

PEDIATRIC TRAUMA

Chapter 11

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Introduction

The care of injured children from combat-related injuries is an unfortunate but consistent consequence of all conflicts. The ability to provide care to injured children is complicated by unfamiliarity with treating severely injured children by most deployed United States (US) combat casualty care (CCC) providers. In addition, lack of pediatric-sized equipment and medications to care for severely injured children increases the difficulty in caring for these patients. The anxiety and emotion that are invoked by an injured child further complicates their management. United States military doctrine clearly states that during combat operations health care providers are to resuscitate all patients with injuries that threaten life, limb, or eyesight. The care of children injured during combat is an opportunity for military personnel to show compassion and to strengthen relationships with the civilian population. Appropriate care and attention towards wounded children are critical and provide opportunities to strengthen mutual respect and understanding.

Epidemiology

Multiple publications have described the epidemiology of injuries suffered by children (patients less than 18 years of age) treated at US military medical facilities in both Iraq and Afghanistan.^{1,2,3,4,5} These reports indicate that CCC providers will frequently treat children. These children often sustain severe injuries that are associated with increased mortality compared to adults.

The relative distribution of pediatric admissions to Level III care facilities between Operation Enduring Freedom (OEF) in Afghanistan (53 percent) and Operation Iraqi Freedom (OIF) in Iraq (47 percent) is similar, as is the mean age of pediatric patients (10 years, \pm 5) in both locations.⁶ Children account for 4 to 7 percent of all admissions to US military hospitals in OEF and OIF, and they account for 10 to 12 percent of all hospital bed days.^{1,5} In Afghanistan, these proportions are increased with children comprising 15 percent of all admissions and 25 percent of all hospital bed days. The mean hospital length of stay, 7 days, is similar in both locations.⁶ In both Iraq and Afghanistan, penetrating trauma accounts for approximately 75 percent of pediatric traumatic injuries. In Iraq, gunshot wounds are the mechanism of injury for 57 percent of pediatric admissions compared to 21 percent in Afghanistan. In Afghanistan, burn and landmine explosive injuries account for 15 percent of admissions each, while in Iraq they are the mechanism of injury for 6 percent and 1 percent of pediatric admissions, respectively.⁶

Combat casualty care providers will frequently treat children who often sustain severe injuries that are associated with increased mortality compared to adults. Children account for 4 to 7 percent of all admissions to US military hospitals in OEF and OIF, and 10 to 12 percent of all hospital bed days.

When data from Iraq and Afghanistan are combined, the overall primary causes of death are traumatic brain injury (29 percent) and burns (27 percent) (Fig. 1).⁶ Death as a result of infection was more common in Afghanistan (12 percent) than Iraq (2 percent), whereas death from penetrating abdominal and thoracic injuries was more common in Iraq (13 percent) than Afghanistan (5 percent).⁶ In a review of children treated at a Combat Support Hospital (CSH) in Iraq, children less than eight years of age, as compared to older children and adults, had an increased severity of injury according to the Injury Severity Score (ISS) and an increased incidence of death after adjusting for increased severity of injury.⁷



Figure 1. Resuscitative efforts in progress at a GSH. This host nation toddler was injured in a civilian motor vehicle accident and sustained 30% TBSA second- and third-degree burn wounds and severe inhalation injury.

Anatomic Considerations

Airway

The pediatric airway is significantly different than an adult airway. In addition to the obvious size differences in airway anatomy, the infant and young child's (less than eight years of age) oropharyngeal cavity is relatively smaller due to a larger tongue-to-cavity ratio in the child. The larger head in relation to body size also makes visualization of the larynx with laryngoscopy more difficult and often requires elevating the shoulders and upper thorax to allow for a more direct line of site of the larynx. The epiglottis in a child is typically omega-shaped (long and narrow) and attached at the vocal cords at an acute angle. The vocal cords are more cephalad and anterior compared to those in an adult. The subglottic area is narrower and cone-shaped, rather than more cylindrical in shape. An endotracheal tube (ETT) that passes easily through the vocal cords may encounter resistance in the subglottic area. Furthermore, children less than 12 years of age have a small, pliable, mobile larynx and cricoid cartilage making a surgical cricothyrotomy difficult to perform.⁸

AGE	PRETERM	NEWBORN	INFANT	1 YR	3 YRS	6 YRS	10 YRS	14 YRS
Laryngoscope Blade Size	0	1	1	1 to 2	2	2	2 to 3	3
ETT Size	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5	6.0 to 6.5	6.5 to 7.0
Suction Catheter (Fr)	5	6	8	8	8 to 10	10	10	10 to 14
Chest Tube	8 to 10	10 to 12	10 to 12	16 to 20	16 to 20	20 to 28	28 to 32	32 to 40
NG Tube or Foley Catheter (Fr)	5	5 to 8	5 to 8	8	8 to 10	10 to 12	12 to 14	14 to 18

Table 1. *Equipment size according to the age of the patient.*

The pediatric airway differs significantly compared to an adult airway. The larynx is more difficult to visualize during laryngoscopy, and the subglottic area is narrow and cone-shaped. An ETT that readily passes through the vocal cords may still encounter resistance in the subglottic area. Furthermore, children less than 12 years of age have a small, pliable, mobile larynx and cricoid cartilage making a surgical cricothyrotomy difficult to perform.

