Pediatric Trauma

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KEYWORDS

• Pediatric trauma • Penetrating • Blunt • TXA • TEG • Blood transfusion • Arrest

KEY POINTS

- In major pediatric trauma, start with the ABCDE evaluation, keeping in mind the anatomical differences, age-appropriate vital signs, and developmental milestones.
- Use weight-based medication dosing and appropriately sized equipment on all pediatric patients.
- Although the guidelines currently recommend crystalloid first in hemorrhagic shock, pediatric studies are promising in the use of whole blood, blood components, and tranexamic acid.
- Penetrating trauma in young children is more often the result of non-missile weapons or other common objects.
- Use a stepwise approach to laboratories and imaging in the hemodynamically stable blunt trauma patient.

INITIAL TRAUMA EVALUATION

The saying "kids aren't just little adults" holds true when discussing the evaluation and management of a critically ill pediatric trauma patient. There are a variety of anatomic and physiologic differences that impact the impressions taken from the examination and objective data and can affect the decisions made in care. Broadly, normal ranges for vital signs change as a child grows, and it is important to interpret vital signs as well as examination findings within the context of age. In addition, hemodynamic compensation is enhanced in children, leading to hypotension as a very late sign of shock. Weight and size become important for both the dosing of medication and the size of the equipment used. References and tools such as the Broselow tape exist to help with estimation of weight as well as dosing of critical medications. Communication can also be difficult, even with children who are verbal. Having a parent at bedside, especially if there is staff available to explain to the parent what is happening, can be helpful for both parent and child. The core of the trauma examination remains

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the same—ABCDE—but each portion of the examination will require subtle adjustments from adult algorithms.

THE CRITICAL TRAUMA

Airway

The pediatric airway develops throughout childhood and adolescence. Infants and young children have an anterior, narrow, and shorter airway, which can lead to difficulties in airway management. The pediatric airway is also easily occluded, either by foreign body or obstruction by the tongue.[1] As children become hypoxic easily and hypoxia can lead to significant hemodynamic effects, knowledge of effective airway management—both intubation and more simple supportive maneuvers—is paramount. Preoxygenation is more important the smaller a child is for these reasons as well.

If airway assessment indicates a need for intervention, consider positioning as well as adjuncts. For younger children, the head is often large, and placement of a shoulder roll can help bring the airway into alignment. For older children and adolescents, especially those who are obese, more standard positioning and even ramping is likely appropriate. The trachea is more compressible in younger patients, so use laryngeal manipulation with caution, as there is a risk of iatrogenic obstruction of the airway. Placement of an airway adjunct—either a nasopharyngeal airway in children with a gag or oropharyngeal airway in those without—may assist in effective oxygenation and ventilation before placement of an advanced airway. Consider using a bedside resource to assist in determination of correct sizing of equipment. The use of cuffed endotracheal tubes in pediatrics has been evolving over the past several years, with the American Heart Association now stating that cuffed tubes are a reasonable option over uncuffed endotracheal tubes in children under 8 years. Much of the recent literature demonstrates safety and improved outcomes with cuffed endotracheal tubes down to the neonatal period.[2,3,4] Video assistive technology is available in pediatric sizes; however, this is not available in many facilities and should not be depended on. First-pass success rate is lower in pediatric patients than in adult patients, and approximately one-third of pediatric patients will have a desaturation event with intubation, so set yourself up for success from the start.[4,5]

Airway obstruction is a rare but serious event with a high mortality rate. The pediatric airway is smaller and the tracheal rings are less calcified than the adult. Because of this traditional cricothyroidotomy is impractical in smaller children. Classically, the teaching has been that a cricothyroidotomy can first be performed between the ages of 10 and 12 years; however, this should also be based on the size of the child.[6] The procedure may be inappropriate in a child who is small for his age. A needle cricothyroidotomy is an alternate procedure that can be used as a temporary means of oxygenation (not ventilation) until either a surgical tracheostomy can be placed or the airway obstruction resolves.[7] If there is complete airway obstruction, the respiratory rate given through needle cricothyroidotomy should be lower than the typical rate to decrease the risk of barotrauma.

Breathing

Respiratory rate slows as an individual grows, with normal respiratory rates in an infant being as high as 60 breaths per minute. If ventilatory assistance is required, it is important to approximate physiologic rates and volumes. There are alternative ventilator setups (namely high-frequency oscillatory ventilation) for infants and young children who are difficult to ventilate. However, the use of these alternatives in the acute trauma setting is unlikely to be appropriate and would best be managed by pediatric critical care.

