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STATEMENT OF FINANCIAL DISCLOSURE

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Pediatric Trauma, Part I

The topic of pediatric trauma is broad, with acute care physicians very aware of the unique features children possess that can complicate a trauma resuscitation. This two-part article will focus on advances and controversies that have emerged in the literature in the last 5 years. New advances in diagnostic evaluation and treatment will be discussed, as well as limitations for each modality. The first part of this article will focus on the unique features of the pediatric trauma patient and advances in this subpopulation. The second part will include sections on imaging the pediatric patient, especially new uses for ultrasound to reduce lifetime radiation exposure; non-accidental trauma; and subtle presentations for non-accidental trauma.

— Ann M. Dietrich, MD, Editor

Introduction

Traumatic injuries continue to be the number one cause of death and disability in children and adolescents. Additionally, these injuries account for one-third of all emergency department (ED) visits in patients younger than age 15 years.[1] Pediatric trauma patients are significantly different than their adult counterparts; they have different mechanisms of injury, injury patterns based on anatomic variations, body proportions, skeletal ossification, physiologic responses to injury, as well as social and emotional needs. This report will review recent/current/future areas of innovation and contrast them to historical practice.

ABCs of Pediatric Trauma Patients

ED physicians should account for several special considerations when resuscitating pediatric patients. In contrast to adult arrests where cardiac issues are the likely culprit, respiratory issues (including hypoxia and inadequate ventilation) are the most common causes of pediatric cardiopulmonary arrest.[2] Survival from pediatric cardiopulmonary arrest is associated with a dismal prognosis. Although in one series, only 0.25% of pediatric trauma patients had no signs of life in the field, only 4.4% of these patients survived to hospital discharge. Thus, airway management is a critical component in the care of pediatric patients. Understanding the differences in pediatric and adult anatomy and physiology is important to properly address the special needs of this population. Tools such as the Broselow resuscitation are helpful to estimate fluid, equipment sizes, and drug dosages through grouping infants and young children into different color zones.

EXECUTIVE SUMMARY

- The Khine formula has been proposed (age in years/4 +3) if use of a cuffed endotracheal tube is preferred; however, most studies suggest (age in years/4 + 3.5) with 3.0 mm tube for infants less than 1 year of age and a 3.5 mm tube for those between 1 and 2 years of age.
- The earliest sign of shock in pediatric patients is tachycardia, and children may move from a compensated state to a decompensated shock very rapidly.
- Central lines, especially femoral lines, may be placed when indicated under ultrasound guidance, but should not take precedence over peripheral or I/O lines.
- The "seat belt sign" can be an important sign of underlying abdominal injury. This is seen as a well-defined area of ecchymosis, erythema, or abrasion along the abdomen caused by the seat belt. This is mostly seen when the belt is improperly fitted and rides too high on the child.
- The spleen is the most commonly injured organ following blunt abdominal trauma, and accounts for up to 45% of all visceral injuries.

Airway

Infants and small children have proportionally larger heads in relation to the rest of their bodies, which result in neck flexion and airway obstruction in an unconscious patient. Children should be placed in the "sniffing position" with the plane of the face parallel to the surface of the board and neck slightly extended. This often requires placing a flattened towel under the shoulder blades. Infants, if not obligate, are highly preferential nasal breathers, so any nasal obstruction should be dealt with quickly.[3,4] Pediatric patients also have large tongues and small oral cavities, as well as anteriorly and superiorly positioned larynxes when compared to adults. This can make visualization of the airway difficult during intubation attempts. A straight (Miller) blade is generally used for pediatric intubation, especially in infants. The more anterior airway and floppy epiglottis of the infant can be overcome by using a straight rather than a curved blade to allow better visualization of the vocal cords during intubation. The narrowest portion of the pediatric airway is subglottic, at the level of the cricoid cartilage, and this narrowness of the airway lumen means that edema (toxic or traumatic) is less well tolerated.[5]

Sizing of the uncuffed pediatric endotracheal tube can be determined by using the modified Cole formula (age in years/4) + 4, with a 3.5 mm tube for infants younger than 1 year and a 4.0 mm tube for those between 1 and 2 years of age; however, length-based sizing may be more accurate.[6,7] Another method often used, and likely easier to remember in a time-critical, high stress, unanticipated situation, is to estimate the diameter of the endotracheal tube by comparing the tube to a child's small finger; however, this method may be less accurate than those previously described.[8]

Once limited to those older than 8 years old due to concerns regarding damage to tracheal mucosa, perhaps largely secondary to early manufacturing issues, cuffed endotracheal tubes seem to be coming more into general practice acceptance. Benefits of cuffed tubes include prevention of hospital-acquired pneumonia, prevention of inadvertent extubation, more accurate titration of ventilation, prevention of tracheal mucosal injury (long the rationale for using uncuffed tubes) when cuff pressures are kept < 20 cm H_2O, and reduced need for reintubation due to air leak — of particular concern in critical situations.[9,10,11,12]

The Khine formula has been proposed (age in years/4 +3) if use of a cuffed endotracheal tube is preferred; however, most studies suggest (age in years/4 + 3.5) with 3.0 mm tube for infants less than 1 year of age and a 3.5 mm tube for those between 1 and 2 years of age.[13,14]

