating chest trauma and cardiopulmonary resuscitation (CPR) for less than 15 minutes, a left anterior thoracotomy may be warranted. Patients with blunt trauma should undergo rapid assessment by ultrasound for tamponade. If tamponade is present and CPR has been performed for less than 10 minutes, then a left anterior thoracotomy may be indicated.[45] Suggested contraindications to ED resuscitative thoracotomy after out-of-hospital CPR include (1) blunt trauma with CPR for longer than 10 minutes with asystole and no signs of life on presentation without ultrasound evidence of cardiac tamponade and (2) penetrating trauma with CPR for greater than 15 minutes and asystole with no signs of life on arrival without ultrasound evidence of cardiac tamponade.[45]

**Pulmonary Contusion.** Penetrating and blunt thoracic trauma may result in the development of a pulmonary contusion. The compliance of the rib cage in children renders them susceptible to the development of pulmonary contusion even in the absence of external signs of chest trauma. Injury to capillary membranes allows blood to collect within the interstitial spaces, resulting in hypoxia and respiratory distress. If bleeding is severe enough, oxygenation and ventilation are impaired. Initial chest radiographs may not show the classic findings of pulmonary consolidation. In addition, in the early stages of injury, blood gases may be normal.

Treatment of pulmonary contusions includes a careful evaluation for the presence of additional injuries because significant force is necessary to cause the contusions. Most patients may be treated with supplemental oxygen and close monitoring. Most pulmonary contusions resolve without sequelae. Rare cases are associated with the development of acute respiratory distress syndrome.

**Traumatic Diaphragmatic Hernia.** Children involved in MVCs who are wearing lap belts are predisposed to the development of diaphragmatic herniation. Mechanisms of injury involve sudden increases in intra-abdominal pressure. Patients initially are in stable condition, with the degree of respiratory distress directly proportional to the amount of abdominal contents that protrude into the pulmonary space. The presence of bruising from lap belt–only compression should alert the clinician to the possibility of diaphragmatic hernia and other intra-abdominal injuries (small bowel injury) and the possibility of associated thoracolumbar spinal insults, such as Chance fractures. Most commonly, the herniation occurs on the left side because the liver prevents herniation of bowel on the right.

Initial management for these patients involves placement of a nasogastric tube to decompress the stomach. In cases of severe respiratory distress, intubation is indicated. BMV is avoided whenever possible. Surgery is required for repair of the injury.

**Cardiac and Vascular Injuries.** Injuries to the heart and large vessels are uncommon in children and rarely happen in isolation. In cardiac and vascular injuries, an electrocardiogram may show tachycardia with low voltage (pericardial tamponade), findings consistent with acute myocardial ischemia, or a variety of other nonspecific abnormalities. Patients with dysrhythmias, ST-segment abnormalities, and hypotension (without another cause) should be admitted with a pediatric cardiologist consulted and undergo further testing (eg, echocardiogram).

The most common traumatic cardiovascular injury sustained by children is myocardial contusion. Patients often have chest wall tenderness or may report generalized chest pain. Tachycardia is the most common finding. Echocardiogram may be diagnostic. Patients with myocardial contusions should be monitored closely for the development of dysrhythmias and impaired myocardial function; however, in most cases of myocardial contusion, there are no long-term sequelae.

The most life-threatening scenario involving the cardiac structures is the development of cardiac tamponade. Penetrating wounds with myocardial penetration and tamponade are potentially survivable if recognized immediately. Extravasated blood fills the pericardial space and impairs cardiac filling during diastole. Clinically, patients demonstrate tachycardia, distant heart sounds, narrow pulse pressure, jugular venous distention, and pulsus paradoxus. In the scenario of profound hypovolemia, venous distention is absent. The final common pathway involves the development of cardiopulmonary failure and pulseless electrical activity. Ultrasound can characterize cardiac tamponade in seconds and guide therapy.

Bedside ultrasound or echocardiography defines the degree of pericardial effusion present and the significance of any diastolic dysfunction present. Pericardiocentesis may be attempted, as treatment involves drainage of the fluid from the pericardial sac. However, significant hemodynamic compromise from an acute traumatic pericardial effusion is rarely adequately addressed with a needle pericardiocentesis, owing to the amount of cardiac bleeding and subpericardial clot. Performance of a thoracotomy or pericardial window is often necessary to evacuate the pericardium adequately.

