Evaluation And Management Of Pediatric Abdominal Trauma

A four-year-old female, who was a lap belt restrained, back-seat-passenger involved in a motor vehicle collision, presents with head pain and right thigh pain. The car she was in hit the guardrail with a frontal impact at 70 mph. The child lost consciousness momentarily. Initial vital signs included a blood pressure of 100/62 mmHg, a heart rate of 136/minute, and a respiratory rate of 36/minute. The only abnormalities on examination included a left parietal contusion and deformity to her right femur. A large-bore intravenous catheter was initiated and 20 mL/kg of 0.9% normal saline solution was administered as she was transported to your emergency department. Your abdominal evaluation revealed a seat-belt contusion with a soft and nontender abdomen.

What are the priorities in the initial evaluation and management of this child? How do you evaluate the potential intra-abdominal injuries?

Trauma is the leading cause of morbidity and mortality in children. Trauma stats include nearly 1.5 million injuries, 500,000 hospitalizations, 20,000 deaths, and over 120,000 permanently disabled victims annually. Blunt trauma accounts for approximately 90% of all pediatric injuries, with falls and motor vehicle collisions representing the most common mechanisms of injury. Head and extremity injuries occur most frequently; however, injury to the abdomen can occur in up to 8% of children, and abdominal injury is responsible for 9% of all trauma deaths. Significant abdominal trauma occurs in 25% of children.
sustaining multisystem injuries. While head and thoracic injuries are the most common cause of trauma-related death, abdominal trauma is the leading cause of initially unrecognized fatal injury in children. These injuries can be potentially life-threatening; therefore, physicians who manage pediatric trauma must have a complete understanding and systematic approach to the presentation, evaluation, and initial management of pediatric patients with blunt abdominal trauma.

**Abbreviations Used In This Article**

- AAST: American Association Of Trauma
- ALARA: As Low As Reasonably Achievable
- ALT: Alanine Aminotransferase
- APSA: American Pediatric Surgical Association
- aPTT: Activated Partial Thromboplastin
- AST: Aspartate Aminotransferase
- CT: Computed Tomography
- DL: Diagnostic Laparotomy
- DPL: Diagnostic Peritoneal Lavage
- ED: Emergency Department
- EMS: Emergency Medical Service
- ERCP: Endoscopic Retrograde Cholangiopancreatography
- FAST: Focused Abdominal Sonography For Trauma
- GCS: Glasgow Coma Scale
- GU: Genitourinary
- HPF: High Power Field
- ISS: Injury Severity Score
- IV: Intravenous
- IVP: Intravenous Pyelography
- MRCP: Magnetic Resonance Cholangiopancreatography
- MRI: Magnetic Resonance Imaging
- PT: Prothrombin Time
- PTS: Pediatric Trauma Score
- RBC: Red Blood Cells
- RTS: Revised Trauma Score
- WBC: White Blood Cell

**Critical Appraisal Of The Literature**

During the last 40 years, interest and research in nonoperative management of blunt abdominal trauma in children with known solid-organ injuries has evolved considerably. With the emergence of the ultrasound for evaluation of suspected injuries, different types of physicians, including surgeons, radiologists, and emergency medicine physicians, have been involved in studying the accuracy of this instrument. Despite the data that has been published, the computed tomography (CT) scan remains the radiologic method-of-choice for most physicians. Most of the literature regarding the evaluation and management of pediatric blunt trauma consists of retrospective reviews of patients with some prospective evaluations, making inference from the literature difficult.

**Anatomical Features**

Unique anatomic features predispose children to a variety of injuries, while particular mechanisms, such as bicycle accidents, pedestrian trauma, nonaccidental trauma, and lap belt complex, lead to specific injuries that might be difficult to identify. Because of their body habitus and relatively immature musculoskeletal system, children are at increased risk of sustaining injuries to intra-abdominal organs after blunt abdominal trauma. Compared with the adult patient, the child’s intra-abdominal organs are proportionally larger and are in relatively close proximity to each other. The small size of a child results in a greater degree of force per body surface area, which can lead to significant injury to multiple organs. Furthermore, there is little fat or connective tissue to cushion organs and the abdominal wall is less muscular, providing little protection to the intra-abdominal contents. The pediatric kidney also retains fetal lobulation, which might lead to easier separation and fracture, while congenital anomalies and tumors might predispose to renal injury. The chest wall consists of an incompletely ossified rib cage which is also higher and thus provides limited protection to the liver, spleen, and kidneys. Abdominal distention following aerophagia from pain or crying is common and is difficult to differentiate from distention due to bleeding. The bladder is an abdominal organ in young children making it easier to be injured from blunt abdominal forces. Finally, the increased ratio of body surface area to volume results in an increased propensity toward hypothermia.

**Differential Diagnosis**

**Mechanisms**

The mechanism of abdominal injuries in children is most commonly caused by motor vehicle accidents (32-66%), followed by pedestrians struck by a cars (24-27%), falls (13-14%), and bicycle accidents (12%). Other less common causes include sports injuries or falls from animals. Intentional injuries, including abuse and assaults, are less common but important mechanisms of injury because of the potential for severe trauma and high mortality. A retrospective study using logistic regression in 793 children identified predictors of abdominal injuries in children after blunt trauma. They found that mechanism of injury, revised trauma score (RTS) less than or equal to 12, abdominal tenderness, abdominal distention, absent bowel sounds, fractured pelvis, gross hematuria, chest trauma, and hematocrit less than 30% were all associated with
abnormal CT scans. Another prospective study of 1095 children found that low blood pressure, abdominal tenderness, femur fracture, hematocrit less than 30%, alanine aminotransferase (ALT) greater than 125 U/L and/or aspartate aminotransferase (AST) greater than 200 U/L, and urinalysis with greater than 5 RBC/HPF (red blood cells per high power field) were significantly associated with abdominal injuries on CT scan.8

Motor Vehicle Accident
Blunt trauma from motor vehicle accidents is the most common cause of abdominal trauma. The majority of children with blunt abdominal trauma caused by motor vehicle accidents have associated nonabdominal injuries.

A detailed history of the motor vehicle accident should be obtained after the initial resuscitation of the patient is performed. Important questions regarding any motor vehicle accident include: the speed and direction of the vehicles, the location of the occupants and whether ejection occurred, whether other persons were injured, the location of the impact in relation to the patient, and whether the type and location of any restraint or deployment of the air bag occurred.

Studies of adult occupants in motor vehicles reveal that accidents involving lateral intrusion more frequently cause trauma to the liver, kidney, spleen, and lung, while head-on collisions more frequently injure the bowel, face, and extremities.10 It is uncertain whether these injury patterns are applicable to children, as back-seat occupancy and the presence of car seats are likely to substantially alter injury patterns.

Restraint use by children involved in crashes has proven effective in reducing both mortality rates and the risk for significant injuries.11 Properly positioned lap belts, when worn with shoulder harnesses, reduce craniofacial injuries, chest injuries, solid organ injuries, and extremity fractures.12-15 Properly restrained children and infants also are less frequently and less severely injured and have a lower mortality rate than their unrestrained counterparts.16 Unrestrained children are more likely to have head and neck injuries, as well as injuries to the face, thorax, and extremities.17 However, restrained children may be more predisposed to abdominal injury. Children are especially vulnerable to blunt abdominal injury as incorrect belt positioning, increased head-to-body ratio, and a poorly developed iliac crest all contribute to abdominal injuries. A three-point restraint is more protective than a two-point restraint but does not necessarily preclude this injury.18 Child seats and booster chairs have an even greater ability to reduce morbidity and mortality than the two-point lap belt.16,19 Despite public awareness and seat belt laws in all 50 states, two-thirds of the children fatally injured in motor vehicle accidents were reported to be unrestrained or improperly restrained.20

Lap Belt Injuries
Children with blunt abdominal trauma who also have a “seat belt sign” (contusion to the torso caused by the seat belt) have an increased incidence of abdominal injury.21-23 The “seat belt syndrome” was introduced in 1962 by Garrett and Braunstein24 to denote a distinctive pattern of injury resulting from the use of lap belts in automobile collisions (Figure 1). This syndrome describes injuries in the plane of the lap belt and includes small and large bowel and their mesentery, stomach, liver, spleen, pancreas, kidneys, lumbar vertebrae (Chance fracture), spinal cord injuries, pelvic fractures, and rib fractures.25,26 In one review, up to 78% of patients with a seat belt contusion had intra-abdominal injuries.27 Other studies have reported that 67-79% had a hollow viscous injury, mostly in the jejunum or ileum.25,28 Anatomic characteristics of children further increase their risk for serious injury. The small anteroposterior diameter of children’s abdominal cavity, the relative lack of protective abdominal muscles, the underdeveloped pelvis and rib cage, and the higher center of gravity make children wearing lap belts especially vulnerable to injury in the event of sudden deceleration. The lap belt type of restraint is designed to be worn at or below the level of the anterior superior iliac spines. The relatively underdeveloped pelvis in children allows the lap belt to ride cephalad from the recommended across-the-hips position to a higher location across the abdominal cavity. When a rapid deceleration force occurs, the lap belt rides above the iliac crests and over the abdomen, which allows the child to submarine forward under the lap belt concentrating most of the force at the level of the upper lumbar spine with intra-abdominal injuries involving a similar level. This results in hyperflexion of the upper...

Figure 1. Lap Belt Ecchymosis

Image courtesy of Dr. Antonio Muñiz.
lumbar spine and compression of abdominal contents between seat belt and spine. 29

Pedestrians Struck By Motor Vehicles
These injuries are the second most common cause of abdominal trauma in children. 4 Common injuries in pedestrians struck by cars involve those to the extremities and head, while 10% have abdominal injuries. 30 Mortality is generally related to the degree of multisystem trauma, with 80% of deaths resulting from head trauma. 30 See the December 2007 Pediatric Emergency Medicine Practice issue, “An Evidence-Based Approach To Severe Traumatic Brain Injury In Children.”

Patient age is an important determinant of location and type of injury. Children less than five years of age are more likely to be run over by a slow moving car in a driveway or parking lot, resulting in crush injuries to the head and trunk. 31 Children older than five years are often injured crossing a street, sustaining impact injuries. Waddel’s triad describes these injuries; although the original description was based on 10 adult patients—the youngest being 21 years of age. The original description was: “… three separate but related injuries; injury about the knee produced by direct impact and valgus strain, injuries to the hip or pelvis, and craniocerebral injury.” 32 This triad occurs as children are hit from the left side by an approaching car, causing left-sided abdominal trauma injuring the spleen and left kidney, extremity trauma (such as a femur fracture), and closed head injury as the child is thrown and the head comes in contact with the pavement. Right-sided abdominal injuries, such as liver injury, are more common in countries where people drive on the left side of the road. However, the predictive accuracy of this injury pattern has come under suspicion. 33 Two studies have shown that the Waddell triad only occurred in less than 2.4% of children who sustained injury after being struck by a car. 33, 34

Bicycle Accidents
Accidents involving bicycles are responsible for a significant proportion of trauma in children, resulting in an estimated 430,000 hospital visits and 275 deaths annually. 35 Two types of mechanisms causing bicycle-related trauma may be seen. First are high-speed mechanisms, in which the rider is thrown from the bicycle or the bicycle collides with a car or stationary object. These mechanisms are often associated with severe multi-system trauma. The second mechanism of injury occurs following a relatively low speed crash, in which the bicycle handlebars strike the rider in the neck, abdomen, or pelvic region. In the typical collision, the front wheel rotates in a plane perpendicular to the child’s body as the child loses control of the bicycle and begins to fall. Subsequently, the child strikes the end of the handlebars, leading to injury. Direct impact from the end of the handlebar is generally underappreciated and typically results in isolated but often severe injuries. The percentage of children with abdominal or pelvic injury after bicycle-related trauma, who sustained direct impact from a handlebar, may be as high as 78%. 36 Injury occurs when the handlebar acts like a spear and effects blunt trauma to the abdomen. The severity of these injuries may be quite significant. Direct-impact handlebar injuries to the liver, spleen, pancreas, duodenum, intestines, kidneys, urethra, and major vessels have all been reported. Splenic injuries, soft-tissue lacerations, pancreatic injuries, liver injuries, and bowel perforation are the most common. Although an abdominal wall contusion or abrasion may often alert the clinician to the potential for significant internal damage, the external signs of trauma to the abdominal wall can be relatively unimpressive in patients with direct handlebar injuries. Injuries to the small bowel and pancreas may become clinically manifest in a delayed manner and are thus associated with delayed hospital presentation and diagnosis. A series of 30 children with handlebar-related injuries found that one-third were examined soon after their accident and discharged before developing vomiting or peritonitis. 37 The mean delay before correct diagnosis of abdominal injury was 24 hours. The mean age of children with this mechanism is about 10 years of age, and males are generally more often affected. Children who sustained direct-impact handlebar injuries are more likely to require operative treatment when compared to children who flipped over the handlebars. 37 The reported incidence of operative intervention ranges from 20-40%. 38-40