Rapid sequence intubation (RSI) has been reported as improving likelihood of successful intubation, with use of etomidate and a short-term paralytic agent preferred.[15,16] However, one recent report suggests that RSI may not be a panacea for staff in training.[17]

A well-accepted rule of thumb for depth of tube placement is using three times the tube size for tube length in centimeters at the lips. For example, a size 5 tube should be placed 15 cm at the lips; however, using Broselow tape, suggested depth of insertion may be more accurate.[18]

Once intubated, pediatric patients are also at an increased risk for tube displacement secondary to their relatively short tracheas (this includes both right mainstem intubation and accidental extubation).[19,20]

A technique for helping reduce the risk of accidental extubation, right mainstem tube migration, or inadvertent hyperventilation is by making sure that the bag is being squeezed with the hand supinated (underhanded). Since flexor carpi ulnaris contraction with associated ulnar hand deviation does not occur in underhanded bagging as it does in overhanded bagging and the bag rests in the hand, less movement of the airway circuit occurs. In addition, overhanded bagging results in more forceful delivery of larger tidal volumes and higher airway pressures with greater potential for barotrauma.[21] This is additionally concerning, since children are known to be particularly prone to iatrogenic hyperventilation.[22]

If a child has a contraindication to endotracheal intubation (i.e., severe orofacial injury or direct laryngeal injury is present), needle cricothyrotomy should be performed only as a last resort if bag mask-ventilation is not possible.[23,24]

Circulation

To accurately assess the hemodynamics of pediatric patients, normal values for pediatric vital signs should be readily available in resuscitation rooms. A general rule is that any heart rate > 150 in a child older than 1 year of age requires close attention. Children are much more reliant on heart rate to maintain cardiac output. Pediatric patients also have a markedly different response to blood loss than adult patients. Children are better able to maintain relatively normal blood pressure despite having significant blood loss. Studies have shown that children can lose 35-40% of their blood volume before becoming hypotensive. Therefore, hypotension is a late finding in children with significant hemorrhage. Increased heart rate accounts for their increased stroke volume and cardiac output during times of blood loss, so any interventions or medications that lower heart rate can lead to a dangerous loss of perfusion. The earliest sign of shock in pediatric patients is tachycardia, and children may move from a compensated state to a decompensated shock very rapidly.[2] Ultrasonography of the inferior vena cava with and without concomitant bedside echocardiography has been studied as a means of acutely determining volume status in children at the bedside; however, adoption has not been paralleled as in the adult community.[25,26]

Another critical aspect of managing the circulation of a pediatric trauma patient is obtaining vascular access quickly. Guidelines suggest that if two peripheral IVs cannot be successfully placed in the first 90 seconds, an intraosseous (IO) line should be placed in the proximal tibia or distal femur.[27,28] There is evidence to suggest that proximal humerus utilization offers advantages over lower extremity insertion sites of increased flow rates and less chance of intervening fracture or vascular injury vs disadvantages of lower insertion success rate and prohibition on raising the upper extremity if desired for CT scanning or tube thoracostomy insertion.[29]

All equipment for placing an IO line should be readily available in the trauma area, and physicians should not hesitate to place the line quickly if IV access is not immediately available. Central lines, especially femoral lines, may be placed when indicated under ultrasound guidance, but should not take precedence over peripheral or IO lines. Venous cutdowns, once a mainstay, have been largely and gladly relegated to paleo-emergency medicine.[2]

A thorough secondary survey is necessary following the initial primary survey. The child needs to be completely undressed, although special care needs to be taken that the child does not become hypothermic. Since pediatric patients have a larger body surface area for weight, they are more prone to heat loss and may require external means to keep body temperatures adequate. Temperature should be monitored carefully, and warm blankets or external heating devices should be used if there is any concern that the child is becoming hypothermic.[30] Interestingly, the incidence of inadvertent hypothermia in adults and children in both trauma and perioperative populations is paradoxically similar, perhaps being more reflective of an endemic level of thermodynamic inattentiveness rather than reflecting the expected result of significant physiological differences.[30,31,32]

Mechanisms of Injury

Common mechanisms for pediatric traumatic injuries vary by age and level of development. Younger pediatric patients tend to be injured by falls, drowning, burns, motor vehicle collisions (MVCs), and non-accidental trauma (NAT). Older children are also injured in MVCs and falls, but also start experiencing sports-related accidents, bicycle accidents, and gunshot wounds.[33]

MVC

Injuries related to MVCs are the leading cause of mortality in children age 5 years and older in the United States and account for more than 50% of the unintentional injuries that cause death in the pediatric population. Being unrestrained or having improperly fitted restraints has been associated with the greatest risk of injury in pediatric patients who are passengers involved in MVCs. Lap belts that are situated over the abdomen instead of the pelvis put a child at risk for abdominal trauma. The "seat belt sign" can be an important sign of underlying abdominal injury. This is seen as a well-defined area of ecchymosis, erythema, or abrasion along the abdomen caused by the seat belt. This is mostly seen when the belt is improperly fitted and rides too high on the child.[34] Children also have a less protective iliac crest than do adults.[35] In addition, children who are front-seat passengers are at risk for head, cervical spine, ocular, and extremity injuries in the case of airbag deployment. This has led the American Academy of Pediatrics to strongly recommend that children under 13 should only sit in rear car seats.

