Diagnosis And Management Of Motor Vehicle Trauma In Children: An Evidence-Based Review

Abstract

Injuries from motor vehicle crashes are the leading cause of mortality in children aged 5 years and older in the United States. This review discusses common injuries in children after motor vehicle trauma and examines the evidence regarding the evaluation and treatment of pediatric patients involved in motor vehicle crashes. Both pre-hospital and emergency department care are discussed along with a differential diagnosis of the injuries most commonly seen in motor vehicle crashes. The various options for imaging modalities are also discussed in this review. A critical appraisal of the existing guidelines for the management of motor vehicle trauma and for the use of appropriate child-safety restraints is presented. Emergency clinicians will be able to use the patient’s history and physical examination findings along with knowledge of common injuries to determine the most appropriate workup and treatment of pediatric patients who present with motor vehicle trauma.
Case Presentations

You receive a call that an 8-year-old child who was in a motor vehicle crash will be arriving by air transport in 8 minutes. The child was the unrestrained passenger in the back seat of a sport utility vehicle that was involved in a high-speed collision on a busy freeway. The child was ejected from the vehicle. When EMS arrived on scene, the child was lying on the side of the road and was moaning in pain. He was noted to have abrasions on his abdomen and swelling of his left thigh. En route to the hospital, the child’s heart rate was 115 beats/min, respiratory rate was 24 breaths/min, and blood pressure was 90/42 mm Hg. While you are waiting in the trauma bay for the patient, you consider the injuries for which he is at risk and the interventions, laboratory studies, and radiographic studies he may require.

A 14-year-old girl is brought in by ambulance after a motor vehicle crash. She was a restrained passenger in the front seat of a car driven by her mother. When the car in front of them stopped suddenly, the patient’s car slammed into it and was then rear-ended by the car behind theirs. She was wearing both her lap and shoulder restraints, and there was no airbag deployment, passenger space intrusion, or damage to the windshield or windows. The girl denied any head injury or loss of consciousness. The girl was ambulatory at the scene, but when EMS arrived, she was placed in a cervical collar, positioned on a backboard, and brought to the ED. On arrival, she is alert and oriented but is complaining of neck and back pain. She has no other associated injuries. You wonder whether the patient’s cervical collar and backboard can be safely removed and what, if any, radiographic studies you should order.

An ambulance arrives with a 3-year-old girl who was involved in a pedestrian-versus-automobile accident. The child was playing in the front yard of her family’s home when the ball she was playing with rolled onto the driveway. She ran out to grab the ball just as her father was backing his car out of the driveway; he felt a “thump” as he backed over her. He immediately got out of the car and found his daughter laying on the driveway underneath the car between the front and rear wheels, crying. An ambulance was called, and the child was placed in a cervical collar and positioned on a backboard and brought to the ED. On arrival, the child is alert and awake with a Glasgow Coma Scale score of 15. Her head and neck examination is within normal limits, but she appears to have some abdominal tenderness and bruising on the lower portion of her abdomen. As you complete the remainder of your examination, you consider the injuries for which this patient is at risk, based on her mechanism of injury, and decide which imaging studies to order.

Introduction

Motor vehicle crashes (MVCs) are the leading cause of morbidity and mortality among children in the United States, and they often present a diagnostic challenge for emergency clinicians, given the variety of injuries that may be sustained. In these situations, the emergency clinician must determine the most likely injuries and decide upon the appropriate workup for each patient. Given that a variety of laboratory and radiographic studies can be used to evaluate these injuries, determining the most appropriate workup for each patient is often a challenge. This issue of Pediatric Emergency Medicine Practice focuses on the evaluation and management of children injured in MVCs, using the best available evidence from the literature.

Critical Appraisal Of The Literature

A PubMed search for articles pertaining to children aged < 18 years published since 1980 was performed using the search terms motor vehicle crash, motor vehicle injury, motor vehicle accident, motor vehicle trauma, motor vehicle collision, traffic accident, road traffic accident, traffic injury, automobile accident, automobile injury, pedestrian, pedestrian injury, pedestrian-versus-automobile, pedestrian accidents, car accident, blunt abdominal trauma, head injury, and cervical spinal injury. More than 2200 articles were identified, and a total of 166 resources relevant to the topic of motor vehicle trauma are included in this review. Although several large prospective studies were included, the majority of studies are retrospective. No randomized controlled trials were identified. A search of the Cochrane Database of Systematic Reviews did not produce any reviews addressing the specific patterns of injury seen in MVCs or the workup and management of these patients.

Epidemiology And Risk Factors For Injury

In the United States, unintentional injuries are the leading cause of death among children aged 1 to 19 years, and they accounted for nearly 9000 deaths in the year 2010 alone.1-3 MVCs (including pedestrian injuries) account for more than 50% of these deaths, resulting in 5 deaths per 100,000 children annually.3

Although driver factors, environmental factors, and seating position all play a role, improper use of child passenger safety restraints is associated with the greatest risk of injury.4,5 Automobile seat belts were first introduced in the United States in the 1960s, and they have significantly reduced the incidence and severity of injury from MVCs.6-11 Compared to restrained children, unrestrained children are at a significantly increased risk for head injury, thoracic injury, intra-abdominal injury, fractures, open wounds, spine and spinal cord injury, and hospitalization.12-14 The relative risk of head injury is 4.2 for unrestrained children compared to restrained children.13 Reported rates of improper restraint use are subject to incomplete
parental disclosure and have the potential for inaccuracy, but in the 1980s, rates as high as 50% to 70% were reported. More recently, there has been an increase in the use of child-safety restraints; however, there remains significant variability in reported rates of usage, from a low of 2% to a high of 52%. Younger children (particularly those aged < 1 y) are more likely to be appropriately restrained than older children. Inappropriate child-safety restraint use is most common among children aged 4 to 8 years. Hispanic and black children are more likely to be inappropriately restrained or unrestrained than children of other ethnicities or races, and they have higher mortality rates.

Restrained drivers are associated with a higher likelihood of child passenger restraint use and, as a result, a decreased risk of child passenger injury. Driver fatality, on the other hand, is associated with increased child passenger injury severity. Concerning mechanisms of injury include ejection from a motor vehicle and pedestrian-versus-automobile accidents. Although ejection from a motor vehicle is rare (0.7% of all MVCs), it is associated with both a higher fatality rate and increased overall injury severity. Reported fatality rates in motor vehicle ejection range from 15% (in children) to 27% percent (in adults). Up to 88% of patients ejected from a vehicle were either improperly restrained or unrestrained. When restraints are properly utilized, they can significantly reduce both injury severity and mortality.

Pedestrian-versus-automobile accidents (including back-over or driveway injuries) are another mechanism that can result in significant and serious injury, particularly in children. Despite the fact that they tend to occur at lower vehicular speeds, pedestrian-versus-automobile accidents have some of the highest morbidity and mortality rates among MVCs, accounting for more than 50% of hospitalizations for pediatric trauma. Emergency clinicians must be particularly vigilant when caring for children with this mechanism of injury, given the evidence suggesting increased injury severity.

Differential Diagnosis

Head Injury

Head trauma is the most common injury in MVCs, and traumatic brain injury is the leading cause of both morbidity and mortality. Compared to other children, younger children have large heads relative to the rest of their bodies, and their skulls are thinner and not yet fully ossified. These factors increase the risk of both head injury and traumatic brain injury, particularly in younger children. The differential diagnosis for head injuries in children includes skull fractures, intracranial hemorrhage (including subdural and epidural hematomas), cerebral contusions, cerebral edema, and concussions. The precise incidence of each of these injury types is unknown, but all must be considered when evaluating a patient in the emergency department (ED).

Skull Fracture

MVC patients who have sustained skull fractures (such as linear skull fractures or depressed skull fractures) typically present with large scalp hematomas, palpalable step-offs, or bony deformities. Basilar skull fractures, on the other hand, often present with characteristic physical examination findings such as Battle sign (the presence of posterior auricular or mastoid hematomas), hemotympanum or bleeding from the ear canal, cerebrospinal fluid otorrhea or rhinorrhea, periorbital ecchymoses (“raccoon eyes”), or cranial nerve palsies. However, given that these are late findings, their absence does not rule out a basilar skull fracture. Unlike other types of skull fractures, basilar skull fractures are frequently associated with intracranial injury even in patients with a GCS score of 15 and a normal neurologic examination. Although the precise incidence of basilar skull fractures in pediatric patients involved in MVCs is unknown, both MVCs and pedestrian-versus-automobile accidents are common mechanisms of injury for these types of fractures.