All-Terrain Vehicle Injuries
All-terrain vehicles (ATVs) account for approximately 33,000 injuries annually and more than 200 deaths per year. 41 Children account for up to 50% of ATV-related injuries and 35% of ATV deaths. A number of risk factors for injury include a younger child age, male sex, rider inexperience, alcohol use, excessive speed, and failure to wear a protective helmet. 52 These vehicles are large, heavy, and difficult for children to control. Rollover accidents, with the vehicle often crushing the driver or passenger, account for 40% of ATV injuries, followed by collisions and falls from the vehicle. Abdominal trauma accounts for a quarter of all injuries and up to 19% of deaths. 43 The spectrum of injuries parallels that of motor vehicle accidents with involvement of all organs. Traumatic brain injuries, orthopedic injuries, and facial fractures were the most common injuries, while abdominal injuries occurred 4% of the time. 44, 55
**Falls**
Falls account for a small number of abdominal injuries in children. Those who sustain injury from falls are typically younger, usually less than two years of age, and more frequently sustain head and extremity injuries. Abdominal trauma is only found in 3% of children admitted to the hospital for falls, and the severity of trauma is generally less than that caused by motor vehicle collisions. A review of 45 children who fell 1-6 stories found that only 2% sustained significant abdominal trauma.

**Sports-Related Injuries**
The incidence of sports-related injuries is 0.73% of sports participants. These injuries are most commonly associated with isolated organ injury, such as a result of a blow to the abdomen. At particular risk is the kidney, spleen, liver, and intestinal tract in children involved in sports-related abdominal injury.

**Abusive Abdominal Injuries (Child Abuse)**
Approximately 1 million children are victims of abuse or neglect in the United States, with 1400 deaths annually. Only 1% of children hospitalized because of child abuse sustain intra-abdominal injury. Children with inflicted abdominal injuries are younger than most trauma patients, usually with a mean of 2-3 years of age, and have more severe injuries. The mortality rate varies from 45% to 50%, making abdominal trauma the second most common form of fatal physical child abuse. In abused children with abdominal trauma, more than half of all involved families have been reported to civil authorities for child abuse.

A reason that inflicted abdominal trauma has significant morbidity and mortality has to do with the difficulty in achieving the diagnosis. Early diagnosis is problematic due to the inaccurate and misleading histories provided by the caregiver and the frequent lack of external abdominal bruising, even in cases of severe injuries. The young age of the abused victim makes both the history and physical examination difficult. Other factors that may contribute to increased mortality is the delay in seeking medical care that occurs frequently after inflicted abdominal trauma.

Head injuries are the most common inflicted injuries and most common cause of mortality. In earlier studies, hollow viscous injury was the most common intra-abdominal injury seen in abused children. In fact, when compared to accidental blunt abdominal trauma patients, the rate of hollow organ injuries was found to be almost three times higher among abused children. Therefore, when a child presents with a hollow viscous organ injury, particularly when another solid organ injury is present, a high index of suspicion of abuse must be maintained. In more recent reports, liver and spleen injuries are the most common, followed by duodenjejunal rupture, duodenal rupture, and pancreatic, vena cava, and renal trauma. These injuries are thought to be due to compression of abdominal viscera against the vertebral column following a punch or kick. Associated non abdominal injuries are common and include soft tissue injuries (95%), head trauma (45%), extremity fractures (27%), and skull fractures (18%).

The most common presentation from abusive abdominal injuries include shock, owing to massive intra-abdominal hemorrhage, followed by peritonitis from hollow viscous rupture, and bilious vomiting, which is due to bowel wall hematomas and visceral trauma.

**Prehospital Care**
It has been shown that the presence of prehospital care providers with advanced life support training lowers pediatric trauma deaths. In contrast, several studies have shown that paramedics often have difficulty with procedural intervention in the field. Successful pediatric intubation by paramedics varies widely from 41% to 89%. In a prospective trial, children less than 12 years of age requiring field airway management were randomized to endotracheal versus bag-valve-mask ventilation. Survival and neurological outcome were not affected by the type of airway procedure used, although children undergoing endotracheal intubation had significantly longer scene duration. Paramedics also have difficulty with venous access, with success rates less than 50% in critically ill children who were less than six years of age.

Controversy has arisen regarding the administration of intravenous fluids to patients with uncontrolled hemorrhage. Several animal studies found that administration of intravenous fluids prior to controlling hemorrhage increased mortality. Postulated mechanisms include hydraulic acceleration of ongoing hemorrhage owing to elevated systemic blood pressure, disruption of thrombus at the bleeding site, and dilution of clotting factors. Prehospital intravenous (IV) fluid administration in hypotensive adults with penetrating torso trauma injuries resulted in increased mortality despite improved blood pressure, compared with victims who did not receive prehospital IV fluids. Administration of fluids was only effective after bleeding was controlled in the operating room. Despite these findings, no studies have evaluated adults with blunt trauma or children with any trauma to determine if prehospital fluid administration can be detrimental. Until this is established, fluid administration remains an accepted standard component of prehospital care.
The Pediatric Trauma Score (PTS) was developed as a prehospital tool to rapidly determine the need for children to be transported to a trauma center (Table 1). Initial studies found that children with a PTS less than 0 had 100% mortality, a PTS of 1-4 had 40% mortality, a PTS of 5-8 had 7% mortality, and a PTS greater than 8 virtually no mortality following trauma. Based on these data, a PTS less than or equal to 8 is the recommended threshold for diverting children to a designated pediatric trauma center. Another score, the Revised Trauma Score (RTS) (Table 2) is as accurate as the PTS for determining injury severity, with improved ability to predict overall outcome, although the PTS is slightly better at determining appropriate emergency department (ED) and hospital disposition. Proponents of the RTS believe that this score is easier to calculate and allows for a single score to be used at all ages. An RTS less than 12 is the recommended threshold for diverting a child to a trauma center. While the RTS and the PTS can stratify the risk of deterioration following trauma, it is important to note that children with isolated abdominal injuries may manifest initial vital sign stability and relatively normal trauma scores. In fact, 86% of children with isolated spleen or liver injuries will have normal heart rates, 94% will have normal systolic blood pressure, and most will have a PTS above 10.

Optimal care of pediatric trauma patients requires that the responsible treating physician and institution have specific expertise and resources. Patient care is different among pediatric trauma centers and adult trauma centers. At pediatric trauma centers it has been shown that treatment outcome for children with blunt trauma is better and there is a higher incidence of nonoperative management of liver and spleen injuries. Therefore, children with significant injuries should be transported to a pediatric trauma center by the EMS system if one is available.

### Table 1. Pediatric Trauma Score

<table>
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<th>Patient features</th>
<th>+2</th>
<th>+1</th>
<th>-1</th>
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<td>Size (kg)</td>
<td>&gt; 20</td>
<td>10-20</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Airway</td>
<td>Patent</td>
<td>Maintainable</td>
<td>Non maintainable</td>
</tr>
<tr>
<td>Systolic BP</td>
<td>&gt; 90</td>
<td>50-90</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>Mental status</td>
<td>Awake</td>
<td>Obtunded</td>
<td>Comatose</td>
</tr>
<tr>
<td>Open wound</td>
<td>None</td>
<td>Minor</td>
<td>Major</td>
</tr>
<tr>
<td>Extremity fracture</td>
<td>None</td>
<td>Close</td>
<td>Open or multiple</td>
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</table>

### Table 2. Revised Trauma Score.

<table>
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<th>Revised Trauma Score</th>
<th>Glasgow Coma Scale</th>
<th>Systolic blood pressure (mm Hg)</th>
<th>Respiratory rate (respirations/min)</th>
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<td>&gt; 89</td>
<td>10-29</td>
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<tr>
<td>3</td>
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<tr>
<td>0</td>
<td>3</td>
<td>0</td>
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</tbody>
</table>

### Emergency Department Evaluation

#### Initial Evaluation And History

A favorable outcome for any pediatric trauma depends upon rapid and accurate diagnosis with prompt treatment of potential life-threatening injuries. Evaluation and management of the injured child should follow the paradigm of the Advanced Trauma Life Support protocols with assessment of airway, breathing, circulation, neurological status, and complete exposure during the primary survey with management of immediate life threats as soon as they are identified. The first step consists of assessment of airway patency and quality of breathing. Once the airway has been secured, evaluate the quality of the circulation. The heart rate is the most sensitive indicator of intravascular volume status in infants and young children. It should be emphasized that hypovolemic shock is heralded by tachycardia long before hypotension is apparent. A child with multiple injuries should undergo placement of two large-bore intravenous catheters. If intravenous access proves to be difficult, insertion of an intraosseous catheter can be life saving in any age group. An intraosseous catheter can be used for fluid resuscitation and administration of medications. The most common location is at least one finger breadth below the tibial tuberosity to make certain the physis is avoided. After the initial resuscitation has been performed using an intraosseous catheter, intravenous attempts are often successful.

Obtaining as much information as possible about a child’s past medical history is always worthwhile even in the abbreviated trauma history and examination. Medical conditions that affect a child’s neurological or developmental baseline are important to obtain. A few examples that may make evaluation more difficult include autism, cerebral palsy, or other medical conditions that result in mental or physical handicaps. Hemophilia patients or patients with recent or concurrent Epstein-Barr virus infection may have delayed splenic rupture and massive bleeding from minor abdominal trauma.

Fear and pain can complicate the management of serious abdominal trauma in children. Children tend to distend the stomach greatly with ingested air and this can significantly decrease the diaphragmatic excursion by overdistention of the abdomen, which can compromise respiratory efforts. Early decompression via nasogastric or orogastric tube insertion should therefore be considered. Children in whom a stable pelvis has been established and who are not at risk for urethral trauma should have a Foley catheter inserted to decompress the bladder. The clinician should then evaluate for the presence of urinary retention and check for the presence of blood in the urine.
ED evaluation and management of blunt trauma is guided primarily by the stability of the patient and the presence of associated injuries. The blood volume of a child is approximately 80 mL/kg. The American College of Surgeons fluid resuscitation guidelines recommend an initial bolus of 20 mL/kg of warm isotonic fluids (0.9% normal saline or lactated Ringer’s) for the thermodynamically unstable child. In addition, other life-threatening injuries should be excluded. If the child remains hemodynamically unstable after 40 mL/kg of isotonic solution, administration of blood at 10-20 mL/kg should be strongly considered, and a thorough evaluation for the source of bleeding should be undertaken. It is imperative that a pediatric surgeon or trauma surgeon be consulted at this point. If hypotension persists and intra-abdominal injury is suspected, additional blood and a laparotomy should be strongly considered.

After completion of the primary survey, perform a thorough secondary survey that consists of a head-to-toe physical examination to identify all traumatic injuries. Physical findings suggestive of intra-abdominal injury include abrasions and contusions on the abdominal wall (seat belt sign), abdominal distention, and tenderness. Abdominal distention may be a sign of hemoperitoneum, but it can also be the result of significant aerophagia leading to massive gastric distention. Placement of a nasogastric or orogastric tube will decompress the stomach and reduce the risk of aspiration. Rectal examination is an important adjunct to the abdominal examination, as is evaluation of the pelvis.