Pedestrians

Pedestrians struck by automobiles is another unfortunately common cause of injury in this population. This includes back-over or driveway injuries. Despite the fact that these accidents often occur at low vehicle speeds, they have some of the highest morbidity and mortality and are associated with increased severity of injury.[36] One reason for the increased morbidity and mortality related to these injuries is that often the child's head will be at the level of the collision, resulting in a direct impact. This is contrary to adult pedestrians being struck by automobiles, where orthopedic injuries are more common due to the level of direct impact.[35]

Penetrating Abdominal Trauma

Unfortunately pediatric penetrating trauma seems to be on the increase.[37] Although a detailed treatment of pediatric penetrating trauma is beyond the scope of this report (but does have some overlap with

Table 1. Spleen Injury Scale

Grade*	Injury Type	Description of Injury
I	Hematoma	Subcapsular, < 10% surface area
	Laceration	Capsular tear, < 1 cm parenchymal depth
II	Hematoma	Subcapsular, 10%-50% surface area intraparenchymal, < 5 cm in diameter
	Laceration	Capsular tear, 1-3 cm parenchymal depth that does not involve a trabecular vessel
III	Hematoma	Subcapsular, > 50% surface area or expanding; ruptured subcapsular or parecymal hematoma; intraparenchymal hematoma ≥ 5 cm or expanding
	Laceration	> 3 cm parenchymal depth or involving trabecular vessels
IV	Laceration	Laceration involving segmental or hilar vessels producing major devascularization (> 25% of spleen)
	Laceration	Completely shattered spleen
	Vascular	Hilar vascular injury with devascularizes spleen

*Advance one grade for multiple injuries up to grade III.

Adapted from: Moore EE, Cogbill TH, Jurkovich GJ, et al. Organ injury scaling: Spleen and liver (1994 revision) *J Trauma* 1995;38:323-324.

blunt abdominal trauma management, which is treated in detail), it should be noted that selective nonoperative management of penetrating abdominal trauma in children is now being explored.[38] While adult criteria have been established for selective nonoperative management of penetrating abdominal trauma, pediatric criteria have yet to be established despite pediatric leadership in selective nonoperative management of blunt trauma.[39] General management of blunt and penetrating thoracic trauma overlap considerably and will be covered in Part II.

Blunt Abdominal Trauma

Blunt abdominal trauma (BAT) most commonly leads to injuries of solid organs and less commonly damages the bowel and mesentery.[40] Incidence of isolated liver, spleen, or renal injuries requiring operative management remains extremely low, while multiple solid organ injury warrants a somewhat more invasive but still largely nonoperative approach.[41] The question of utilization of imaging, which modality, and for what purpose, now becomes the more paramount question. Has CT imaging become more a modality primarily for prognosticating healing time rather than acute intervention?[42] As such, can other modalities be used for these purposes to reduce cost and potentially deadly radiation exposure for nonlethal injuries?

Splenic Injury

The spleen is the most commonly injured organ following BAT, and accounts for up to 45% of all visceral injuries. Symptoms of splenic injury may include left upper quadrant or generalized abdominal pain, possibly radiating to the left shoulder due to diaphragmatic or phrenic nerve irritation (Kehr's sign). Radiographic findings may include left lower rib fractures. A triad of other radiographic findings has been described and includes left diaphragmatic elevation, left lower lobe atelectasis, and left pleural effusion. Other radiologic possibilities include a medially displaced gastric bubble or inferior displacement of the splenic flexure.[43]

The degree of splenic injury depends on the force of impact, degree of deceleration, and anatomic characteristics of the spleen. A splenic contusion is defined by parenchymal lesions, whereas splenic rupture is associated with hematoma. If the capsule is also ruptured this will be associated with hemoperitoneum. A splenic laceration that extends through two surfaces is referred to as a fracture. The hemoperitoneum associated with splenic injury is usually present in the left paracolic gutter into the rectouterine space in girls and the rectovesical space in boys.[43] *See Table 1 for the American Association for the Surgery of Trauma (AAST) grade and classification of splenic injuries.*

Management. Historically, splenic injuries were treated by prompt splenectomy, although over time treatment has evolved into handling the majority of cases nonoperatively or by performing splenorrhaphy. It has been shown that children tolerate higher-grade splenic injuries with nonoperative management vs adults. As long as a child is hemodynamically stable, nonoperative management is the standard of care for all grades of splenic injury. Conservative management includes hospital admission, generally 2-5 days of bed rest and IV hydration, monitoring of vital signs and hemoglobin, and possible antibiotic therapy.[43] Angioembolization of splenic blunt trauma is currently being utilized as an alternative to laparotomy for relatively stable patients with persistent bleeding.[44] The American Pediatric Surgical Association (APSA) Trauma Committee developed consensus guidelines to direct care for these patients including hospital length of stay, imaging, and post-discharge activity restriction. APSA does not recommend any additional pre- or post-discharge imaging. It does recommend between 3-6 weeks of activity restriction based on the grade of injury.[43]

Liver Injury

The liver is the second most commonly injured organ in blunt abdominal trauma and is most common after trauma to the upper right abdomen or right hemithorax. Injuries are most often in the right lobe secondary to location and size. Due to the blood supply from systemic and portal circulation, liver injuries can lead to significant blood loss. For this reason, liver injuries tend to be more significant than splenic injuries and are associated with higher morbidity and mortality. Patients may complain of right upper quadrant pain or right shoulder pain.