**Commotio Cordis.** Commotio cordis is a disorder described in pediatric patients that results from sudden impact to the anterior chest wall (eg, when a child is struck in the chest with a thrown or hit baseball), which causes cessation of normal cardiac function. The patient may have an immediate dysrhythmia or ventricular fibrillation that is refractory to resuscitation efforts. Significant morbidity and mortality are associated with this disorder, and although most patients recover completely, some require extended treatment with antiarrhythmic agents, cardiac pacemaker placement, inotropic agents, or an intra-aortic balloon pump.[46] In patients with prolonged cardiac instability, cardiogenic shock and death may occur despite maximal therapeutic intervention.

## Abdominal Injury

### Principles

Abdominal trauma is the third leading cause of traumatic death in children after head and thoracic injuries.[1] Blunt trauma related to MVCs causes more than half of abdominal injuries in children and is the most lethal. "Lap belt" injury, including small bowel injury and Chance fractures, may occur in restrained children involved in MVCs.[47] Another common cause of abdominal injury involves handlebar injuries from bicycle crashes.[48-50] Often, the effects of bicycle injuries may not be seen on initial presentation, with the mean elapsed time to onset of symptoms being nearly 24 hours after injury. All children with epigastric pain after blunt trauma, especially when concentrated force has been applied in this area, should be considered to have a duodenal hematoma or pancreatic injury.

Sports-related injuries are another common cause of pediatric abdominal trauma. Sports-related injuries are associated most commonly with isolated organ injury as a result of a blow to the abdomen.[39,51] At particular risk are the spleen, kidney, and intestinal tract. Finally, abdominal injury is second only to head injury as a cause of death in child abuse cases. All abuse victims should be screened carefully for abdominal trauma (see Chapter 177).[52,53]

The anatomy of the child lends special protection from some abdominal injury patterns and predisposes the child to other types of injuries. Children have proportionally larger solid organs, less subcutaneous fat, and less protective abdominal musculature than adults. Therefore they have relatively more solid-organ injury. Children have relatively larger kidneys with fetal lobulations that predispose them to renal injury. Children also have a fairly flexible cartilaginous rib cage that allows for significant excursion of the lower chest wall, permitting compression of the internal organs. The combination of these factors provides the basis for the differences in abdominal injury patterns seen between children and adults.

### Clinical Features

Pediatric patients with multiple injuries often have blunt abdominal injury. In children, history is often limited, traditional signs of decompensation are often not as evident, and physical examination can be difficult.

Signs and symptoms of abdominal injury in children include tachypnea from impaired diaphragmatic excursion, abdominal tenderness, ecchymoses, and signs of shock. Restrained children involved in MVCs with abdominal bruising are much more likely to have an intra-abdominal injury than those without bruising. Abdominal distention is a common nonspecific finding that is often the result of air swallowing subsequent to a painful event.

Children with hepatic and splenic injuries may have trouble localizing their pain. Kehr's sign (left shoulder pain with spleen injury) may be the only indication of an intra-abdominal injury. Any abdominal tenderness on examination should prompt further evaluation of the abdomen. Vomiting can be associated with duodenal hematoma or traumatic pancreatic injury but is usually a late sign. Signs of small bowel injury may be delayed and noted clinically only with serial examinations.

Pelvic bone stability should be assessed in cases of abdominal trauma, and a genital examination searching for signs of injury should be performed. Rectal examination is insensitive and nonspecific when used as a general screening test for all patients after serious trauma.[10] Rectal examination should only be performed in patients with concern for specific injuries: such as for rectal tone when there is concern for spinal injury, or to evaluate for blood in the case of penetrating colon injury.

Even minor falls can result in significant splenic injury. Repeated examination, prolonged observation, and close attention to vital signs are warranted for children who have sustained a direct blow to the abdomen. Any child with clinically suspicious abdominal examination findings or significant direct trauma should be evaluated further with additional radiologic and laboratory studies or admission for serial examinations.

### Diagnostic Testing and Management

In patients with suspected abdominal injury, management and resuscitation must be rapid. In children who have undergone major trauma and have no evidence of urethral trauma, a urinary catheter should be considered for bladder decompression, evaluation for the presence of urinary retention, examination for the presence of blood in the urine, and monitoring of urine output. Urinary catheter size estimates are shown in Box 165.2.