Circulation

Hemodynamic assessment of the pediatric patient is nuanced secondary to robust compensatory mechanisms. Blood pressure is often maintained after injury even with up to 30% blood loss, leading to hypotension being a late sign of shock.[8] Tachycardia presents before hypotension but can take longer to develop as well. Capillary refill can be used as a marker of impending shock, although this can be misleading due to temperature differences, individual range of response to hypovolemia, and potential variability in interobserver reliability.[9] The pediatric total blood volume can be as small as 250 to 300 mL in a term newborn. This is an important consideration both in the drawing of laboratories as well as in fluid and blood resuscitation. For resuscitation, it may be more effective to hand push fluids or blood as opposed to using a pressure bag. The hand push fluids use a stopcock to perform the “push-pull” method where a bolus is drawn into a syringe from a larger bag and then pushed manually into the patient. Many of the commercial products for massive transfusion and blood warming will be inappropriate for the pediatric patient due to minimum volume and flow requirements, although some products make inserts and/or adaptors to allow for pediatric and neonatal volume needs.[10] Children are particularly susceptible to hypothermia, and even warmed blood at lower flow rates can lose heat in intravenous (IV) tubing. Warming equipment and insulated IV tubing for pediatric transfusion exists but may not be available in all centers.[11] If warming blood is not situationally possible, monitor for hypothermia and use other forms of warming to attempt to maintain normothermia.

Massive transfusions are a rare event and associated with high morbidity and mortality.[12] Evidence to guide the timing of use and the choice between crystalloid fluids and blood products is not robust, and controversy exists. Some pediatric protocols may still advocate for isotonic fluid resuscitation up to 60 mL/kg (in aliquots of 20 mL/kg) before initiation of blood; however, newer literature suggests a benefit to earlier blood administration.[13] The most recent edition of Advanced Trauma Life Support also takes note of this research, recommending only one 20 mL/kg bolus of isotonic fluid before initiating blood transfusion.[14] Blood products should be transfused in aliquots of 10 mL/kg. Early research into whole blood administration in children also shows promise with a potential to decrease transfusion requirements and also decrease time to resolution of shock.[15] The definition of “massive transfusion” is also not consistent throughout the literature, and ranges from transfusion of 50% of blood volume (or about 40 mL/kg) to 100% of blood volume in 24 hours. Studies have shown that up to half of children who receive blood volumes that constitute a massive transfusion do not receive any platelets or fresh frozen plasma (FFP).[16] Ideal product ratios have yet to be definitively determined for the pediatric population, although newer studies lean toward a 1:1 ratio of packed red blood cells and FFP.[17–19] Coagulopathy is of particular concern in neonatal populations, as the hemostatic system is not fully developed until approximately 6 months of age.[16]

Given the difficulty in predicting which pediatric patients will require a massive transfusion, potential triggers have been assessed. Tools to help determine the need for massive transfusion are currently limited; one possible upcoming method is the base deficit, INR, and GCS (BIS) score which includes base deficit, International normalized ratio (INR), and a pediatric shock index (shock index, pediatric age adjusted [SIPA]) (Phillips).[19] The BIS score has not yet undergone prospective external validation. In the adult population, thromboelastography (TEG) has been shown to reduce mortality when guiding massive transfusion resuscitation (Philips 21, WIKKEL).[20,21] A retrospective analysis of 117 patients 18 years and younger compared patients who received greater than 40 cc/kg of blood to those who did not. This study showed that patients who required greater than 40 cc/kg of blood had a lower alpha angle, maximal amplitude (MA) value, and platelet count. The investigators concluded that TEG could help identify patients who may benefit from transfusion of cryoprecipitate or platelets.[20]

IV access can be difficult to establish in smaller children or children with depleted blood volumes. Intraosseous (IO) access is generally the preferred method for initial resuscitation if IV is unable to be established (within 2–3 attempts or 90 seconds) or is insufficient for resuscitation. Potential sites for IO access in a young child include the distal femur in addition to both proximal and distal tibia. The humeral head can be used once the greater tuberosity can be palpated, at approximately 6 years of age.[22] Central venous access is an option, but can be technically difficult in younger children, requires appropriately sized equipment, and has a higher risk of complications. Surgical cut down should remain a last resort.[23] Code drugs can be given endotracheally for the patient in arrest; however, this is a suboptimal means of delivery due to variable absorption and does not allow for volume resuscitation.

Disability

The Glasgow Coma Scale (GCS) has a validated pediatric format with verbal subscores broken down by more specific age ranges to allow for comparison to an age-appropriate norm. The pediatric GCS also incorporates minor changes to the motor and eye-opening scoring to allow for scoring of children who are too young to understand commands. A GCS score of 8 or lower is concerning for severe brain injury and may necessitate intubation as in adults, although assessment of the individual clinical scenario is important as well as the performance of controlled intubation when possible. Neurologic examination may be more challenging in younger populations; however, many movements and responses may be able to be elicited by drawing the child's attention in various directions with assistance from a parent if available. A basic understanding of developmental milestones may also help in interpreting examination findings as normal or abnormal.