It is recommended that basic laboratory studies be collected in cases of BAT, as they may help guide additional diagnostic evaluation. Very high aspartate aminotransferase (AST) and alanine aminotransferase (ALT) levels may correlate with severity of liver injury, although some studies suggest that half of all patients with no discernable liver injury on CT still had elevated AST or ALT levels.[43] Some current studies suggest that normal AST and ALT levels can essentially rule out liver parenchymal damage.[45] Liver enzymes should be measured and used in conjunction with physical exam and imaging in order to guide management of possible liver injury. *See Table 2 for AAST grade and classification of liver injuries.*

Management. In hemodynamically stable patients, liver injuries (like injuries to the spleen) are also managed conservatively. Surgery may be required if patients are hemodynamically unstable, needing blood transfusions over 30 mL per kg in the first 24 hours, or are having peritoneal irritation or evidence of concomitant hollow organ perforation.[45] Another emerging option is hepatic artery angioembolization (rather than surgery) if there is evidence of ongoing bleeding (seen with contrast extravasation on CT).[46]

Kidney Injury

Blunt kidney injury in children was once thought to be more frequent than in adults, but this has come into question. Microscopic hematuria used to be an indication for CT scanning, but imaging is currently reserved for patients with gross hematuria and/or hemodynamic instability.[47] *See Table 3 for AAST classification of renal injury.*

Management. Management of renal injuries is once again largely nonoperative as in other solid organ injury. One case in which surgery may be required in the relatively hemodynamically stable patient may be when there is a single kidney with

Table 2. Liver Injury Scale

Grade*	Injury Type	Description of Injury
I	Hematoma	Subcapsular, < 10% surface area
	Laceration	Capsular tear, < 1 cm parenchymal depth
II	Hematoma	Subcapsular, 10%-50% surface area intraparenchymal, < 10 cm in diameter
	Laceration	Capsular tear 1-3 parenchymal depth, < 10 cm in length
III	Hematoma	Subcapsular, > 50% surface area of ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma > 10 cm or expanding
	Laceration	> 3 cm parenchymal depth
IV	Laceration	Parenchymal disruption involving 25% to 75% hepatic lobe or 1-3 Couinaud's segments
V	Laceration	Parenchymal disruption involving > 75% of hepatic lobe or > 3 Couinaud's segments within a single lobe
	Vascular	Juxtahepatic venous injuries; ie, retrohepatic vena cava/central major hepatic veins
VI	Vascular	Hepatic avulsion

*Advance one grade for multiple injuries up to grade III.

Adapted from: Moore EE, Cogbill TH, Jurkovich GJ, et al. Organ injury scaling: Spleen and liver (1994 revision) *J Trauma* 1995;38:323-324.

Table 3. Kidney Injury Scale

Grade*	Injury Type	Description of Injury
I	Contusion	Microscopic or gross hematuria, urologic studies normal
	Hematoma	Subcapsular, nonexpanding without parenchymal laceration
II	Hematoma	Nonexpanding perirenal hematoma confirmed to renal retroperitoneum
	Laceration	< 1.0 cm parenchymal depth of renal cortex without urinary extravagation
III	Laceration	< 1.0 cm parenchymal depth of renal cortex without collecting system rupture or urinary extravagation
IV	Laceration	Parenchymal laceration extending through renal cortex, medulla, and collecting system
	Vascular	Main renal artery or vein injury with contained hemorrhage
V	Laceration	Completely shattered kidney
	Vascular	Avulsion of renal hilum which devascularizes kidney

*Advance one grade for bilateral injuries up to grade III.

Adapted from: Moore EE, Shackford SR, Pachter HL, et al. Organ injury scaling: spleen, liver, and kidney. *J Trauma* 1989;29:1664-1666.

Table 4. Small Bowel Injury Scale

Grade*	Injury Type	Description of Injury
I	Hematoma	Contusion or hematoma without devascularization
	Laceration	Partial thickness, no perforation
II	Laceration	Laceration < 50% of circumference
III	Laceration	Laceration ≥ 50% of circumference without transection
IV	Laceration	Transection of the small bowel
V	Laceration	Transection of the small bowel with segmental tissue loss
	Vascular	Devascularized segment

*Advance one grade for multiple injuries up to grade III.

Adapted from: Moore EE, Cogbill TH, Malangoni MA, et al. Organ injury scaling: Pancreas, duodenum, small bowel, colon, and rectum. *J Trauma* 1990;30:1427-1429.