Intracranial Injury

Intracranial injuries can be divided into 2 primary categories: (1) focal lesions such as epidural, subdural, or intraparenchymal hematomas, and (2) diffuse injuries such as cerebral edema or diffuse axonal injury. Physical examination findings concerning for intracranial hemorrhage include altered level of consciousness on arrival or any focal neurologic findings on examination. Although the prevalence of these injuries is low in a child with a normal neurologic examination (including a GCS score of 14 or 15), the consequences can be devastating if they are missed. Diffuse axonal injury is a generalized intracranial injury that occurs primarily as a result of acceleration and deceleration forces. Although the precise incidence of diffuse axonal injury in pediatric MVCs is unknown, previous studies have estimated that it occurs in up to 40% of children with severe traumatic brain injury. With increasing use of magnetic resonance imaging (MRI), these injuries can now be more accurately diagnosed, whereas they may have been missed in the past.

Spine And Spinal Cord Injury

Cervical Spine Injury

MVCs are the most common cause of cervical spine injury in children. Cervical spine injuries in children are relatively rare, occurring in < 1% of children presenting for evaluation after trauma. Despite their relative rarity, the pediatric anatomy
predisposes children to injuries of the cervical spine. Young children have relatively larger heads than bodies, weaker cervical musculature, increased ligamentous laxity, and immature vertebral joints with horizontal articular facets, all factors that result in greater mobility of the upper cervical spine. Consistent with these anatomical features, younger children are more likely to sustain injuries to the upper cervical spine, while adults and children aged > 8 years are more likely to injure the lower cervical spine. In general, injury to the cervical spine is rare in children aged < 2 years and is most common in children aged ≥ 8 years. Certain medical conditions, such as Down syndrome, Klippel-Feil syndrome, and specific mucopolysaccharidoses, are associated with an increased risk of cervical spinal injury in children.

Thoracolumbar Spine Injury
Pediatric patients involved in MVCs are also at risk for injuries to the thoracolumbar spine. Although the incidence of thoracolumbar spinal injuries in children is low, both lumbar compression fractures and Chance fractures may occur in children and have been described as part of the “seat-belt syndrome” (which also includes abdominal ecchymoses and intra-abdominal injury). Chance fractures, which are caused by flexion-distraction injuries resulting in rupture of the posterior spinal ligaments, are transverse fractures of the spinous processes, pedicles, and vertebral bodies. These fractures occur either when the lap portion of the seat belt rides up onto the abdomen or when the lap belt is worn alone.

Spinal Cord Injury Without Radiographic Abnormality
Children who are involved in MVCs are also at risk for spinal cord injury without radiographic abnormality (SCIWORA). SCIWORA refers to spinal cord injuries that occur in the absence of identifiable bony or ligamentous injury on adequate plain radiographs or computed tomography (CT) scans. Clinical manifestations of SCIWORA include vital sign abnormalities, neck pain, back pain, or focal neurologic deficits such as numbness, tingling, sensory deficits, weakness, or paralysis. Even transient deficits or those that resolve completely in the ED may be indicative of SCIWORA. The same anatomic features that predispose children to cervical spine injury also predispose them to SCIWORA. The majority of cases of SCIWORA occur in the cervical region and are the result of hyperextension injury, hyperflexion injury, longitudinal distraction injury, or spinal cord infarction. The true incidence of SCIWORA in children with spinal cord injuries remains unknown, with rates ranging from 4.5% to 35% reported. Contrary to what is suggested by the name, the majority of children with SCIWORA have abnormalities on MRI, sparking debate regarding whether these patients should truly be classified as having SCIWORA. Children with clinical findings concerning for SCIWORA should undergo imaging with MRI. MRI can also be used to identify ligamentous injuries in patients with continued pain or persistent neurologic symptoms.

Abdominal Injury
MVCs and pedestrian-versus-automobile accidents are the most common causes of blunt abdominal trauma in children. As with head injuries, the pediatric anatomy predisposes children to intra-abdominal injuries secondary to blunt trauma. Young children, in particular, have poorly developed abdominal musculature and protuberant abdomens that provide relatively less protection for their larger solid intra-abdominal organs. Additionally, children have less intra-abdominal fat surrounding their organs, and the organs are in a smaller space, which increases the risk of solid organ injury as well as multiple organ injury. The differential diagnosis for blunt abdominal trauma in children is broad but can be classified into 3 major categories: (1) solid organ injuries, (2) hollow viscus injuries, and (3) injuries to the abdominal vasculature. Injuries to the solid organs are most common, followed by injuries to the hollow viscus. The most commonly injured organs in blunt trauma are the spleen and the liver, followed by the kidneys. In children, the larger size of the liver in conjunction with a more flexible rib cage results in an increased risk of hepatic injury.

Hepatic Injury
The liver is one of the most commonly injured solid organs in blunt abdominal trauma, and it is the greatest source of mortality due to blunt abdominal trauma. Children with hepatic injuries have significant potential for hemorrhage because of the liver’s dual blood supply and close proximity to the inferior vena cava. Liver injuries that occur in blunt abdominal trauma include liver hematomas, lacerations, and vascular injuries. These injuries are categorized into grades of severity ranging from I to VI per guidelines set forth by the American Association for the Surgery of Trauma. (See Figure 1 on page 5.) Hepatic injuries of grade III or higher are associated both with increased mortality and an increased need for interventional radiology or surgical interventions. Children with hepatic injuries may present with abdominal bruising (as part of the seat-belt syndrome), abdominal pain, tenderness, abdominal distension, or pain radiating to the shoulders.

Spleen Injury
Splenic injuries, including lacerations and hematomas, are also commonly seen in blunt abdominal
trauma. The severity of splenic injuries is classified into grades ranging from I to V based on the American Association for the Surgery of Trauma guidelines.\(^{65,67}\) (See Figure 1.) As with hepatic injury, mortality increases with increasing grades of splenic injury.\(^{65}\) Classic physical examination findings include diffuse or left upper quadrant abdominal pain and the presence of the Kehr sign, which is left shoulder pain caused by irritation of the diaphragm from free intra-abdominal fluid.\(^{64,66}\)

**Renal Injury**

Renal injury is the third most common solid organ injury in children after blunt abdominal trauma, with motor vehicle trauma as the most common cause of renal injury. Children are more susceptible to renal trauma than adults because of their weaker abdominal musculature, more compliant rib cage, and decreased perirenal fat.\(^{68,69}\) Common renal injuries after blunt trauma include contusions, lacerations, and hematomas, which are graded from I to V based on severity.\(^{65}\) (See Figure 1.) Increasing grades of injury severity are associated with increasing mortality.\(^{65}\) Characteristic physical examination findings in renal trauma overlap with those of hepatic and splenic injuries and include abdominal tenderness and hematuria.\(^{68-70}\)

**Clinical Implications Of Abdominal Wall Ecchymoses**

One particular physical examination finding that increases concern for intra-abdominal injuries (including both solid organ and hollow viscus injuries) is the presence of a seat-belt sign, which is a term used to describe a well-defined linear area of abdominal wall ecchymosis caused by a lap belt worn during a MVC.\(^{71}\) The seat-belt sign was first described in 1962 as part of the seat-belt syndrome, which is a constellation of findings including vertebral Chance fractures, abdominal wall bruising, and intra-abdominal injury.\(^{71-73}\) These injuries are caused by improper use of the lap belt, which is more common in children aged 4 to 12 years. When worn properly, the lap belt should be anchored over the pelvis; however, young children are not tall enough for the lap belt to sit across the pelvis, so the lap belt ends up across their abdomen. Additionally, children have smaller pelvises that are unable to properly anchor the lap portion of the seat belt. During a MVC, sudden deceleration can result in flexion over the lap portion of the seat belt, resulting in the constellation of symptoms seen in the seat-belt syndrome.\(^{70,72}\)

Several studies have demonstrated that the presence of a seat-belt sign on examination is associated with an increased risk of intra-abdominal injury.\(^{71}\) In a large-scale 2004 retrospective study, the seat-belt sign on physical examination was associated with a 232 times higher odds of intra-abdominal injury.\(^{74}\) Similarly, a prospective study from 2005 compared the relative risk of intra-abdominal injury in patients with a seat-belt sign to those without and found that presence of the seat-belt sign carried a relative risk of 2.9 for intra-abdominal injury and a relative risk of 12.8 for gastrointestinal injury.\(^{75}\) A more-recent prospective study of 12,044 children found that the presence of a seat-belt sign or evidence of abdominal wall trauma on examination was significantly associated with intra-abdominal injury requiring intervention.\(^{76}\) Although the presence of a seat-belt sign has been associated with intra-abdominal injury, the patient’s overall clinical picture must be taken into consideration when determining the risk of intra-abdominal injury.

**Thoracic Injury**

Although thoracic injuries in children are relatively rare when compared to head and abdominal injuries, they carry with them a significant risk of mortality. MVCs are the most common cause of blunt thoracic trauma in children. Children, in particular, are at increased risk of thoracic injury from pedestrian-versus-automobile accidents because their thorax is often situated at the height of a car bumper. They are also at risk for thoracic trauma in MVCs from improperly fitted restraints.\(^{77}\) The differential diagnosis of thoracic injuries in children can be divided into 3 major categories: (1) pulmonary pathology, (2) chest wall injuries, and, rarely, (3) cardiac injury.

