Pediatric Trauma for the Adult Surgeon

Jeremy W. Cannon, MD, SM, FACS
Lucas P. Neff, MD, FACS

Editorial Review: Stephanie A. Savage, MD
Joseph Galante, MD
Clay Cothren Burlew, MD

Injury/Disease Demographics

- Trauma is the leading cause of death in children over the age of 1.
- Approximately 10,000 deaths from serious injury annually with an annual incidence of 19/100,000 in boys and 10/100,000 in girls.
- Blunt injuries predominate in this population (90-99%).
- Falls are the dominant mechanism of injury up to age 14 and MVCs are the dominant mechanism from age 14-19. MVCs are the most common cause of fatal pediatric injuries.
- TBI accounts for the majority of deaths (80%) followed by hemorrhage (20%).

Clinical Presentation

- Normal vital signs in children vary significantly by age (Table 1). Younger patients generally have a high respiratory rate, high average heart rate and a low mean blood pressure. Bradycardia in a child is often a pre-terminal event.
- Most pediatric patients have a large physiologic reserve and robust compensatory mechanisms. When these reserves are depleted, they decompensate quickly.
- Pediatric patients have a small total blood volume (e.g. approximately 500 mL in a 1 year-old child). Limit blood draw volumes as much as possible. Be aware that shock can result from what might seem like a trivial amount of external hemorrhage or even a scalp hematoma.
    - Pediatric blood volume approximately 80 mL/kg
    - 10 kg child = 800 mL total blood volume
    - 160 mL blood loss = 20% loss (class 2 hemorrhagic shock) (Table 2)
- Pediatric equipment and supplies should be readily available such as a Broselow Pediatric Emergency Tape, pediatric IV lines, pediatric endotracheal tubes, pediatric resuscitation catheters and a-lines, and appropriately sized chest tubes.
- Standard immobilization procedures and patient assessment protocols should be followed in the initial evaluation of the pediatric trauma patient. Children have a prominent occiput—use a pad to bump up the torso and better align the neck for intubation. Children also have a relatively large surface area putting them at increased risk for hypothermia—limit environmental exposure as much as possible and use warming adjuncts such as a Bair Hugger liberally.

Table 1. Normal vital signs for different age ranges.

Age Range	Approximate Weight (kg)	Respiratory Rate	Heart Rate	Systolic Blood Pressure
Newborn	3	40	120-140	50-70
1-5 years	10-20	20-30	100-130	80-120
6-10 years	20-30	15-30	75-100	85-115
Adolescent	30-50	12-20	60-100	100-140

Table 2. Stages of shock in pediatric patients.

	Class I	Class II	Class III	Class IV
	Very Mild Hemorrhage	Mild Hemorrhage	Moderate Hemorrhage	Severe Hemorrhage
	<15% TBV loss	15-25% TBV loss	25-40% TBV loss	>40%TBV loss
Heart Rate	Normal	Mild Tachycardia	Significant Tachycardia	Extreme Tachycardia
Tear Production	Normal	Dimished	Absent	Absent
Capillary refill	Brisk	Dimished	Delayed >4-5sec	Absent
Peripheral Pulses	Palpable	Dimished	Absent	Absent
Anterior Fontanelle	Normal, full	Flat	Sunken	Sunken
LOC	Normal, Awake, crying	Irritable, confused	Somnolent, arousable	Lethargic
	Modified from American College of Surgeons. Advanced Trauma Life Support Course. 4th ed. Chicago, Ill; American College of Surgeons; 1992			

Evaluation & Diagnostics

- Follow the standard sequence of primary survey, FAST exam, radiographs, and secondary survey as in adult resuscitations.
    - **Airway** Pediatric intubations can be difficult due to compact anatomy, redundant tissues, and pliable cartilaginous support
        - cricoid pressure can inadvertently cause obstruction
        - the airway is very anterior, especially in the very young
    - **Breathing** Critially injured children often have little respiratory reserve.
        - respiratory insufficiency can rapidly lead to cardiac arrest
        - gastric distention from bag-valve mask ventilation or use of an uncuffed endotracheal tube can compromise functional residual capacity
    - **Circulation** Physical findings in addition to pulse and blood pressure should be used to identify shock (Table 2)
    - **Disability** The Pediatric Galsgow Coma Scare (PGCS) uses a modified verbal score for young children (Table 3).
    - **Exposure** Children rapidly lose heat through their relatively large body surface area.
        - Limit exposure times as much as possible during the primary and secondary survey
        - An under-body warming device (e.g. Baer hugger) can help maintain body temperature during the exam