Table 5. Colon Injury Scale

Grade*	Injury Type	Description of Injury
I	Hematoma	Contusion or hematoma without devascularization
	Laceration	Partial thickness, no perforation
II	Laceration	Laceration < 50% of circumference
III	Laceration	Laceration ≥ 50% of circumference without transection
IV	Laceration	Transection of the colon
V	Laceration	Transection of the colon with segmental tissue loss
	Vascular	Devascularized segment

* Advance one grade for multiple injuries up to grade III.

Adapted from: Moore EE, Cogbill TH, Malangoni MA, et al. Organ injury scaling: Pancreas, duodenum, small bowel, colon, and rectum. *J Trauma* 1990;30:1427-1429.

a significant renovascular injury. Most renal injuries can be managed nonoperatively with angioembolization, a therapeutic option even in Grade 4 injuries.[48]

Bowel, Duodenal, and Pancreatic Injury

Patterns of blunt injury to the bowel differ in children and adults but utilize the same injury scoring system. Children have a much higher incidence of duodenal injury with a significant number of these cases secondary to "classic handlebar injuries."[49] Duodenal injuries offer unique challenges in comparison to other bowel injuries, hence, their own scoring system. There is often accompanying pancreatic injury in patients with duodenal injuries with therapeutic implications.[50] *See Tables 4 and 5 for AAST classification of bowel injuries, Table 6 for AAST classification of duodenal injuries, and Table 7 for AAST classification of pancreatic injuries.*

Management. Blunt bowel perforation is rare and frequently initially missed. It is a source of morbidity but typically not mortality. Treatment of less serious bowel injuries, in contradistinction, remains largely nonoperative and supportive.[51] Isolated nonperforated duodenal injury is treated much the same way.[50] Management of isolated pancreatic injury largely depends on presence and location of injury to the pancreas and its main duct but also associated duodenal injury. Unlike other solid abdominal organs, pancreatic injuries often require operative management. Minor injuries without suspected injury to the main pancreatic duct are initially managed nonoperatively with serial re-evaluation for development of complications such as pseudocyst or pancreatic fistula. Patients with suspected main pancreatic duct injury require surgery and either distal pancreatectomy for duct injuries to the left of the superior mesenteric vein, closed drainage for injury where main duct injury is felt to be to the right of the superior mesenteric vein, and for severe injuries to the pancreatic head usually in combination with severe duodenal injury — primary pancreatoduodenectomy or damage control surgery followed by pancreatoduodenectomy.[50] Management of combined duodenal and pancreatic injury must both be considered in devising operative strategy.[50] Due to the rarity of serious pancreatic injury in children, some have advocated nearly universal early nonoperative management; however, this is accompanied by a high failure and complication rate.[52,53] It should be noted that nonoperative management of pancreatic duct injuries by endoscopic stenting can be done selectively in children.[52]

Imaging in BAT

Patients sustaining blunt abdominal trauma rarely need to be managed surgically. However, there is a need to quickly and accurately identify those patients with injuries that will need rapid surgical intervention. The gold standard diagnostic test for evaluation of intra-abdominal injuries (IAI) is an intravenous contrast-enhanced CT scan. Although CT scans may remain the gold standard for diagnosing IAI, they do come with a substantial exposure to ionizing radiation, which may significantly increase a child's lifetime risk of developing a lethal malignancy.[54] This is especially worrisome in IAIs where children can sometimes receive multiple scans, for example, after transfer from community

Table 6. Duodenum Injury Scale

Grade*	Injury Type	Description of Injury
I	Hematoma	Involving single portion of duodenum
	Laceration	Partial thickness, no perforation
II	Hematoma	Involving more than one portion
	Laceration	Disruption < 50% of circumference
III	Laceration	Disruption 50%-75% of circumference of D2
		Disruption 50%-100% of circumference of D1, D3, D4
IV	Laceration	Disruption > 75% of circumference of D2
		Involving ampulla or distal common bile duct
V	Laceration	Massive disruption of duodenopancreatic complex
	Vascular	Devascularization of duodenum

*Advance one grade for multiple injuries up to grade III. D1-first position of duodenum; D2-second portion of duodenum; D3-third portion of duodenum; D4-fourth portion of duodenum

Adapted from: Moore EE, Cogbill TH, Malangoni MA, et al. Organ injury scaling: Pancreas, duodenum, small bowel, colon, and rectum. *J Trauma* 1990;30:1427-1429.

Table 7. Pancreas Injury Scale

Grade*	Injury Type	Description of Injury
I	Hematoma	Minor contusion without duct injury
	Laceration	Superficial laceration without duct injury
II	Hematoma	Major contusion without duct injury or tissue loss
	Laceration	Major laceration without duct injury or tissue loss
III	Laceration	Distal transection or parenchymal injury with duct injury
IV	Laceration	Proximal** transection or parenchymal injury involving ampulla
V	Laceration	Massive disruption of pancreatic head

*Advance one grade for multiple injuries up to grade III.