A careful examination and diagnostic laboratory testing can be useful in identifying children at lower risk for intraabdominal injury. Intraabdominal injury is unlikely in the absence of the following: hypotension (age-adjusted), abdominal tenderness, a femur fracture, increased liver enzyme levels (serum aspartate aminotransferase concentration >200 U/L or serum alanine aminotransferase concentration >125 U/L), microscopic hematuria (urinalysis >5 RBCs/high powered field), or an initial hematocrit level less than 30.[54,55] Liver enzyme testing is particularly useful to risk stratify patients with equivocal examination finings. Victims of suspected child abuse should also undergo liver enzyme testing and those with transaminase levels more than 80 U/L should undergo CT of abdomen and pelvis to assess for abdominal injury.[52]

The diagnostic test of choice to assess intra-abdominal injury in stable patients at high risk for injury is abdominal CT. The FAST examination can be a useful adjunct.[4,5] The finding of intraperitoneal hemorrhage alone on ultrasound is not necessarily an indication for surgery in a stable pediatric patient; but when the FAST is positive, it will clarify the need for abdominal CT, close observation, and possible repeat ultrasound examinations.

**BOX 165.11**

### Indications for Laparotomy

- Hemodynamic instability despite aggressive resuscitation and appropriate ED procedures (eg, a decompression hemothorax or tension pneumothorax)
- Hemodynamic instability despite resuscitative efforts and evidence of intraperitoneal free fluid on bedside ultrasound examination (FAST)
- Transfusion of ≥50% of total blood volume because of massive intraperitoneal bleeding
- Radiographic evidence of pneumoperitoneum, intraperitoneal bladder rupture, grade V renovascular injury
- Gunshot wound to the abdomen
- Evisceration of intraperitoneal or stomach contents
- Signs of peritonitis

*ED,* Emergency department; *FAST,* focused assessment with sonography in trauma.

In hemodynamically unstable children, FAST may point to the abdomen as the source of hemorrhage and may expedite the decision to operate.

Indications for laparotomy are listed in Box 165.11. Patients who remain hypotensive after adequate crystalloid infusion, have active arterial bleeding on CT scan, or have consistent decreases in their hemoglobin level are likely candidates for early invasive intervention. Exploratory laparoscopy or laparotomy is often required for these critically injured patients, but patients with a known source of bleeding may be appropriate candidates for arterial embolization in an angiography suite.[55]

**Spleen Injury.** Injuries to the spleen are the most common injuries in pediatric abdominal trauma. Children with injuries from MVCs, sudden deceleration injuries, and contact sports–related injuries may sustain splenic trauma. Typical findings include left upper quadrant abdominal pain radiating to the left shoulder. The abdominal examination may show evidence of peritoneal irritation in the left upper quadrant of the abdomen. Patients may be hemodynamically stable or, after significant splenic rupture or laceration, may be persistently hypotensive or in fulminant cardiovascular collapse. Stable patients may undergo CT for radiologic evaluation.

Most often with minor splenic trauma, bleeding is controlled spontaneously without operative intervention; however, all patients with a splenic injury should be evaluated by a surgeon. In patients with a contained splenic subcapsular hematoma, extracapsular bleeding may occur days after capsular rupture. Patients with splenic injury should be admitted to the hospital for close observation and repeated examinations. Because of the desire for splenic salvage to maintain immunocompetency, an injured spleen is often left in place as long as the patient can be resuscitated adequately with crystalloid and blood products.

**Liver Injury.** The liver is the second most commonly injured solid organ in the pediatric patient with abdominal trauma; however, it is the most common cause of lethal hemorrhage. Tenderness on palpation of the right upper quadrant of the abdomen, the complaint of abdominal pain in this region, and pain in the right shoulder are signs of possible liver injury. Patients managed conservatively with crystalloid and/or blood transfusion often do well. Once liver injury is detected on CT scan, close observation in the hospital, serial abdominal examinations, and serial hemoglobin measurements are recommended.