Table 3. Pediatric Glasgow Coma Scale score

PEDIATRIC GLASGOW COMA SCALE (PGCS)				
	> 1 Year		**< 1 Year**	**Score**
EYE OPENING	Spontaneously		Spontaneously	4
	To verbal command		To shout	3
	To pain		To pain	2
	No response		No response	1
MOTOR RESPONSE	Obeys		Spontaneous	6
	Localizes pain		Localizes pain	5
	Flexion-withdrawal		Flexion-withdrawal	4
	Flexion-abnormal (decorticate rigidity)		Flexion-abnormal (decorticate rigidity)	3
	Extension (decerebrate rigidity)		Extension (decerebrate rigidity)	2
	No response		No response	1
	> 5 Years	**2-5 Years**	**0-23 months**	
VERBAL RESPONSE	Oriented	Appropriate words/phrases	Smiles/coos appropriately	5
	Disoriented/confused	Inappropriate words	Cries and is consolable	4
	Inappropriate words	Persistent cries and screams	Persistent inappropriate crying and/or screaming	3
	Incomprehensible sounds	Grunts	Grunts, agitated, and restless	2
	No response	No response	No response	1
TOTAL PEDIATRIC GLASGOW COMA SCORE (3-15):				

- Intravenous access should include 2 attempts at peripheral access followed by IO access (medial aspect of the tibia angled away from the growth plate). If attempting central venous access, consider using ultrasound guidance as the femoral artery and vein may be oriented A/P (i.e. on top of one another) rather than side by side in children. The external jugular is often very prominent in children and can be used in those with limited access options.
- Femoral arterial access is quite challenging, especially in a hypotensive child and is rarely needed, especially considering iatrogenic injury is the most common mechanism for femoral vascular injury in the hospital setting.
- Bolus fluids and blood products in increments of 10 mL/kg (standard) or 20 mL/kg (severely injured). It is useful to have a person dedicated to pulling up fluid aliquots and medication doses in mg/kg for very small children and preparing syringe pumps for infusion. Consider infusing all fluids and blood products through a warming device.
- FAST exam has been described in children. It has no role in the assessment of hemodynamically normal patients (i.e. it will not spare the child a CT, if indicated), but in a hypotensive child with an unclear source of hemorrhage, there is little harm in an experienced surgeon performing a FAST.
- Resuscitative thoracotomy has a role in pediatric patients, particularly in pulseless penetrating trauma patients with signs of life.

Imaging

- Given the potential risk of future malignancies from CT-associated radiation exposure, there should be a thoughtful and judicious use of this imaging modality for the routine pediatric trauma patient. PECARN and the "Image Gently" campaign (https://www.imagegently.org/) provide guidance on the indications for imaging and optimal techniques for limiting radiation exposure.
- Axial imaging (CT scan, MRI) should be obtained in patients with significant mechanisms of injury and/or those in whom the initial assessment indicates possible injuries.
- CT of the head should be obtained in all children with a GCS <= 14, agitation, somnolence, repetitive questioning, or slow response to verbal communication (PECARN Head CT Decision Rule). In addition,
    - For children <2, palpable skull fracture, scalp hematoma, LOC (>=5 sec), severe mechanism of injury (motor vehicle crash with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by a motor vehicle; fall >3 feet), or not acting normally per parent
    - In children >=2 CT head should also be obtained if there is any sign of a skull base fracture; loss of consciousness, vomiting, severe headache; or a severe mechanism of injury
- Cervical spine clearance in children relies heavily upon the clinical exam (if available) and plain films (PECARN Cervical Spine Clearance Decision Rule). If these are unavailable, unreliable, or poor quality, obtain a CT. As in adults, MRI is used to evaluate patients with an abnormal neurologic exam or prolonged obtundation.
- Screening for blunt cerebrovascular injuries (BCVI) has historically not been commonly performed in children. However, risk factors appear to be similar to those seen in adults.
    - Basilar skull fracture
    - Cervical spine fracture
    - Cervical ligamentous injury
    - Diffuse axonal injury
    - Le Fort II or III facial fracture
- CT of the abdomen/pelvis should be obtained in children with external signs of abdominal trauma, a depressed GCS with possible abdominal trauma, high risk mechanism, or those with abdominal complaints and abnormal labs (UA, LFTs, amylase/lipase).
    - High risk mechanisms include
        - MVA with ejection, fatality in the vehicle, rollover
        - Fall from > 5 feet
        - Large object falling on the child
        - Child struck by a vehicle
        - Bicycle with unhelmeted rider
    - IV contrast should be used when obtaining torso images in pediatric trauma patients. In very young patients, the injection may need to be done by hand to minimize the risk of contrast extravasation.

