9 Pediatric Trauma Resuscitation

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9.1 Introduction

From the assessment of vital signs to the administration of resuscitative fluids and medications, the physician must adapt his or her approach to the pediatric trauma patient depending on the age, weight, and degree of injury. Special challenges such as the difficulty of obtaining vascular access, the utilization of gastric decompression for infants who are obligate diaphragmatic breathers, and the need to maintain a high level of suspicion for solid organ/hollow viscus injury despite negative ultrasound findings are likely to come into play. This chapter is meant to serve as a primer to guide further reading and to highlight key issues in the care of pediatric trauma patients but, by no means is a complete discussion of the topic, which is an active area of research and development.

9.2 Epidemiology

Pediatric trauma significantly impacts the lives of children and families in the United States. In any given year, there are over 1.5 million injuries and close to 500,000 hospitalizations as a result of pediatric trauma. Injury, both intentional and unintentional, accounts for over 50% of deaths in children younger than 18 years. Although there is a rise in the incidence of penetrating trauma, which now accounts for up to 10–20% of trauma activations, the majority of pediatric injuries result from blunt trauma, the morbidity of which is often a result of closed head injuries undergoing nonoperative management. Although it is out of the scope of this chapter, injury prevention should be an area of importance for all trauma systems, particularly in the United states, where for every 100,000 children, the pediatric-injury death rate is more than twice that of Sweden, Great Britain, or Italy.

9.3 History

Specialized pediatric trauma care is a relatively nascent field, as is the field of emergency pediatric care in general. The first pediatric trauma centers appeared in the 1970s and 1980s, while other hospitals began opening pediatric intensive care units (PICUs) dedicated to the care of critically ill children. The concept of nonoperative management in trauma was first described in children as early as 1968 in the management of splenic injury and has now become standard practice in both adult and pediatric patients alike. In the 1980s, a series of studies highlighted the disparity in outcomes between adult and pediatric trauma patients (often citing that given the same severity of injury, the outcomes in children tended to be worse), some of which were attributed to deficits in prehospital personnel training and access to specialized equipment. These deficits were addressed by an increase in federal funding and the designation of pediatric trauma centers in several cities. In addition, recognition that many deaths in children were a result of preventable trauma resulted in an uptick of state laws requiring child safety seats, helmets, pool fencing, window guards, and the like throughout the 1980s and 1990s. Despite these major improvements, the national network of pediatric trauma care remains incomplete, and much work remains to be done, especially in rural areas, to improve delivery of specialized pediatric trauma care.

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9.4 Initial Assessment, Resuscitation, and Stabilization

9.4.1 Primary Survey (A, B, and C)

As in adults, the primary survey should focus on the identification of acute life-threatening injuries. Attention to the airway, breathing, and circulation (A, B, and C), including hemorrhage control, supersedes all other interventions in the initial resuscitation phase. All centers that care for children should have sequestered equipment designed for children, i.e., endotracheal tubes, laryngoscopes, catheters, and passive warming lamps. Room temperature should be kept warm to limit insensible heat losses in small children. The Broselow Pediatric Emergency Tape aids in estimating the weight of the child by measuring his/her length. A color-coded bar on the tape measures the height of the child and indicates the appropriate equipment sizes and medication doses often used in emergency resuscitation on the child. Designated resuscitation equipment is contained in corresponding color-coded equipment pouches or drawers (Fig. 9.1).

Fig. 9.1 Broselow pediatric emergency resuscitation tape

9.4.2 Normal Pediatric Vital Signs

Pediatric vital signs vary by age (Table 9.1). Children maintain normal blood pressures until late hemorrhagic shock (>30% blood loss), and therefore, subtle changes in heart rate and respiratory rate must be monitored. As a general rule, the lower limit of acceptable systolic blood pressure is estimated as: (SBP) = (Age × 2) + 70 mmHg. For newborns, an acceptable SBP is 60 mmHg or greater (Table 9.1).