Cervical spine immobilization also can present challenges in children of all ages—from finding an appropriately sized cervical collar to encouraging a child to leave it on. Sizing is particularly important as an incorrectly sized collar can create excessive flexion or extension and rates of pediatric cervical spine injuries tend to be higher in the areas where movement may occur. If a correctly sized cervical collar is unavailable or conventional collars are inappropriately shaped for a child (which can occur with some dysmorphia), roll towels and tape them in place for stabilization. The majority of spinal injuries in the pediatric population occur in the cervical spine, so appropriate immobilization is important.[24]

The routine use of backboards is not recommended. Studies show no change in rates of spinal cord injury with routine use. There are concerns for increased time to definitive care, pressure injuries, pain secondary to the backboard, and risk of respiratory compromise.[25–28] Much of the literature on prehospital backboard use is in adult patients, but the results can be extrapolated to the pediatric population, who face the same challenges. Although backboards may be necessary for extrication in the prehospital setting, patients should be removed from backboards as soon as is feasible. Patients should be logrolled for placement and removal from the backboard, at which time it is appropriate to assess for risk of spinal injury to determine need for continued logrolling. It is common and appropriate for Emergency Medical Service (EMS) to bring a child to the hospital in the car seat if the child is stable and without apparent neurologic deficits and the car seat has no visible damage.[29] When removing a child from the car seat, manual in-line stabilization should be used, even if a cervical collar is in place. After the child is unbuckled and in-line stabilization is held, the back of the car seat should be placed parallel to the ground and the child slid out the superior portion of the car seat onto the stretcher to maintain spinal alignment.

Exposure

Just as in adult patients, injuries must be uncovered to be visualized. The removal of all coverings for thorough examination is important, including the diaper. Younger children will become hypothermic more quickly and easily than adults, however, and this carries with it the usual trend toward coagulopathy. Aggressively cover children with warm blankets or use noninvasive warming devices as necessary to maintain normothermia.

WORKUP AND INITIAL MANAGEMENT OF THE CRITICAL TRAUMA PATIENT

As noted, the ABCDE algorithm should be addressed. Another important initial step is estimation of weight and size. Most medications are dosed in a weight-based fashion and equipment varies based on the size and weight of the child. The most used tool for estimation of weight in the pediatric population is the Broselow tape. This is found in many pediatric code carts and is the tool that many physicians are familiar with. Although there are concerns that it may underestimate weight in obese children, it provides a starting point and many initial medications, such as pain control, anesthetics, and vasoactive, can be titrated to effect.[30]

Numerous trauma mortality assessment tools can be applied to pediatrics with the Injury Severity Score being the most widely used and outperforms other pediatric trauma scores (pediatric trauma score, BIG score, and the revised trauma score) when predicting mortality.[31–33] This score is not intended to be a bedside emergency tool, but can be used in the research setting and may allow for prognostication after initial stabilization.[31,34,35] Knowledge of the mortality risk may help counsel families and facilitate communication between facilities during transfer.[31]

Internal Trauma Activation

Trauma centers have their own internal systems for activating hospital resources and trauma teams. Gutierrez and colleagues[36] showed that the use of physiologic criteria for activating internal trauma systems is a more accurate predictor of significant injury compared with both physician discretion and mechanism of injury. Although the majority of internal trauma activations are due to EMS prehospital alerts, Rubens and colleagues[37] found that 15% of pediatric patients arriving outside of EMS required immediate operative intervention or ICU-level care, but these patients represented only 1.8% of the trauma activations. This could delay definitive care and subspecialty consults and lead to unnecessary testing or worse outcomes.[38] Internal trauma activation systems should be based on objective data and be applied irrespective of mode of arrival.

Laboratory Testing

Laboratory work will be similar for pediatric and adult patients with clear multisystem injuries. Laboratories including a complete blood count, comprehensive metabolic panel, lipase, type and screen, coagulation factors, and urinalysis should be obtained. Lactate and base deficit have both been studied for their applicability in the pediatric population. Base deficit has some evidence to show that it may assist in prediction of the need for blood product transfusion.[38] The evidence is not robust enough to state that obtaining a Venous Blood Gas (VBG) for base deficit should be standard of care, but it is reasonable to obtain as an adjunct in determining the full picture. Elevated lactate levels (with cutoffs varying from 2.9 up to 5.1 mmol/L) have been associated in multiple studies with an increase in mortality; however, exact utilization in practice and changes in management are still unclear.[38] This again is a reasonable value to obtain. Troponin and Electrocardiogram (EKG) are indicated if concern for blunt cardiac injury exists. Toxicologic screening and pregnancy tests should be obtained as indicated by the clinical scenario.