- Patients with a blush on CT can be followed clinically rather than proceeding to angiography +/- embolization
- Angiography with embolization can be used in the management of pelvic fractures and solid organ injuries. The indications are generally for hemodynamic compromise rather than radiographic findings such as injury grade, a blush, or hemoperitoneum.
    - Transfusion of 40 mL/kg can be used as a guide for angiography or surgery
- CT chest-is only indicated in the presence of abnormal mediastinal findings on CXR.

Pediatric Resuscitation

- The ideal target ratio for blood products in pediatric patients receiving a massive transfusion (40 mL/kg all blood products) remains poorly defined. A ratio of FFP:PLT:PRBC of 1:1:2 is probably adequate for most.
- TXA can be given in children as a hemostatic adjunct but has very little supporting evidence. The most common dose is 15 mg/kg as a bolus (max 1 g) followed by a 2 mg/kg/hr infusion over 8 hours.

General Considerations for Solid Organ Injury

- The vast majority of solid organ injuries (spleen, liver, pancreas, kidney) are managed non-operatively in children.
- The rate of failure of NOM is 3-4% overall with higher rates of failure in Grade IV (26%) or V (29%) injuries.
- A comprehensive management protocol is contained in the ATOMAC guidelines (Table 4)
- An abbreviated protocol has also been validated (St Peter, et al)
    - Admission with bedrest for 1 night (grade I-II injury) or 2 nights (grade III-V injury)
    - Hemoglobin check performed 4 hours after ambulation.
- Routine re-imaging of liver or spleen injuries is not recommended. Re-imaging of high-grade renal injuries should be done at 3 months with US, CT or MRI.
- Activities are restricted for several weeks after injury using the formula of Grade of injury + 2 weeks (e.g. no gym or contact sports such as football, soccer, lacrosse, hockey, water polo, or diving for 5 weeks in those with a grade III injury).