Physical Examination

Prompt and accurate assessment of injuries is necessary to optimize the outcome. However, children sustaining blunt abdominal trauma pose a challenging dilemma because the initial abdominal examination is often unreliable and inaccurate, with a high rate of missed abdominal injuries. The initial abdominal examination may fail to show significant abdominal pathology (up to 45%), and sequential examinations are essential to exclude an evolving abdominal problem. Studies have demonstrated the difficulty in assessing abdominal tenderness on physical examination of pediatric trauma patients. In children with significant hemoperitoneum, 40% had no clinical abdominal signs. Delays in diagnosis can be fatal in some patients. In addition, there are injuries that may develop symptoms very slowly, such as small gastrointestinal perforations, pancreatic contusions, pseudocyst or ductal injury, urinoma, obstructing duodenal hematoma, or hematobilia.

Bruising of the abdominal wall has been reported previously as an indicator of intra-abdominal injury. Abdominal wall bruising has been associated with the use of suboptimal restraint, such as the lap belt only restraint. Significant intra-abdominal injury occurs in 6-16% of patients. Children with physical signs such as abrasions, contusions, pain and tenderness are more likely to have abdominal injury.

Laboratory Evaluation

Difficulties in the evaluation of the injured child and the inherent risk for missed injuries and subsequent morbidity have led to standardized management protocols, including screening tests obtained during resuscitation. Before CT was readily obtained, “trauma panels” were performed as a means of predicting serious intra-abdominal pathology.

Despite prior studies showing a limited use for trauma panel, their use is still recommended but controversial. The utility of the trauma panels, however, may be increased through use on select subsets of injured patients. These panels may include some or all of the following laboratory tests: a complete blood cell count, serum chemistries, and coagulation profiles along with organ-specific markers of injury such as liver function tests, amylase, lipase, and urinalysis.

A retrospective review of the utility of a trauma panel in children showed that no laboratory screen was clinically significant for abdominal pathology. Elevated AST and ALT levels, in addition to microscopic hematuria and an abnormal physical examination, are associated with an intra-abdominal injury. Elevation of glucose and white blood cell (WBC) count may occur as a stress response to the trauma and has no correlation with injury severity or impact on patient management.

Initial hemoglobin and hematocrit levels might be normal in children with significant bleeding, as it may take hours for body fluid spaces to equilibrate and reflect the degree of hemorrhage. Serial hemoglobin and hematocrit levels are more useful tools that reflect the presence of ongoing blood loss.

Coagulation studies, including platelet count, prothrombin time (PT), and activated partial thromboplastin time (aPTT) are seldom useful acutely in previously healthy children. A review of 830 pediatric blunt trauma victims found that during hospitalization, an elevated PT or aPTT developed in 37% who were hypotensive, 18% with a PTS less than or equal to 8, 17% with open or multiple fractures, 16% with major open wounds, and 19% with a pediatric Glasgow Coma Scale (GCS) score of less than or equal to 13. Children who receive multiple units of blood are also at risk for developing transfusion-related coagulopathies. Patients with an isolated intra-abdominal injury generally do not require...
coagulation studies if one of the above factors does not exist.

Electrolyte abnormalities are uncommon in acute trauma. A multicenter prospective study of 715 children with electrolyte panels obtained in the ED found that 1 of 42 children with trauma requiring blood or fluid resuscitation in the ED had an electrolyte abnormality. However, in children with shock caused by acute blood loss, metabolic acidosis and an elevated serum lactate level are expected. Base deficit is a useful marker for the presence of abdominal injury requiring surgery. A study of 3223 patients, mainly adults, with blunt abdominal trauma found that patients with a normal base deficit (-2 to 2) had a 4% probability of abdominal injury requiring surgery. The probability of abdominal trauma requiring surgery rose to 9% for a mild base deficit (-3 to -5), to 28% for a moderate base deficit (-6 to -14), and to 31% for a severe base deficit (less than -15). Other electrolyte abnormalities that occur primarily following massive transfusions include hyperkalemia, metabolic alkalosis, hyperphosphatemia, and hypocalcemia.

Hematuria is an important marker of serious renal and non-renal trauma in children. In one study, the most commonly injured organ in children with hematuria was not the kidney (26%), but the spleen (37%) and liver (33%). A study of 378 children evaluated after blunt abdominal trauma found that splenic injury was present in 11% and liver injury in 10% of patients with hematuria, while renal injury occurred in only 8% of children with hematuria. Renal trauma was found in 22% of those with gross hematuria, splenic injury in 17%, and liver injury in 8%. While the degree of hematuria correlated with a higher risk of abdominal injury, all children with hematuria and organ injury had other indications for CT, such as abdominal pain or abnormal abdominal examination. Hematuria can indicate trauma at any location within the genitourinary system. Conversely, hematuria might be absent in up to 50% patients with renal pedicle injuries. Blood in the urine may also come from the placement of a Foley catheter. A study of 285 consecutive children with minimal to moderate injury found that the abdominal examination combined with urinalysis detected 98% of all intra-abdominal injuries.

Children with hepatic transaminase abnormalities were more likely to have liver injury than children presenting with normal levels. Only transaminases in excess of 400 IU/L, however, were predictive of liver injury identifiable with abdominal imaging. Of note, in each child presenting with a transaminase level in excess of 400 IU/L, abdominal imaging was deemed necessary because of either injury mechanism or physical examination findings, such as decreased level of consciousness, abdominal tenderness, or shock, and was not influenced by these laboratory results. Another study showed that a serum AST greater than 400 IU/L and/or ALT greater than 250 IU/L predicted hepatic injuries. In addition, the degree of elevation of hepatic transaminases does not correlate with the degree of injury or outcome. Since CT is recommended to identify and grade suspected liver injuries, liver function tests are generally not required in managing liver injuries. Their main use might be to identify unsuspected injuries in children who do not undergo CT.

Elevated serum amylase and lipase may suggest pancreatic injury. However, serum values alone are not reliable as screening studies for pancreatic injury in the pediatric trauma population. Elevation of serum amylase has some correlation with injury to the pancreas in children. Some studies have noted elevated serum amylase levels in children with pancreatic injury, yet others do not. These tests have poor sensitivity in detecting pancreatic injury, with elevations reported in only 25-77% of CT or laparoscopic proven cases. Sensitivity might be increased if repeated values are obtained, especially in those with increasing abdominal pain. The magnitude of serum amylase elevation, however, does not predict the severity of injury to the pancreas. Serum amylase levels may be normal even in cases of major injury to the pancreatic duct. Serum amylase levels do not alter the management of patients with abdominal trauma in several large series and were felt to be of limited value in predicting pancreatic trauma. Amylase and lipase also are poor at discriminating between pancreatic and non-pancreatic trauma. In one study, 45 patients (53%) had an elevation of one of these tests and only one (1%) had a pancreatic injury. Furthermore, several studies have shown that severe head injury in the absence of pancreatic injury may result in hyperamylasemia in the early post-injury period. Therefore, inclusion of amylase and lipase values as a part of a trauma screening panel results in a significant number of elevated values that do not correlate with abdominal injury.

In addition to the laboratory evaluation early in the resuscitation process, any multiply injured child should have blood drawn and sent for cross-match.

**Diagnostic Studies**

Liberal use of diagnostic imaging has become an integral part of the initial assessment of pediatric blunt abdominal trauma because both the clinical assessment and laboratory evaluation are considered unreliable. Many diagnostic methods currently exist, such as abdominal radiographs, abdominal ultrasonography, CT, diagnostic peritoneal
lavage (DPL), and diagnostic laparoscopy (DL), for the evaluation of abdominal injuries in traumatized children. In spite of these technologies, it is still often difficult to evaluate the presence of intra-abdominal injuries in children.

**Plain Abdominal Radiographs**

Plain abdominal radiographs are primarily useful in penetrating trauma to detect pneumoperitoneum and foreign bodies. Their use in blunt trauma is less useful since they are normal in greater than 95% of cases and only serve to delay evaluation and management of these patients.\(^\text{122}\)

**Focused Abdominal Sonography For Trauma (FAST)**

The use of ultrasound for abdominal trauma was described initially by Kristensen and colleagues in 1971.\(^\text{123}\) The term Focused Assessment with Sonography for Trauma (FAST) was coined by Rozycki et al in 1996.\(^\text{124}\) Examination of Morrison’s pouch (the potential space between Gerota’s fascia of the kidney and Glisson’s capsule covering the liver), the pouch of Douglas (retrovesical pouch), the left flank to include the perisplenic anatomy (splenorenal recess), and the subxiphoid view to visualize the pericardium, is the standard four-view focused abdominal sonography for trauma examination. Others have included a six-view examination, which adds visualization of the right and left paracolic gutters.

In detecting intra-abdominal injuries in trauma patients, the governing paradigm has always been to quickly recognize those patients who require laparotomy and to prevent further morbidity and mortality. In the child with multiple injuries who is hemodynamically unstable, one must quickly determine whether an intra-abdominal injury is an important source of bleeding. Historically, DPL had been used to determine the presence of hemoperitoneum in such children.\(^\text{125,126}\) However, a FAST examination quickly performed in the ED might be more efficient and less prone to complications (Figure 2). The bedside examination may be useful as a rapid screening study, particularly in patients too unstable to undergo an abdominal CT scan.\(^\text{127,128}\) FAST is poor at identifying organ-specific injury and may under-diagnose intra-abdominal injuries, which is a serious limitation in the context of non-operative management of abdominal injuries.\(^\text{129,130}\) Because most intra-abdominal injuries in children can be managed non-operatively, the mere presence of free fluid alone in the peritoneal cavity is not enough to warrant operative exploration. In addition, accurate assessment of injuries is critical if non-operative management is to be used. Unrecognized injuries could have potentially serious consequences in this physically active patient population. The view of many experts is that injuries with no intraperitoneal fluid require the same treatment as injuries associated with fluid. Therefore, a screening test should identify both types of injury. At this point, FAST may have a role as a screening tool, but it is not a replacement for CT scan or visualization with laparoscopy, if indicated. However, rather than a tool for definitive diagnosis, ultrasound still retains its function as an effective triage tool to detect significant intra-abdominal injury requiring immediate attention.

While ultrasound is fast, inexpensive, non-invasive, portable, easily repeated, fairly accurate at identifying children requiring laparotomy, and does not require contrast or radiation exposure, the role of the FAST examination in the pediatric population is less well-defined.\(^\text{131,132}\) FAST can be performed during the primary survey of trauma resuscitation and could provide timely information regarding the presence of intraperitoneal fluid. Theoretically, children are ideal candidates for ultrasound examination. Their abdominal cavities are small and not clouded by the large fat deposits so often seen in adults. Some studies have supported the routine use of ultrasound in evaluating the abdomen of pediatric blunt trauma patients, but others question the use of ultrasonography in this setting.\(^\text{129,133,134}\) The sensitivity of ultrasound for pediatric trauma patients has been a point of criticism. The documented sensitivity rates range from 55% to 100% and specificities range from 83% to 98%; it has a positive predictive value of 86-91% and a negative predictive value of 50-99% in detecting intra-abdominal injuries.\(^\text{134-143}\) One limitation common to many of these studies reporting high sensitivities, however, is that patients frequently did not have more definitive abdominal evaluations beyond ultrasonography.\(^\text{139,140,144,145}\) It is, therefore, possible that patients with negative ultrasound findings without further definitive abdominal evaluations

**Figure 2. A Positive FAST Examination Showing Free Fluid In The Pelvis**

*Image courtesy of Dr. Antonio Muñiz.*
had unidentified intra-abdominal injury. This may have falsely elevated the sensitivity of ultrasound scan in these studies. However, the injuries that are missed are generally grade I or II solid organ injuries that usually require no treatment. Although ultrasound may have a limited sensitivity, it has proven to be very specific in the detection of intraperitoneal fluid. Because the negative predictive value of sonography for free fluid is too low for routine screening and the lack of free fluid on sonography does not negate serious organ injury, sonography is not reliable as a screening tool in the evaluation of hemodynamically stable children with blunt abdominal trauma.

The use of ultrasound appears to be accurate in those children who present to the ED with hypotension because it identified intraperitoneal fluid in all patients with hypotension and hemoperitoneum in a retrospective review. Most important, none of the patients with hypotension and negative abdominal ultrasound findings had hemoperitoneum or an intra-abdominal injury that required emergent therapy. In these cases, ultrasound scan likely provided crucial information for further management of the hypotensive child.