Imaging

Imaging in critical trauma is also similar in pediatric and adult patients. Computerized tomography (CT) scan use should be considered more judiciously given the risk of radiation, but with concern for significant multisystem trauma it can still be appropriate to use scans of the head, neck, chest, and abdomen with the addition of x-rays as clinically indicated. Hemodynamically unstable patients who are not stable enough for CT should be considered for Operating Room (OR). Focused Assessment with Sonography for Trauma Evaluation (FAST) is used less commonly in pediatric trauma than in adult trauma but has been studied. The negative predictive value of FAST is lower in pediatric patients with between 26% and 35% of patients with hemoperitoneum on CT not being detected on FAST. A positive FAST in an unstable pediatric trauma patient, however, is helpful evidence of the need for emergent operative management.[8] Chest x-ray is a useful screening before chest CT even in an ill child, as a normal chest x-ray in the pediatric population is a good rule-out test for thoracic injury that will require intervention. Chest CT should be reserved for patients with physical examination findings to suggest major thoracic trauma, abnormal x-ray, or a suspected tracheo-bronchial injury.[39] Pelvic x-ray has a role for the hemodynamically unstable patient in whom a pelvic fracture is suspected, but sensitivity for pelvic fracture in the pediatric population is as low as 50%, making it inappropriate as a basis for ruling out pelvic fracture.[40]

Pain Management

Depending on the age of the child, communication may be limited or difficult. Infants experience pain and have physiologic stress responses as a result of pain. Pain control should be given just as freely in adults. Sedation of the pediatric patient should be considered if stable enough, before painful procedures such as fracture reduction or burn debridement.

Tranexamic Acid

The CRASH-2 trial showed decreased mortality and bleeding deaths in patients who received tranexamic acid (TXA).[41] In pediatric patients, the correlation between hemorrhage and mortality has not been as strong as in the adult population, possibly related to pediatric patients having a much lower rate of penetrating trauma.[42] Early coagulopathy, however, is linked to pediatric mortality, raising the possibility that TXA may have some benefit in this population.[42] Routine surgical procedures in pediatric cardiac, spine, and craniofacial surgeries have shown a decrease in intraoperative blood loss and transfusion needs with an acceptable safety profile when TXA was used.[41,43] Given the lack of large studies, there is significant variability in usage and dosing of TXA.[43] A survey of centers caring for victims of pediatric trauma showed that 35% are using TXA in these patients with the most common initial dose being 15 mg/kg and many giving a subsequent infusion of 2 mg/kg/h for 8 h.[43]

The PED-TRAX study was one of the first trials to examine TXA administration in the pediatric trauma population specifically.[41] Ten percent of the 766 patients 18 years and younger in this study received TXA. In this combat zone population, the investigators found that TXA use was independently associated with decreased mortality without any difference in thromboembolic or cardiovascular complications.[41] A standard dose of 1 gram IV within 3 hours of injury was used with redosing decided by the treating team.[41] Another study looked at 48 patients 16 years and younger who received blood products under the institutions massive transfusion protocol.[42] TXA (15 mg/kg to a maximum of 1 gram over 10 minutes with an infusion of 2 mg/kg/h over 8 hours) was used in 60% of these patients with no difference in mortality or thrombus.[42] A different study also looked at patients who received massive transfusions and TXA and showed that patients who received TXA were less likely to die (with an odds ratio of 0.35) in the hospital compared with those who did not receive TXA.[44] The TIC-TOC study is a multicenter study looking at the benefits of TXA in the pediatric trauma patient with hemorrhage involving the torso or brain. This study is an ongoing look at placebo versus two different weight-based dosing therapies.[45] The limited data currently available from this study do not seem to show an increase in thromboembolic events and there may be an improvement in mortality among those patients who require massive transfusion. The results of the TIC-TOC study will help to confirm these thoughts and provide guidance on proper dosing.

PEDIATRIC TRAUMATIC ARREST

Patterns in pediatric traumatic arrest are similar to adult traumatic arrest, with penetrating trauma and drowning most likely to have the best outcomes. Blunt trauma and strangulation/hanging have dismal outcomes. The incidence of pediatric traumatic arrest is low, and literature on the topic is sparse, but some small studies have attempted to describe the epidemiology and use of interventions.

Epinephrine has been a topic of study and debate in adult cardiac arrest and has been de-emphasized in adult traumatic cardiac arrest, but the pediatric data are quite limited. Once recent study found an association between early epinephrine administration and increased mortality in cardiac arrest due to hemorrhagic shock, however this is not yet definitive and more data are required before drawing actionable conclusions.[46–48] This serves as a reminder of the importance of other priorities in traumatic arrest such as hemorrhage control, fluid resuscitation, and high-quality Cardiopulmonary Resuscitation (CPR).[46]

There are not clear, widely accepted guidelines for when performance of resuscitative thoracotomy is appropriate in the pediatric population. Most case studies are small and report poor outcomes. Several studies involve patient ages ranging up to 18 years, with a trend toward older patients, which limits their applicability to younger populations. What has been established is that patients most likely to have a good outcome are those with penetrating injury, specifically cardiac injury.[43] It has also been demonstrated that patients presenting with signs of life (organized electrocardiographic activity, pupillary response, attempt at spontaneous respiration or movements, or an unassisted blood pressure) have better outcomes, and it has been proposed that the presence of signs of life should be a strong criterion in the decision to perform a resuscitative thoracotomy.[49]