Splenic injury

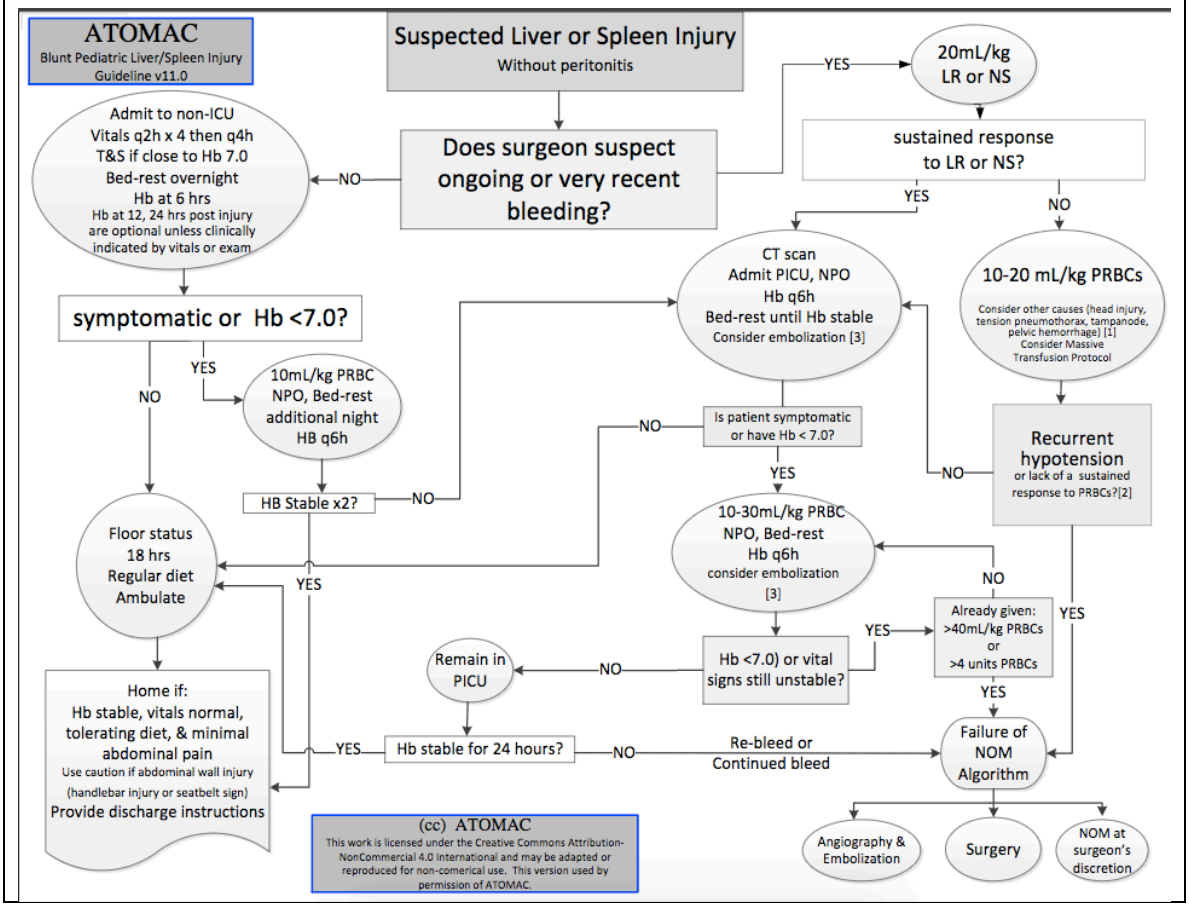
- The spleen is the second most commonly injured organ in children.
- Non-operative management is successful in the majority of patients.
- Angioembolization should be considered in the setting of a falling hemoglobin and/or a transfusion requirement.
- Continued transfusion requirement (e.g. 40 mL/kg) and/or hemodynamic instability unresponsive to transfusion should undergo operative intervention.
- Splenic salvage during operative exploration is reasonable. Options include topical hemostatic agents and splenorraphy with a sheet of vicryl mesh.

- In very young children (newborn to 3 years, 4-15kg), the abdominal cavity is more round than long; so a supraumbilical transverse incision provides excellent access to all quadrants of the abdomen in these patients. This surgical exposure consideration is less important for children over ~20kg.

Liver injury

- The liver is the most commonly injured organ in children.
- Non-operative management is successful in the majority of patients.
- These injuries are invariably associated with an elevation of liver function tests (AST/ALT)
- Indications for operative exploration and surgical techniques are similar to adults.

Figure 1. ATOMAC guidelines for nonoperative management of liver or splenic injury Reproduced from Notrica DM, Eubanks JW 3rd, Tuggle DW, et al. Nonoperative management of blunt liver and spleen injury in children: evaluation of the ATOMAC guideline using GRADE. J Trauma Acute Care Surg. 2015 Oct;79:683-93, permission pending.