Selecting an appropriately sized ETT is a crucial first step when preparing to intubate a pediatric trauma victim. A number of methods intended to assist physicians with selecting the optimal ETT have been published. Using the internal diameter of the external nasal nares or nailbeds of the fifth digits of the child has been reported to facilitate the selection of an appropriately sized ETT.⁹ While these approaches may provide reasonable approximations of ETT sizing, they require the physical presence of the patient. This precludes the ability of careproviders to have this equipment prepared prior to patient arrival. Using the age (in years) added to 16 divided by 4 to represent the internal tube diameter in millimeters has also been recommended.⁹ Irrespective of the initially selected tube size, the physician should always be prepared to use either smaller or larger diameter tubes if the patient's airway dictates it (Table 1). The Broselow® tape is a commonly used and helpful method to standardize the approach to the resuscitation of children.¹⁰ It provides a valuable reference source for the appropriate sizing of pediatric airway equipment and dosing of medications.



Figure 2. *Cuffed versus uncuffed endotracheal tubes. With an uncuffed ETT, the narrowed subglottic space should provide an adequate seal around an appropriately selected ETT. Cuffed tubes are likely just as safe as uncuffed tubes, and may protect against tube dislodgment and gastric content aspiration by creating tighter seals.*

The issue of whether or not to use cuffed or uncuffed ETT in younger children often arises (Fig. 2). Advocates for using uncuffed tubes contend there is no need for a cuffed tube in children less than eight years of age.^{11,12} Their rationale is that the narrowest part of a young child's airway is subglottic in location. The narrowed subglottic space should provide an adequate seal around an appropriately selected ETT. Cuffed tube critics also believe these tubes decrease tracheal mucosal blood flow and increase the incidence of post-extubation laryngeal edema and tracheal stenosis.¹³ Proponents of using cuffed tubes believe that modern day low pressure (less than 25 cm H₂O), high-volume ETT cuffs are safer than the older models. They claim appropriately used, cuffed endotracheal tubes are just as safe as uncuffed endotracheal tubes.¹⁴ They believe cuffed tubes provide added protection against tube dislodgment and gastric content aspiration by creating tighter seals. Special caution must be exercised to avoid overinflating ETT cuffs. Monitors are now available that will measure cuff pressures and should be used to maintain cuff pressures less than or equal to 25 cm H₂O to minimize the incidence of cuff-related tracheal injury.¹⁴

Selecting an appropriately sized ETT is crucial; $(\text{age} + 16)/4$ may help in selecting ETT diameter. Current pediatric standards taught in the Pediatric Advanced Life Support (PALS) course recommend the use of cuffed endotracheal tubes to optimize oxygenation and ventilation in all children.

One method of providing an immediate surgical airway for a child less than 12 years of age is to perform a needle cricothyrotomy and initiate percutaneous transtracheal ventilation (PTTV) (Fig. 3).^{15,16} Percutaneous transtracheal ventilation is performed by having a 14- or 16-gauge angiocatheter inserted through the cricothyroid membrane, positioned intratracheally, and attached to a high-flow oxygen source.¹⁷ Regular oxygen tubing may be attached to a three-way stopcock, which is attached to the angiocatheter. Alternatively, a 14- or 16-gauge angiocatheter may be attached to one prong of a dual-pronged nasal cannulae, while the other end of the nasal cannulae is attached to a high-flow oxygen source. A one-second inspiratory and three-second expiratory cycle will allow time for adequate oxygenation and ventilation. The oxygen source should provide at least 50 pounds per square inch of air pressure (i.e., deliver flow rates of 15 liters per minute). Unfortunately, PTTV will not protect the airway from aspiration of gastric contents. In addition, this technique may eventually fail to provide adequate ventilation. Over time, progressive hypercarbia and acidemia may ensue. Percutaneous transtracheal ventilation technique should be viewed as a temporizing measure until a definitive airway in the form of a tracheostomy is established. If high-oxygen flow (jet) ventilation is not possible, an adapter from a 2.5 millimeter or 3.0 millimeter-sized ETT can be used to attach the angiocatheter to bag-valve-mask, thus enabling manual ventilation.