A consensus paradigm for ultrasound use can be included in hemodynamically unstable patients. A positive FAST examination may increase the chance of the need for a therapeutic laparotomy; a negative FAST examination warrants examination for an extra-abdominal source of hemorrhage. In hemodynamically stable patients, a positive FAST examination should be followed by an abdominal CT scan to better define the injury, and a negative FAST examination should be followed with serial examinations for six hours and a follow-up ultrasound or abdominal CT scan, depending on the clinical scenario. However, variations in this practice are commonplace since there is no validation of this paradigm. For example, given a significant mechanism of injury and a negative FAST examination, a stable patient may still undergo CT scanning. An unconscious patient with severe head injury requiring operative intervention who has a negative FAST examination may also still undergo CT scanning to provide preoperative clearance. Suffice it to say that stable patients with a negative FAST examination are a more ambiguous population. Patients can have significant intra-abdominal injuries without free fluid or they may have delayed fluid accumulation, especially if the examination is performed shortly after the injury. Up to 45% of pediatric abdominal injuries have no identifiable free fluid on CT. In one study of hepatic injuries, CT scans showed 25% had no free fluid, and the majority were grade I or II injuries. Yet the detection of solid organ injuries has therapeutic implications, such as the need for hospitalization, duration of bed rest, resumption of activity, and need for follow-up.

False-positive FAST results can occur when the examination shows a small amount of retrovesical fluid. This fluid can be either physiologic in pubertal girls after ovulation or due to incorrect interpretation of the sonogram. In one series, a small amount of pelvic fluid was noted in 31% of children with blunt abdominal trauma, and organ injury was detected in only 3.5% of these children. However, in the presence of peritoneal fluid outside the pelvic cavity, an organ injury was detected in 92.3% of the cases.

**Computed Tomography (CT) Scanning**

In recent years, abdominal CT scanning has emerged as the diagnostic modality of choice for the evaluation of pediatric abdominal trauma. The purpose in imaging injured children is not to look for fluid, but to look for a specific organ injury, and CT is decidedly better in this regard than the FAST examination. Specifying the lesion could provide information about prognosis, risk stratification, and length of stay. On the other hand, CT is not without drawbacks. Sedation, gastric tubes, lack of portability, and contrast material may create problems. Deterioration of the patient during the study is a real consideration. Despite these limitations, 86% of pediatric surgeons in the U.S. prefer the CT scan as their modality of choice in assessing abdominal injuries. It is considered the gold standard in assessing the extent and severity of intra-abdominal injuries in children. It is noninvasive and an accurate method for identifying and qualifying the extent of abdominal injury and has reduced the incidence of nontherapeutic exploratory laparotomy. Solid organ injury is clearly defined by CT scanning (Figure 3). Unfortunately, bowel injury is often difficult to diagnose by CT scan. Extravasation of oral contrast or free intraperitoneal air is diagnostic for injury to a hollow viscus. Bowel wall thickening, multiple fluid-filled loops of bowel, and free fluid in the pelvis without solid organ injury are suggestive of, but not pathognomonic for, intestinal injury. Extraluminal air has been found in only 47% of children with gastrointestinal perforation following trauma. Others have confirmed that extraluminal air is present in only a minority of children with gastrointestinal perforation, with completely normal CT findings in up to 25% of cases. The diagnosis of intestinal injuries requires a combination of strong clinical suspicion, serial physical examinations, and careful evaluation of CT scan results.

CT is even less accurate in diagnosing pancreatic trauma, with normal scans in 33-53% of patients with laparoscopically proven pancreatic
The most common CT finding in pancreatic trauma is nonspecific and includes intra-peritoneal, lesser sac, peripancreatic, and retroperitoneal fluid. Less common findings include thickened Gerota’s fascia, mesenteric fluid or hematoma, fluid separating the pancreas from the superior mesenteric vein or duodenum, and fluid surrounding the superior mesenteric and periportal veins. Mesenteric, bladder, and diaphragmatic trauma are other injuries that might present with normal CT findings.

Indications for abdominopelvic CT scanning after blunt abdominal trauma are shown in Table 3. Use of intravenous contrast is essential to provide optimal vascular and parenchymal enhancement. The practice of administering oral contrast material to pediatric patients undergoing abdominal CT for blunt trauma is controversial. The administration of an oral contrast agent is generally accepted as useful in the CT evaluation of abdominal trauma. Proponents of oral contrast use argue that oral contrast is safe, and opacification of the bowel may help to identify bowel and pancreatic injuries. The use of oral contrast increases scanning times, increases the number of potentially unnecessary nasogastric tube, may lead to vomiting of contrast, and can cause aspiration of contrast with development of pneumonitis. Moreover, contrast reaches the small and large bowel in less than half the cases and may not help identify intestinal perforation, mesenteric injury, and pancreatic injuries. Furthermore, pediatric trauma centers that have omitted oral contrast report similar rates of detecting perforations and other abdominal injuries compared to centers that use oral contrast. In addition, due to the lack of a large prospective randomized study with a definitive finding that oral contrast agents are not useful for CT of pediatric blunt abdominal trauma, most institutions continue to administer oral contrast to these patients.

Interestingly, water has been shown to be just as effective, less expensive, and more quickly administered than contrast in pediatric trauma patients undergoing CT scanning. Water also offers another advantage since aspiration of contrast can lead to chemical pneumonitis.

Disadvantages of the use of CT scan include moving the patient to the radiology suite, requiring expensive equipment, use of ionizing radiation, use of contrast and potential allergic reaction or subsequent renal dysfunction, use of sedation in children, and results are dependent on the experience of the interpreter.

An increased risk of cancer, estimated at 1 per 1000 CT examinations, has been reported in the pediatric population exposed to low-dose radiation during CT examination. It has been estimated that 600,000 pediatric CT scans are performed each year, and 500 of these children will die secondary to cancer attributed to CT radiation. To minimize radiation exposure, it is suggested that hospitals implement the “as low as reasonably achievable” (ALARA) concept. This consists of limiting the number of CT examinations obtained routinely and making size-based adjustments of the radiation exposure scanning parameters. A trauma patient may receive multiple scans on admission followed by repeat scanning to evaluate progression of the trauma during their hospitalization. This can lead to a rapid accumulation of doses, placing these children at increased risk for such cancers. Unfortunately, approximately 67-73% of CT scans of the abdomen in children were found to be normal.Diagnostic Peritoneal Lavage (DPL)

DPL is a technique that involves the insertion of a catheter under direct visualization into the peritoneal cavity. Aspiration of blood indicates a positive tap; if no blood is detected, saline is infused. The indications for DPL are shown in Table 3.

### Table 3. Indications For Abdominopelvic CT After Blunt Abdominal Trauma

- Suspected blunt intra-abdominal injury based on injury pattern.
- Significant initial fluid resuscitation requirement without obvious blood loss.
- Multisystem trauma, such as severe pelvic, thoracic, or cranial injury.
- Inability to perform adequate abdominal examination, such as altered mental status, suspected head injury, or alcohol or drug intoxication.
- Hemoglobin less than 10 g/dL without obvious blood loss.
- Positive screening laboratory tests (elevated AST or ALT).
- Spinal cord injury.
- Ecchymosis on the abdominal wall (lap belt or handle bar injuries).
- Hematuria greater than 50 RBC/HPF or associated with additional signs and symptoms of intra-abdominal injury.
- Child abuse suspected.
- Slowly declining hematocrit or requirement for persistent fluid resuscitation.
- Require general anesthesia for other injuries.
through the catheter at a volume of 10 mL/kg. The effluent is allowed to drain passively and is then sent for cell count and chemistries. A positive DPL is shown in Table 4.

DPL is rarely used in the pediatric population. This procedure will identify abnormalities in more than 98% of patients with intra-abdominal injury, and in fact, DPL is more sensitive than CT and US at identifying abdominal injury.182,183 DPL can provide useful information in children with injuries that are often undetectable with CT, such as bowel, pancreatic, and mesenteric trauma. However, DPL will be falsely positive in a significant number of children with blunt trauma, leading to an unnecessary laparotomy rate of 42-63%.184,185

The limitations of DPL, besides its invasive nature, are similar to those of a FAST examination. A positive DPL for blood simply indicates the presence of hemoperitoneum, with no information regarding the source of the bleeding. Since many solid-organ injuries may be successfully managed non-operatively in children, the mere presence of blood in the abdomen is not an indication for operation in the hemodynamically stable child. Because of these drawbacks, several pediatric centers rarely use this procedure. In addition, there are complications inherent to the procedure, such as bladder or bowel perforation or mesenteric or iliac vessel perforation. It also does not provide information about the specific organ injured, does not identify retroperitoneal injury, and introduces fluid and air into the abdominal cavity, potentially altering future abdominal examination and diagnostic tests.182

DPL may be utilized to exclude abdominal trauma in children requiring immediate surgical intervention for life-threatening cranial and thoracic injuries when no time exists to perform an abdominal CT scan or when a FAST examination is not available. DPL should be considered in injured children who require ongoing blood products when CT or US are unavailable.

**Diagnostic Laparoscopy (DL)**

DL has been shown to be both diagnostic and therapeutic in the setting of abdominal trauma.186,187 However, there is a paucity of data on the role of laparoscopy in pediatric abdominal trauma. The literature is restricted to mainly case reports.188-193 Indications for DL may include a hemodynamically stable patient with blunt abdominal trauma who either has a suspicious physical examination and laboratory evaluation with developing peritonitis or declining hematocrit.194 It has been considered by some as the gold standard for the evaluation of hollow viscus injury.194

Drawbacks may include the inability to completely assess the small bowel and to evacuate hemorrhage.195 This procedure is not without risks. These risks include a 20% morbidity rate, 0-5% mortality, and a 3% long-term risk for bowel obstruction.196 Therefore, most pediatric trauma centers will still use less invasive tests, such as CT or ultrasound, for most initial evaluations of abdominal injuries.

**Intravenous Pyelography (IVP)**

IVP is primarily reserved for a few select situations. It can be used preoperatively in unstable children selected for laparotomy to identify major renovascular injuries.197 It might be indicated in children suspected of only having renal contusion and not deemed at risk for abdominal injury. Renal imaging is indicated if greater than or equal to 50 RBC/HPF or gross hematuria is present or there is persistence or worsening of lesser degree of hematuria. Even in this group, CT scan is more accurate at identifying renal lesions.

**Treatment**

Since the beginning of modern surgery, splenectomy had been the procedure of choice for splenic injury. To do otherwise was believed to invite disaster as the spleen could not heal on its own and there was a tendency to rupture in a delayed fashion.198 In 1952, the immunologic dangers of removing the spleen were demonstrated, although this did not alter management.199 It was not until 1973, when data on incidence and mortality from sepsis from splenectomy became available, that the ramifications of this practice became evident.200 Indeed, overwhelming sepsis occurs in children who have undergone splenectomy at more than 85 times the rate of the normal population and may result in a 50% mortality rate.201 This new information led to the revolutionary concept of splenic preservation after splenic injury and has become the priority in children after blunt abdominal trauma.202 This approach is particularly important in children who face a lifelong risk of overwhelming post-splenectomy infections of 3-5%.203

In 1968, successful nonoperative treatment of select children presumed to have splenic injury was first demonstrated.202 By the 1980s, nonoperative management became the treatment of choice for pediatric blunt splenic trauma.204-206 Simultaneously, the expanding introduction and use of CT

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**Table 4. Criteria For Positive Diagnostic Peritoneal Lavage**

- Greater than 100,000 red blood cells/mL.
- Greater than 500 white blood cells/mL.
- Gram-satin with bacteria present.
- Presence of feces, vegetable fibers, bile, alkaline phosphatase (greater than 6 IU/L), or amylase (greater than 175 IU/L).
Clinical Pathway For Management Of Pediatric Blunt Abdominal Trauma

**Initial Assessment**
- Airway
- Breathing
- Circulation
- Disability
- Exposure

**Vital signs stable**

**Abdominal Examination**
- Non tender
- No distracting injuries
- GCS score 15 or normal for age

**YES**
- Serial examinations
  - FAST
  - CT scan

**NO**
- 20 mL/kg crystalloids
  - Vital signs stable?
  - 20 mL/kg crystalloids
  - Vital signs stable?
  - 10-20 mL/kg packed red blood cells (PRBCs)
    - Pediatric or trauma surgery consult
    - Vital signs stable?
    - Exploratory laparotomy
      - More packed red blood cells (PRBCs)
Nonoperative management has been shown to be safe, with success rates by pediatric surgeons of 89-99%.208-210 There has, however, been a disparity in non-pediatric trauma or non trauma centers to reach the same results as those encountered in pediatric trauma centers.211 The Trauma Committee of the American Pediatric Surgical Association (APSA) developed evidence-based guidelines for the nonoperative management of hemodynamically stable children with blunt splenic or liver injury.209 Their recommendations were based on analysis of patient data collected from 32 pediatric surgical groups, nonrandomized trials, historical controls from the literature, expert clinical experience, and a consensus conference. But non-pediatric trauma or non trauma hospitals fail to achieve nonoperative success rates commensurate with that of pediatric trauma centers for blunt splenic injuries.211,212 Management of children by non-pediatric surgeons or in non-pediatric trauma centers is known to have a negative effect on transfusion rates, length of stay, and mortality of pediatric patients who undergo a laparotomy.213-215 The aggregate conclusions of these authors were that training, experience, and available resources, such as intensivists, blood banking, and a pediatric intensive care unit, were the measures of differences between pediatric surgeons and adult surgeons caring for pediatric patients. Therefore, to be successful in the nonoperative management of pediatric abdominal blunt organ injury requires the following:

- Frequent examinations.
- Close monitoring of vital signs.
- Frequent laboratory tests (done with microvalve technique).
- Close monitoring by nursing personnel experienced in the pediatric intensive care unit (PICU).