**Renal Injury.** The kidney is more susceptible to injury in children than in the adults due to the potential for remnant fetal lobules, increased organ mobility with rapid deceleration mechanisms, and lack of protective intraabdominal musculature; there is also a tendency for congenital renal abnormalities, which are susceptible to injury (eg, the horseshoe kidney) to be discovered at a young age after trauma. For these reasons, even though the kidney is less susceptible to trauma from forces applied to the anterior abdomen, it is often injured in the pediatric patient with multiple injuries.[56,57] Because this organ is retroperitoneal, signs and symptoms of kidney injury are often less obvious and more diffuse than signs and symptoms of other abdominal organ injuries. Often, dull back pain, ecchymosis in the costovertebral region, and hematuria are the only clues to renal injury. CT and renal ultrasound may be used in a stable patient to assess the degree of renal involvement. For most patients, initial CT scan of the abdomen to assess for genitourinary injury is indicated when there is gross hematuria, microscopic hematuria and shock, and penetrating injury to the abdomen with or without hematuria. Major deceleration injuries also pose a risk of genitourinary injury and low threshold for imaging in these cases even with microscopic hematuria should be exercised.

Other organs, such as the pancreas and gastrointestinal tract, are less frequently injured in pediatric patients but may have delayed presentations.

**Penetrating Injury.** Penetrating wounds to the abdomen usually require rapid evaluation by a surgeon and consideration of operative intervention. With hemodynamic instability, or peritonitis, urgent laparotomy is indicated. In the hemodynamically stable patient, further evaluation with a CT scan, local wound exploration, diagnostic laparoscopy, and observation may be warranted. Diagnostic peritoneal tap (DPT) and diagnostic peritoneal lavage (DPL) have been largely supplanted by other diagnostic modalities in modern practice, such as CT and diagnostic laparoscopy.[58] Children with a positive DPL should receive fluid and or transfusion in the ED, and children with a positive DPL do not necessarily require surgical intervention because of splenic salvage.

**Radiology.** Pediatric patients frequently sustain injury to the spleen, liver, kidneys, and gastrointestinal tract. CT of the abdomen with IV contrast can provide high sensitivity and specificity for identification of these injuries while being relatively noninvasive.[59] Abdominal CT has a high negative predictive value.[60] Oral contrast should not be used; it does not add to the accuracy of CT for trauma and can lead to a delay in evaluation, and risk of aspiration.

Although radiologic evaluation can provide important diagnostic information in a pediatric patient with possible abdominal trauma, any patient with unstable vital signs from an obvious surgically correctable cause should receive immediate operative intervention and not be subjected to delay while radiographic screening studies are obtained. Children with persistent or recurrent hypotension, continued abdominal pain, or persistent abdominal distention should undergo evaluation by a surgeon.

## DISPOSITION

The primary role of the emergency clinician is to evaluate and stabilize the patient before admission or transfer to a facility with a higher level of care available. Infants and younger children who are moderately to severely injured have improved outcomes in pediatric specific ICUs.[61]

Before any transport, the patient should be maximally stabilized. This may include the involvement of general surgeons, definitive surgery, or temporizing surgery (such as, packing the abdomen). The emergency clinician should communicate directly with the accepting physician at the tertiary care center. In general, the emergency clinician should refrain from completing extensive radiologic testing in a facility that is potentially unable to manage the injury being screened for, unless the clinician is confident that it will not delay the transfer to definitive care. All documents and test results should be sent with the patient. Parents should be informed of the reason for transfer and exact location to which the child is being taken.

Indications for admission include operative intervention and need for ongoing monitoring. The threshold for admission should be low in cases in which the health care team does not believe the child will have the social support or oversight necessary to be appropriately observed or to recover at home.