**Pulmonary Injury**

The differential diagnosis for pulmonary injuries following motor vehicle trauma includes pulmonary contusions, pulmonary lacerations, hemothoraces, pneumothoraces, and disruption of the tracheobronchial tree. Of these injuries, pulmonary contusions are the most common.\(^{78-81}\) Pulmonary contusions are the result of direct high-energy trauma applied to the lung parenchyma, and they typically present with hypoxemia, hypoventilation, and consolidation on chest radiography. Unlike adults, children have relatively elastic chest walls and incompletely ossified ribs, so pulmonary...
contusions may occur either with or without the presence of concurrent rib fractures.\textsuperscript{77,82-84}

\textbf{Rib Fractures}

Though less common in children than in adults (because of the increased compliance of the pediatric rib cage), rib fractures still account for the second most common thoracic injury in pediatric blunt trauma.\textsuperscript{78,79} Because of the force required to cause rib fractures in children, the presence of rib fractures (in particular, fractures of the first rib) is indicative of a significant mechanism of injury and has been associated with the occurrence of hemothoraces.\textsuperscript{77,85}

\textbf{Pneumothoraces, Hemothoraces, And Other Thoracic Injury}

Following pulmonary contusions and rib fractures, pneumothoraces and hemothoraces are the most commonly seen injuries in children with blunt thoracic trauma.\textsuperscript{78,80} Presenting features of pneumothoraces and hemothoraces include decreased or absent breath sounds. Hypotension may also be present, particularly in the setting of a tension pneumothorax or massive hemothorax. Although the aforementioned injuries are most common, other rare thoracic injuries that can occur in the setting of blunt thoracic trauma include disruption of the tracheobronchial tree, cardiac contusions or rupture, disruption of the great vessels, flail chest, or rupture of the diaphragm or esophagus.\textsuperscript{78,81,83} Cardiac tamponade may also occur, but it is extremely rare and did not occur in any of the studies reviewed.\textsuperscript{78-80,83}

Because thoracic trauma may be difficult to diagnose in children, a 2002 study set out to create a decision rule by which children with thoracic trauma could be identified. The presence of tachypnea, a GCS score < 15, abnormal findings on thoracic examination, abnormal chest auscultation findings, hypotension, or a femur fracture were all predictive of thoracic injury.\textsuperscript{79} Although a GCS score of < 15 was found to be predictive of thoracic injury, we do not recommend thoracic CT scanning of all patients meeting this criterion. Rather, we recommend that patients with an abnormal respiratory rate or oxygen saturation, abnormal findings on cardiac or respiratory examinations, or a high-intensity mechanism of injury undergo an evaluation for thoracic trauma.

\textbf{Prehospital Care}

Prehospital providers play an essential role in the management of pediatric trauma and can have a significant impact on the outcomes of these patients. The primary goals of the prehospital provider are: (1) to identify the patients with the most severe injuries and injuries with the potential to result in rapid decompensation of the patient, and (2) to transport these patients safely and quickly to the nearest hospital capable of caring for these injuries. In order to accomplish this task, the Advanced Trauma Life Support\textsuperscript{86} (ATLS\textsuperscript{®}) guidelines set forth by the American College of Surgeons are often utilized for the evaluation of individual patients.\textsuperscript{86}

When assessing a patient in the field, the first task that must be completed is an assessment of the patient’s airway, breathing, and circulation (ABCs). Basic maneuvers such as a jaw thrust, placement of an oral airway, and bag-mask ventilation in patients with respiratory failure are indicated to assure patency of the airway and adequate ventilation. Airway maneuvers performed on a trauma patient must be done with simultaneous protection of the cervical spine with manual inline stabilization, which should be performed by a separate provider. In contrast to adult trauma patients, endotracheal intubation in the field for pediatric patients does not improve mortality rates; rather, complications are increased (compared to bag-mask ventilation or other airway adjuncts, such as laryngeal mask airways).\textsuperscript{87-90}

Once assessment of the airway and breathing are complete, the prehospital provider must assess for adequate circulation and attempt to identify any uncontrolled sources of hemorrhage. For pediatric trauma patients without evidence of spontaneous circulation, cardiopulmonary resuscitation (CPR) and Pediatric Advanced Life Support (PALS) algorithms should be initiated. If uncontrolled external hemorrhage is present, direct pressure should be applied to stop the hemorrhage. Although assessment of airway, breathing, and circulation and stabilization of the spine are all crucial tasks that should be performed prior to transport, the ultimate goal of the prehospital provider is to transport the patient safely and as quickly as possible to the nearest hospital capable of caring for the patient. Both the cervical collar and backboard should remain in place until the patient is safely transported to an ED or trauma center. Multiple studies have demonstrated increased mortality and morbidity with longer transport times, so every effort should be made to minimize field and transport time.\textsuperscript{91-93}

\textbf{Emergency Department Evaluation}

Upon arrival to the ED, evaluation of a motor vehicle trauma patient should be done in a systematic fashion, in accordance with the ATLS\textsuperscript{®} guidelines. The ATLS\textsuperscript{®} guidelines can be divided into 2 primary sections: (1) the primary survey, and (2) the secondary survey; both are discussed in detail as part of the ATLS\textsuperscript{®} course.\textsuperscript{87} The primary survey can be summarized with the mnemonic ABCDE: Airway, Breathing, Circulation, Disability (neurologic status), and Exposure. The goal of the primary survey is to assess each of these components in a sequential manner and to perform any life-saving interventions prior
to moving on to the next component. The secondary survey, which should be performed only after the primary survey has been completed, is a systematic head-to-toe examination of the patient, along with a brief history of how the event occurred.

**Primary Survey**

As part of the primary survey, the airway, breathing, and circulation should be thoroughly assessed. The first step in the evaluation of any patient is to assess the patency of the airway and to secure the airway as soon as possible, if necessary. As with patients in the field, basic airway maneuvers (such as a jaw-thrust maneuver and ventilation with a bag mask) should always be attempted on patients with evidence of airway compromise before moving on to more advanced airway techniques. Patients without airway compromise should be given supplemental oxygen. A definitive airway (such as a cuffed endotracheal tube) should be placed as soon as possible in patients requiring such an intervention while maintaining inline cervical immobilization. The position of the endotracheal tube should be confirmed by auscultation of bilateral breath sounds and end-tidal carbon dioxide (EtCO₂) tracing.

In some trauma patients (such as those with significant facial trauma), endotracheal intubation may not be possible. In these patients, airway adjuncts such as intubation with a video laryngoscope or placement of laryngeal-mask airway may be required as a temporizing measure prior to insertion of a definitive airway. If none of these maneuvers are successful, a needle cricothyroidotomy may be required for oxygenation until a more definitive airway can be established. A surgical cricothyroidotomy should generally not be performed in children under 10 to 12 years of age because of the risk of damaging the cricoid cartilage and surrounding structures and potentially causing further airway compromise.⁹⁴,⁹⁵ In prepubescent children, the tracheal cartilages are very soft and pliable and provide minimal support to the upper airway. As a result, the cricoid cartilage is the only circumferential support for the trachea, and it is the primary structure responsible for maintaining airway patency.⁹⁵ Additionally, children who undergo surgical cricothyroidotomy are at increased risk for the development of subglottic stenosis as they grow older.⁹⁶,⁹⁷

Once an airway is established, the presence of equal bilateral breath sounds should be confirmed. In patients with diminished or absent breath sounds, the possibility of either a tension pneumothorax or a massive hemothorax should be considered, and, if confirmed, needle decompression and/or placement of a chest tube should be performed. Diagnosis of a pneumothorax can be confirmed with bedside ultrasound in the form of the extended focused abdominal sonography for trauma (eFAST), although this imaging technique is less well studied for hemothoraces⁹⁸–¹⁰⁰. Performance of the eFAST should not delay needle decompression if the patient has a critical presentation.

As with the assessment of circulation in the field, patients without evidence of spontaneous circulation should be managed utilizing PALS algorithms, while patients with uncontrolled external hemorrhage will require temporizing measures such as application of direct pressure or a tourniquet to stop the bleeding. Patients with uncontrolled internal hemorrhage who cannot be stabilized may require immediate surgical intervention. A GCS score should be calculated as part of the assessment of disability, and the patient should be fully exposed, with clothing removed to facilitate the secondary survey. The child should be covered with sheets or blankets as soon as possible to prevent hypothermia. This entire process should be performed with a rigid cervical collar and triple immobilization or with manual inline immobilization of the cervical spine while the patient remains on the backboard.

**Secondary Survey**

Once the primary survey has been completed and all life-threatening conditions stabilized, a secondary survey should be performed and additional history about the event should be obtained. While there is little controversy regarding how to manage severely injured patients requiring urgent operative intervention or patients with only minor injuries, it is often the patients with intermediate injury severities that are the most difficult to manage. For these patients, the secondary survey provides the best opportunity to assess for more subtle—but still potentially serious—injuries requiring intervention.

