Abdominal Trauma Evaluation for the Pediatric Surgeon

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KEYWORDS

- Pediatric trauma • Abdominal evaluation • Pediatric surgeon
- Nonoperative management solid organ injury • Abdominal injury

KEY POINTS

- The evaluation of abdominal trauma in children should be guided by the Advanced Trauma Life Support algorithms accounting for the unique anatomy and physiology of pediatric patients.
- In children with mild trauma who are clinically stable, physical examination, laboratory results, and imaging avoiding ionizing radiation should be used; computed tomography imaging is reserved for more severe injury.
- Nonoperative management of many injuries, including solid organ trauma, has become the standard of care for children, although hemodynamically unstable patients must receive expeditious intervention.

INTRODUCTION

Trauma is the leading cause of childhood mortality. More than 20 million children are injured each year, and unintentional injury is the leading cause of death for children in all age groups over 1 year of age. Abdominal trauma is the third leading cause of death in this population, after head and thoracic injuries. It is the most common cause of death owing to unrecognized injury.[1] The evaluation of the injured child with a focus on abdominal trauma is a significant portion of the practice of pediatric surgery. Pediatric trauma differs from adult trauma by mechanisms, injury patterns, anatomy, and long-term effects on growth and development. A focus on clinical examination and, when appropriate, reduction in ionizing radiation, are important considerations. We

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focus this discussion on a systematic evaluation of injured children, centering on abdominal injuries, and highlighting areas where significant differences exist with an adult workup.

BACKGROUND

Intraabdominal injury (IAI) can result from blunt or penetrating mechanisms. Blunt injuries are much more common than penetrating injuries (85% vs 15%). Among children with blunt abdominal trauma, 5% to 10% sustain IAI. Despite improvements in emergency diagnostics and evaluation, controversy still exists regarding the optimal assessment and management of pediatric trauma patients with IAI.

Certain mechanisms of injury are more common in the pediatric population. Infants and young children are likely to sustain injuries from motor vehicle collisions (MVC), drowning, suffocation, burns, falls, and abuse. School-aged children are susceptible to MVC, pedestrian injuries, bicycle injuries, and firearm injuries. Adolescents are at risk from MVC, firearm injuries, falls, and intentional injuries.[2]

Unfortunately, socioeconomic and ethnic disparities related to pediatric trauma exist and vary by age and mechanism. African Americans and Native Americans are at higher risk of fatal injuries than other ethnic groups.[3] Their care and outcomes also differ along these same ethnic lines. Algorithms and guidelines that aim to standardize care may work to reduce some of these disparities.

PRESENTATION AND DIAGNOSIS

Children are more susceptible to blunt injury than adults. A smaller body size allows for a greater distribution of injury; therefore, children often suffer multiple traumatic injuries in several regions. Additionally, pediatric internal organs are more likely to be injured owing to a smaller torso, larger and more mobile viscera, and decreased amount of intraabdominal fat.[4]

There are several common mechanisms leading to blunt abdominal trauma in children. The leading cause is MVC, accounting for more than 50% of pediatric abdominal trauma. Physical examination findings from blunt trauma include ecchymosis, abrasions, lacerations, abdominal tenderness, or abdominal distention. The liver and spleen are the most common solid organs injured. The most concerning and often subtle finding results from abrasions or ecchymosis from restraining belts, the “seat belt sign.” When these belt marks are not over the bony pelvis, significant injury may result. The injuries can result from either the lap portion of the belt being too high or the shoulder portion being too low (**Fig. 1**). Patients with a seat belt sign are at greater risk for intraabdominal injury, particularly hollow viscus injury.[5] These injuries are also associated with Chance fractures, flexion–distraction injuries of the spine at the area of the lap belt, owing to limited mobility of the spine from the compressing seat belt. Chance fractures occur in about 5% of restrained children involved in an MVC.[6] The belts may also injure solid organs including the liver, spleen, or pancreas. We have seen several associated aortic injuries in our patient population resulting from the similar compression that causes spine fractures. These injuries can be very difficult to address in young children and should not be overlooked.

Other causes of abdominal trauma include sport injuries, bicycle and all-terrain vehicle injuries, pedestrian injuries, falls, and child abuse. Sports-related injuries are more commonly associated with isolated organ injury as a result of impact to the abdomen, in particular the spleen, kidney, and gastrointestinal tract. Although