**Proximal pancreas is to the patients' right of the superior mesenteric vein

Adapted from: Moore EE, Cogbill TH, Malangoni MA, et al. Organ injury scaling: Pancreas, duodenum, small bowel, colon, and rectum. *J Trauma* 1990;30:1427-1429.

hospital to pediatric trauma centers and to follow up on known injuries. IV contrast given along with the CT also has the potential to induce nephropathy. As few as 2% of all pediatric patients obtaining abdominal CT scan for blunt trauma required surgery.[55] Thus, CT has a fairly low yield for identifying injuries requiring surgery and is essentially used as a tool to identify and determine prognosis in patients who will survive.[56]

BATiC Score

The Blunt Abdominal Trauma in Children (BATiC) score uses readily available lab values, Doppler ultrasound results, and physical exam findings to assess trauma patients without the use of imaging requiring radiation. The score combines the results of abdominal Doppler ultrasound with three physical exam findings (abdominal pain, peritoneal irritation, and hemodynamic instability) and six laboratory values (AST, ALT, WBC, LDH, lipase, and creatinine).[57]

The Blunt Abdominal Trauma in Children (BATiC) score assigns points as follows:

- 4 points for an abnormal Doppler evaluation of the renal arteries on abdominal ultrasound
- 2 points each for abdominal pain, signs of peritoneal irritation on physical exam, hemodynamic instability, AST > 60 IU/L, and ALT > 25 IU/L
- 1 point each for peripheral white blood cell count > 9.5 g/L, lactate dehydrogenase > 330 IU/L, lipase > 30 IU/L, and creatinine > 50 µg/L

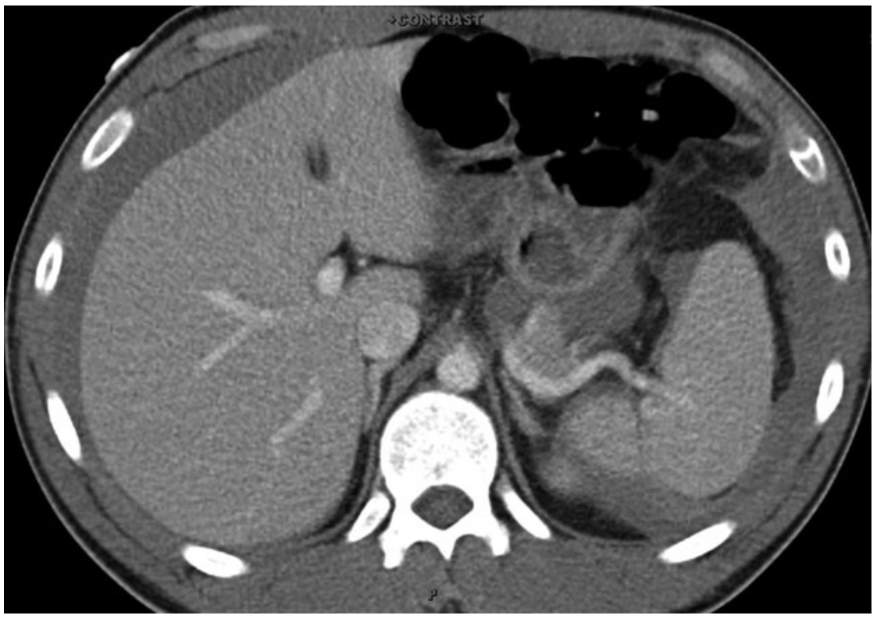
A BATiC score cutoff of > 6 (out of a possible score of 18) resulted in a sensitivity of 100% and specificity of 87% for IAI. A cutoff of 7 resulted in a sensitivity of 89% and a specificity of 94%. Using cutoffs of 6 and 7 could have avoided 47% and 56%, respectively, of the 34 computed tomography scans performed.

Willem-Jan et al studied the validity of the BATiC score on 216 trauma patients minus Doppler ultrasound and found that it had a 99% negative predictive value, and, therefore, could be used to reliably rule out IAI. They did suggest that a positive score should lead to subsequent CT scan.[58] The use of the BATiC score could help reduce the amount of unnecessary CT scans, reducing radiation exposure as well as cost.

Focused Assessment with Sonography in Trauma (FAST) remains an item of contention in pediatric trauma.[59] Some authors advocate not to use it at all.[60] In part, this likely stems from its inability to identify abdominal parenchymal injury when used in its simplest B-mode implementation. However, the addition of Doppler ultrasound — preferably power Doppler, which is more sensitive for any flow, vs color Doppler, whose directionality is unneeded under investigation and termed c-FAST (for color), vs the more accurate but socially unacceptable alternative acronym for using recommended power Doppler (p-FAST) — will permit identification of solid organ injuries not visualized by B-mode and not accompanied by free fluid. Power Doppler highlights parenchymal injuries via deformation of vascular arcades by relatively isoechoic intraparenchymal hematomas, absence of typical regional parenchymal vascularity (ultrasonographic Westermark sign), and linear truncation of parenchymal vascular arcades — with administration of ultrasound contrast likely to improve sensitivity even further.[61] (*See Figures 1, 2, and 3.*) There are two commercially available ultrasound agents in the United States and three in Europe. Their usable half-life is about 5 minutes and they can only be re-dosed once, hence limiting patient re-evaluation but they do facilitate parenchymal injury detection. Power Doppler viewing is best utilized by obtaining a "hilar" long axis view of the organ in question and fanning through the organ using a single window when feasible. Given the confounding problem of aerophagia in children, low intercostal views are preferred vs abdominal views when scanning intra-abdominal organs. The liver is more complex to scan given its size, lack of a simple hilum, and "non-bean" morphology. By identifying vascular structures in the liver, such as hepatic veins' origination from inferior vena cava and/or portal vein and tracing branches out to the periphery, the entire territory of the liver can be covered in an organized fashion and the power Doppler utility fully leveraged. The reliability of these techniques in children by nonradiologists vs CT scan has yet to be established. Neither Karam nor Willem-Jan indicated that they looked for free air, highly diagnostic for perforated hollow viscus, or that they detected it in perforated hollow viscus cases, implying that it was not screened for. Intra-abdominal free air is easily detected on ultrasound with suprahepatic-subdiaphragmatic free air (the most common location) easily seen when viewing Morrison's pouch.[62] As such, ultrasound offers the ability to screen for free air long before the onset of peritonitis. Visualization of the pancreas is problematic given the prevalence of pediatric aerophagia and lack of suitability of intercostal windows.