## KEY CONCEPTS

- Trauma is the leading cause of death in children in the United States.
- Avoid hypoxia and hypotension by early administration of oxygen and assisted ventilation, and fluid resuscitation with crystalloid at 20 mL/kg increments. Initiate transfusion of 10 mL/kg of PRBCs if hypotensive or remains with signs of hypovolemic shock after 40 mL of crystalloid is infused.
- Key pediatric anatomic and physiologic differences include:
  - Children are smaller, so force is more widely distributed through the body of a child, making multi-system injuries more likely.
  - The infant's head-to-body ratio is greater, creating a relatively higher center of gravity. This combined with a less myelinated brain and thinner cranial bones may result in more serious head injury.
  - Children have a higher anatomic fulcrum in the cervical spine (C2 to C3 in children <8 years old). This leads to higher C-spine injuries.
  - Children have more lax ligaments of the cervical column. This leads to an increased risk of SCIWORA.
  - Children have more horizontally positioned ribs meaning that with inspiration, the ribs move only up and not out. This leads to a limited ability to increase tidal volume and risk for respiratory failure with chest or diaphragmatic injury.
  - Children have more elastic chest walls that allow for pulmonary injury without skeletal injury.
  - Children have thinner abdominal walls and have more anterior livers and spleens. This results in a greater chance of injury to those organs.
  - Children have excellent compensatory mechanisms. They can remain normotensive until they lose large amounts of intravascular volume. Hypotension is a very late sign.
- Continuous monitoring and reassessment of the trauma patient is essential to recognize early signs of deterioration and to discover all injuries.
- Most minor head trauma may be managed with observation and without CT imaging. Clinical decisions rules when applied may reduce imaging and exposure of children to ionizing radiation.
- In major trauma patients indications for intubation include respiratory failure or a GCS less than 9.
- Most cases of shock in trauma are due to hypovolemia so fluid resuscitation with normal sale is recommended, and the addition of packed cell transfusions should be initiated in a pediatric trauma patient with hypotension or with signs of shock after 40 to 60 mL/kg normal saline.
- The diagnostic test of choice for the evaluation of intra-abdominal injury in a stable patient with high suspicion for injury is CT of the abdomen.
- Splenic injuries are generally treated conservatively in children to ensure immunocompetence.

*The references for this chapter can be found online by accessing the accompanying Expert Consult website.*

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## CHAPTER 165: QUESTIONS & ANSWERS

**165.1.** A 5-year-old male is struck by a car while riding a bicycle. On presentation, he exhibits hypotension, a normal heart rate, and quadriplegia. You suspect neurogenic hypotension secondary to spinal shock and attempt to correct the hypotension with fluids but are not successful. Which of the following should be your first choice for a vasopressor?

**A.** Dobutamine
**B.** Dopamine
**C.** Epinephrine
**D.** Phenylephrine

**Answer: D.** Spinal shock is related to decreased systemic vascular resistance (SVR). A pressor with primarily alpha vasoconstrictive effects, such as phenylephrine or norepinephrine, is the best choice for increasing SVR without having other physiologic effects.

**165.2.** A 6-week-old infant is brought to your emergency department (ED) by his mother after he reportedly fell 3 feet from his changing table approximately 45 minutes ago. His mother reports that the child did not lose consciousness and "seems fine." She is concerned, however, by a large scalp hematoma that developed almost immediately. What is your most important intervention at this point?

**A.** Consulting a social worker to help screen for child abuse
**B.** Head computed tomography (CT) scan
**C.** Ice packs for the scalp hematoma
**D.** Observation in the ED for 4 hours
**E.** Skull radiographs

**Answer: B.** A 6-week old infant is at high risk for intracranial injury given the softness/deformability of the skull. Scalp hematomas signify possible skull fracture and thus CT of the head is indicated.

**165.3.** Which of the following is the most commonly injured solid organ in pediatric patients with abdominal trauma?

**A.** Bladder
**B.** Duodenum
**C.** Kidney
**D.** Liver
**E.** Spleen

**Answer: E.** Injuries to the spleen are the most common injuries in pediatric abdominal trauma. Children involved in motor vehicle collisions (MVCs), sudden deceleration injuries, and contact sports–related injuries may sustain splenic trauma. Treatment includes fluid resuscitation and blood transfusion as needed. Splenic salvage is important for immunocompetence in children and operative intervention is avoided as long as the patient can be stabilized with fluid resuscitation.

**165.4.** A 4-year-old female is brought to your emergency department (ED) from the scene of an motor vehicle collision (MVC). Paramedics intubated the child in the field because she was unresponsive at the scene. On arrival, her vital signs are within normal limits. Before transport to the computed tomography (CT) scanner, however, you note that she is becoming mildly bradycardic and hypertensive. Her left pupil becomes dilated and nonreactive. Which of the following should be your next immediate action?