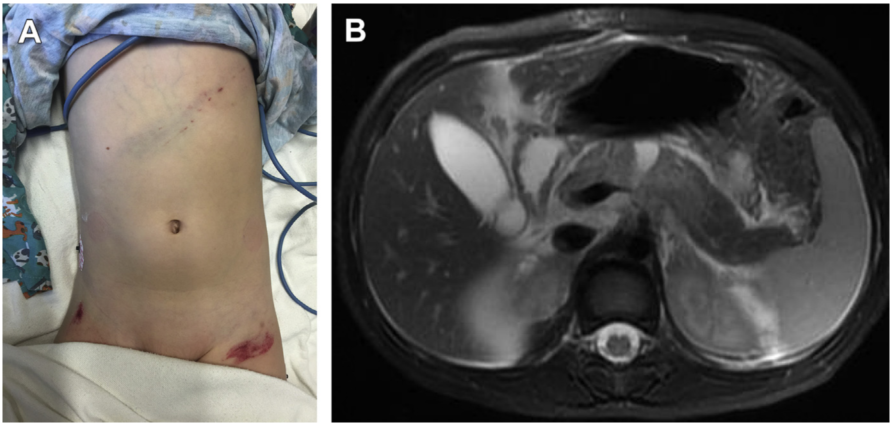

Fig. 1. Seat belt injuries. A 3-year-old restrained back seat passenger in a booster seat with lap and shoulder restraints presented with upper and pelvic bruising from the restraining belts. The lower abrasions over the anterior superior iliac spines demonstrate appropriate positioning and did not contribute to injury. The shoulder belt was too low over the upper abdomen, resulting in a pancreatic transection. (*A*) Clinical photo. (*B*) MRI demonstrating pancreatic laceration.

abdominal injury secondary to child abuse only occurs in about 5% of total child abuse cases, it is the second most common cause of death from abuse.

Penetrating trauma represents about 15% of abdominal trauma. The overwhelming majority of penetrating abdominal injuries are secondary to gunshots and stabbings.[7] More than 90% of gunshots occur in children 12 years or older.[8] Other causes of penetrating traumas include stab wounds and impalements. Trajectories of knives and projectiles may require whole body survey to evaluate for multiple wounds and guide clinical decision making (**Fig. 2**). The most commonly injured structures secondary

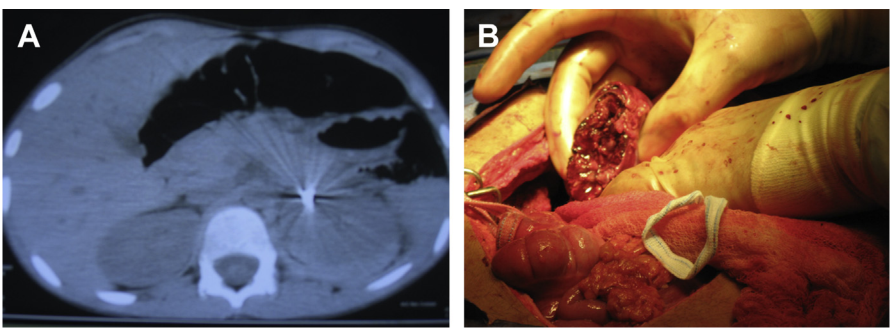

Fig. 2. Gunshot wound to the abdomen. An 8-year-old with a gunshot wound to the flank. Owing to an unclear trajectory and hemodynamic stability of the child, a computed tomography (CT) scan was undertaken, demonstrating tract of bullet into the left kidney with active extravasation of contrast. At laparotomy, an isolated renal injury was demonstrated and treated with partial nephrectomy. (*A*) CT demonstrating tract of projectile into left kidney. (*B*) Operative image demonstrating a well-perfused kidney with a laceration amenable to partial nephrectomy.

to penetrating trauma in this location are the gastrointestinal tract, liver, abdominal vasculature, kidney, and spleen.[9]

Other types of injuries include disasters, combat, and blast-type injuries. These injuries often combine blunt and penetrating mechanisms owing to the force of explosions and air-borne high-velocity projectiles. Explosions cause polytrauma to multiple organ systems including significant burn injuries, requiring multidisciplinary management for adequate resuscitation, evaluation, and treatment of these significantly injured patients.

INITIAL EVALUATION AND STABILIZATION

The initial management of abdominal trauma is similar in the pediatric and adult populations. The core principles of the Advanced Trauma Life Support[10] algorithm apply, with the primary survey evaluating airway, breathing, circulation, disability, and exposure (ABCDE). Any emergent interventions that are needed are performed during the primary survey, such as establishing an airway, decompression of tension pneumothorax, or recognition of life-threatening hemorrhage. In addition, control of exsanguinating hemorrhage has been show to be the most efficacious maneuver performed in prehospital resuscitation of children with relation to improved mortality.[11]

The airway is assessed by asking the patient verbal patients questions or assessing for phonation in nonverbal patients. Indications for intubation include: inability to ventilate by bag–valve–mask ventilation, Glasgow Coma Scale score of less than 8, hypoxemia, hypoventilation, decompensated shock patient not responsive to fluid resuscitation, or loss of protective airway reflexes. Intubation of a child requires consideration of age, size, and mechanism of injury. In general, cuffed endotracheal tubes have been shown to be safe in infants and young children. However, uncuffed tubes are generally used in children less than 8 years old unless there is need for a cuffed tube. For children ages 1 to 10 years, the following formulas estimate the proper size of endotracheal tube:

$$\text{Uncuffed endotracheal tube size (mm internal diameter)} = (\text{age in years} + 16)/4$$

$$\text{Cuffed endotracheal tube size (mm internal diameter)} = (\text{age in years} + 12)/4$$

Breathing is assessed by chest rise, respiratory rate, and auscultated breath sounds. Tachypnea may be a sign of impending respiratory collapse. Pulse oximetry is an excellent adjunct to assess oxygenation and should be used in the trauma bay on all patients. Capnography is a vital adjunct in confirming endotracheal tube position.