**Head And Neck**

The secondary survey should begin with an examination of the head and neck, including a thorough inspection for any lacerations, abrasions, skull depressions, and contusions. Because the scalp is extremely vascular in nature, direct pressure should be applied to any large lacerations or open wounds until they can be closed with either staples or sutures. The pupils should be inspected and the facial bones palpated. The eyes should be examined for conjunctival hemorrhages, penetrating injury, lens dislocation, and ocular entrapment. Visual acuity should be checked, and contact lenses should be removed before edema develops. Signs of basilar skull fracture such as hematympanum, “raccoon” eyes, and Battle sign should be noted, although these are late findings and their absence should not falsely reassure the emergency clinician. The ear canals, the nasal passages, and the oropharynx should be thoroughly inspected. The neck should be palpated (while the cervical spine remains immobilized) to assess for...
crepitus, which could be indicative of perforation of the aerodigestive tract or laryngeal injury and could lead to airway compromise. Examination of the neck should also include assessment for signs of vascular injury such as the presence of hematomas, ecchymoses, bruises, or palpable thrills.

**Cardiac And Respiratory Systems**

Cardiovascular examination should include an assessment of vital signs as well as heart sounds. Muffled heart sounds, distended neck veins, or precordial bruising may be signs of cardiac tamponade. The respiratory examination should include an assessment for equal breath sounds in all areas. Decreased or absent breath sounds should prompt concern for either a pneumothorax or hemothorax.

**Abdominal And Genitourinary Systems**

Careful inspection and palpation of the abdomen should be performed to assess for distension or tenderness and the presence of bowel sounds. The presence and pattern of bruising should be noted. The pelvis should be examined once (preferably by the managing orthopedist) with gentle palpation and application of downward-medial pressure to the pelvic ring and inspection for any overlying ecchymoses. Pressure should not be applied in patients in shock or in patients with obvious pelvic fractures. An external genitourinary examination should be performed to assess for blood at the urethral meatus or vaginal opening as this may be indicative of vesicoureteral, pelvic, or intra-abdominal injury. Though conventional teaching was that a digital rectal examination is required in all trauma patients, it may not be beneficial in the pediatric population.34

**Musculoskeletal**

Visual inspection, palpation of the extremities, and range of motion of the joints should be carefully performed to identify any obvious deformities that may indicate underlying fractures. The extremities should be inspected for contusions and evidence of compartment syndrome. Peripheral pulses should also be assessed.

**Neurologic**

Although an initial neurologic assessment is conducted as part of the primary survey, a more thorough neurologic examination should be performed as part of the secondary survey. The patient’s mental status, gross motor function, and sensation should be assessed. The mnemonic AVPU (Awake, Verbal, Pain response, Unresponsive) is a quick method to assess mental status. Each patient should also be log-rolled (with inline stabilization of the cervical spine) so that the back can be thoroughly examined. The presence of midline spinal tenderness or step-offs should be noted, as these signs may be indicative of fractures or spinal cord injury.

**Clinical History**

As part of the secondary survey, additional history about the inciting event should be obtained. One helpful mnemonic for obtaining a fast and focused history is AMPLE: Allergies, Medications, Past medical history, Last oral intake, Events or environmental factors leading up to the event.86 Good communication with prehospital providers is crucial to obtaining a complete and accurate history. Prehospital providers will often have the most information regarding the circumstances surrounding the trauma. Information should be obtained on the mechanism of injury, the circumstances of the MVC, the use of restraints, the position of the patient, the condition of the patient on scene, the condition of other individuals in the vehicle, and the condition of the vehicle, as these are all factors that may affect the types of injuries for which the patient is at risk. Examples of questions that should be asked include the following:

1. **Mechanism of injury**: Was this a pedestrian-versus-automobile injury or was this a collision between 2 vehicles? Was the pedestrian on a bicycle or skateboard, and, if so, was he wearing a helmet? Was the patient ejected from the vehicle?

2. **Specific circumstances of the accident**: How fast was/were the vehicle(s) moving? Where was the site of impact on the vehicle? Was there compartment intrusion? Did the airbags deploy? Was there any damage to the windshield or windows? Was the car able to be driven away from the scene?

3. **Restraints**: Was the child restrained during the crash? What type of restraint system was used? Was the restraint system age appropriate for the child? Was it utilized correctly (ie, forward-facing or rear-facing child-safety seat)?

4. **Passenger position**: Where was the child seated in the car? Was the child in the front seat or rear seat at the time of impact? Was the child seated on the side of impact?

5. **Condition of the patient**: What was the GCS score of the patient on scene? Was the patient ambulatory on scene? Did the patient have any specific complaints, including loss of consciousness?

6. **Condition of other individuals**: What is the condition of the other passengers in the car? Were there any fatalities? Did any individuals require extrication from the vehicle?

While these questions may appear to be quite detailed, many of these features are associated with increased injury severity and/or specific patterns of injury, and the information can be extremely valuable in the evaluation of these patients.
Diagnostic Studies

One of the challenges in evaluating pediatric patients presenting after motor vehicle trauma is determining the most appropriate laboratory and radiologic workup. Although a variety of laboratory and radiologic studies exist, it is important to undertake this workup in a methodical fashion such that all clinically significant injuries are identified without unnecessary laboratory or radiographic testing.

Laboratory Studies

Although many pediatric patients undergo laboratory testing on arrival to the ED, a standardized “trauma panel” does not exist, and the use of one is not recommended. Instead, a variety of laboratory studies are often ordered, depending on the institution where the patient is receiving care. Among the tests that are frequently ordered are a complete blood count (CBC), a blood type and crossmatch, serum aspartate aminotransferase (AST) and serum alanine aminotransferase (ALT), urinalysis, prothrombin time (PT), and partial thromboplastin time (PTT).

Detection Of Occult Hemorrhage

The preferred diagnostic study for the detection of hemorrhage or other forms of occult injury is serial hematocrits. Although there is minimal pediatric literature on the subject, the utility of serial hematocrits has been demonstrated in adult populations. Serial hematocrits are a reliable indicator for ongoing blood loss and major injury, although the absence of a hematocrit drop cannot be used to exclude major injury. Based on these data in adults, serial hematocrits may be helpful in the detection of internal hemorrhage in children. A type and crossmatch should also be ordered in patients with hemorrhage in whom a blood transfusion may be required. Critically hemorrhaging children can always receive O-negative blood products, but proper crossmatching may minimize overuse of the local O-negative supply.

Detection Of Intra-Abdominal Injury

Identification of intra-abdominal injury in children who have sustained blunt abdominal trauma has remained a challenge for emergency clinicians. Studies have been performed to determine the utility of specific features of the history and physical examination, along with laboratory studies, as predictors for intra-abdominal injury. The presence of abdominal tenderness, gross or microscopic hematuria, abdominal wall bruising, abnormal liver function studies, pelvic fracture, or a history concerning for assault or abuse have all been shown to be associated with intra-abdominal injury. Prior studies have demonstrated that elevated AST and ALT values can be used to identify children at risk for intra-abdominal injuries, although the AST and ALT cutoffs varied from study to study. A 2013 study by Holmes et al derived a clinical decision rule to identify children at very low risk for intra-abdominal injuries; this particular decision rule did not employ laboratory studies, although the authors recommended use of laboratory studies to further risk stratify patients meeting some, but not all, low-risk criteria.

Additionally, recent review articles support obtaining liver function studies when there is a high clinical suspicion for intra-abdominal injury. Urinalysis is another laboratory test that may aid in the diagnosis of intra-abdominal injury, specifically renal injury. Children with ≥ 50 red blood cells/high-powered field, gross hematuria, vertical deceleration injuries, or physical examination findings concerning for renal injury (such as flank pain or ecchymoses) should undergo CT of the abdomen and pelvis (with intravenous contrast) to identify renal injuries.

Trauma-Induced Coagulopathy

Trauma-induced coagulopathy is a well-known phenomenon that occurs in trauma patients, particularly those with traumatic brain injury, and it is often associated with a poor prognosis. The preferred laboratory studies for the identification of trauma-induced coagulopathy are coagulation studies such as PT, PTT, and a platelet count. While the precise etiology of this coagulopathy is unknown, it is likely multifactorial in origin and related to tissue hypoxia and acidosis, consumption of coagulation factors and platelets, increased fibrinolysis, and dysfunction of the platelet and coagulation system. In the pediatric population, reported rates of coagulopathy after traumatic brain injury range from 37.9% to 77%. Risk factors for coagulopathy in children after traumatic brain injury include evidence of significant multisystem trauma, injury severity score ≥ 16, the presence of cerebral edema on CT scan, the presence of chest and/or abdominal injury, and a low GCS score. Based on these data, children who are suspected to have intracranial injury based on their mechanism of injury, GCS score on arrival, or physical examination findings should have a platelet count and coagulation panel drawn as part of their initial evaluation.