If these requirements are followed, there should be an increase in nonoperative management of children who are admitted to non-pediatric trauma centers with better outcomes, lower complication rates, and lower transfusion rates.215 There must also be a wider dissemination of the APSA guidelines for management of the pediatric trauma victim to these non-pediatric trauma hospitals.216 This is especially important since most children with splenic injuries are treated in non-pediatric trauma centers.209

Nonoperative management of injury to solid organs is not without complications. There is an overall 5% nonoperative management failure rate in solid organ injuries, including spleen, liver, kidney, and pancreas.217 Multivariate analysis logistic regression analysis controlling of Injury Severity Scores (ISSs) and Glasgow Coma Scales scores (GCSs) found five variables associated with a significantly increased risk for failure of nonoperative management; these included:

- Bicycle-related injury mechanism.
- Isolated pancreatic injury.
- One solid organ injury.
- Summary Abbreviated Injury Scale (sAIS) greater than or equal to 4.
- Isolated grade 5 injury.

Other factors that predict the likelihood of failure of nonoperative management of solid organ injury include the degree of hemoptoemenum noted on physical examination or radiographic studies, the hemodynamic response to fluid therapy, or the finding of contrast blush on CT scans.150,218-220

Angioembolization has been shown to diminish nonoperative management failure rate in blunt splenic and hepatic injuries.221-223 However, there may be an increase in complications, including bleeding, bile duct injuries, abdominal compartment syndrome, and abscesses.224,225 The ideal candidate for angioembolization is the patient with active solid organ bleeding who is hemodynamically stable.221

Analgesics should be considered in children with significant pain. Trauma patients and especially children receive less analgesia than do adults.226,227 Many excuses have been used as reasons to not give analgesics to pediatric trauma patients. One is the belief that localized pain assists in diagnosis and that the masking of the patient’s symptoms may lead to a delay in diagnosis. Others fear the potential harmful side effects from opioid analgesics, including respiratory depression, hypotension, and altered level of consciousness. Pain control may also not be a priority among trauma medical personnel.228,229 The surgical literature is full of studies that demonstrate that analgesics do not significantly alter the abdominal examination.230,231 While these studies are mostly concerned with non traumatic causes of abdominal pain, they still have some validity in the trauma patient. If a small bowel perforation is suspected, the child should receive appropriate antibiotics (Table 5). A pediatric surgeon should be consulted for definitive repair of their injury.

The decision to operate in pediatric patients is based not on the anatomy or radiographic grade of the injury, but on the physiologic response to the injury and the evolution of the physiological response to resuscitation. Indications to operate after blunt abdominal trauma are shown in Table 6. Laparoscopic exploration and repair of traumatic...
abdominal injuries offers many conceptual advantages over the traditional trauma laparotomy in carefully selected patients and is becoming more popular in children. A minimally invasive approach to the traumatized patient maintains the intestines within the peritoneal cavity, preventing tissue desiccation and minimizing fluid and temperature shifts that may result in ileus and may adversely affect the postoperative course. Theoretically, patients who have a laparoscopic approach to the repair of bowel injuries may have less pain, more rapid return of intestinal function, earlier hospital discharge, reduced total health care costs, and an earlier return to out-of-hospital activities.

Furthermore, a minimally invasive procedure may allow for quicker recovery after an exploration with negative findings. Finally, inspection of the abdominal contents with magnification during laparoscopy may aid in the detection of subtle injuries.

### Specific Circumstances

#### Splenic Injuries

The spleen is the most frequently injured intra-abdominal organ in children. Injury to the spleen may aid in the detection of subtle injuries.

#### Table 5. Antibiotics And Dosages For Suspected Small Bowel Perforation

<table>
<thead>
<tr>
<th>Antibiotics</th>
<th>Doses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cefotaxime</td>
<td>150-200 mg/kg/day divided 3-4 times/day</td>
</tr>
<tr>
<td></td>
<td>(maximum 2 g/dose)</td>
</tr>
<tr>
<td>Piperillin/tazobactam</td>
<td>300-400 mg/kg/day divided 3-4 times/day</td>
</tr>
<tr>
<td></td>
<td>(maximum 3.375 g/dose)</td>
</tr>
<tr>
<td>Ampicillin/subbactam</td>
<td>150-300 mg/kg/day divided 3-4 times per day</td>
</tr>
<tr>
<td></td>
<td>(maximum 3 g/dose)</td>
</tr>
<tr>
<td>Ticarcillin/clavulanate</td>
<td>200-300 mg/kg/day divided 4-6 times/day</td>
</tr>
<tr>
<td></td>
<td>(maximum 3.1 g/dose)</td>
</tr>
</tbody>
</table>

#### Table 6. Indications After Blunt Abdominal Trauma For An Exploratory Laparotomy In Children

- Children with hemodynamic instability despite aggressive resuscitation or blood product transfusion requirement total greater than 50% total blood volume (40 mL/kg) over the first 24 hours during the hospital course.
- Grade IV and V renovascular injury.
- Hollow visceral bowel injuries (pneumoperitoneum).
- Evisceration of abdominal contents.
- Rectal or vaginal lacerations.
- Peritoneal irritation on examination.
- Intraperitoneal bladder rupture.
- Large extraperitoneal bladder rupture associated with pelvic fractures.
- Major pancreatic duct injury or pancreatic injury unresponsive to conservative treatment (fistula, pseudocyst, or persistent duodenal obstruction).
- Evidence of fecal or bowel contamination on DPL.

Typically results from a direct blow to the left upper quadrant. The most common mechanism is motor vehicle collisions, but other mechanisms include pedestrians hit by cars, falls, bicycle accidents, assaults, sports-related injuries, blows to abdomen, and motorcycle accidents. Diseases that increase the size of the spleen, such as infectious mononucleosis, lymphoproliferative disorders, or systemic lupus erythematous predispose patients to rupture, even with minor trauma.

A number of patients will complain of left shoulder pain at the time of presentation. This phenomenon is known as Kehr’s sign (referred pain to the left shoulder) and is the result of diaphragmatic irritation by blood released from the ruptured spleen. Findings that suggest splenic trauma on physical examination include left upper-quadrant abrasions, tenderness, and abdominal distention. Because of the elasticity of the chest wall, rib fractures are uncommon in children with splenic trauma. Findings such as marked tachycardia, weak pulses, decreased capillary refill, or pallor suggest significant blood loss and incipient hemorrhagic or hypovolemic shock.

Chest radiographs are usually normal but may have findings suggestive of splenic injury, such as lower left rib fractures, elevation of the left hemidiaphragm, pleural effusion, or a medially displaced gastric bubble. Stable children with suspected splenic injury should undergo an abdominopelvic CT scan. CT can accurately determine the degree of splenic injury, associated intra-abdominal organ injury, and the amount of free fluid in the abdomen (hemoperitoneum). The American Association of Trauma (AAST) adopted a classification of splenic injuries based on a CT scan grade system (Table 7).

In the literature, the incidence of the “blush sign” in blunt abdominal trauma varies between less than 1% in early series to more than 30% in more recent series. The radiologic “blush sign” is the result of an active pooling of contrast material within or around the injured organ. This radiologic finding has been described for various intra-abdominal organ injuries, including the spleen, liver, kidney, adrenal, and mesentery. In adult patients, the “blush sign” could predict the failure of nonoperative management and warrants early embolization or surgery. In children, management decisions are based on the physiologic response to the injury rather than the radiologic features of the injury, calling into question the significance of a “blush sign” in this population. However worrisome the presence of a blush sign is, most pediatric patients can still be treated successfully.
without operation. The role of angiographic embolization in pediatric spleen injuries has yet to be determined but may become useful in the hemodynamically stable child with active splenic bleeding.

Once the extent of injury has been defined, management depends upon the child’s hemodynamic status and the presence of associated injuries. Children with hemodynamic instability, despite aggressive resuscitation, after blunt abdominal trauma should be taken to the operating room for exploratory laparotomy after completion of the primary and secondary surveys. Splenectomy is more likely in children with splenic injury after motor vehicle or bicycle accidents or who have an ISS greater than 15, a GCS score less than or equal to 8, or who have a grade IV and/or V injury. Older children and those presenting with hypotension or tachycardia also had an increase in splenectomy rate. Children with associated injuries, such as head, thorax, non splenic, pelvic or extremity injuries, were more likely to undergo splenectomy. At the time of exploration, attempts should be made to preserve the spleen. Splenorrhaphy and partial splenectomy are two techniques used to control bleeding while preserving splenic parenchyma. In the critically ill child, or in the case of a completely shattered spleen, splenectomy may be required. Laparoscopic splenectomy with either the anterior or posterior approach has been shown to be safe in children. Nonoperative management of isolated splenic injuries has become the standard of care in pediatric trauma centers and is successful in 90-95% of cases. The ultimate goal of nonoperative or operative management of blunt splenic trauma in the pediatric population is preservation of splenic immune function and avoidance of overwhelming post-splenectomy infection. The estimated incidence of overwhelming postsplenectomy infection is 0.23-0.42% per year, with a lifetime risk of 3.2-5%. The mortality associated with overwhelming postsplenectomy infection ranges from 38% to 69%. Streptococcus pneumoniae is the most frequent causative agent of overwhelming postsplenectomy infection. Vaccination against encapsulated bacteria, including S. pneumonia, Haemophilus influenzae type b, and Neisseria meningitides, is recommended after splenectomy or nonoperative management of a severely damaged spleen.

The APSA’s Trauma Committee has developed a series of evidence-based guidelines for the management of isolated splenic and hepatic injuries. According to these guidelines, children can return to their normal activities after a period consisting of the grade of injury plus two weeks. Late complications of splenic injuries, while rare, can include pseudoaneurysm formation, delayed rupture, pseudocyst formation, wound infection, or intestinal obstruction from adhesions.

### Liver Injury

The liver is the second most commonly injured intra-abdominal organ. Liver injuries are generally more severe than splenic injuries, are more likely to re-bleed on a delayed basis, and are the most common lethal abdominal injury in blunt abdominal trauma from hemorrhage. The right lobe is injured slightly more frequently than the left, probably because of its size. The dual blood supply of the liver and its close proximity to the inferior vena cava predisposes it to severe hemorrhage after blunt trauma to the abdomen.

Mechanisms of injury include motor vehicle crashes, pedestrians struck by motor vehicles, falls, assaults, bicycle injuries, and child abuse. Trauma to the liver may result in subcapsular or intrahepatic hematoma, contusion, vascular injury, or biliary disruption. The spleen is the most common associated injury, followed by the kidney. Children who sustain injury to the liver occasionally complain of right shoulder pain (Kehr’s sign). The majority exhibit right upper abdominal or right lower chest pain and tenderness and have associated injuries, a reflection of the mechanism of injury.