Circulation is assessed by physical examination findings including pulse, skin color, and capillary refill. Children have an extraordinary capacity for vasoconstriction, so a normal blood pressure does not rule out hemorrhagic shock. Minimum acceptable systolic blood pressures based on age are:

60 mm Hg in term neonates (0–28 days)
70 mm Hg in infants (1–12 months)
70 mm Hg + (2 $\times$ age in years) in children 1 to 10 years of age
90 mm Hg in children 10 years of age or older

In a hypovolemic patient, a bolus infusion of 20 mL/kg of isotonic crystalloid should be initiated promptly. In a patient with obvious hemorrhage, we advocate blood products as the initial resuscitative measure with prompt surgical control of bleeding.

Disability is then assessed via neurologic examination and a Glasgow Coma Scale score is given to the patient. Finally, the primary survey includes exposure, which involves removing all clothing to adequately proceed with the secondary survey. Hypothermia can occur rapidly in children owing to increased surface area relative to weight in children compared with adults. Warming measures should be in place from the onset of evaluation.

The secondary survey is then conducted to identify any traumatic injuries not identified on primary survey along with a more detailed history. A head-to-toe inspection is performed, focusing on pupillary size and reactivity; palpation of cranium and cervical spine; palpation of the mid face for stability; palpation of the chest and abdomen for crepitus or tenderness; inspection of each extremity for deformity, strength, and sensation; inspection and palpation of the cervical, thoracic, and lumbar spine for tenderness or deformity; and examination of the perineum for injury or open fracture often with a rectal examination for sphincter tone. An AMPLE history may be taken, which includes *a*llergies, *m*edications, *p*ast medical history, *l*ast meal, and *e*vents and details explaining the injury.

EVALUATION OF ABDOMINAL TRAUMA

Once a patient is appropriately stabilized with a secure airway and controlled breathing, a focus on abdominal trauma is appropriate. In a patient with profound instability or peritonitis, this evaluation may require emergent laparotomy as the initial diagnostic and therapeutic measure. We advocate a policy of direct transport to the operating room for the initial evaluation of all patients deemed unstable during the course of transport. This is a resource-intense practice and may not be appropriate for all centers. In our center, the computed tomography (CT) scanner is adjacent to the trauma operating rooms allowing transport to and from the operating room after stabilization, if appropriate (**Fig. 3**). If imaging is not warranted by mechanism or patient stability,

Fig. 3. Unstable trauma patient direct operating room transport. An 18-month-old sustained a crush injury from a motor vehicle collision with severe right-sided injuries, including a grade 4 spleen injury and completely devascularized left kidney with active extravasation. The patient was stable on initial evaluation at transferring facility, but during transport became hemodynamically unstable and was transported directly to the operating room for further evaluation. Laparotomy demonstrated a nonsalvagable spleen and left renal injuries. (*A*) External signs of significant trauma. (*B*) Computed tomography scan obtained during period of stability demonstrating severe spleen and left renal injury.

surgical intervention is not delayed. The hemodynamically stable patient allows for a more measured approach to the evaluation of abdominal injuries that, in addition to physical examination, includes laboratory studies, imaging, and diagnostic tests.

Laboratory Studies

Laboratory studies are an important aspect of the trauma evaluation. Often, blood is drawn and sent during the primary and secondary survey. However, there is no single value that can reliably predict IAI. For the stable patient without signs or symptoms of IAI, a hemoglobin, hematocrit, urinalysis, and liver function tests are typically sufficient. For patients with suspected intraabdominal injury, a complete blood count, lipase, blood gas, and type and screen are added. For the unstable patient, a coagulation panel, complete metabolic panel, and type and cross of blood are included, although none of these results should delay intervention.[12]

The usefulness of elevated transaminases to predict clinically significant liver injury is debatable. A study of blunt abdominal trauma revealed a correlation between AST and ALT levels and the severity of injury. However, about 50% of patients with elevated transaminases did not have any IAI on CT scan.[13] In nonaccidental trauma, elevated AST or ALT greater than 80 IU/L correlated with IAI, even in children with minimal physical examination findings.[14] The general usefulness of laboratory testing is limited, although anemia is an obvious predictor of hemorrhage, and significant acidosis with elevated lactate or base deficit may have prognostic value. Our practice is to use abnormal laboratory findings to increase the suspicion for injury and subsequent need for imaging, particularly in nonverbal or obtunded patients.

Imaging

Multiple imaging modalities exist for the trauma patient. Plain films of the chest and pelvis are often obtained in the trauma bay. The chest radiograph is often the only imaging that is needed in an unstable patient to confirm adequate placement of the endotracheal tube, as well as excluded pathology that should be immediately addressed (tension pneumothorax, significant hemothorax). Plain films of the abdomen are of limited usefulness in the trauma patient outside of identifying projectile trajectory/retention and identify grossly unstable fractures. Plain imaging of the cervical spine has some usefulness in clearance from injury in the stable, communicative patient without neck tenderness.