Figure 1. Unremarkable Spleen in B-mode in 19 yo Trauma Patient

Figure 2. CT Scan of Figure 1 Patient Showing Fracture of Medial Aspect of Spleen Undetected on B-mode



Conclusion

With the advent of child safety devices and practices, the incidence of serious pediatric trauma, in the youngest, most difficult to treat age groups, has declined. In addition, Broselow tapes and advances in airway and vascular access have

Figure 3. Patient Showing No Obvious Splenic Fracture

Patient from Figures 1 and 2 showing no obvious splenic fracture. However, medial aspect of spleen is devascularized suggesting presence of fracture seen on CT.

improved the ability of providers to stabilize a child's vital functions rapidly and effectively.

Nonoperative management for BAT remains dominant, with even fewer operative procedures necessary with advancements in interventional radiological procedures. Reserving the utilization of CT scanning for those in whom the risk-benefit ratio exceeds future cancer risk is critical. Advances in ultrasound may enable clinicians to further decrease CT scanning rates, while maintaining diagnostic accuracy.

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CME Questions

1. Which of the following can lead to a dangerous loss of perfusion in a pediatric trauma patient?
   A. Supine positioning
   B. Medications that lower heart rate
   C. Endotracheal intubation
   D. IV fluids
2. What is the most commonly injured organ after blunt abdominal trauma?
   A. Liver
   B. Spleen
   C. Kidney
   D. Bowel
3. How do you determine hypotension in a pediatric patient?
   A. It is the same as an adult
   B. SBP < 70 mmHg
   C. SBP < 70 mmHg + 2 times the age in years
   D. Evidence of end organ dysfunction
4. In which of the following scenarios is surgery absolutely required?
   A. Grade V liver laceration
   B. Positive seat belt sign and heart rate of 120
   C. Evidence of intestinal perforation
   D. Tibia fracture
5. The ultrasound feature best suited for detecting blood flow is:
   A. M-mode.
   B. B-mode.
   C. Com-mode.
   D. Power Doppler.

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Upon completion of this educational activity, participants should be able to:

- recognize specific conditions in pediatric patients presenting to the emergency department;
- describe the epidemiology, etiology, pathophysiology, historical and examination findings associated with conditions in pediatric patients presenting to the emergency department;
- formulate a differential diagnosis and perform necessary diagnostic tests;
- apply up-to-date therapeutic techniques to address conditions discussed in the publication;
- discuss any discharge or follow-up instructions with patients.

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Pediatric Trauma, Part I

Spleen Injury Scale

Grade*	Injury Type	Description of Injury
I	Hematoma	Subcapsular, < 10% surface area
	Laceration	Capsular tear, < 1 cm parenchymal depth
II	Hematoma	Subcapsular, 10%-50% surface area intraparenchymal, < 5 cm in diameter
	Laceration	Capsular tear, 1-3 cm parenchymal depth that does not involve a trabecular vessel
III	Hematoma	Subcapsular, > 50% surface area or expanding; ruptured subcapsular or parecymal hematoma; intraparenchymal hematoma ≥ 5 cm or expanding
	Laceration	> 3 cm parenchymal depth or involving trabecular vessels
IV	Laceration	Laceration involving segmental or hilar vessels producing major devascularization (> 25% of spleen)
	Laceration	Completely shattered spleen
	Vascular	Hilar vascular injury with devascularizes spleen

*Advance one grade for multiple injuries up to grade III.

Adapted from: Moore EE, Cogbill TH, Jurkovich GJ, et al. Organ injury scaling: Spleen and liver (1994 revision) *J Trauma* 1995;38:323-324.