Elevated transaminases are highly suggestive of a liver injury. The chest radiograph is often normal but may show indirect signs of liver injury, such as right lower rib fracture, elevation of right hemidiaphragm, and right pleural effusion. The mainstay of diagnosis in the hemodynamically stable child is CT scan. It can provide useful information.
regarding the severity of injury, associated injuries, and the amount of free fluid (hemoperitoneum). The AAST adopted a classification of liver injuries based in a CT scan grade system; this is shown in Table 8.237 This classification has not correlated with outcome. ISS and the presence of associated injuries are the factors that correlate with outcome.262

Management of liver injuries is usually nonoperative with careful repetitive physical examinations. About 20 years ago, most liver injuries were treated with surgical repair and approximately 70% spontaneously stopped bleeding with no intervention; therefore, a selective nonoperative approach was adopted.260 Today, the selective, nonoperative management of blunt liver trauma in hemodynamically stable patients is well established and accepted in most pediatric trauma centers, and nonoperative management can be successful in 85-90% of hepatic injuries.260-267 Indications for nonoperative management are the same as for splenic injuries: hemodynamic stability and absence of peritoneal signs. Complications of nonoperative management may include biliomas, risk of delayed bleeding, and abscess formation.268 Most of these complications will be amenable to nonoperative treatment such as endoscopic retrograde cholangiopancreatography (ERCP) or percutaneous drainage.269 Compared with children who sustain splenic injuries, a greater number of children with hepatic injuries will require blood transfusion or operative intervention. However, in the setting of hemodynamic instability and transfusion requirements of greater than 25-40 mL/kg/day, most would agree that surgical intervention is necessary.270 For patients who meet these transfusion requirements but who maintain hemodynamic stability, selective hepatic arterial embolization may be considered.271 Children who sustain higher grades of liver injury are more likely to require exploratory laparotomy.272 Other risk factors for surgery include lower PTS owing to multisystem trauma, transfusion required within two hours of presentation, and associated retrohepatic vena cava or major hepatic vein trauma.269 Tamponade of the bleeding with laparotomy pads, temporary abdominal closure, and a planned second look procedure is preferred over major hepatic resection. Once the child has been stabilized and the coagulopathy and hypothermia have been corrected, the child is returned to the operating room for re-exploration and removal of packing. Complications from surgery may include abscess formation, pancreatic fistula, hematemesis from hemobilia, biliary obstruction, bilioma, stress gastric ulceration, sympathetic pleural effusion, abdominal compartment syndrome, delayed bleeding, wound infection, and bowel obstruction from adhesions.261,273

Similar to the guidelines for splenic trauma, children who sustain an isolated hepatic injury are restricted from contact sports and strenuous physical activity for a period consisting of the grade of injury plus two weeks.

### Pancreatic Injury

Injuries to the pancreas occur in 1.7-12% of children sustaining blunt abdominal trauma.111,118,161,274,275 Major pancreatic ductal injury is rare.113,275-277 Diagnosis of pancreatic injuries is difficult because of its retroperitoneal location and is based on clinical, radiographic, and laboratory data. About two-thirds of children with traumatic pancreatitis are diagnosed within the first 24 hours.146 Pancreatic injury frequently is underestimated or missed initially.111-113,278 Delay in diagnosis is associated with increased morbidity and mortality rates.275,276

The mechanism of injury most commonly involves compression of the pancreas against the rigid spinal column or by discrete intrusion forces. Young children with flatter diaphragms, thinner abdominal walls, and higher costal margins sustain pancreatic injuries from blows to the abdomen, which are less likely to cause pancreatic injury in adults. Mechanisms of pancreatic injuries have included motor vehicle crashes, cars striking pedestrians, bicycle crashes, direct blows to abdomen from objects, bicycle injuries, falls, sports-related injuries, and child abuse.111,121 Associated injuries occur in 25-68% of children with pancreatic injuries and include liver, spleen, kidney, stomach, and small bowel.113,275,277 Non abdominal injuries involve the head, chest, and extremities.

Clinical examination and a history suggestive of

<table>
<thead>
<tr>
<th>Grade</th>
<th>Extent of Liver Injury</th>
</tr>
</thead>
</table>
| 1     | Hematoma: subcapsular, non expanding, < 10% of surface area  
       | Laceration: capsular tear, non bleeding, with < 1 cm deep parenchymal disruption |
| 2     | Hematoma: subcapsular, non expanding, hematoma 10-50%, intraparenchymal non expanding, < 2 cm in diameter  
       | Laceration: < 3 cm of parenchymal depth, < 10 cm in length |
| 3     | Hematoma: subcapsular, > 50% of surface area or expanding, ruptured subcapsular hematoma with active bleeding, intraparenchymal hematoma > 2 cm  
       | Laceration: > 3 cm of parenchymal depth |
| 4     | Hematoma: ruptured central intraparenchymal hematoma  
       | Laceration: parenchymal disruption involving 25-75% of the hepatic lobe |
| 5     | Hematoma: parenchymal disruption > 75% of hepatic lobe  
       | Vascular: juxta-hepatic venous injury (retrohepatic cava/major hepatic veins) |
| 6     | Vascular: hepatic avulsion |
trauma to the upper abdomen can increase suspicion of injury to the pancreas and help direct diagnostic studies. Although children with pancreatic and other internal organ injuries may present with obvious abdominal tenderness, those with isolated pancreatic injury may experience a delay of hours or even days before the onset of abdominal symptoms. Although the post-traumatic symptoms of abdominal pain, nausea, vomiting, and fever are nonspecific, they should heighten the level of suspicion for pancreatic injury in the setting of blunt abdominal trauma. A slowly enlarging abdominal mass may occur after the development of a pseudocyst.

Elevations of amylase greater than 200 IU/L and lipase of greater than 1800 IU/L correlate with a major pancreatic injury. However, serum values alone are not reliable as screening studies for pancreatic injury in the pediatric trauma population.

Abdominal radiographs are usually normal but may show sentinel loops of dilated intestines over the area of the pancreas. CT scans identified traumatic injury to the pancreas with a sensitivity of 85%. Findings on CT scan indicative of acute pancreatic injury include a visualized transection, thickening of the gland with accompanying edema, peri-pancreatic fluid collections, or ductal dilatation. CT scan, on occasion, may miss major pancreatic injuries, especially pancreatic ductal injuries. A grading system has been described to grade the severity of pancreatic injuries (Table 9). Other radiographic studies, such as ERCP and magnetic resonance cholangiopancreatography (MRCP), have been shown to be effective in the diagnosis of injury to the pancreas, especially ductal injuries, but are costly and not readily adaptable in the acute trauma setting.

The management of pancreatic injuries continues to be controversial. Management strategies for pancreatic injuries largely have been determined by injury severity, injury location, and the presence or absence of associated abdominal injuries. While some authors advocate aggressive nonoperative management for most pancreatic injuries irrespective of grade, others recommend a lower threshold for operation relative to standard management protocols for other solid organ injuries. Pancreatic injuries do not behave as other solid organ injuries and have been shown to have a nine-fold increase in need for operative management. It may well be that the pancreas should not be included as a standard solid organ in nonoperative management protocols. However, pancreatic injuries without a major ductal injury usually resolve with nonoperative management using bowel rest and parenteral nutrition, with a low prevalence of subsequent pseudocyst formation.

Early operative therapy is warranted for the treatment of a distal transection of the pancreas. The spleen-preserving distal pancreatectomy is associated with lower rates of complications and shorter hospitalization than nonoperative management. Treatment of major ductal injuries involving the head of the pancreas is controversial. The adult literature describes early radical interventions such as pancreaticoduodenectomy, pancreatojejunostomy, onlay Roux-en-Y loop to cover damaged tissue, pyloric exclusion, and duodenal diverticulization; however, they are associated with significant morbidity. There is no clear recommendation in pediatric patients. Many use nonoperative management of these injuries and later drainage of any pseudocyst that develops. However, this plan of management usually involves prolonged hospitalization with bowel rest and hyperalimentation, waiting for the pseudocyst to develop over four to six weeks. Delayed diagnosis of pancreatic ductal injury may also result in other complications such as recurrent pancreatitis, fistula, or abscess. Others will perform ERCP with stent placement. ERCP is a very accurate technique for determining the location and type of duct disruption, and it allows appropriate therapeutic intervention with endoscopic placement of stents. ERCP can be indicated in children if the results of enhanced CT show low attenuation in the pancreatic parenchyma and heterogeneous staining of the pancreas. The advantages of therapeutic ERCP for ductal injury are the avoidance of a major abdominal operation with potential risk to the spleen, elimination of the waiting period for pseudocyst development from continuing pancreatitis, shortened hospital stay, and faster return to normal activity.

Pseudocyst formation is the main complication of nonoperative management of pancreatic injuries. Therefore, repeat imaging by CT, ultrasonography, or ERCP should be obtained if a pancreatic injury is found. A pseudocyst is a loculated collection of pancreatic juice from a ductal injury. Occasionally, small pseudocysts will resolve with bowel rest and parenteral nutrition. Octreotide (somatostatin) has been used to accelerate resolution of traumatic pseudocysts in children. Large cysts that have been present for 4-6 weeks will likely require drainage. The standard for management of post-traumatic pancreatic pseudocyst is internal drainage, either into the stomach or duodenum via a

### Table 9. Classification Of Pancreatic Injuries

<table>
<thead>
<tr>
<th>Classes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>Contusion or laceration without duct injury</td>
</tr>
<tr>
<td>Class II</td>
<td>Distal transaction or parenchymal injury with probable duct injury</td>
</tr>
<tr>
<td>Class III</td>
<td>Proximal transaction or parenchymal injury with probable duct injury</td>
</tr>
<tr>
<td>Class IV</td>
<td>Combined pancreatic and duodenal injury</td>
</tr>
</tbody>
</table>
Roux-en-Y limb into the intestine. Percutaneous and endoscopic drainage procedures have also been successful but may have higher failure rates. Another complication is the development of acute pancreatitis,276

**Duodenal Injuries**

Injuries of the duodenum are rare. They present in two forms: perforation and hematoma. The duodenum has an increased vascular blood supply, resulting in larger amounts of blood loss when traumatized. The force disrupts the vessels between submucosa and muscularis, causing development of an intramural hematoma that can almost obstruct the duodenal lumen. Similar to other intestinal injuries, duodenal perforations can be difficult to diagnose. Mechanisms of injuries include motor vehicle accidents, bicycle accidents, contact-sport injuries, falls onto blunt objects, and child abuse.300

Symptoms at the time of presentation include abdominal pain, nausea, vomiting, hematemesis, and abdominal distention. If the perforation is into the retroperitoneum, peritoneal irritation will not be obvious upon presentation and free air may not be seen on radiographs, resulting in diagnostic delay. Associated injuries may include injury to the pancreas, spleen, or liver, hollow viscous injury, rib fractures, and thoracic vertebral fractures. A high output in the nasogastric tube is suggestive of a duodenal injury.

Elevation of serum transaminases, amylase, and lipase may be seen. CT scanning is diagnostic in only 60% of cases of duodenal perforation. CT scanning can be used to determine the extent of injury (Table 10).300 Persistent abdominal pain or development of peritonitis in a child with signs of upper abdominal trauma, especially in the face of CT findings of free fluid without evidence of solid-organ injury, necessitates abdominal exploration. Operative management of these injuries is dependent on the extent, associated injuries, and the amount of retroperitoneal contamination. Relatively small, fresh injuries can be effectively treated with simple closure of the perforation and drainage. More complicated injuries, particularly if they involve a large segment of the duodenal wall or pancreas, may require pyloric exclusion and creation of a gastrojejunostomy to allow for adequate healing. Other newer techniques may include duodenal decompression by a lateral duodenostomy tube, placement of a retrograde jejunostomy tube, or pyloric exclusion and proximal tube decompression without gastrojejunostomy.301,302 Mortality from duodenal perforations, particularly if there is a delay in diagnosis of greater than 24 hours, is significant. Mortality in the 1970s was approximately 25%, which has been decreased to 19% with the use of pyloric exclusion with gastrojejunostomy.303 Complications of surgery may include fistula formation, anastomosis leak, and infection.