CT imaging is often the modality of choice for most trauma patients, given it is easily accessible, noninvasive, and accurate. The adoption of the use of CT imaging in stable patients has decreased significantly the rate of nontherapeutic laparotomies in the traumatically injured child. Indications for CT imaging include abdominal tenderness, seat belt sign, elevated transaminases, gross hematuria, downtrending hematocrit, inability to get an accurate examination with suspicious mechanism, or positive Focal Assessment with Sonography in Trauma (FAST) examination. However, unstable patients should not undergo CT scanning. These patients must first be adequately resuscitated or undergo laparotomy/thoracotomy if unable to resuscitate. Alternate imaging may be obtained via the modalities described elsewhere in this paper. The overuse of CT in stable, minimally injured children is another important area of concern that provides a stark contrast to adult trauma protocols.[15–17]

The FAST examination has been validated in the pediatric population.[18] The FAST examination includes ultrasonography of the pouch of Morrison in the right upper quadrant, pouch of Douglas around the bladder, the splenorenal plane in the left upper quadrant, and a subxiphoid view to look for pericardial fluid around the heart. This bedside examination has a high specificity rate to rule in free abdominal fluid, but low sensitivity, signifying its poor ability to rule out significant IAI. The use of FAST increases with clinician suspicion of abdominal injury, and patients who undergo FAST have a lesser chance of receiving an abdominal CT scan if clinician suspicion for IAI is low.[19]

Diagnostic peritoneal lavage (DPL) was once a mainstay of trauma evaluations. However, it is an invasive test, and with the advent of newer assessment tests such as FAST or CT scanning, it has largely been replaced by these faster and often more reliable noninvasive diagnostic tests. There may still be a role for DPL in an unstable patient who cannot undergo CT imaging where they may be multiple sites for blood loss. It may also be used for occult bowel injury where abdominal free fluid was attributed to solid organ injury. Finally, DPL may be considered in a patient undergoing emergent decompressive craniotomy before adequate evaluation of the abdomen owing to impending herniation. Our practice is to use diagnostic laparoscopy in this circumstance with DPL used rarely.

Diagnostic laparoscopy is an excellent modality for further investigation in the hemodynamically stable patient. Unlike bedside tests such as FAST or DPL, laparoscopy can readily localize injury and reduce the rate of negative laparotomy. Our use of diagnostic laparoscopy has increased steadily. We use it as a tool for evaluation in suspected diaphragmatic injuries, suspected bowel injury, and in cases of penetrating injury to evaluate for violation of the peritoneum. In the stable patient, we have expanded the role of laparoscopy beyond diagnostic realms and routinely use minimally invasive techniques for the repair of injuries including the diaphragm, pancreas, bowel, and colon.

Diagnostic cystoscopy is another adjunct that can be extremely useful. It can be used to diagnose bladder injuries as well as treat any ureteral injury with stent placement. It can be used with fluoroscopy to evaluate and treat injuries of the lower gastrointestinal tract as well. Evaluation of the ureters is best accomplished with intravenous contrast CT scan with delayed imaging. Suspected injuries can be further evaluated using retrograde fluoroscopic imaging at time of cystoscopy in both blunt and penetrating trauma.

The evaluation of penetrating trauma to the abdomen remains the same as blunt injury. However, in the unstable patient with penetrating trauma, expedient resuscitation with blood products and operative intervention should be used. In the stable patient, many of the modalities including imaging to determine projectile/stab tract may be used.

For the stable patient with penetrating trauma, FAST is a useful modality to assess for free peritoneal fluid. If the FAST is positive, the patient has a greater likelihood of needing operative exploration. CT scanning is the preferred imaging to definitely identify injuries. In patients with superficial wounds who are stable, local wound exploration is another option. If the injury penetrates the fascia, it requires further workup. If the injury does not penetrate the fascia, the wound can be irrigated and closed at the bedside without further imaging. Owing to anxiety in children, we rarely used the emergency department for wound exploration, usually conducting these in the operating room and often using diagnostic laparoscopy as a more definitive evaluation if suspicion is high.

Finally, angiography plays both a diagnostic and therapeutic role in the evaluation of abdominal trauma. Bleeding in locations that are difficult to access or can result in exsanguinating hemorrhage when approached in an open operative manner can be diagnosed expediently and addressed with embolization. The most common sites in children include troublesome pelvic bleeding, as well as significant liver and spleen injuries. We have found, however, that its usefulness in pediatric liver and spleen injuries is more limited. Often children who have an arterial “blush” signifying active extravasation of contrast and thus hemorrhage from liver and spleen injuries can be managed without embolization if clinically stable according to solid organ injury protocols described elsewhere in this paper. A majority of these injuries will tamponade and cease bleeding without intervention. The usefulness of angiography in the diagnosis of most other vascular injuries has been largely replaced with enhanced CT angiography protocols, but its therapeutic role continues to increase.