Liver Injury Scale

Grade*	Injury Type	Description of Injury
I	Hematoma	Subcapsular, < 10% surface area
	Laceration	Capsular tear, < 1 cm parenchymal depth
II	Hematoma	Subcapsular, 10%-50% surface area intraparenchymal, < 10 cm in diameter
	Laceration	Capsular tear 1-3 parenchymal depth, < 10 cm in length
III	Hematoma	Subcapsular, > 50% surface area of ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma > 10 cm or expanding
	Laceration	> 3 cm parenchymal depth
IV	Laceration	Parenchymal disruption involving 25% to 75% hepatic lobe or 1-3 Couinaud's segments
V	Laceration	Parenchymal disruption involving > 75% of hepatic lobe or > 3 Couinaud's segments within a single lobe
	Vascular	Juxtahepatic venous injuries; ie, retrohepatic vena cava/central major hepatic veins
VI	Vascular	Hepatic avulsion

*Advance one grade for multiple injuries up to grade III.

Adapted from: Moore EE, Cogbill TH, Jurkovich GJ, et al. Organ injury scaling: Spleen and liver (1994 revision) *J Trauma* 1995;38:323-324.

Kidney Injury Scale

Grade*	Injury Type	Description of Injury
I	Contusion	Microscopic or gross hematuria, urologic studies normal
	Hematoma	Subcapsular, nonexpanding without parenchymal laceration
II	Hematoma	Nonexpanding perirenal hematoma confirmed to renal retroperitoneum
	Laceration	< 1.0 cm parenchymal depth of renal cortex without urinary extravagation
III	Laceration	< 1.0 cm parenchymal depth of renal cortex without collecting system rupture or urinary extravagation
IV	Laceration	Parenchymal laceration extending through renal cortex, medulla, and collecting system
	Vascular	Main renal artery or vein injury with contained hemorrhage
V	Laceration	Completely shattered kidney
	Vascular	Avulsion of renal hilum which devascularizes kidney

*Advance one grade for bilateral injuries up to grade III.

Adapted from: Moore EE, Shackford SR, Pachter HL, et al. Organ injury scaling: spleen, liver, and kidney. *J Trauma* 1989;29:1664-1666.

Small Bowel Injury Scale

Grade*	Injury Type	Description of Injury
I	Hematoma	Contusion or hematoma without devascularization
	Laceration	Partial thickness, no perforation
II	Laceration	Laceration < 50% of circumference
III	Laceration	Laceration ≥ 50% of circumference without transection
IV	Laceration	Transection of the small bowel
V	Laceration	Transection of the small bowel with segmental tissue loss
	Vascular	Devascularized segment

*Advance one grade for multiple injuries up to grade III.

Adapted from: Moore EE, Cogbill TH, Malangoni MA, et al. Organ injury scaling: Pancreas, duodenum, small bowel, colon, and rectum. *J Trauma* 1990;30:1427-1429.

Colon Injury Scale

Grade*	Injury Type	Description of Injury
I	Hematoma	Contusion or hematoma without devascularization
	Laceration	Partial thickness, no perforation
II	Laceration	Laceration < 50% of circumference
III	Laceration	Laceration ≥ 50% of circumference without transection
IV	Laceration	Transection of the colon
V	Laceration	Transection of the colon with segmental tissue loss
	Vascular	Devascularized segment

* Advance one grade for multiple injuries up to grade III. *863.41,863.51-ascending;863.42, 863.52-transverse;863.45,863.53-descending; 863.44,863.54-rectum.

Adapted from: Moore EE, Cogbill TH, Malangoni MA, et al. Organ injury scaling: Pancreas, duodenum, small bowel, colon, and rectum. *J Trauma* 1990;30:1427-1429.

Duodenum Injury Scale

Grade*	Injury Type	Description of Injury
I	Hematoma	Involving single portion of duodenum
	Laceration	Partial thickness, no perforation
II	Hematoma	Involving more than one portion
	Laceration	Disruption < 50% of circumference
III	Laceration	Disruption 50%-75% of circumference of D2
		Disruption 50%-100% of circumference of D1, D3, D4
IV	Laceration	Disruption > 75% of circumference of D2
		Involving ampulla or distal common bile duct
V	Laceration	Massive disruption of duodenopancreatic complex
	Vascular	Devascularization of duodenum

*Advance one grade for multiple injuries up to grade III. D1-first position of duodenum; D2-second portion of duodenum; D3-third portion of duodenum; D4-fourth portion of duodenum

Adapted from: Moore EE, Cogbill TH, Malangoni MA, et al. Organ injury scaling: Pancreas, duodenum, small bowel, colon, and rectum. *J Trauma* 1990;30:1427-1429.

Pancreas Injury Scale

Grade*	Injury Type	Description of Injury
I	Hematoma	Minor contusion without duct injury
	Laceration	Superficial laceration without duct injury
II	Hematoma	Major contusion without duct injury or tissue loss
	Laceration	Major laceration without duct injury or tissue loss
III	Laceration	Distal transection or parenchymal injury with duct injury
IV	Laceration	Proximal** transection or parenchymal injury involving ampulla
V	Laceration	Massive disruption of pancreatic head

*Advance one grade for multiple injuries up to grade III.

**Proximal pancreas is to the patients' right of the superior mesenteric vein

Adapted from: Moore EE, Cogbill TH, Malangoni MA, et al. Organ injury scaling: Pancreas, duodenum, small bowel, colon, and rectum. *J Trauma* 1990;30:1427-1429.

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