Table 9.1 Pediatric vital signs

	Pulse (beats/min)	Systolic blood pressure (mmHg)	Respiration (breaths/min)
Newborn (<1 month)	95–145	60–90	30–60
Infant (1 month–1 year)	125–170	75–100	30–60
Toddler (1–2 years)	100–160	80–110	24–40
Preschool (3–4 years)	70–110	80–110	22–34
School age (4–12 years)	70–110	85–120	18–30
Adolescent (>12 years)	55–100	95–120	12–16

9.4.3 A = Airway (C-Spine Immobilization)

Cardiac arrest in a child is most often of respiratory etiology. An injured child who is obtunded, unresponsive, or combative may need to be intubated for airway protection. An uncooperative child who needs radiologic imaging may also need to be intubated for the purposes of image quality. Intubation must be performed with the jaw thrust technique to maintain in-line cervical stabilization. General anatomic differences in children include a larger tongue, more anterior/superior glottis, shorter trachea, and less cartilaginous epiglottis—many operators prefer a straight Miller blade. The appropriate size endotracheal tube (ETT) can be estimated by the size of the patients' fifth digit (or the formula = [age + 16]/4). As mentioned above, the Broselow Pediatric Emergency Resuscitation Tape is also a useful tool to estimate ETT. Uncuffed ETT is preferred in children <8 years old or <60 lbs., as the subglottic trachea is narrowed and provides a sufficient seal. However, cuffed ETT may be used (except in newborns); if appropriate, cuff pressures are used. As in adults, rapid sequence intubation (RSI) is standard procedure, including preoxygenation with 100% FiO_2, medication administration (Table 9.2), cricoid pressure, cervical spine stabilization, laryngoscopy, and advancement of the tube to an appropriate distance beyond the cords. Confirmation is with colorimetric exhaled CO_2 detector and CXR while the tube is secured in place. In the rare event of acute airway obstruction requiring emergency surgical airway, needle cricothyroidotomy with a 14 g catheter is preferential to open cricothyroidotomy because of the increased incidence of subglottic stenosis.

9.4.4 B = Breathing

Assess for potential life-threatening thoracic injuries: pneumothorax (open chest wound or tension pneumothorax), hemothorax, flail chest, and rib fractures with splinted breathing. The mediastinum of a child is very compliant and can lead to rapid decline from a tension pneumothorax,

Table 9.2 Common emergency medication doses in children

Medication	Dose
Adenosine	0.1 mg/kg IV first dose (max 6 mg) rapid push
	0.2 mg/kg IV second dose (max 12 mg)
Amiodarone (VF/VT arrest)	5 mg/kg IV (max 15 mg/kg/day)
Atropine sulfate	0.02 mg/kg IV (min 0.1 mg, max 0.5 mg)
	0.04 mg/kg IV for second dose
Calcium chloride (10%)	10–20 mg/kg IV
Calcium gluconate (10%)	15–60 mg/kg IV
Diazepam	0.5–1.0 mg/kg IV
Dobutamine	2–20 mcg/kg/min IV
Dopamine	2–5 mcg/kg/min IV (>15 mcg/kg/min for alpha effect)
Epinephrine (asystole/ PEA arrest)	0.01 mg/kg IV first dose (repeat Q3–5 min during CPR)
Epinephrine infusion	0.1 mcg/kg/min IV, then titrate (range: 0.1–1 mcg/kg/min)
Lidocaine	1 mg/kg IV push
	20–50 mcg/kg/min IV
Magnesium sulfate	25–50 mcg/kg IV over 10–20 min (max 2 g)
Morphine sulfate	0.1 mg/kg IV
Midazolam	0.1 mg/kg IV (max 5 mg)
Naloxone	0.1 mg/kg IV (if less than 5 years old or 20 kg)
	2 mg IV (if greater than 5 years or 20 kg)
Pancuronium	0.1–0.2 mg/kg IV
Sodium bicarbonate	1–4 mEq/kg IV
Succinylcholine	2.0 mg/kg (if < 10 kg)
	1.0–1.5 mg/kg (if > 10 kg)
Thiopental	4–6 mg/kg IV
Vecuronium	0.2 mg/kg IV

VF ventricular fibrillation, *VT* ventricular tachycardia, *PEA* pulseless electrical activity

which should be rapidly treated with needle decompression at the second intercostal space at the mid-clavicular line versus emergency thoracostomy tube placement. Children are diaphragmatic breathers, and therefore, gastric distension can be an unrecognized contributor to respiratory distress, especially in the young child who is distended from swallowing air while crying. If concerned about gastric distension, a nasogastric tube (or orogastric tube in very young children who are obligate nose-breathers) should be placed to decompress the stomach.