SPECIFIC INJURIES

Liver and Spleen

The liver and spleen are the 2 most commonly injured solid organs in blunt abdominal trauma, with an injury incidence of about 33% each. Many liver and spleen injuries can now be successfully managed nonoperatively. Indeed, isolated blunt liver and spleen injuries are managed nonoperatively more than 90% of the time. The classification of severity of injury remains an important aspect of nonoperative management. Liver and spleen injury scales as according to the American Association for the Surgery of Trauma are displayed in **Table 1**.[20] Please see David M. Notrica and Maria E. Linnaus's article, "Nonoperative Management of Blunt Solid Organ Injury in Pediatric Surgery," in this issue on solid organ injury for more detail regarding pediatric solid organ injuries.

Stomach and Small Bowel

Hollow viscus injury is much less common than solid organ injury in blunt trauma, occurring less than 10% of the time. The viscera are susceptible to injury via crush, compression, or shearing forces at points of fixation such as the ligament of Treitz or ileocecal region. Blunt bowel injuries may not be immediately apparent on initial CT imaging. CT findings to suggest bowel injury include free fluid without solid organ injury, bowel wall thickening or enhancement, extraluminal air, mesenteric stranding,

Table 1
Classification of spleen and liver injuries in trauma

Grade	Type	Description
I	Hematoma	Subcapsular, <10% surface area
	Laceration	Capsular tear, <1 cm depth
II	Hematoma	Subcapsular, 10%–50% surface area, intraparenchymal <5 cm (Spleen), <10 cm (liver) diameter
	Laceration	Capsular tear, 1-3 cm depth, does not involve trabecular vessel (spleen), <10 cm length (liver)
III	Hematoma	Subcapsular, >50% surface area, intraparenchymal >5 cm (spleen), >10 cm (liver) diameter
	Laceration	>3 cm depth, involves trabecular vessel (spleen)
IV	Laceration	Spleen: Segmental or hilar vessels producing >25% devascularization Liver: 25%–75% hepatic lobe or >3 Couinaud's segments
V	Laceration	Spleen: Completely shattered or hilar injury resulting in devascularization Liver: >75% of hepatic lobe or >3 Couinaud's segments
	Vascular	Juxtahepatic venous injuries, retrohepatic vena cava/central major hepatic veins
VI	Vascular	Complete hepatic avulsion

From Tinkoff G, Esposito TJ, Reed J, et al. American Association for the Surgery of Trauma organ injury scale I: spleen, liver, and kidney, validation based on the national trauma data bank. J Am Coll Surg. 2008;207(5):648; with permission.

or bowel wall discontinuity. In children with these findings, it is challenging to decide if or when to intervene. Although a delay in surgical management could lead to adverse events, a study of 214 patients with bowel injury owing to trauma did not show any difference in complications or duration of hospital stay based on time to intervention.[21] Injuries to the stomach and small bowel can typically be repaired during the initial operation. Stomach injuries typically occur on the greater curvature and debridement with primary repair is sufficient. Small bowel injuries can be resected with primary anastomosis, even in the setting of contamination, if the patient is hemodynamically stable. We routinely observe these patients with serial abdominal examinations before intervention.

Genitourinary

Owing to the retroperitoneal position of the kidneys, signs of renal injury are often more occult. Patients often have dull back pain, ecchymosis in the costovertebral region, or hematuria. Renal ultrasound and CT examinations are useful modalities to assess degree of renal injury. However, CT scanning is preferred for the evaluation of hematuria in the trauma patient because the evaluation of the bladder and associated injuries to intraperitoneal structures can also be accomplished simultaneously. The American Association for the Surgery of Trauma has a similar grading scale for kidney injuries. Injuries to the ureters have also been classified by the American Association for the Surgery of Trauma, but with a slightly distinct schema. The injuries are graded with increasing severity as simple hematomas, transection ($\leq$50% or >50%), or based on amount of devascularization (<2 or >2 cm) in the setting of complete transection.

Pancreas

Pancreas injuries occur around 3% to 12% in children with blunt abdominal trauma. Treatment of pancreatic injuries remains controversial, because individual centers have small sample sizes and thereby treatment is largely based on surgeon preference. One case series concluded that distal injuries should be treated with distal pancreatectomy, proximal injuries with observation, and pseudocysts with observation or cyst gastrostomy.[22] Endoscopic retrograde cholangiopancreatography is also an excellent modality to diagnose and treat pancreatic duct injuries via stent placement. Other studies show excellent results with nonoperative management in almost all cases of pancreatic injury.[23] Later data showed increased complication rates and dependency on total parenteral nutrition in the nonoperative management of high-grade pancreatic injuries.[24] Several ongoing studies are investigating the role of the nonoperative management of blunt pancreatic injuries in the setting of major duct disruption.

Colon and Rectum

Similar to the stomach and small bowel, the colon is susceptible to similar forces in trauma. Shearing can occur at the rectosigmoid junction, causing contamination of the abdominal cavity. However, repair in colon injuries is usually delayed compared with small bowel injuries. Often, colon injuries are not immediately apparent owing to a retroperitoneal position of some injuries, resulting in fecal contamination. Classically, an end-colostomy with Hartmann's pouch was the recommended intervention in this setting. In the pediatric population, most injuries can be handled with primary repair in the hemodynamically stable patient without significant fecal contamination. Diversion is more often the exception rather than the rule.