Radiographic Evaluation

Radiographic studies are frequently utilized in the evaluation of motor vehicle trauma. Although a variety of modalities may be utilized, plain radiographs, ultrasound, and CT scanning are the most common. The modality selected is dependent on the region that is injured, injury severity, the presenting history, and the resources available at a given institution.
Imaging Of The Head
CT scanning of the brain is the preferred imaging modality when there is suspicion for intracranial injury. Although skull fractures may be visible on plain radiographs, plain radiographs provide no information about underlying intracranial injuries.\(^4\) When there is a mechanism of injury or a physical examination finding concerning for head injury, CT scanning of the head is the diagnostic test of choice. In order to reduce the use of unnecessary CT scanning and excessive radiation exposure, clinical prediction rules have been developed to aid the emergency clinician in decision making regarding the use of CT in the evaluation of head trauma.\(^4\),\(^12\),\(^25\) Findings that have been associated with intracranial injury include severe mechanism of injury, abnormal GCS score, loss of consciousness, persistent vomiting, signs of a basilar skull fracture, or focal neurologic deficit.\(^4\),\(^12\),\(^25\) The largest derivation study was conducted by Kupperman et al and the Pediatric Emergency Care Applied Research Network (PECARN). Published in 2009, it was a prospective cohort study of 42,412 children presenting to the ED with head trauma.\(^4\) The study found that children aged < 2 years with normal mental status, loss of consciousness for < 5 seconds (or no loss of consciousness), nonsevere mechanism of injury, only frontal scalp hematomas (or no hematoma at all), no palpable skull fractures, and those acting normally (per their parents’ report) were at extremely low risk for traumatic brain injuries and did not require evaluation with a CT scan. In children aged > 2 years, the presence of a normal mental status, no loss of consciousness, no severe headache, no vomiting, a nonsevere mechanism of injury, and no signs of basilar skull fracture on examination were all associated with a very low risk of traumatic brain injuries; children aged > 2 years meeting all of these criteria do not routinely require evaluation with a CT scan.\(^4\) The clinical prediction rule for children aged < 2 years had a sensitivity of 100% and a specificity of 53.7%, while the sensitivity was 96.8% and the specificity was 59.8% for children aged > 2 years.\(^4\) Given the lethal malignancy risks secondary to exposure to ionizing radiation from CT scan, a period of observation may be a preferred management strategy to decrease CT use.\(^12\),\(^25\)

Imaging Of The Cervical Spine
Several studies have been conducted to identify risk factors associated with cervical spinal injury after blunt trauma, and 3 primary decision rules have been created: the PECARN rules, the National Emergency X-Radiography Utilization Study (NEXUS) low-risk criteria, and the Canadian Cervical Spine rules.\(^4\),\(^13\)-\(^15\) Of these 3 rules, only the PECARN and NEXUS criteria have been studied in children.\(^4\),\(^15\) Factors that were associated with cervical spinal injury in these studies were: the presence of altered mental status, inability to ambulate, substantial torso injury, focal neurologic deficits, complaint of neck pain or torticollis, midline cervical tenderness, or a high-risk mechanism such as a serious MVC or a diving accident. (See Tables 1 and 2.)

One area of controversy that remains is the radiographic evaluation of the pediatric cervical spine. Two potential imaging modalities exist for imaging of the cervical spine: plain radiographs and CT. Although CT is the preferred imaging modality and is the definitive method of diagnosing bony injuries to the cervical spine, the amount of ionizing radiation exposure for CT is 30 times higher than for plain radiographs.\(^4\) This is a particular concern for the pediatric population, given that children are more sensitive to ionizing radiation than adults and are at increased risk for malignancies.\(^126\)-\(^128\) Plain radiographs have a sensitivity of 90% for identifying injuries of the cervical spine and are often the most appropriate initial study.\(^4\),\(^13\) A CT of the cervical spine should be considered in patients with abnormal physical examination findings, abnormal radiographs, inadequate cervical spine radiographs, inconclusive plain radiographs, or normal radiographs with persistent pain.\(^13\) If a patient has neurologic symptoms with a normal cervical spine x-ray and CT, an MRI should be considered for further evaluation of the spine and spinal cord.

Which children require cervical spine radiographs? Several studies have set out to answer this question.\(^4\),\(^15\) The first of these studies, which evaluated the NEXUS low-risk criteria in pediatric trauma patients, found that the presence of all criteria was associated with a low risk of cervical spinal injury.\(^15\) (See Table 2.) However, the primary limitation of this study is that very few children aged < 8 years were included and no children aged < 2 years were included, thus limiting the use of these criteria to children aged ≥ 8 years. A second case-control study from 2012 found that the presence of focal neurologic findings, altered mental status, neck pain, torticollis, substantial injury to the torso, history of a diving accident, history of a high-risk MVC, or history of a condition predisposing to cervical spine injury significantly increased the risk of cervical spine injury.\(^4\) The presence of 1 or more of these risk factors had a sensitivity of 98% and a specificity of 26% for cervical spine injury.\(^4\) Unlike the NEXUS study, this study included more children aged < 8 years and is applicable to children of all ages, but it has yet to be validated.

Controversies In Management: Clinical Clearance Of The Pediatric Cervical Spine: Despite the volume of research that has been conducted on cervical spinal injuries in children, there remains significant controversy over whether or not the cervical spine can be clinically cleared in children, particularly in young children who are nonverbal. Consensus
guidelines have been created for the evaluation of cervical spinal injuries in children.135 According to these consensus guidelines, pediatric patients can be divided into 2 subgroups: (1) those with reliable physical examinations (awake, alert, and cooperative, with a GCS score of 15), and (2) those with unreliable physical examinations. The protocol for patients with reliable physical examinations utilizes a combination of the NEXUS criteria and the Canadian Cervical Spine rules to clinically clear the cervical spine.135 In children with reliable physical examinations in whom the cervical spine cannot be clinically cleared, further evaluation with radiographic studies such as plain radiographs, CT of the cervical spine, or MRI of the cervical spine is recommended. In children with unreliable physical examinations (eg, those who are unconscious or have an altered level of consciousness with a GCS score < 15), a separate protocol exists and essentially requires imaging in the form of either radiographs or a CT scan in order to clear the cervical spine.135 Even with the existence of these algorithms, significant caution should be used when applying them to children aged < 2 years. Based on the evidence available, it is possible to clinically clear the pediatric cervical spine in children with reliable physical examinations.

### Imaging Of The Abdomen

When evaluating injuries of the abdomen, the primary imaging modalities available are ultrasonography and abdominal CT. The primary ultrasonographic technique used in the assessment of trauma patients is the FAST examination. The purpose of the FAST examination is to identify free fluid within the abdomen; however, it cannot be reliably used to identify hollow viscus or solid organ injuries. A 2007 meta-analysis examined the performance of abdominal ultrasonography for the detection of intra-abdominal injuries in children and found a sensitivity between 66% and 80%, depending on which studies were included.136 A prospective observational study from 2011 found similar (but somewhat less promising) results with a sensitivity of only 52% but a specificity of 96%.137 Based on these data, it can be concluded that while a positive FAST examination is suggestive of intra-abdominal injury, a negative FAST examination does not aid in decision making.137 Two recent review articles concluded that, because of the variable sensitivity of the FAST examination, it is most useful when utilized in select patient populations such as hemodynamically unstable patients in whom a quick bedside assessment is required.71,138 Hemodynamically unstable patients with a positive FAST examination should be taken to the operating room for an exploratory laparotomy to identify the source of free intra-abdominal fluid, although patients with a negative FAST examination may also require operative intervention. Although FAST examination may be a helpful adjunct in specific patient populations, ultimately, the results of a FAST examination should be interpreted in the context of the patient’s overall clinical picture.

CT is the diagnostic modality of choice for the evaluation of abdominal trauma, although it is much less sensitive for the identification of hollow viscus injuries compared to solid organ injuries.71,138,139 Abdominal CT scanning can also be used to identify both hemorrhage and free fluid within the peritoneum as well as associated bony injury.138 Along with providing helpful diagnostic information, abdominal CT scans can be used to guide nonoperative management decisions, length of hospitalization, and follow-up.71

The primary risk associated with CT scanning, aside from the additional cost, is the increased radiation exposure. Several studies have demon-

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**Table 1. PECARN Predictors Of Cervical Spine Injury In Children**

- Altered mental status
- Focal neurologic deficit
- Complaint of neck pain
- Torticollis
- Predisposing medical condition
- Substantial injury to the torso
- Diving accident
- High-risk motor vehicle crash

Presence of 1 or more factors is 98% sensitive and 26% specific for cervical spine injury.