**A.** Hyperventilation to a carbon dioxide ($CO_2$) level between 30 and 35 mm Hg
**B.** Mannitol administration
**C.** Nicardipine infusion
**D.** Phenytoin administration
**E.** Proceed immediately to the CT scanner

**Answer: A.** The patient's sudden onset of dilated, nonreactive pupil, along with bradycardia and hypertension, is indicative of acute brain herniation. Immediate hyperventilation to a goal of $CO_2$ between 30 and 35 mm Hg has been shown to reduce brain injury. CT scanning should not be performed before this potentially lifesaving intervention. The administration of a hyperosmolar agent, such as mannitol or hypertonic saline, is indicated but should not take precedence over hyperventilation. Phenytoin is arguably indicated in this patient but not necessary in the acute setting. Nicardipine and other antihypertensive agents have no place in the management of a head-injured child. Her hypertension is a physiologic response to brain herniation, in which increasing mean arterial pressure (MAP) preserves cerebral perfusion pressure (CPP).

**165.5.** A 7-year-old girl is brought into the emergency department (ED) by emergency medical service (EMS) personnel from the scene of an motor vehicle collision (MVC). On your primary survey, she is noted to have a clear airway, decreased breath sounds in the right lung field, subcutaneous emphysema, and tracheal deviation to the left. She has thready distal pulses. What is your next step in stabilizing this patient?

**A.** Airway control with endotracheal intubation (ETI)
**B.** Bag-mask ventilation (BMV)
**C.** Immediate needle thoracostomy in the second midclavicular space on the right
**D.** Portable chest radiograph to confirm diagnosis

**Answer: C.** This patient is presenting with signs of tension pneumothorax. In this case, immediate decompression with a needle thoracostomy, followed by the placement of an appropriately sized chest tube or immediate chest tube placement is required to avoid cardiovascular collapse.

**165.6.** Which of the following statements regarding chest injuries in children is correct?

**A.** Aortic transection is more likely in a pediatric patient than in an adult patient.
**B.** Multiple rib fractures without significant underlying lung injury are common in children.
**C.** Penetrating chest trauma is more common than blunt chest trauma in pediatric patients.
**D.** Significant pulmonary contusions may be present in the absence of rib fractures in children.

**Answer: D.** The pediatric rib cage has more compliance than an adult rib cage. This makes children predisposed to pulmonary injury in the absence of bony injury. Rib fractures are more rare in the pediatric population because of this, and their presence is concerning for underlying lung injury. Blunt chest trauma is more common than penetrating chest trauma in pediatric patients and concurrent chest and abdominal injuries are common. Aortic transection is more common in adults.

**165.7.** A 12-year-old male fell while climbing over a 12-foot barbed-wire fence and sustained a deep 10-cm laceration to his medial left thigh. There is active bleeding from the laceration. What is the first step in the management of this patient?

**A.** Apply a tourniquet to the leg.
**B.** Begin with a primary survey and assess the patient's airway and breathing.

**C.** Obtain intravenous (IV) access and begin blood transfusion immediately.
**D.** Pack the wound to decrease hemorrhage.

**Answer: B.** The primary survey should quickly assess the airway, breathing, and circulation (ABCs). Initial wound management involves the application of direct pressure to the wound. Approaching trauma patients in a systemic fashion will ensure that large, obvious injuries do not distract from the detection of other injuries. Oftentimes multiple interventions would be done simultaneously. Jaw thrust to open an airway and then another health care providers quickly applying hemorrhage control. The child in the question also fell from a fence and may have other fall-related injuries.

**165.8.** Which of the following statements regarding imaging of a multi-trauma pediatric patient is correct?
**A.** A negative computed tomography (CT) scan of the cervical spine rules out spinal cord injury, and if normal, immobilization can be discontinued.
**B.** A negative focused assessment with sonography in trauma (FAST) examination rules out traumatic intra-abdominal injury, making a CT scan unnecessary.
**C.** In a hemodynamically stable pediatric trauma patient, CT imaging should be complete before transfer to a pediatric trauma facility, even if it delays transfer.
**D.** In a hemodynamically stable pediatric patient with a high level of concern for intra-abdominal trauma, CT scan is the imaging test of choice.

**Answer: D.** CT scan is the diagnostic test of choice for evaluation of intra-abdominal trauma in children. Spinal cord injury without radiologic abnormality (SCIWORA) is more common in pediatric patients, and normal cervical spine CT scan does not rule out spinal trauma. Although often a useful adjunct, a FAST examination does not rule out intra-abdominal injury. In a hemodynamically stable patient, CT imaging does not need to be complete before transfer to a pediatric trauma center and should not delay transfer. With clinical concern for elevated intracranial pressure (ICP), treatment (eg, hyperventilation, mannitol, or hypertonic saline) should be initiated immediately.