Diaphragm

Patients in MVC wearing seat belts are at increased risk of diaphragmatic herniation. Sudden compressive force to the abdomen results in increased intraabdominal pressure, resulting in rupture of the diaphragm. Patients often have concurrent seatbelt signs and are at risk for small bowel injury or Chance fractures. These injuries are not always obvious on CT imaging, depending on the degree of abdominal content herniation. One study in the adult literature reported CT imaging alone was only 80% sensitive in finding diaphragmatic injuries.[25] Treatment requires surgical repair but not emergently depending on concomitant injuries. Stabilization of the associated pulmonary contusion and evaluation/treatment of liver/splenic injury takes priority. In our center, laparoscopy/thoracoscopy is used to diagnose and occasionally repair suspected diaphragm injury, based on the appearance on imaging or location of penetrating injury (greater suspicion if injury spans from nipples to costal margin).

DECISION MAKING AND TREATMENT

Imaging Protocols

Pediatric Emergency Care Applied Research Network

The Pediatric Emergency Care Applied Research Network sought to develop a prediction tool to identify very low-risk patients for IAI needing acute intervention, and thereby defer CT scanning in the emergency department.[26] They prospectively studied more than 12,000 children at 20 emergency departments with blunt torso trauma; 46% received CT scans in the emergency department and 6.3% were diagnosed with IAI. They identified 7 variables of patient history and physical examination making IAI less likely in descending order: evidence of abdominal wall trauma or seatbelt sign, a Glasgow Coma Scale score of less than 14, abdominal tenderness, evidence of thoracic wall trauma, complaints of abdominal pain, decreased breath sounds, and vomiting. The study did not incorporate laboratory findings or FAST examination, because these modalities were variable across institutions. Children without any of these findings had a 0.1% risk for IAI undergoing acute intervention. This tool had a 98.9% negative predictive value if all 7 variables were negative, and CT imaging was deemed to be unnecessary. Children with 1 or more positive variables do not necessarily need CT imaging, but may need further evaluation with laboratory studies, FAST, further observation, or consideration of CT scan based on clinical suspicion for injury. The tool helps to risk stratify patients with blunt abdominal trauma and avoid CT imaging in children at low risk for IAI, although clinical judgment must still be applied in all cases.

Doernbecher/Randall children's evaluation algorithm

We have developed a clinical protocol for the evaluation of stable pediatric patients with abdominal trauma (**Fig. 4**).[26,27] The first and second decision points are based on the Pediatric Emergency Care Applied Research Network prediction rule. The use of laboratory studies and the FAST examination were also incorporated into this algorithm for the pediatric trauma patient. Although patient history, physical examination, laboratory studies, and the FAST examination have been validated individually as predictors of IAI, this comprehensive clinical algorithm is presently being validated and has shown promising results.

Solid Organ Injury Protocols

Over the past 30 years, there has been a large shift to nonoperative management in hemodynamically stable patients with traumatic solid organ injuries, with subsequent decreases in morbidity and mortality. However, there remains great variability in the

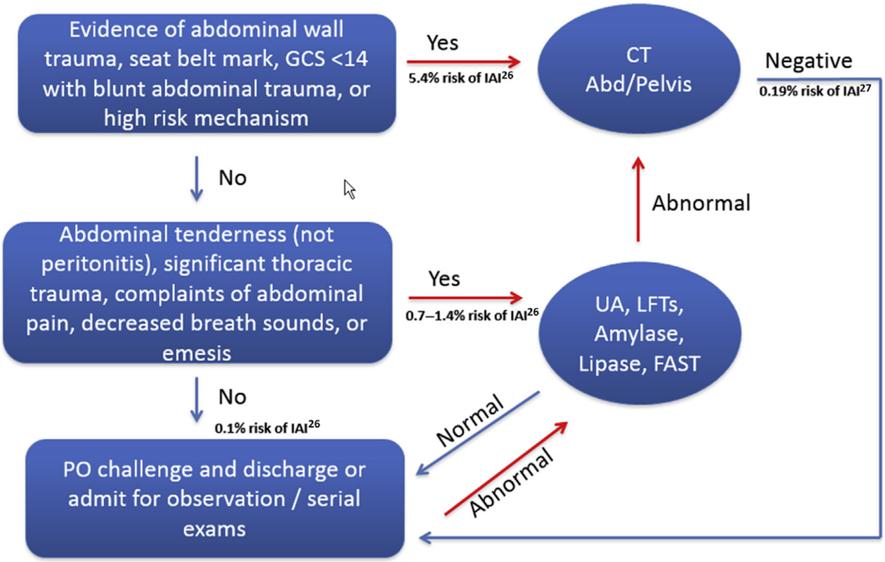

Fig. 4. Pediatric Abdominal Trauma Evaluation. Abd, abdomen; CT, computed tomography; FAST, Focal Assessment with Sonography in Trauma; GCS, Glasgow Coma Scale; IAI, intraabdominal injury requiring intervention; PO, oral; UA, urinalysis. (*Data from* Holmes JF, Lillis K, Monroe D, et al. Identifying children at very low risk of clinically important blunt abdominal injuries. Ann Emerg Med. 2013;62(2):107–16.e2; and Hom J. The risk of intra-abdominal injuries in pediatric patients with stable blunt abdominal trauma and negative abdominal computed tomography. Acad Emerg Med 2010;17(5):469–75.)