**Table 2. NEXUS Low-Risk Criteria**

- Normal level of alertness
- No midline cervical tenderness
- No focal neurologic deficit
- No painful, distracting injury
- No intoxication

Patients must meet all 5 criteria to be classified as low risk for cervical spine injury. This decision rule has a sensitivity of 99% and a specificity of 12.9%.

Abbreviation: NEXUS, National Emergency X-Radiography Utilization Study.

strated that exposure to ionizing radiation from CT scans may increase a child’s lifetime risk of malignancy. A recent study by the PECARN network from 2013 derived a clinical decision rule to identify children at very low risk for intra-abdominal injuries in whom an abdominal CT would be unnecessary. The study found that history and physical examination characteristics that were associated with a very low risk of intra-abdominal injury. (See Table 3.) Children who met all 7 criteria had a 0.1% risk of intra-abdominal injury requiring intervention, which is less than the risk of radiation-induced malignancy from a single abdominal CT scan. This prediction rule has a sensitivity of 97% and a specificity of 42.5%. Several other clinical prediction rules aimed at reducing the rate of CT scanning have been derived; however, these studies have yet to be prospectively validated.

Utility Of Plain Radiographs In The Evaluation Of Motor Vehicle Trauma
Although CT is the preferred imaging modality for intracranial, intra-abdominal, and cervical spinal injury, plain radiographs play an important role in the evaluation of motor vehicle trauma. Plain radiographs are the preferred imaging modality for the evaluation of the thorax, pelvis, spine, and extremities; chest and pelvic radiographs are considered adjuncts to the primary survey per the ATLS guidelines. Chest radiography is the preferred initial imaging modality for the evaluation of pediatric thoracic trauma and can be used to diagnose a variety of conditions, including pneumothoraces, hemothoraces, pulmonary contusions, pneumomediastinum, pneumopericardium, and bony injuries such as rib fractures. Although CT scanning of the thorax may be required to further evaluate these injuries, chest radiography is the most appropriate and cost-effective initial screening study.

| Table 3. PECARN Clinical Prediction Rule To Identify Children At Very Low Risk Of Intra-Abdominal Injury |

| No evidence of abdominal wall trauma or presence of a seat-belt sign |
| GCS score > 13 |
| No abdominal tenderness |
| No thoracic wall trauma |
| No complaints of abdominal pain |
| No decreased breath sounds |
| No vomiting |

Patients must meet all 7 criteria to be classified as very low risk (0.1% risk of intra-abdominal injury requiring intervention). Abbreviation: PECARN, Pediatric Emergency Care Applied Research Network.

Treatment

The first goal of treatment in the ED is to identify and treat conditions that will lead to rapid deterioration of the patient, such as airway obstruction, respiratory failure, tension pneumothoraces, massive hemorhages, cardiac tamponade, or uncontrolled hemorrhage. All of these conditions require emergent procedural interventions (such as endotracheal intubation, needle cricothyroidotomy, needle decompression, tube thoracostomy, or pericardiocentesis), and they should be identified and initially managed during the primary survey.

While the primary survey is being performed, it is crucial that reliable vascular access in the form of an intravenous line, intraosseous line, or central venous catheter is obtained for the administration of intravenous fluids, blood products, and medications. Peripheral intravenous lines and intraosseous lines are preferred over central venous catheters, given the time it takes to place a central venous catheter. In a hemodynamically unstable child, an intraosseous line should be placed after 2 unsuccessful intravenous attempts. Rapid administration of intravenous fluid in the form of warmed normal saline or lactated Ringer’s solution should be given to all patients with evidence of shock after blunt trauma. A total of 3 crystalloid boluses of 20 mL/kg each should be given, and the patient’s response to the fluids should be assessed after each bolus. In general, children will require a volume of crystalloid fluid equivalent to 3 times the estimated blood loss. While tachycardia is an early sign of hemorrhage, hypotension may not develop until 30% to 45% of blood volume has been lost. Transfusion of blood products is indicated for patients who only transiently improve with crystalloid infusions and should be considered in pediatric patients requiring a third bolus of crystalloids.

Once these initial steps in the stabilization of the patient have been completed, whether or not the patient requires immediate operative intervention must be determined. In the past, many solid organ injuries to the liver and spleen were managed operatively. Today, the standard of care for nearly
all solid organ injuries in children is nonoperative management; however, exceptions to this management strategy do exist.\textsuperscript{6,7,15} For example, children who are hemodynamically unstable after blunt abdominal trauma, those with signs of peritonitis on examination, those with penetrating abdominal injuries, and those with radiographic evidence of pneumoperitoneum should be taken to the operating room for emergent laparotomy.\textsuperscript{6,15,150} Although these guidelines exist, the decision about whether or not a child requires urgent operative intervention should be made on a case-by-case basis in consultation with the managing surgeon.

### Disposition

For patients who do not require emergent operative intervention, it must be determined whether or not they should be admitted to the hospital for observation, monitoring of vital signs, and serial physical examinations and laboratory studies or whether they can be safely discharged home from the ED. In some circumstances, this decision is clear. For example, patients with altered mental status, documented intracranial, intra-abdominal, or significant orthopedic injuries, hemodynamic compromise, or respiratory compromise must be admitted to the hospital. However, in a child with normal vital signs and normal imaging studies without evidence of intracranial and intra-abdominal injury, discharge home with specific return precautions may be appropriate.\textsuperscript{40,151} Despite this, many trauma centers still admit these patients for observation and serial abdominal and laboratory examinations.\textsuperscript{71} Ultimately, this decision is made on a case-by-case and a center-by-center basis.

### Special Circumstances

#### Airbag-Related Injuries In Children

Airbag-related injuries in the pediatric population were first well described in 1995 in a report published by the Centers for Disease Control and Prevention.\textsuperscript{152} In this report, 8 cases were described in which children who were in relatively minor MVCs died of cervical spine and intracranial injuries as a result of airbag deployment. All 8 of these children would have survived had it not been for the deployment of the airbags.\textsuperscript{152} Since the publication of this report, a myriad of other injuries related to frontal airbag deployment have been described, including brain, skull, cervical spine, ocular, and extremity injuries.\textsuperscript{152-155} New airbag safety standards were enacted in 1998 by the National Highway Transportation Safety Administration (NHTSA), which resulted in airbag redesign. The redesigned airbags are no longer inflated by a gas-generating propellant, and the volume and extent of the airbags has been decreased (though not necessarily based on passenger weight).

Although these redesigned second-generation airbags have resulted in decreased fatality and injury rates when compared to first-generation airbags, they still remain a significant source of injury. The most recent airbag safety standards require that all airbags be tested for all sizes of occupants, including children, and airbag redesign efforts remain ongoing. Until airbags can be redesigned to assure child safety, the American Academy of Pediatrics strongly recommends that all children aged < 13 years should sit in the rear seats of vehicles. When this is not possible, as in the case of vehicles with a single row of seats (such as pick-up trucks), front airbags should be deactivated or turned off.\textsuperscript{7}

### Motor Vehicle Accidents Complicated By Drowning Or Hypothermia

Although most MVCs occur on roads or highways, in rare cases, MVCs may be complicated by submersion in a body of water. It has been estimated that submerged motor vehicles are responsible for 400 deaths per year in North America.\textsuperscript{156,157} There are minimal data regarding the management of these patients.\textsuperscript{156} What is known is that in these circumstances, mortality is often related to drowning rather than injuries from the MVC itself.\textsuperscript{157} Additionally, these patients are at significant risk of accidental hypothermia.\textsuperscript{158} Resuscitation of these patients requires rewarming in addition to the usual measures undertaken during resuscitation.\textsuperscript{158} Cardiopulmonary resuscitation should be continued in these patients until rewarming is complete and the core body temperature has been restored to a normal range.

### Injury Prevention Strategies

Although the emergency clinician’s primary focus is often on the medical management of patients, it is equally important to dedicate time to learning about and teaching injury prevention strategies. Though there is not a single intervention that can prevent MVCs from occurring, there are several strategies that can be used to decrease injury severity. These include: (1) improving the driving environment with lighting, guardrails, and crash barrels to mitigate crash forces; and (2) redesigning motor vehicles with improved safety features such that the impact from a vehicle collision is minimized. Legislative strategies include: (1) graduated driver’s licensing laws, (2) elderly driver laws, (3) strict blood alcohol level laws, (4) primary and secondary seat belt enforcement laws, (5) primary and secondary seat belt enforcement laws (with primary enforcement, a driver can be pulled over just for not wearing a seat belt), and (5) child passenger safety laws for car seat use by children. Use of an age-appropriate child-safety restraint has been consistently proven to decrease injury severity and fatalities in children.\textsuperscript{7,8,159} (Continued on page 19)
Clinical Pathway For Evaluation Of Head Injury After Motor Vehicle Trauma In Children Aged < 2 Years

Does the patient have any of the following?
- GCS score ≤ 14
- Altered level of consciousness
- Palpable skull fracture

**YES**

Head CT (Class I)

**NO**

Does the patient have any of the following?
- Nonfrontal scalp hematoma
- Loss of consciousness ≥ 5 sec
- Severe mechanism of injury*
- Not acting normally (per parent)

**YES**

Observation for several hours versus head CT (Class I)

**NO**

Head CT not recommended (Class I)

*Severe mechanisms of injury include the following: rollover accident, ejection from a motor vehicle, death of another passenger, or pedestrian or bicyclist without helmet struck by motor vehicle.