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is becoming more commonplace in adult traumatic resuscitation, but the translation to pediatrics is unclear. The balloon manufacturer does not recommend its use in aortas less than 15 mm in diameter which has been correlated with approximately 12 years of age although case reports exist of other balloon catheters being used off label.[50,51] The lowest documented age of successful REBOA use is 9 years old. Concerns also exist over the size of the femoral sheath versus the femoral artery in smaller children, although a 7 Fr option now exists as opposed to the original 12 Fr sheath.[50] Although there may be situations in which use is appropriate, these would be in larger children/adolescents, and care must be taken not to overinflate the balloon. REBOA is not a standard practice and should be generally reserved for extraordinary or investigative scenarios for smaller children.

PEDIATRIC PENETRATING TRAUMA

Penetrating injuries occur less often in the pediatric population compared with the adult population. Although there is scant literature and consensus on how to approach these patients, some key differences in the initial management of the pediatric penetrating trauma patient can be outlined here.

Head Injuries

Pediatric penetrating head injuries are rare and carry a mortality of up to 40%.[52] When assessing the pediatric patient, the examination should include a GCS and age-appropriate neurologic examination. Admission GCS score has been shown to be a reliable prognostic indicator in the pediatric population.[52] The mechanism of head injuries is also different in children. Although adolescents may be more prone to GSW or intentional self-inflicted head trauma, younger patients tend to suffer from accidental injuries. In accidental injuries, objects tend to enter the thinner roof of the orbit or the squamous part of the temporal bone.[52] Children are also more prone to infectious complications in penetrating head injury compared with their adult counterparts, with infections seen in up to 50% of pediatric patients. Risk factors for infections include cerebrospinal fluid (CSF) leak, sinus involvement, and injury materials such as graphite or wood.[52] Antibiotics to cover *Staphylococcus*, gram-negative bacteria, and *Clostridium* should be routinely administered in the emergency department (ED).[52] Data for seizure prophylaxis in younger children are lacking, but practice patterns suggest the prophylactic use of anticonvulsant medications initially and deferring to the treating neurosurgery team on the long-term prophylactic anticonvulsant therapy.[52]

Vascular Injuries

Vascular injuries are typically the result of gunshot wounds but are seen with non-missile projectiles that can be as innocuous as woodchips.[53] If vascular injury to the head or neck is suspected, the initial study of choice is CTA of the brain/neck as it can provide additional information such as trajectory, retained foreign body, and associated injuries not seen with digital subtraction angiography (DSA).[52] DSA remains the gold standard for the diagnosis of cerebrovascular injuries as CTA has a sensitivity of 73% for detecting these injuries.[53] DSA should be used for diagnosis and treatment planning.[53]

Neck injuries

Pediatric penetrating neck trauma is exceedingly rare, with hypotension on ED presentation or vascular injury being associated with death.[54] Injury pattern differs by age. In patients 0 to 5 years, there is a higher likelihood of injury to the aerodigestive tract. Patients aged 5 to 14 years more commonly injure the vasculature, nerves, or spinal cord in comparison with the younger age group.[55] Evaluation and surgical management decisions align with the management of the adult patient. Hard signs, such as active hemorrhage, expanding or pulsatile hematoma, pulse deficit, significant subcutaneous emphysema, respiratory distress, shock, or airway compromise mandate surgical exploration.[56] In the absence of these hard signs, a CTA of the neck is recommended before any surgical intervention.[55]

Palate injuries

Penetrating palate injuries are fairly unique to the pediatric population and typically result from a fall with an object in the mouth. Complications include retropharyngeal abscess, phlegmon, mediastinitis, internal jugular (IJ) thrombosis, and retained foreign body.[57] Prophylactic antibiotics are not recommended unless the associated laceration is larger than 1 to 2 cm or the wound is grossly contaminated.[57,58] Although most patients do well without intervention, a rare complication (occurring in <1% of these patients) is injury to the internal carotid artery, which could present as a delayed stroke.[57,58] The initial carotid injury would require a CTA.[57,59] Unfortunately, the location, appearance, or severity of the wound has not been correlated with the likelihood of neurological sequalae.[57,60] Outside of multiple case series and reports, the most recent retrospective study done in 2010 by Hennelly and colleagues[60] showed that the morbidity from penetrating palate trauma in the well-appearing patient was very low, with no cases of stroke seen in 122 patients. The decision to obtain a CTA in these patients is still not clear-cut. Decision-making should be shared with the parents while weighing the risks and benefits of imaging and definitive diagnosis with radiation and potential sedation.[57,59,60] One study has found promising results with a reduced-dose-targeted CT protocol specifically for penetrating palate injuries which includes images from the skull base to the hyoid bone. This technique would help to reduce radiation while maintaining diagnostic accuracy.[59]