decision-making algorithms used by individual surgeons and institutions. Multiple solid organ injury protocols exist to aid in decision making and help to standardize care for these patients (see detailed description in David M. Notrica and Maria E. Linnaus's article, "Nonoperative Management of Blunt Solid Organ Injury in Pediatric Surgery," in this issue). The Oregon Health and Science University has created a protocol for managing liver and splenic injuries based on grade of injury and stability of the patient (**Fig. 5**).

American Pediatric Surgery Association Trauma Committee

In 2000, the American Pediatric Surgery Association Trauma Committee proposed guidelines for the management of stable patients with isolated blunt spleen or liver injuries, including standards for intensive care admission, duration of hospital stay, and interval imaging. These guidelines led to reductions in intensive care stay, hospital stay, follow-up imaging, and activity restriction.[28] The severity of injury was classified by CT grade, and all grade V patients were excluded. Five guidelines were proposed: intensive care unit admission for grade IV injury only, limited hospital stay, no predischarge or postdischarge imaging, and progressive activity restrictions. One center created clinical practice guidelines based on the American Pediatric Surgery Association recommendations and did not have any deaths or splenectomy for isolated blunt splenic trauma over the past 20 years.[29] They had reductions in duration of hospitalization, despite increases in splenic trauma severity. Despite these advances, the 2000 guidelines were still based on historical data and conservatively chosen to avoid any secondary injury as a patient was mobilized. Several studies within the past 5 to 10 years have demonstrated that more aggressive enhanced recovery pathways based on the patient's physiologic parameters can be adopted safely.[30,31]

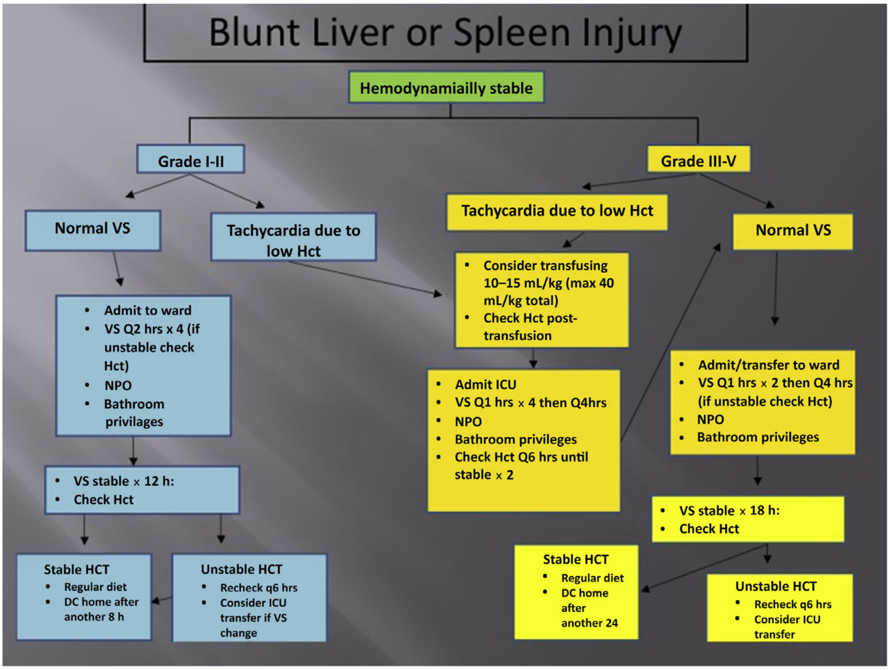

Fig. 5. Pediatric solid organ injury protocol. DC, discharge; Hct, hematocrit; ICU, intensive care unit; NPO, nil per os; VS, vital signs.

Doernbecher/Randall children's solid organ injury protocol

An abbreviated solid organ injury protocol with decreased hospital stay, abbreviated bed rest, and decreased phlebotomy is presently being studied at our institutions and has demonstrated clinical success with no increase in morbidity.

CONTROVERSIAL TOPICS

Focal Assessment with Sonography in Trauma Examination

The use of the FAST examination remains a point of debate in the pediatric population.[32] The FAST aims to detect intraperitoneal fluid, whether from hemorrhage, succus, bile, or urine. Although multiple studies have shown a high specificity for the FAST examination, its sensitivity remains variable. One study revealed more than one-third of low-grade liver and spleen injuries did not have any free fluid on ultrasonography.[33] Another study proposed the use of FAST in conjunction with transaminases. A negative FAST with transaminases of less than 100 IU/L was sufficient to rule out IAI and avoid CT scanning.[34] We use FAST in all injured children, although we have noted that its accuracy is less predictable in younger children.