Abbreviations: CT, computed tomography; GCS, Glasgow Coma Scale.


Class Of Evidence Definitions

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

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

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

**Class II**
- Safe, acceptable
- Probably useful

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

**Class III**
- May be acceptable
- Possibly useful

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

**Indeterminate**
- Continuing area of research
- No recommendations until further research

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

Clinical Pathway For Evaluation Of Head Injury After Motor Vehicle Trauma In Children Aged > 2 Years

Does the patient have any of the following?
- GCS score ≤ 14
- Altered level of consciousness
- Signs of basilar skull fracture

**YES**

Head CT (Class I)

**NO**

Does the patient have any of the following?
- Loss of consciousness
- Severe mechanism of injury*
- History of vomiting
- Severe headache

**YES**

Observation for several hours versus head CT (Class I)

**NO**

Head CT not recommended (Class I)

*Severe mechanisms of injury include the following: rollover accident, ejection from a motor vehicle, death of another passenger, or pedestrian or bicyclist without helmet struck by motor vehicle.

Abbreviations: CT, computed tomography; GCS, Glasgow Coma Scale.

Clinical Pathway For Evaluation Of The Cervical Spine In Children With A Reliable Clinical Examination

Is the patient alert and awake with a GCS score of 15? NO Go to pathway for unreliable clinical examination (page 17)

Reliable clinical examination

Does the patient meet these criteria?
• No focal neurological deficits
• Normal level of alertness
• No midline cervical spine tenderness
• No intoxication
• No painful or distracting injuries
• Moves head in flexion and extension without pain
• Rotates head 45° without pain

NO

Normal neurological examination?

NO MRI of cervical spine (Class II)

YES

• Cooperative: anteroposterior/lateral/odontoid x-rays
• Uncooperative: anteroposterior/lateral x-rays

X-rays normal and adequate?

NO CT cervical spine (Class II)

YES

Age > 8 years?

NO

Clinically clear; discontinue cervical collar (Class II)

YES

Is repeat examination normal?

NO MRI of cervical spine (Class II)

YES CT head down to C3 to rule out injuries to upper cervical spine (Class II)

Plan for head CT?

NO

YES

Abbreviations: CT, computed tomography; GCS, Glasgow Coma Scale; MRI, magnetic resonance imaging.
See class of evidence definitions on page 14.
Clinical Pathway For Evaluation Of The Cervical Spine In Children With An Unreliable Clinical Examination

Is the patient alert and awake with a GCS score of 15?  

- **YES**  
  Go to pathway for reliable clinical examination (page 16) (Class II)

- **NO**  
  Unreliable clinical examination

Neurological examination normal?  

- **YES**  
  - Anteroposterior and lateral cervical spine x-rays
  - Consider CT of cervical spine
  
  - NORMAL
  
  - Reassess level of consciousness in first 24-48 h

- **ABNORMAL**  
  - Consult spine service
  - Consider MRI (Class II)

  - LEVEL OF CONSCIOUSNESS IMPROVING
  
  - If patient alert and cooperative, go to pathway for reliable clinical examination (page 16) (Class II)

  - LEVEL OF CONSCIOUSNESS NOT IMPROVING  
  
  - Consult spine service
  - Consider MRI (Class II)

Abbreviations: CT, computed tomography; GCS, Glasgow Coma Scale; MRI, magnetic resonance imaging.  
See class of evidence definitions on page 14.
Clinical Pathway For Evaluation Of Pediatric Blunt Abdominal Trauma

Is the patient hemodynamically unstable or hypotensive?

YES

FAST examination (Class III)

POSITIVE

To operating room for exploratory laparotomy (Class I)

NEGATIVE

• Consider operating room for exploratory laparotomy versus further workup and treatment of hypotension
• Stabilize and treat hypotension

NO

Does the patient have abdominal tenderness?

YES

CT abdomen/pelvis (Class II)

NO

Does the patient have abdominal tenderness?

YES

Check laboratory tests: AST/ALT

NO

Does the patient have any of the following?
• Thoracic wall trauma
• Abdominal pain
• Decreased breath sounds
• Emesis

YES

Discharge home versus observation in the ED (very low risk for intra-abdominal injury requiring intervention: 0.1%) (Class I)

NO

• AST > 200 U/L or
• ALT > 125 U/L

CT abdomen/pelvis (Class II)

• AST ≤ 200 U/L or
• ALT ≤ 125 U/L

Consider admission for serial examinations (Class II)

Abbreviations: ALT, alanine aminotransferase; AST, aspartate aminotransferase; CT, computed tomography; ED, emergency department; FAST, focused assessment with sonography in trauma.

Please see class of evidence definitions on page 14.
The American Academy of Pediatrics has released a policy statement on child passenger safety detailing the appropriate child-safety restraint for each age group. The height and weight restrictions for each child-safety restraint are indicated on the individual manufacturer’s label along with an expiration date for the device. Although the benefits of child-safety restraints are well established, there remain several barriers to use. They are often costly, challenging to install, and require parental education to ensure proper usage. To help alleviate this problem, national programs have been created to provide education regarding appropriate child-safety seat use along with providing actual car safety seats to families. These programs have been demonstrated to both improve knowledge about car safety seats and to increase rates of compliance; despite this, child passenger safety remains a significant problem in the United States. As physicians, we have the opportunity to counsel families regarding child passenger safety, even in the ED setting.

Summary

MVCs are a leading cause of morbidity and mortality among children in the United States. Because of their unique anatomic considerations and stature, children are particularly vulnerable to specific injury types and patterns when involved in MVCs. Unlike adults, children have relatively large heads, more pliable thoracic cavities, larger intra-abdominal solid organs, and less intra-abdominal fat and musculature, all of which are factors that increase their risk for injury. One additional issue that arises when treating very young children is their diminished ability to localize their injuries. As such, emergency clinicians must rely on history and physical examination findings to guide both workup and treatment. Details regarding the circumstances of the MVC such as collision speed and direction, fatalities and injuries among other passengers, and patient restraint use are all factors that can aid in medical decision-making. Knowledge of specific patterns of injury associated with particular mechanisms and characteristic physical examination findings can further guide evaluation and treatment of these patients.

### Case Conclusions

All 3 children are at risk for specific injury types based on their presenting histories and complaints. Of the 3 patients, the 8-year-old and the 3-year-old are at greatest risk for severe injuries based on their mechanisms of injury: ejection from a motor vehicle and pedestrian-versus-automobile injury in the form of a driveway injury, respectively.

The 8-year-old was hypotensive and tachycardic on arrival, with abdominal abrasions and swelling of his left thigh. These findings are concerning for intra-abdominal injury along with a left femur fracture. Although the child’s airway was patent, he was moaning incoherently and his GCS was 8 on arrival, so you made the decision to intubate him with an endotracheal tube. A chest x-ray and ETCO₂ monitoring confirmed position of the endotracheal tube and breath sounds were equal bilaterally. An emergent head CT did not demonstrate any intracranial hemorrhage. At this point, the child’s hypotension and tachycardia worsened, and you determined that the most immediate potential threat to life was compromised circulation secondary to hemorrhage from an intra-abdominal injury. A FAST examination was performed, which demonstrated significant intra-abdominal free fluid. An unstable intra-abdominal bleed was suspected, and he was taken immediately to the operating room for further management.

The 14-year-old girl was complaining of neck and back pain after a low-speed MVC. Her GCS score on scene was 15, and she was ambulatory. Based on her mechanism of injury, she was at risk for injuries to the neck and spine. Her primary survey was within normal limits. Her secondary survey did not demonstrate any tenderness to palpation of the thoracic or lumbar spine and no step-offs were noted, so she was removed from the backboard. Her cervical collar was left in place. Because her mental status was at baseline, she was not intoxicated, and she did not have any painful or distracting injuries on your initial examination, she was a candidate for clinical clearance of the cervical spine. On your examination, she had no midline cervical tenderness, had no focal neurologic deficits, and was able to move her head in flexion, extension, and lateral rotation without pain, so you were able to clinically clear her cervical spine. You gave her a dose of ibuprofen for pain and discharged her home from the ED with instructions to return for new or worsening symptoms.