Thorax injuries

With penetrating thorax trauma, there should be a high suspicion for multiple injuries and potential decompensation.[61] In pediatric penetrating thoracic trauma, mortality is inversely proportional to patient age, and death occurs in up to 14% of cases.[62,63] Hemothorax and concomitant head injury are independently associated with mortality. Compared with the adult population, pediatric patients have a lower risk of rib or sternal fractures, flail chest, and hemothorax.[62] Pediatric patients with penetrating thoracic trauma have also been shown to need a greater amount of blood products per kilogram compared with their adult counterparts.[62] Up to 35% of these patients will require operative intervention, and approximately one-third of these injuries will be able to be managed with tube thoracotomy alone.[63]

Abdominal injuries

In penetrating abdominal injuries, the small bowel is injured more often than the large bowel, which is injured more often than the liver. The risk of complications can be predicted by clinical shock, the number of organs injured, the mL/kg of blood transfusions needed, and concomitant thoracic trauma.[64] In a study looking at solid organ injuries related to penetrating stab wounds, the kidneys were the most commonly injured organ, followed by the liver and the spleen. Hollow viscus injuries were also found in a substantial portion of these patients.[65]

Exploratory laparotomy has been considered the gold standard for management of pediatric patients with penetrating abdominal trauma, but recent studies are show that minimally invasive laparoscopic surgery, or observation, can be used in the hemodynamically stable patient.[65,66] This approach may decrease morbidity and mortality associated with exploratory laparotomy.[67] In one study with 102 cases of penetrating pediatric trauma, minimally invasive surgery identified all of the injured organs.[66] Butler and colleagues[68] conducted a study in which surgeons were asked how they would manage a 9-year-old with a stab wound to the abdomen. The surgeons were asked to choose between observation, diagnostic laparoscopy, exploratory laparotomy, and local wound exploration.[68] The largest percentage (39.1%) of surgeons chose observation, 31.5% chose laparoscopy, and 29.5% chose local wound exploration; no respondent chose the laparotomy. Pediatric surgeons were more likely to choose laparoscopy over observation.[68]

PEDIATRIC BLUNT TRAUMA

Head Injuries

Head injury is particularly common, especially in infants and young children, due to their proportionally large heads and weak cervical muscles. The widely used PECARN criteria were studied and implemented in an attempt to decrease unnecessary CT scans in the pediatric population. This objective has had variable success nationwide, but it has been demonstrated that usage can decrease rates of CT scan, so PECARN criteria should be evaluated when deciding on brain imaging for a stable child with a GCS of 14 or greater.[69–71] For patients with a recommendation of observation versus imaging, there is not a definitive rule in which patients may benefit from imaging, but take into consideration ease and likelihood of return to care if patient worsens on discharge as well as family and provider comfort. Patients with GCS of less than 14 or concern for basilar skull fracture should have imaging. Although CT has been the imaging modality of choice, fast MRI protocols have been becoming more available, represent a reasonable alternative for stable patients, and do not involve radiation.[72] MRI can also be used to monitor progression of injuries.

Similar injury patterns can be seen in children and adults—including epidural, subdural, subarachnoid, and intraparenchymal hemorrhages as well as cerebral contusions and diffuse axonal injury.[73] The etiology of epidural hematomas is often different in children, with bleeding from the edges of fracture sites, often venous in nature, being the predominant cause.[74] Subdural hematomas may be associated with more severe injury to various structures in children in comparison with epidural hematomas.[74] A pathology unique to the neonate is the subgaleal hemorrhage. Subgaleal hemorrhages originate from the emissary veins which connect the scalp veins to the dural sinuses, although most cases are associated with birth trauma, cases have also been attributed to traumatic causes including nonaccidental trauma (NAT) and bleeding disorders.[75–77] The subgaleal space can expand enough to accommodate blood loss of up to 70% of an infant's circulating volume. Although subgaleal hematomas can occur in older individuals, they are unlikely to represent a source of significant blood loss. Intracranial bleeding without a developmentally appropriate traumatic etiology should prompt workup for NAT. Either concurrently or, if the workup for NAT is negative, consider evaluating for bleeding disorders.