Multiple scoring systems using ultrasonography have been proposed to effectively rule out IAI. The Blunt Abdominal Trauma in Children (BATiC) score uses physical examination findings and laboratory values in conjunction with Doppler ultrasound imaging.[35] The BATiC score includes 10 clinical parameters to predict IAI with the following scoring system: abnormal abdominal Doppler ultrasound examination (4 points), abdominal pain (2 points), peritoneal irritation (2 points), hemodynamic instability (2 points), AST greater than 60 IU/L (2 points), ALT greater than 25 IU/L (2 points), white blood cell count greater than 9.5 g/L (1 point), lactate dehydrogenase greater than 330

IU/L (1 point), lipase greater than 30 IU/L (1 point), and creatinine greater than 50 μg/L (1 point). A BATiC score of less than or equal to 7 have has a negative predictive value of 97%, which would obviate the need for CT imaging or hospital admission. However, a formal Doppler ultrasound examination and multiple laboratory values take time to obtain, potentially limiting the practicality of this scoring system.

Contrast-enhanced ultrasound imaging has also been studied to enhance the detection of IAI. There is evidence to suggest contrast-enhanced ultrasound imaging is more accurate than conventional ultrasonography in children in detecting solid organ injuries.[36] Wider use and clinical experience with this modality is necessary before its routine use can be advocated. MRI presently does not have a large role in the acute evaluation of abdominal trauma, but newer "quick" protocols may have usefulness in the future. We do use MRI/MR cholangiopancreatography in the evaluation of the pancreaticobiliary tree in patients with suspected bile duct and pancreatic duct injuries after their initial evaluation (usually with CT scanning).

All of these studies seek to find alternatives to CT imaging in the pediatric population. There is utility in applying these scoring systems to patients; however, the ultimate decision to obtain CT imaging remains with the practicing clinician in the appropriate clinical situation.

Negative Workup

Traditionally, children with normal physical examinations and CT imaging were admitted to the hospital for serial abdominal examinations to avoid missing a delayed bowel injury. An observational study of 1085 children with normal CT imaging revealed that 737 (68%) were still admitted to the hospital. Although 2 patients were subsequently found to have IAI, neither required intervention.[37] Another study reviewed data from almost 2600 patients with negative abdominal CT scans and found the incidence of IAI was 0.19%. Two patients required laparotomy, one for bowel perforation and one for mesenteric hematoma with serosa tear.[27] The overall negative predictive value of abdominal CT was 99.8%, making it an extremely reliable test to rule out IAI. Routine admission after abdominal trauma in the setting of normal initial CT imaging may not be necessary. We use discharge from the emergency department in the appropriate setting or a short period of observation in the emergency department before discharge if any suspicion remains. This has been an effective and reliable means to decrease the need for admission in the child with minor injuries and negative imaging.

Adult Versus Pediatric Trauma Centers

Differences in the evaluation and management of pediatric trauma patients have been documented between adult and pediatric centers. The use of whole body CT imaging in trauma varies based on location. Pediatric patients managed at adult trauma centers were 1.8 times more likely to receive whole body CT imaging with the associated increased risk of radiation without a difference in clinical outcomes.[38] It is crucial for adult trauma practitioners to be aware of the increased risk of malignancy in children and the current Pediatric Emergency Care Applied Research Network and other clinical guidelines for the use of CT imaging in children.

We have demonstrated in our own center that a focus on reduction in ionizing radiation through a focused cervical spine imaging protocol reduced use of CT imaging for other sites. This unintended benefit was the result of decreasing imaging in children with lower injury severity scores. This likely is owing to a greater focus on serial examinations in stable patients and a more measured approach to the evaluation of children with minor injuries. The overall reduction in radiation exposure and subsequent risk of malignancy was substantial.[39] This has led to guidelines for imaging all areas, including the head, chest, cervical spine, and abdomen.

Additionally, mass dissemination of imaging and solid organ injury protocols needs to occur. It has been shown that children treated outside of a pediatric trauma center have a higher rate of surgical exploration for blunt spleen injuries compared with children at dedicated trauma facilities. One study showed the risk-adjusted odds ratio for laparotomy at a nonpediatric facility to be as high as 6.2.[40] Dissemination of imaging and solid organ injury protocols is paramount to create practice changes in the management of traumatic solid organ injuries in children. However, the ability to manage these injuries relies on the surgeon's comfort with pediatric guidelines and experience with nonoperative management.

SUMMARY

The field of trauma is ever evolving and pediatric trauma is no exception. With the advent of newer technologies, clinical guidelines, and minimally invasive and percutaneous interventions, the world of trauma care is dramatically different today than just a few years ago. The field of pediatric trauma continues to build on research done in the adult world, but also needs to be tailored for the pediatric patient. Multiple imaging and treatment protocols exist for clinicians to follow; yet each pediatric trauma patient remains unique owing to the mechanism of injury, personal history, and access to care. The main challenge for any clinician caring for the pediatric abdominal trauma patient remains to align these individual characteristics with the most current and safest approach to management of traumatic injuries.

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