9.4.5 C = Circulation (Hemorrhage Control)

Hemorrhage is the most common etiology of shock in trauma, but do not overlook obstructive etiologies (cardiac tamponade and tension pneumothorax) and distributive etiologies (neurogenic shock).

Assessment of volume status and shock is difficult in the child. Children have impressive physiologic reserve and can maintain SBP until late-stage hypovolemic shock (>30% blood loss). As in adults, tachycardia, tachypnea, altered level of consciousness, and poor peripheral perfusion (mottled cool extremities, weak thready pulses, narrowed pulse pressure, delayed capillary refill) are early and important signs of hypotensive shock.

Establishing vascular access in an injured child is a priority and can be challenging. Peripheral IVs are ideal, but after two unsuccessful attempts, an intraosseous line (IO) should be considered. IO lines offer a quick and reliable alternative for high-volume infusion of any fluid (crystalloid, blood products), and medications, including pressors. An IO line is placed in the anteromedial tibia, 2–3 cm distal to the tibial tuberosity after a quick skin prep for sterility (Fig. 9.2), avoiding wounds, fractures, or infected/burned skin. IO lines

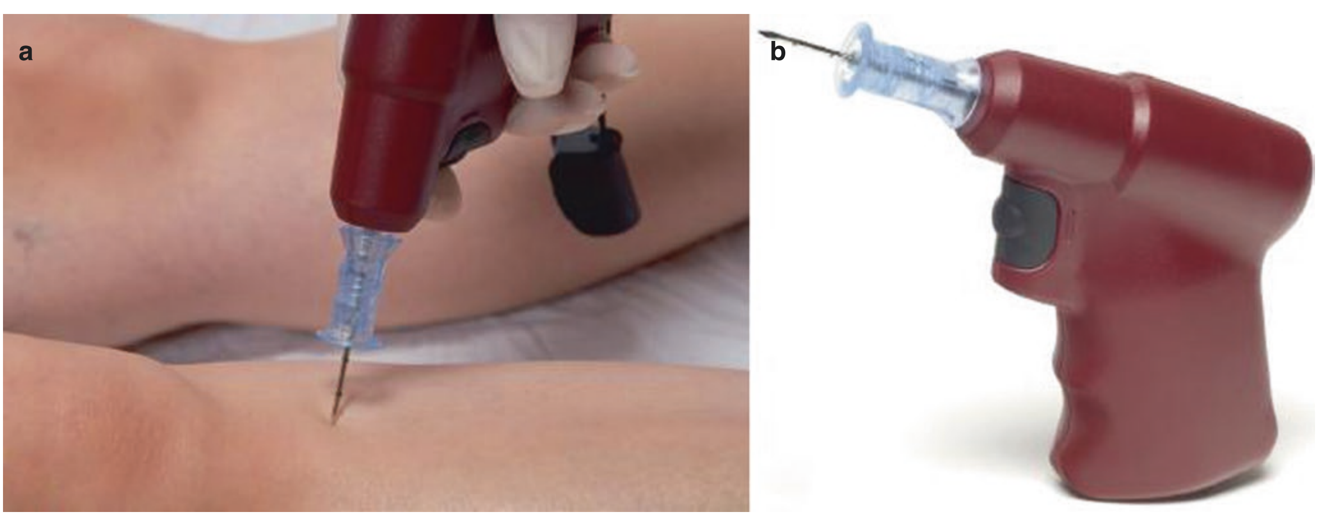

Fig. 9.2 (**a**) Intraosseous line placement. (**b**) EZ-IO drive

Table 9.3 Fluid management in children

Resuscitation fluids (NS or LR)	
If hypotension or signs of shock	Bolus 20 mL/kg. Then switch to blood product transfusions (10 mL/kg)
Daily maintenance fluid requirements (D5 1/2NS or D10 1/2NS)	
Weight < 10 kg	100 mL/kg/day
Weight 11–20 kg	1000 mL + 50 mL/kg/day (for every kg over 10)
Weight > 20 kg	1500 mL + 20 mL/kg/day (for every kg over 20)

should be placed with a single attempt—multiple holes can lead to leakage of fluids and resultant compartment syndrome. Definitive IV access can also be obtained with a central line in the femoral vein (the preferred location in a pediatric patient, under US guidance if available) or a peripheral vein cutdown (i.e., saphenous vein).