Intracranial bleeding should be managed in conjunction with neurosurgical consultation. If concern for herniation is present, hyperosmolar therapy with either mannitol or hypertonic saline is appropriate. Evidence for hypertonic saline is more robust and mannitol has less high-quality evidence but is still commonly used.[78] A recent study suggests possible superiority of hypertonic saline due to both a decrease in intracranial pressure and an increase in cerebral perfusion pressure (CPP) versus an isolated increase in CPP with mannitol.[79] At this time, the decision should be driven by availability of agents and consultant or institutional preference, but should lean toward hypertonic saline if available. The Guidelines for the Management of Pediatric Severe Brain Injury give a level II recommendation for an initial bolus dose of 3% hypertonic saline at 2 to 5 mL/kg given over 10 to 20 minutes.[78]

Skull fractures are not uncommon and can be seen either in conjunction with intracranial hemorrhage or as an isolated injury. Simple linear skull fractures are often appropriate for supportive care, but depressed or comminuted fractures require neurosurgical input and potential intervention.[80] Concussions are also common in the pediatric population; they can range from mild symptoms that resolve quickly to near debilitating symptoms that can take months to resolve. Pediatric patients can take longer to recover than adults. For the athlete, evaluations such as the CHILD SCAT5 can be used to help guide return to play. Consider referring the patient for neurology or concussion specific follow-up, especially if symptoms do not resolve after 2 to 4 weeks.[81]

Neck Injuries

Cervical spine trauma, though uncommon, is the most common form of spine trauma in pediatrics and can carry with it significant morbidity and mortality. Injuries are more common in the lower cervical spine in older children. Under 8 years, common injuries are in the upper cervical spine secondary to this being the area of maximal mobility.[24] Specifically, atlantooccipital dislocation is the most common injury under 2 years of age, whereas from ages 2 to 7 atlantoaxial rotatory subluxation becomes common as well. X-rays are the initial test of choice for cervical spine injury, with an initial lateral view being used often for screening. Sensitivity in pediatric patients has been demonstrated to be as high as 90% in the setting of blunt trauma.[82] It is important to note that there are several normal findings on pediatric cervical spine x-ray that can mimic pathology, so films should be read with the pediatric normal in mind. CT should be considered in the case of injury seen on x-ray that needs to be characterized, high clinical suspicion that requires the diagnosis be made quickly, or inability to perform adequate x-rays. MRI should also be considered when feasible when the cervical collar is unable to be cleared clinically and the patient is stable, especially given the risk for ligamentous injury in pediatrics.[24]

Clearance of the cervical collar is not as clear an issue in pediatric patients as it is in adults. The Canadian Cervical Spine Rule was studied in patients 16 and older, which limits the generalizability, although the NEXUS trial included pediatric patients, the numbers were small. NEXUS guidelines can reasonably be applied to developmentally normal children 8 year of age and older, whereas caution should be used with younger children. Other proposed guidelines have similar criteria as NEXUS.[82] It is helpful to have a written protocol for cervical spine clearance for pediatric patients as there is not a definitive standard of care and there is a wide variability in practice.[83] Blunt cerebrovascular injury (BCVI) is rare in pediatrics. Out of over 69,000 blunt pediatric trauma patients, less than 0.2% had BCVI. Factors that were independently associated with BCVI included skull base fracture, cervical spine fracture, intracranial hemorrhage, GCS of eight or less, and a mandibular fracture.[84] Motor vehicle accidents were not independently associated with BCVI in this study.[84] Multiple screening tools have been proposed, but to date none have external validation showing appropriate sensitivity and specificity.[84,85] Treatment of BCVI in pediatrics is not standardized; a recent study showed no difference in rates of complications between antiplatelet and anticoagulation therapy. The study found a nonsignificant trend toward better rates of healing with use of antiplatelet therapy, but the numbers were small.[86]

Thoracic Trauma

Pediatric thoracic trauma is uncommon but carries with it a proportionally high morbidity and mortality. The rib cage is more flexible due to non-ossification of the costal cartilage, allowing higher forces to be transmitted to the underlying organs but decreasing the rates of rib fractures. The mediastinal structures also have increased mobility, leading more commonly to tension physiology.[87] Pulmonary contusions, pneumothorax, and hemothorax are all common. Mediastinal injuries are rare but can cause mortality rates of up to 32% in the first hour.[87] Chest x-ray is the most appropriate screening tool for thoracic injury.[34] Otherwise, diagnosis and treatment of these injuries is similar to that of adult patients.

Abdominal Trauma

Abdominal organs in pediatric patients are proportionally larger than in adults as well as less protected by the rib cage, secondary to the flexibility noted above. Workup should start with physical examination, with generalized abdominal pain and tenderness being a sensitive marker for intra-abdominal injury in a neurologically intact patient. Abdominal distention and bruising (including seatbelt signs) are also concerning markers.[8] Laboratory work can be used as a screening tool for intra-abdominal injury in the hemodynamically stable patient. Elevated transaminases with an AST above 200 U/L or ALT above 125 U/L in known blunt abdominal trauma or an elevation above 80 U/L of either in the setting of NAT should prompt CT imaging. If microscopic hematuria is present, renal imaging should be considered.[8] Amylase and lipase levels have been classically part of the screening evaluation, although they will not be elevated at initial presentation even in the setting of pancreatic injury. Handlebar injuries in particular can cause delayed presentation and commonly involve pancreas and hollow viscus injuries.[9] These injuries are frequently missed and misdiagnosed, so have a high index of suspicion for this type of injury based on historical features. Solid organ injuries (spleen, liver, and kidney) are common and often can be managed nonoperatively. Multicenter studies show failure rates of nonoperative management less than 5% for hemodynamically stable patients.[9]

CT has classically been the test of choice in evaluation for intra-abdominal injury; however, given concerns about ionizing radiation, alternative evaluation tools have been studied. Contrast-enhanced ultrasound (CEUS) has shown promise. A 2021 systematic review from Italy showed a range of sensitivity of 85.7% to 100% and specificity of 89% to 100% for solid organ injury.[88] CEUS may represent a reasonable alternative to CT for screening tests, but it is not yet widely available and in use. MRI may be useful in the follow-up imaging of some conditions but does not currently have a role in imaging acute abdominal trauma.