Pancreas injury

- Pancreatic injury with concern for/evidence of disruption of the pancreatic duct at *any* location (head, body or tail) is not an immediate indication for laparotomy.
- Transection injuries (AAST grades III-V) can often be managed non-operatively in children with equivalent lengths of hospital stay as lower-grade injuries.
- MRCP /ERCP are effective diagnostic tools for assessing duct disruption, and in skilled hands, ERCP can be therapeutic with ductal stenting.
- Percutaneous drainage of eventual pseudocysts is appropriate, but the majority of peripancreatic fluid collections will resolve with observation along.
- Enteral feeding (jejunal or gastric) can be given with pain and sparing use of pancreatic enzyme levels used to gauge tolerance

Hollow viscus injury

- The relative paucity of intraabdominal fat and connective tissue in children can predispose the duodenum and small bowel in particular to blunt injury with either hematoma formation or perforation.
- Bicycle handlebar injuries and other focal blunt forces to the epigastrium (e.g. lap belt injury) should raise the index of suspicion for a hollow viscus injury.
- Duodenal hematomas are often diagnosed on initial cross-sectional imaging or, in delayed fashion, as a proximal bowel obstruction with bilious emesis on upper GI series.
- Non operative management for duodenal hematomas has been shown to be quite effective in children as in adults
- Free abdominal fluid in the absence of a solid organ injury, mesenteric stranding, bowel thickening, or pneumoperitoneum should raise concerns for a possible overpressure hollow viscus perforation.
- In such a patient, exploration can be done with either laparotomy or laparoscopy (depending on the surgeon's experience and comfort level with the latter).

Major vascular injury

- Pediatric vessels are highly muscular and vasoreactive. Often vessels in spasm can constrict to the point of transient distal ischemia.
- Primary repair of arterial injuries is preferable, but the anastomotic technique must include interrupted sutures to accommodate for future growth of the vessel.
- For interposition grafts, autologous conduit options may be limited by patient size. The internal jugular vein may be used to achieve an appropriate size match. Alternatively, a panel or spiral graft may be necessary.
- BCVI are generally managed with antiplatelets or anticoagulants as in adults.

Thoracic injury.

- Most thoracic injuries can be managed non-operatively in children.
- Injury to underlying abdominal organs should be considered given the compliant nature of the ribs in young children.
- When monitoring chest tube output as a guide for operative exploration, 15-20mL/kg volume of initial output corresponds to 1.5L of bloody output in an adult.

- As with adults, regional anesthesia is a helpful adjunct for multiple rib fractures/flail chest.
- Early recognition of retained hemothorax is possible by liberal use of chest ultrasonography.
- The use of TPA infusions/dwells (4mg of TPA in 40mL of saline with a 1-hour dwell time q 24hrs) can improve drainage and potentially avoid lung entrapment.

Post-Operative Management

- Following acute interventions, children tend to be resilient and recover quickly
- Duration of antibiotics should follow standard practice guidelines
- VTE chemoprophylaxis is generally only given to children over 15 years old and in post-pubertal children (regardless of age) who are severely injured (ISS>25).
- Services such as Child Life and Physical Therapy should be engaged early in the post-injury course.

Complications

- Pediatric trauma patients are at risk for all the same complications as adult trauma patients including missed injuries, infectious complications, retained hemothorax, and failure of non-operative management.
- In pre-verbal patients, tertiary surveys are limited by communication; so the risk of a missed injury may be increased
- Some complications such as thromboembolic events and failure of non-operative management are lower than in adults (see above).
- Lead poisoning can result from retained bullet fragments.
    - Obtain a baseline serum lead level
    - Lead toxicity can occur at >**5** μ g/dL.
    - Chelation therapy should be considered for an elevated level.

Considerations for Special Populations

- Pediatric trauma patients are evaluated in a range of locations from free-standing pediatric trauma centers to community hospitals without a trauma designation.
- Those with a concerning mechanism and/or significant injuries should be transported to a designated pediatric trauma center (either free-standing or within an adult center).
- Non-accidental trauma or child maltreatment (i.e. an intentional injury by a caregiver) should be suspected with the following:
    - Discrepancy between the injury story and physical findings (e.g. severe injuries after seemingly a low-energy or age-inappropriate mechanism)
    - Long interval between the injury and presentation
    - History of multiple injuries
    - Retinal hemorrhages

- Subacute subdural hemorrhage
- Rib or metaphyseal fractures

Recommended Readings

- Arbuthnot MK, Mooney DP, Glenn IC. Head and cervical spine evaluation for the pediatric surgeon. Surg Clin North Am. 2017 Feb;97(1):35-58.
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