Duodenal hematomas are the result of blunt force trauma to the epigastrium. In addition to abdominal pain and tenderness, children with this type of injury often present with bilious emesis, the result of obstruction of the duodenal lumen by the hematoma. The diagnosis can be made by CT scanning, upper gastrointestinal contrast studies (which show the “coiled-spring” sign), or by ultrasound. Most duodenal hematomas can be successfully managed non operatively with nasogastric decompression and parenteral nutrition. Most resolve by 10 days but may take up to three weeks. If the hematoma has not resolved after three weeks of bowel rest, operative evacuation of the hematoma is indicated.

**Table 10. Grading System For Duodenal Injuries**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Extent of Duodenal Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hematoma involving single portion of wall</td>
</tr>
<tr>
<td></td>
<td>Laceration: partial thickness, no perforation</td>
</tr>
<tr>
<td>2</td>
<td>Hematoma involving more than 1 portion</td>
</tr>
<tr>
<td></td>
<td>Laceration: &lt; 50% circumference disruption</td>
</tr>
<tr>
<td>3</td>
<td>Laceration: disruption of 50-75% circumference of second portion</td>
</tr>
<tr>
<td></td>
<td>Disruption of 50-100% circumference of first, third, or fourth portions</td>
</tr>
<tr>
<td>4</td>
<td>Laceration: disruption of &gt; 75% circumference of second portion</td>
</tr>
<tr>
<td></td>
<td>Involvement of ampulla or distal common duct</td>
</tr>
<tr>
<td>5</td>
<td>Laceration: massive disruption of duodenopancreatic complex</td>
</tr>
<tr>
<td></td>
<td>Duodenal devascularization</td>
</tr>
</tbody>
</table>

**Small Intestine Injury**

The small intestine is injured much less frequently than either the spleen or liver and only 2-5% of children with blunt abdominal trauma will have intestinal injury.305,306 However, in restrained occupants of motor vehicle collisions with sufficient force to produce visible abdominal wall ecchymosis and vertebral column fracture, the incidence of intestinal injury may exceed 50%.307-309 The jejunum is the most commonly injured segment of the bowel, followed by the duodenum and the ileum. However, intestinal injuries can often pose a diagnostic dilemma, resulting in a delay in diagnosis. Injuries occur because of direct blows over a fixed point, such as the ligament of Treitz or ileocecal valve, or from a sudden deceleration resulting in a shearing force at the mesenteric attachment. In the latter, trauma may cause only local injury to the small bowel or its mesenteric supply. This may result in either a very small perforation or delayed perforation owing to necrosis.310 Blunt trauma to the
abdomen results in transmission of shearing forces to the small bowel causing injury. The most typical injury is a seromuscular tear where the submucosa is torn from the inner circular muscular layer.\textsuperscript{311} This can result in mesenteric bleeding and can progress to delayed perforation when the underlying submucosa and mucosa subsequently lose viability. Other injuries that can occur include closed loop perforation, complete transaction of the bowel, or crushing of the bowel against the spine.\textsuperscript{311-313} Mechanisms for small bowel injury include motor vehicle crashes, lap-belt injuries, struck pedestrians, bicycle accidents, blunt object impacts, motor cycle accidents, sports-related injuries, falls, and child abuse.\textsuperscript{314} Up to 14-51\% of patients with hollow viscous organ injury will have associated intra-abdominal solid organ injury.\textsuperscript{312,315} Other associated extra-abdominal injuries include head injuries, extremity fractures, fracture pelvis, and pneumothorax.\textsuperscript{316}

Small bowel injuries are difficult to diagnose. Serial examination in the non-head-injured pediatric patient has been shown to be accurate in the diagnosis of hollow viscous injury.\textsuperscript{317,318} Peritoneal signs are initially present in only 30-38\% of patients with bowel injury.\textsuperscript{305,319} The neutral pH, low bacterial concentration, and low enzymatic activity of the small bowel contents cause minimal inflammatory reaction, resulting in few clinical signs at early stages after blunt abdominal trauma. In addition, functional closure of small perforations by bowel spasm and/or omentum also leads to delay in diagnosis. Free air may not be seen for several hours or more, and sometimes never in the course. Associated head and spinal cord injury or other distracting injuries, such as long bone fractures, are other factors making physical examination difficult and misleading.\textsuperscript{305,315,320,321} Although initial physical examination findings are often mild, all children with hollow viscous injury will develop progressive features suggesting bowel injury, such as peritonitis, fever, tachycardia, and diminished urine output over the ensuing 12-24 hours.\textsuperscript{305} However, time to laparotomy is likely to be increased using a conservative approach.

Laboratory investigations, including WBC count and blood biochemistry, may be helpful in the diagnosis. The peripheral WBC count is routinely elevated following trauma, and a progressive rise in serial measurements may give indirect evidence of bowel injury.\textsuperscript{316} In addition, serial measurement of liver transaminases may also demonstrate an elevation but are nonspecific findings.\textsuperscript{316} Plain films may show intra-abdominal air in 10-50\%,\textsuperscript{312,316,319,320,322} The presence of pneumoperitoneum can occur from bowel injury but also may occur from air dissection from the pleura or mediastinum into the abdomen via the retroperitoneum. Ultrasound examination may show free pelvic fluid

but will not tell where this fluid came from, which could include solid organ injury or hollow viscous injury.\textsuperscript{323} CT findings following bowel injury can be nonspecific. In one study where hollow viscous injury was proven during celiotomy, five of the six children had normal CT scan and the contrast material was only in the proximal portion of bowel.\textsuperscript{324} This finding may represent an ileus or not enough time elapsing between administration of the contrast and obtaining of the CT scan, making the CT scan less effective in identifying bowel injury. Free air initially may be present in CT scan in only 23-47\% (Figure 4).\textsuperscript{314,325} Improved specificity (96\%) and sensitivity (95\%) of CT scanning can be achieved by looking for the presence of one or more of:\textsuperscript{314,326}

- Moderate-to-large amounts of unexplained fluid.
- Unexplained extraluminal air.
- Bowel wall enhancement.
- Bowel wall thickening.
- Bowel dilatation.
- Extravasation of contrast.
- Multiple fluid-filled loops of bowel.

However, in one study, CT scan findings suggested injuries to the bowel, but one-third of those studied did not have any injury upon laparotomy.\textsuperscript{158} Free fluid alone, however, is not pathognomonic for intestinal injury and does not necessarily mandate immediate surgical exploration. This fluid can be either physiologic in pubertal girls after ovulation or due to incorrect interpretation of the sonogram. Other conditions that have free fluid with no obvious solid-organ or hollow viscous injury include mesenteric injury not affecting the bowel lumen or hypovolemic shock syndrome resulting in transudation of intraperitoneal and retroperitoneal fluid. In children with free intraperitoneal fluid with no solid organ damage, only 6-25\% will need a therapeutic laparotomy.\textsuperscript{324,327,328} The probability of bowel injury

![Figure 4. CT Scan Showing Free Air From A Jejunal Perforation](image_url)
increases when the free fluid is associated with seat belt ecchymosis on the abdominal wall and when the peritoneal fluid is in more than one location. Therefore, the mere finding of free intraperitoneal fluid does not dictate immediate surgical exploration in children. Identification of intestinal injuries requires a combination of strong clinical suspicion, serial physical examinations, and thoughtful interpretation of the results of CT scanning. If a DPL is performed, the presence of bile or amylase is indicative of an injury.

Once a small bowel perforation is suspected, the child should receive appropriate antibiotics (Table 5 on page 15) and should have adequate resuscitation with intravenous fluids. A pediatric surgeon should be consulted for definitive repair of their injury.

Delay in the diagnosis of hollow visceral injury and a delay in laparotomy might increase morbidity and mortality, prolong hospitalization, increase complications, and may result in death. The risk of delayed diagnosis or missed injury has led some to advocate an aggressive diagnostic approach using DPL, exploratory laparotomy, or empiric laparotomy in selected patients. Some series have found worse outcomes in patients with a laparotomy more than 24 hours post injury. Other pediatric series have found no increase in morbidity and mortality with delayed laparotomy. However, mortality is usually due to another associated injury, such as head injury or major vessel injury.

Admit patients with an isolated finding of peritoneal fluid who do not undergo immediate surgery based on physical findings, and perform sequential abdominal examinations and serial hematocrit evaluations. When the abdominal examination and hematocrit level remain stable, begin oral intake. Those with bowel injury should have worsening abdominal tenderness and will require surgical repair. Operative management generally involves either simple surgical closure or segmental resection with primary anastomosis. Creation of a proximal colostomy is less common. Laparoscopic exploration and repair of traumatic bowel injuries is now more commonly used in children and offers many advantages over traditional trauma laparotomy in carefully selected children. Complications after surgery may include delayed abscess, delayed obstruction, superficial wound infection, fistula formation, later onset of small bowel obstruction, pneumonia, pleural effusion, peritonitis, sepsis, acute respiratory distress syndrome, and death.

### Renal Trauma

Injury to the kidney from blunt or penetrating trauma is the most common urinary tract injury. Renal trauma accounts for about 10% of blunt abdominal injuries in children. Blunt abdominal trauma is responsible for more than 90% of pediatric renal injuries. Minor injuries account for 85% of the total renal injuries, lacerations occur in 10%, and severe injuries (such as renal rupture, fractures, or pedicle injuries) occur in 3% of cases. One should consider renal injury with a blow to the flank or abdomen, deceleration injury, hematuria, or pelvic fracture. In children, the kidney is at greater risk for injury because of its proportionally greater size, limited thoracic cage and perirenal fat protection, weaker abdominal wall musculature, and more flexible thoracic cage. In addition, pediatric kidneys may retain fetal lobulations, permitting easier parenchymal laceration after blunt trauma. Pre-existing or congenital renal abnormalities, such as hydronephrosis, tumors, or abnormal position, may predispose the kidney to trauma despite relatively mild traumatic forces. Historically, congenital abnormalities in injured kidneys have been reported to vary from 1% to 21%. However, most recent reviews have shown a decreased incidence of 1-5%.

The most common mechanisms include motor vehicle collisions, falls, pedestrians struck by cars, bicycle crashes, sports-related injuries, crush injuries, animal kicks, and inflicted injuries. Half of the injuries occur in one kidney. Renal trauma was associated with multiple other injuries in 51-80%; head injuries and skeletal fractures are the most common, accounting for 70% of all associated injuries.

The AAST adopted a classification of renal injuries based on a CT scan grade system (Table 11). Due to the retroperitoneal location of the

<table>
<thead>
<tr>
<th>Grade</th>
<th>Extent of renal injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Contusion: microscopic or gross hematuria, no depiction of injury with any imaging method Hematoma: subcapsular hematoma with no parenchymal laceration</td>
</tr>
<tr>
<td>2</td>
<td>Nonexpanding perirenal hematoma or cortical laceration less than 1 cm deep with no urinary extravasation</td>
</tr>
<tr>
<td>3</td>
<td>Parenchymal laceration extending greater than 1 cm into the cortex with no urinary extravasation</td>
</tr>
<tr>
<td>4</td>
<td>Parenchymal laceration extending through the corticomedullary junction and into the collecting system</td>
</tr>
<tr>
<td>5</td>
<td>Multiple major lacerations resulting in a shattered kidney or avulsion of renal hilum that devascularizes the kidney</td>
</tr>
</tbody>
</table>
kidneys, clinical manifestations are less obvious. Dull flank tenderness, flank hematoma, abdominal tenderness, and hematuria are often the only clues to renal injury.