Extremity Trauma

Extremity trauma is exceedingly common in pediatrics, and there are a few important considerations to note. The Salter–Harris classification is used for fractures involving the growth plate, which comprise up to 20% of pediatric fractures. Salter–Harris I fractures involve only the physis and may not be apparent on x-ray because of this.[89] If there is a clinical suspicion based on history and there is bony point tenderness on examination, these patients should be immobilized. Other important fractures to be aware of are those in a nonmobile infant, injuries that do not match the description of events or do not have a clear story, and multiple injuries at an early age. Some fracture patterns such as classical metaphyseal lesions (corner or bucket handle fracture) are more common in NAT; however, many fractures are nonspecific. Emergency physicians should be vigilant about accounting for the circumstances of all injuries.[90]

Peripheral vascular injury is uncommon but occurs in pediatrics and management practices have variability. CT is used frequently although Doppler ultrasound may also be effective in diagnosis. A significant proportion requires operative management with subsequent anticoagulant or antiplatelet therapy. There is little dedicated pediatric literature to inform practice on either management or optimal imaging.[91]

PEDIATRIC VERSUS ADULT TRAUMA CENTERS

Pediatric patients are better served at pediatric trauma centers (PTCs) with the advantage shown the clearest in younger and more severely injured children.[92] A study conducted by Kahil and colleagues, looked at just over 10,000 children in the National Trauma Data Bank. Patients were divided into two age groups: 0 to 14 years and 15 to 18 years. Primary outcomes were ED and inpatient mortality depending on whether they were taken to a PTC or an adult trauma center (ACT). Secondary outcomes included hospital length of stay, complication rate, ICU length of stay, and ventilator days.[93] Children in the 0 to 14 year age group had lower ED and inpatient mortality when treated at PTCs. This age group was also more likely to be discharged home and have fewer ICU and ventilator days when treated at PTCs. There was no difference in ED mortality or inpatient mortality in the 15- to18-year age group between PTCs and Adult Trauma Center (ATCs). There were no differences in complication rates in either age group between PTCs and ATCs.[93] In the case of penetrating injuries, there were equivalent survival outcomes between ATCs and PTCs in the Kahil and colleagues study, but Miyata and colleagues showed that younger penetrating trauma patients may have better functional outcomes when treated at PTCs.[93,94] The literature suggests that children aged 0 to 14 should ideally be evaluated primarily at PTCs, this may not always be feasible.[93] ATCs should therefore remain prepared to resuscitate critically ill pediatric trauma patients and may elect to transfer these patients to a PTC after stabilization.

SUMMARY

Emergency response to the pediatric trauma patient starts with the basics—ABCDE. Certain important differences in pediatric patients, such as airway physiology and drug dosing, must be considered, but standardized resources are available. Pediatric blunt and penetrating trauma evaluation and treatment also have mechanisms and nuances that distinguish them from adult cases. Much of the current treatment literature has its foundation in the adult literature, so future additions to the literature of pediatric trauma may establish evidence for important distinctions in testing or treatment between adult and pediatric trauma patients.

CLINICS CARE POINTS

- Use a systematic method for evaluation (ABCDE) to avoid missed data or being distracted by visible injury.
- Be aware of age appropriate vital signs and try to normalize vital signs to these values when resuscitating.
- Volume resuscitation begins with crystalloids for pediatric patients, but consider switching to blood products at 20 mL/kg of volume resuscitation and transfuse in 10 mL/kg aliquots.
- Utilize intraosseous access early if there are difficulties in peripheral intravenous access. Consider age appropriate development in interpretation of the neurologic exam.
- Children become hypothermic easily, cover and provide warming measures as soon as feasible to prevent this.
- Ionizing radiation should be used judiciously in pediatrics - for stable patients consider starting workup with focused physical exam and laboratory studies.
- FAST can provide helpful insight in the hemodynamically unstable patient, but can be falsely reassuring in the hemodynamically stable patient.

- Remember to evaluate for and treat pain, even in patients too young to verbalize their symptoms. Consider sedation for painful procedures.
- Think about non-accidental trauma when the injury is suspicious or the mechanism does not suggest the injury seen.

DISCLOSURE

The authors have nothing to disclose.

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