Initial fluid resuscitation is indicated when there are signs of hypovolemic shock. Initial bolus consists of 20 mL/kg of warmed normal saline or lactated Ringer's solution. Updated 2019 ATLS guidelines now recommend all further resuscitation be via balanced 10–20 mL/kg boluses of pRBC, FFP, and platelets. Balanced resuscitation, though demonstrating survival advantage in adults, has yet to be supported by the limited available data in pediatric populations. If cross-matched, type-specific blood is not immediately available, O-negative blood is indicated. Once resuscitated, maintenance fluid requirements (Table 9.3) can be estimated using the "4–2–1" rule and should be administered as D5 1/2NS (or D10 1/2NS for neonates). The "4–2–1" rule estimates hourly fluid requirements and is calculated = 4 mL/kg/h (for the first 10 kg) + 2 mL/kg/h (second 10 kg) + 1 mL/kg/h (all subsequent kg).

As in adults, hemodynamic instability in a trauma patient is considered hemorrhagic shock in a child until proven otherwise and must be controlled expeditiously. Notably, extended focused abdominal sonography in trauma (eFAST) is less reliable in pediatric populations and thus a negative eFAST exam should not dissuade the provider from obtaining further cross-sectional imaging if concern for injury is present. In contrast to adults with closed head injuries, in an infant, prior to suture closure of the skull, intracranial hemorrhage may produce hemodynamic instability. Adjunctive treatment with antifibrinolytics such as tranexamic acid (TXA) has come into routine use in the adult trauma population. Data now suggests that TXA may have similar hemostatic benefits in pediatric trauma patients with hemorrhagic shock, likely with a low-risk profile, though more pediatric-specific data is needed and routine pre-hospital administration, such as is often done in adult patients, is not recommended at this time. Dosing for children over the age of 12 is the same as adults (1 g loading dose, then an additional 1 g given over 8 h), while younger children should receive a weight-based dose (15 mg/kg loading dose, and infusion of 2 mg/kg/h for 8 h).

Table 9.4 Modified Glasgow coma scale in children

	Infant	Child
Eye opening		
4	Spontaneous	Spontaneous
3	To verbal stimuli	To verbal stimuli
2	To pain only	To pain only
1	None	None
Verbal response		
5	Coos and babbles	Oriented, appropriate
4	Irritable cries	Confused
3	Cries to pain	Inappropriate words
2	Moans to pain	Incomprehensible sounds
1	None	None
Motor response[a]		
6	Moves spontaneously and purposefully	Obeys commands
5	Withdraws to touch	Localizes painful stimuli
4	Withdraws in response to pain	Withdraws in response to pain
3	Abnormal flexion posture in response to pain	Flexion in response to pain
2	Abnormal extension posture in response to pain	Extension in response to pain
1	None	None

[a]If a patient is intubated, unconscious, or preverbal, the most important part of this scale is motor response and should be closely evaluated

9.4.6 D = Disability (Neurologic Assessment)

Head injury accounts for the highest degree of morbidity and mortality in children and is the principal determinant of patient outcomes. However, on the whole, children have more frequent and robust recovery from even serious head injury, when compared to similar injuries in adults. Therefore, careful attention to preventing secondary injury and maximizing tissue perfusion to the brain can greatly improve outcome. These secondary insults include ischemia, hypoxia, hypotension, hyperthermia, hypercapnia, acidosis, and increased intracranial pressure. The Glasgow Coma Scale is modified in young children who are preverbal to measure neurologic function and prognosis. The motor response scale tends to provide the most reliable assessment of function in a preverbal or intubated child (Table 9.4).

9.4.7 E = Exposure for Secondary Survey

In preparation for the secondary survey, the child must be exposed completely for a complete head-to-toe physical examination. Keep in mind pediatric patients have a larger body surface area to volume ratio and therefore lose heat quickly. The prudent use of warm fluids, forced-air warming blankets, warming lights, and warm ambient room temperature can prevent heat loss in a child.

9.5 Secondary Survey

Children are more prone to multisystem trauma due to their small body size and more compliant body (less protective bones, muscle, and fat of the torso). They can sustain internal injuries without significant external signs of trauma. Careful attention to a bruise on the abdominal wall resulting from a bicycle handlebar should lead to a more thorough investigation of the abdomen—a classic mechanism for pancreatic injury. A lap belt mark across the abdomen may raise concerns of lumbar spine fracture (Chance fracture), with an associated risk of small bowel injury.