In the pediatric population, gross hematuria is the most reliable indicator for serious urologic injury; therefore, any child presenting with gross hematuria requires radiographic evaluation. The need for imaging in the pediatric patient with blunt trauma and microscopic hematuria is not as clear. The degree of hematuria does not always correlate with the degree of injury. Renal vascular pedicle avulsion or acute thrombosis of segmental arteries can occur in the absence of hematuria in up to 40%, whereas mild renal contusions can present with gross hematuria. Detection of significant renal injury was found to increase to 8% with significant microhematuria (greater than 50 RBC/HPF) and to 32% in those with gross hematuria. The presence of multisystem trauma significantly increases the risk for significant renal damage. Gross hematuria, shock, or significant deceleration injury are reliable indicators for the presence of renal injuries. Patients with blunt abdominal trauma, microscopic hematuria, and no associated injuries are unlikely to have significant renal injury. Significant renal injuries are more likely in patients with multiple intra-abdominal injuries and hematuria. A review of 12 studies with 1048 total children who had radiographic imaging following blunt trauma showed that 32% of children with gross hematuria, 8% with greater than or equal to 50 RBC/HPF, and 2% with less than 50 RBC/HPF had significant renal injuries. Most importantly, all children with significant renal injuries and less than 50 RBC/HPF were seriously ill and all had other indications for abdominal CT scan. Therefore, imaging is not recommended in the initial evaluation in patients with insignificant microscopic hematuria (less than 50 RBC/HPF) without associated organ injury, but it should be performed when there is persistent microscopic hematuria. The chest radiograph may suggest a renal injury when there is obliteration of the renal and psoas shadows, scoliosis with concavity toward the injured side, fractures of lower posterior ribs, or adjacent transverse spinous process or pelvic fractures. Renal ultrasound has been recommended in screening of renal injuries, but its efficacy has not been yet proven. In addition to determining the severity of renal injuries, CT scan can demonstrate or exclude other intra-abdominal injuries. The CT scan can determine degree of renal parenchymal injury, evaluate presence of nonviable tissue, demonstrate extravasation and perirenal collections, and diagnose most pedicle injuries. Intravenous pyelography (IVP) has traditionally been the imaging study of choice for suspected renal trauma. However, it has been reported that the IVP is interpreted as normal in up to 20% of patients with major renal injuries. When compared with CT scan, the sensitivity of IVP may be as low as 50%. However, IVP is 100% sensitive in grade IV and V injuries on showing the urinary extravasation and a nonfunctioning kidney. It may be used preoperatively in unstable children selected for laparotomy to identify major renovascular injury. IVP findings suggestive of renal injury include delayed excretion of contrast by injured kidney, nonvisualization of caliceal system, or extravasation of contrast into the perinephric tissues. It may miss injuries, but its importance lies in rapidly assessing overall function and anatomical integrity of the kidney, as well as the presence of congenital anomalies. When the CT scan does not show excretion of contrast agent in to the renal collecting system, magnetic resonance angiography or digital subtraction angiography should be performed. The indications for CT in the evaluation of renal injuries are shown in Table 12.

The management of children with suspected renal trauma, especially major renal injuries, remains controversial. Non operative management can be accomplished in up to 95% of children. Older studies have shown a nonoperative success rate of 84-89%. Prior reported high rates of failure of nonoperative therapy for renal injuries may have been related to historical management bias, particularly the inclusion of patients before the broad application of routine nonoperative management protocols for solid organ injury. In addition, it is now generally considered safer to manage the complications associated with nonoperative therapies, such as urinoma, than to risk excessive intraoperative hemorrhage or renal parenchymal loss by intervening in cases that might otherwise heal spontaneously. Complicated lacerations with urinary extravasation may be amenable to adjunctive techniques, such as urethral stenting or percutaneous nephrostomy, to decompress the urinoma and allow spontaneous healing of the leak. Persistent urinary extravasation has successfully been managed by percutaneous drainage. Adjunctive interventions may be required in 7.4% of cases. Although 5% require surgical repair or nephrectomy, the overall renal salvage rate is 98.9%. Table 12. Indications For CT Scanning For Suspected Renal Injuries

- Hematuria greater than 50 RBC/HPF.
- Microscopic hematuria with shock.
- Gross hematuria.
- Penetrating trauma to abdomen.
- Physical findings consistent with renal trauma.
- Significant mechanism that warrant genitourinary tract evaluation.
- Hematuria after a minor mechanism (exclude congenital abnormality or tumor).
1. “I didn’t think I had to evaluate for intra-abdominal organ injury after the child fell off the bicycle handle.”
   Children have intra-abdominal organs that are proportionally larger and not well protected by their weaker abdominal musculature and cartilaginous ribs. Therefore, minor traumatic forces can easily cause injury to these intra-abdominal organs.

2. “I didn’t get a lumbar x-ray of that child involved in a car accident who was restrained in a lap-belt.”
   Children in motor vehicle accidents who wear a lap-only seat belt are prone to intra-abdominal solid organ, hollow viscous, and lumbar spine injuries. Due to their underdeveloped pelvis, the seat belt rides higher on the abdomen and rapid deceleration causes the child to sustain a hyperflexion injury of the upper lumbar spine and compression of the abdominal organs between the seat belt and the spine.

3. “I didn’t suspect that child would go into shock from her inflicted abdominal injuries.”
   Children who sustain intra-abdominal injuries from abuse are usually younger. The injuries are usually severe and because the history is inadequate and the time to presentation is usually delayed, these children frequently present in shock.

4. “The emergency medical technician told me the child had a PTS score of 4, and I told him it was okay to bring the child to my level 3 hospital.”
   A PTS score less than 8 is the recommended threshold for diverting children to a designated trauma center. Children with a PTS score greater than 8 have virtually no mortality. Significantly injured children have a better outcome in a dedicated trauma center.

5. “I didn’t think the child was in shock since his blood pressure was normal.”
   The heart rate is the most sensitive indicator of intravascular volume status in infants and young children. Hypovolemic shock is heralded by tachycardia long before hypotension becomes apparent.

6. “I didn’t think he had a liver injury because his liver function tests were normal.”
   If the liver function tests are elevated, there is an increased chance of a liver injury. However, normal liver functions tests do not exclude a small liver injury.

7. “The FAST examination shows free fluid in the peritoneal cavity; this child must go to the operating room for an exploratory laparotomy.”
   The decision to take a child to the operating room for a solid organ injury depends on the hemodynamic status of that child. If after appropriate fluid and/or blood resuscitation, the child remains hemodynamically unstable then the decision to go to the operating room must be addressed.

8. “The FAST examination is normal; there is no need for an abdominal CT scan in this child who was kicked in the abdomen by a horse.”
   The FAST examination is intended to detect abnormal fluid collections in the peritoneum. It is very limited in the accuracy of detecting solid organ injury that is not actively bleeding. Therefore, in a child with a significant injury mechanism that may result in intra-abdominal trauma with a normal FAST examination, a CT scan of the abdomen should be ordered.

9. “I didn’t call the pediatric surgeon until the child became hypotensive.”
   A pediatric or trauma surgeon should be consulted early in the management of any child who may have a significant intra-abdominal injury, especially if not responding to intravenous crystalloid solution. The hemodynamically unstable child has a higher chance of requiring surgical repair of injuries.

10. “I didn’t think this child had a pancreatic injury because the CT scan was normal, but he did have an elevated lipase.”
    The accuracy of the CT scan is poor for certain types of pancreatic injuries. It does very well in detecting major pancreatic duct injuries but is poor at detecting minor contusions. If the lipase is elevated, serial lipase determinations will clarify if there is a pancreatic injury.
Angiographic embolization is an alternative to surgery in a hemodynamically stable patient in whom persistent gross hematuria signifies persistent low-grade hemorrhage from the injured kidney. Minor renal injuries constitute most blunt renal injuries and usually resolve without incident.337 When conservative management is chosen, supportive care with bed rest, hydration, and serial hemoglobin and vital sign monitoring are required for uneventful healing. After gross hematuria resolves, limited activity is allowed for 2-4 weeks until microscopic hematuria ceases.

Complications of managing grade IV and V injuries non operatively are recurrent hemorrhage, extravasation, urinoma, infection, infarction, or segmental hydronephrosis. Hypertension is a rare but reported complication of renal injury and the true risk is unknown, but earlier studies have shown an incidence rate of 0-9.4%.351,355,356 Hypertension in most instances is treated medically. Renal insufficiency may also occur.357 Other complications may include delayed nephrectomy or infection.344,358

Summary

Timely diagnosis and a systematic approach to non operative versus operative management of intra-abdominal injuries in children are critical in providing the best pediatric trauma care. Suspicion of intra-abdominal injury is based on mechanism of injury and findings on clinical examination. Subsequent evaluation and management of intra-abdominal injury is dictated by the patient’s hemodynamic status and the presence of other extra-abdominal injuries. The hemodynamically unstable child with suspected intra-abdominal injuries may require emergent laparotomy if the child’s hemodynamic status continues to be unstable and not correctable by adequate resuscitation, including blood product administration. The hemodynamically stable child is evaluated using laboratory and imaging studies. Stable children with solid organ injuries are almost always managed nonoperatively, whereas small bowel perforations and pancreatic injuries with main ductal disruption require laparotomy.

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 reference, where available. In addition, the most informative references cited in this paper, as determined by the authors, will be noted by an asterisk (*) next to the number of the reference.

Key Points

- Significant abdominal trauma occurs in 25% of children sustaining multisystem trauma.
- Children’s anatomically unique features predispose them to abdominal injuries that are rarely seen in adults.
- The most common mechanism for producing abdominal injuries includes motor vehicle accidents, pedestrians struck by cars, falls, and bicycle accidents.
- Incorrectly placed lap belts can predispose children to injuries to solid organs, hollow viscous fractures, and lumbar spine fractures (Chance fracture).
- Children with abusive abdominal injuries are younger and may have severe injuries with high mortality rates.

The PTS and the RTS are useful in determining which injured child should be transported to a trauma center.

- The physical examination of a child sustaining blunt abdominal trauma is unreliable and may initially fail to show significant abdominal pathology.
- The laboratory evaluation is unreliable in predicting which child has significant abdominal injuries.
- The CT scan is the radiographic procedure of choice for detecting significant abdominal injury.
- The decision to perform an exploratory laparotomy in children sustaining abdominal organ injuries is dependent on their hemodynamic status.
Posttraumatic peritoneal fluid: is it a reliable... 


235. Renz BM, Feliciano DV. The length of hospital stay after an unnecessary splenectomy in children with blunt splenic trauma. J Trauma 1998; 45(2): 247-250 (Prospective review, 29 patients)


1. The most common cause of mortality in children is trauma.
   a. True
   b. False

2. All of the following anatomic features predispose children to intra-abdominal injuries EXCEPT:
   a. Smaller size of the child
   b. Less fat
   c. Strong abdominal wall musculature
   d. Incomplete ossification of the ribs
   e. Proportionally larger intra-abdominal organs

3. The most common cause of pediatric death from trauma is from intra-abdominal injuries.
   a. True
   b. False

4. Which injuries have not been associated with the lap belt?
   a. Lumbar fracture
   b. Liver contusion
   c. Small bowel perforation
   d. Femur fracture
   e. Kidney laceration

5. Which one of the following patients does not need to be taken to a designated trauma center:
   a. PTS = 4
   b. GSC = 6
   c. PTS = 10
   d. RTS = 11
   e. RTS = 3

6. The abdominal examination of a child who sustained blunt abdominal trauma is an accurate assessment tool for detecting intra-abdominal injury.
   a. True
   b. False

7. The FAST examination evaluates each of these areas EXCEPT:
   a. The gallbladder fossa
   b. Morrison's pouch
   c. Pouch of Douglas
   d. Splenorenal recess
   e. Subxiphoid area

8. Which modality is the best at detecting and deciding management for a child who sustained an intra-abdominal injury?
   a. Focused abdominal sonography for trauma (FAST)
   b. Computed tomography (CT)
   c. Plain abdominal radiograph
   d. Intravenous pyelography (IVP)
   e. Diagnostic peritoneal lavage (DPL)

9. The majority of children who sustain an intra-abdominal injury will require an exploratory laparotomy.
   a. True
   b. False

10. Indications for an exploratory laparotomy after blunt abdominal trauma in children include all of the following EXCEPT:
    a. Intraperitoneal bladder rupture
    b. Peritoneal irritation on examination
    c. Hemodynamic instability despite adequate crystalloid and blood administration
    d. Hollow viscous bowel injury
    e. Grade IV liver injury

11. Splenectomy is more likely in all of these patients EXCEPT:
    a. Glasgow Coma Scale score < 8
    b. Injury Severity Score < 15
    c. Injury occurred after a motor vehicle collision
    d. Hemodynamically unstable
    e. Injury occurred after a bicycle accident
12. Liver injuries are more likely to necessitate an exploratory laparotomy than splenic injuries.
   a. True
   b. False

13. Indications for computed tomography scan for suspected renal injuries include all of the following EXCEPT:
   a. Hematuria < 50 RBC/HPF
   b. Severe flank pain after blunt trauma
   c. Hematuria after a minor injury
   d. Microscopic hematuria with shock
   e. Gross hematuria

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

Goals & Objectives: Upon completion of this article, 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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