### Table 4. American Academy of Pediatrics Child Passenger Safety Recommendations

<table>
<thead>
<tr>
<th>Age</th>
<th>Recommended Child Passenger Restraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2 years</td>
<td>Rear-facing car safety seat until weight limit is reached</td>
</tr>
<tr>
<td>≥ 2 years</td>
<td>Forward-facing car safety seat until weight limit is reached</td>
</tr>
<tr>
<td>≥ 2 years and heavier than weight limit for car safety seat</td>
<td>Belt-positioning booster seat until child reaches 57 inches in height</td>
</tr>
<tr>
<td>Children taller than 57 inches and aged &lt; 13 years</td>
<td>Lap and shoulder restraint in rear seat</td>
</tr>
<tr>
<td>Children taller than 57 inches and aged ≥ 13 years</td>
<td>Lap and shoulder restraint</td>
</tr>
</tbody>
</table>
Risk Management Pitfalls For Motor Vehicle Trauma In Children

1. “There were no rib fractures on chest film, so his chest must be fine.”
   Pediatric rib cages are pliable and, as a result, significant pulmonary injury in the form of pulmonary contusions or hemothoraces can occur without overlying rib fractures. Emergency clinicians should consider pulmonary injuries in children with tachypnea, hypoxemia, or bruising of the thorax even in the absence of rib fractures.

2. “She had a femur fracture on examination, but I didn’t see any other injuries, so I didn’t get any further imaging.”
   The presence of a femur fracture is often indicative of a serious mechanism of injury. Even when an obvious femur fracture is seen, a full evaluation for other injuries should still be performed.

3. “The child wasn’t hypotensive, so he couldn’t have lost that much blood.”
   Hypotension is a late finding in children with significant hemorrhage. Unlike adults, children can often effectively compensate for hemorrhage until 30% to 45% of the blood volume has been lost.

4. “He was wearing a lap and shoulder belt, so his injuries probably aren’t severe.”
   Because of their stature, young children are at increased risk for injuries from seat belts. Without a booster seat, the lap belt often rides up onto the abdomen and the shoulder belt often rides up onto the neck, increasing the risk for intra-abdominal injuries, thoracolumbar spinal injuries, and injuries to the neck.

5. “She’s younger than 2 years of age, so she must have been in a car seat.”
   Although the American Academy of Pediatrics recommends that children aged < 2 years be restrained in a rear-facing car safety seat, rates of unrestrained and improperly restrained children in the United States remain high, putting these children at increased risk for injury.

6. “She was backed over in her driveway at a very low speed, so her injuries probably aren’t severe.”
   Although back-over or driveway injuries occur at a low vehicular speed, they are associated with a significantly greater injury severity than other types of MVCs or pedestrian-versus-automobile accidents. Emergency clinicians must maintain a high index of suspicion for occult injuries with this mechanism of injury.

7. “His FAST examination was negative, so he can’t have a serious intra-abdominal injury.”
   Although the utility of the FAST examination has been demonstrated in adults, its utility in the pediatric population remains unclear, given its low sensitivity. While a positive FAST examination can be helpful in decision-making, a negative FAST examination is of minimal utility and cannot be used to rule out intra-abdominal injury.

8. “We removed her cervical collar while we were intubating her, since there was no risk of her moving on her own.”
   In patients who are unconscious or chemically paralyzed, it is crucial to either leave the cervical collar in place during intubation or to maintain inline stabilization of the cervical spine during intubation. Although the patient is unable to move, passive movements that occur during intubation could cause further damage to the spinal cord.

9. “His abdominal CT showed a splenic laceration; he will definitely need a splenectomy.”
   Although, historically, both splenic and hepatic lacerations were managed operatively, the current standard of care for most pediatric solid organ injuries is nonoperative management. Only patients who are hemodynamically unstable require urgent operative intervention.

10. “He’s just a child. We can’t clinically clear his cervical spine.”
    Although it may be challenging to obtain a reliable physical examination in some children, it is possible to clinically clear the cervical spine in many pediatric patients. Particular caution should be exercised, however, in children aged < 2 years.
The 3-year-old who was brought to the ED after a pedestrian-versus-automobile accident was complaining of abdominal pain. Her vital signs on arrival to the ED were stable. You noted that she was maintaining her airway and had equal breath sounds bilaterally, so you decided to closely monitor her respiratory status and provide supplemental oxygen but to not intervene further at that time. Her secondary survey demonstrated abdominal tenderness and lower abdominal bruising in the setting of stable vital signs. You obtained an abdominal CT, and it demonstrated a grade III hepatic laceration. You consulted pediatric trauma surgery, and she was admitted for non-operative management.

**References**

Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.

To help the reader judge the strength of each reference, pertinent information about the study, such as the type of study and the number of patients in the study will be included in bold type following the references, where available. The most informative references cited in this paper, as determined by the author, will be noted by an asterisk (*) next to the number of the reference.


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**Time-And Cost-Effective Strategies**

1. **Use your clinical history and physical examination to guide the workup.**
   Using the information from your initial evaluation to guide the workup allows the workup to remain efficient and focused. Not every patient will require every diagnostic study. In most cases, a careful history and physical examination will determine which tests will be highest yield.

2. **Approach the workup of motor vehicle trauma in a step-wise fashion.**
   Although a patient may require laboratory examinations, an ultrasound, and a CT scan during the course of his evaluation, not all of these tests need to be performed simultaneously. Instead, by proceeding in a logical, step-wise fashion, the number of unnecessary or redundant studies that are ordered can be minimized.

3. **Choose the simplest study that will provide the necessary information before moving on to more complex diagnostics.**
   Often, a simple study such as a plain radiograph may provide the necessary diagnostic information, and a CT scan may not be required. By starting with the simplest examination, risks and costs from unnecessary studies can be minimized.

4. **Prioritize the workup.**
   In the workup of a trauma patient, not every test carries the same weight. Certain studies may be more important than others and more likely to provide useful clinical data; these studies should be prioritized.

5. **Do not be afraid to rely on your clinical judgment.**
   Not every trauma patient will require a laboratory or radiographic study during the course of their evaluation. In some cases, a thorough history and physical examination are the only diagnostic tests required.


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CME Questions

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1. When compared to properly restrained children, unrestrained children are at increased risk for which of the following:
   a. Head injury
   b. Intra-abdominal injury
   c. Musculoskeletal injury
   d. Thoracic injury
   e. All of the above

2. Which of the following mechanisms of injury is NOT associated with SCIWORA?
   a. Acceleration-deceleration injury
   b. Hyperextension injury
   c. Hyperflexion injury
   d. Longitudinal distraction injuries

3. A 6-year-old restrained passenger is brought to the ED after a high-speed MVC. She is noted to have abdominal wall bruising and distension. Which other injury is most likely to be present in this patient?
   a. Intracranial injury
   b. Intra-abdominal injury
   c. Cervical spine injury
   d. Pulmonary contusion

4. Which of the following is the most appropriate initial diagnostic study for a patient in whom an intracranial injury is suspected?
   a. Plain radiographs of the skull
   b. Head CT with contrast
   c. Head CT without contrast
   d. Coagulation studies
5. Which of the following patients with a closed head injury does NOT require a head CT?
   a. A 14-year-old with an initial GCS score of 14
   b. An 18-month-old with a palpable skull fracture
   c. A 12-year-old with left hemotympanum and a mastoid ecchymosis
   d. A 15-month-old with 2 episodes of emesis after a fall

6. Plain radiographs are the preferred imaging modality for all of the following regions EXCEPT:
   a. Pelvis
   b. Head
   c. Chest
   d. Extremities

7. A 15-year-old girl is brought to the ED in a cervical collar after being rear-ended in a car. She complains of neck and back pain on arrival, but her GCS score is 15. On examination, she has no midline tenderness, has no focal neurologic deficits, has no other associated injuries, is not intoxicated, and is able to fully flex, extend, and rotate her neck without pain. Which of the following is the most appropriate next step?
   a. Clinically clear the cervical spine
   b. Radiographs of the cervical spine
   c. CT scan of the cervical spine
   d. MRI of the cervical spine

8. Which of the following is responsible for the greatest decrease in pediatric morbidity after a MVC?
   a. Presence of airbags
   b. Proper usage of child-safety restraints
   c. Graduated drivers' licensing programs
   d. Improved motor vehicle design

9. An 18-month-old boy is brought to the ED after a minor MVC that happened on the day prior to presentation. His mother asks about child passenger safety restraints. Which of the following is the most appropriate child passenger safety restraint for this patient?
   a. Belt-positioning booster seat
   b. Forward-facing car safety seat
   c. Rear-facing car safety seat
   d. Lap and shoulder restraint
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To read a letter from Dr. Adam Vella, Editor-in-Chief, about this exciting achievement, please visit www.ebmedicine.net/MEDLINEPEMP.

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Target Audience: This enduring material is designed for emergency medicine physicians, physician assistants, nurse practitioners, and residents.

Goals: Upon completion of this activity, you should be able to: (1) demonstrate medical decision-making based on the strongest clinical evidence; (2) cost-effectively diagnose and treat the most critical ED presentations; and (3) describe the most common medicolegal pitfalls for each topic covered.

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