9.6 Diagnostic Modalities

Physical examination in a child can be technically challenging, and adjunct diagnostic modalities and imaging may be used to provide additional information in the evaluation of a pediatric trauma patient. Screening C-spine and AP chest radiographs can help diagnose fractures, dislocations, hemo-/pneumothorax, and mediastinal injury. AP pelvic films are of limited utility in the pediatric population but can be considered in select circumstances, though if suspicion for pelvic injury is high, CT imaging should be obtained. Extended focused assessment with sonography in trauma (e-FAST) exam can be performed quickly and exposes the patient to no potential harm from delay or ionizing radiation. However, the higher incidence of solid organ injury without free fluid in pediatric populations renders e-FAST a less sensitive modality in children than in adults, and should not be used in isolation to rule out intra-abdominal injury when there is a clinical suspicion of significant injury. Sensitivity of e-FAST in pediatric populations is reported as 40–90% and specificity of 79–100%. Of course, a standard battery of laboratory tests, including a type & cross, liver function tests, blood gas, complete blood count and metabolic panel, is useful in the diagnosis and treatment of the injured child.

9.7 Non-accidental Trauma

Non-accidental trauma is the leading cause of trauma in children and often goes unrecognized. Suspect non-accidental trauma in certain specialized circumstances: discrepancy between the reported history and physical exam findings; injuries are not consistent with an infant's developmental capability; injuries of different chronological age (bruises or fractures at different stages of healing); delay in seeking medical care; sharply demarcated burns (scald); injuries related to bite marks, cigarette burns, rope marks, or involving perineal/genital region; multiple subdural, subarachnoid, or retinal hemorrhages without external signs of trauma (shaken baby syndrome); or multiple rib fractures (especially of different stages of healing). Specialty consultations should be initiated, including skeletal survey and ophthalmologic exams, when suspicion for non-accidental trauma is present.

Important Points

- ATLS is similar in adults and children, but there are some key physiologic and anatomic differences in children that are important to remember.
- Blunt trauma (i.e., handlebar) can produce injuries that resemble penetrating injuries (i.e., bowel perforation) in children with compliant abdominal walls.
- Broselow Pediatric Resuscitation Tape helps estimate a child's weight to determine device size and medication doses.
- Cardiac arrest is often of respiratory etiology in a child. Use a Miller blade for intubation and an ETT the size of the child's pinkie finger.
- Gastric distension can cause respiratory distress in children who swallow air while crying, because they are diaphragmatic breathers. Place nasogastric tube (orogastric in infants who are obligate nose-breathers) to decompress.
- Children have impressive physiologic reserve and maintain BP until severe blood loss (>30%). Lowest acceptable SBP = (Age × 2) + 70 mmHg.
- Intraosseous line may be placed for emergency vascular access if peripheral IVs are not possible.
- Crystalloid bolus = 20 mL/kg. Blood transfusion "unit" = 10 mL/kg.
- e-FAST exam has limited value in a pediatric trauma patient.
- Many solid organ injuries in children can safely be managed nonoperatively.
- Suspect non-accidental trauma when the story does not add up.

Evaluation and treatment of the pediatric trauma patient have some key differences from the adult patient. Blunt trauma is the most common mechanism of injury, but because of abdominal wall compliance, it can produce injuries that resemble penetrating mechanisms (i.e., handlebar injury producing small bowel perforation). Cardiac arrest is most often respiratory in etiology, and Miller blade and cuffless endotracheal tube (the size of a child's fifth digit) are used for rapid sequence intubation. Nasogastric tube decompression can relieve respiratory distress from gastric distension in a crying child who has swallowed air. Children have impressive physiologic reserve and can maintain SBP until severe blood loss (>30%), so providers should not be falsely reassured by normal blood pressure. Intraosseous line is an excellent source of vascular access when peripheral IVs cannot be established. If there are signs of hypovolemia, a bolus of crystalloid (20 mL/kg) may be administered while assessing response. According to 2019 guidelines, subsequent volume resuscitation should be with blood products (10 mL/kg). Many solid organ injuries in children can safely be managed nonoperatively. A high index of suspicion for non-accidental trauma must be maintained by any practitioner caring for pediatric trauma patients.

Suggested Reading

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