Figure 3. *Percutaneous transtracheal ventilation (PTTV)*. *Illustrator: Chris Galapp.*

One method of providing an immediate surgical airway for a child less than 12 years of age is to perform a needle cricothyrotomy and initiate PTTV. Percutaneous transtracheal ventilation should be viewed as a temporizing measure until a definitive airway in the form of a tracheostomy is established. Percutaneous transtracheal ventilation will not protect the airway from aspiration of gastric contents, and the technique may eventually fail to provide adequate ventilation.

It is the opinion of the authors and many experienced pediatric surgery and otolaryngology specialists that when a surgical airway is emergently needed in a child less than six years of age, a tracheotomy should be performed. At this age, cricoid cartilage versus tracheal anatomy is difficult to discern. Extra care needs to be exercised to stay well below the cricoid cartilage in order to avoid subglottic stenosis during the healing phase after the surgical airway. In younger children (e.g., less than three years of age), the concern with performing a needle cricothyrotomy is that it will be very difficult to place the needle in the airway. This is due to the laxity of the airway, and since the diameter of the airway is so small the risk of going through its posterior wall is high. The neck anatomy is better defined in older children (i.e., over six years of age), and it is easier to perform a needle cricothyrotomy. The choice of performing a surgical airway versus needle cricothyrotomy in children of all ages is dependent upon the comfort and experience of the provider in performing these procedures. If tracheostomy is attempted, the use of a cuffed ETT will be required. Accessing the correctly sized tracheostomy tube (lengthwise) will be nearly impossible in a combat environment where supplies are limited. Cuffed ETT of all sizes are not always available. As a result, advanced planning will be required regardless of the type of airway intervention.

Head and Spinal Cord

The risk of head injury is higher in children compared to adults, while the risk of spinal cord injury is lower.^{18,19,20} This is a result of the relative increase in head-to-body size and more flexible cervical ligaments of children compared to adults. There is also less subarachnoid space and fluid in children compared to adults. The anatomy of an infant's head with an open fontanelle and mobile cranial sutures allows for significant isolated intracranial bleeding. In addition, extracranial bleeding such as caput succedaneum, cephalohematoma, or subgaleal hematoma can cause severe anemia and hyperkalemia secondary to bleeding and eventual thrombolysis.^{19,20,21,22,23} The incidence of spinal cord injury in children is low and is likely related to flexible vertebral interspinous ligaments and anteriorly wedged vertebrae. As a result, with flexion injuries vertebral bodies slide forward minimizing the risk of spinal cord injury. However, spinal cord injury without radiographic abnormality (SCIWORA) does exist, and children injured by way of blast mechanisms are at risk. Diagnosis is difficult. Attention needs to be given to the presence of pain, tenderness on palpation of the spine, and the neurologic examination.

The risk of head injury is higher in children compared to adults. The anatomy of an infant's head with an open fontanelle and mobile cranial sutures allows for significant isolated intracranial bleeding. Extracranial bleeding such as caput succedaneum, cephalohematoma, or subgaleal hematoma can cause severe anemia and hyperkalemia secondary to bleeding and eventual thrombolysis.

There are several important radiographic variations in the pediatric cervical spine that warrant mentioning. Being aware of these variations is necessary in order to avoid misinterpreting these normal findings as injured spinal segments. The prevertebral soft-tissue of the pediatric cervical spine is prone to great variation. Emergency radiologic evaluation of the pediatric cervical spine can be challenging because of

the confusing appearance of synchondroses, normal anatomic variants, and injuries that are unique to children.²⁴ Cervical spine injuries in children are usually seen in the upper cervical region owing to the unique biomechanics and anatomy of the pediatric cervical spine. Knowledge of the normal embryologic development and anatomy of the cervical spine is important to avoid mistaking synchondroses for fractures in the trauma setting. Familiarity with anatomic variants is also important for correct image interpretation.²⁴ These variants include pseudosubluxation, absence of cervical lordosis, wedging of the cervical vertebra, widening of the predental space, prevertebral soft-tissue widening, intervertebral widening, and “pseudo Jefferson fracture” (normal C1 vertebra variant in young children).²⁴ In addition, familiarity with mechanisms of injury and appropriate imaging modalities will aid in the correct interpretation of radiologic images of the pediatric cervical spine.²⁴ Using prevertebral soft-tissue swelling to detect injury is neither a sensitive nor specific indicator of acute injury in pediatric patients. In adults, a predental space of greater than three millimeters is regarded as abnormal. Children have more laxity of their spinal segments, and a predental space of up to five millimeters in children age 13 or younger is deemed within normal limits.²⁵



Figure 4. *Physiological pseudosubluxation on pediatric cervical spine radiograph. Normal displacement of C2 on C3 may be so pronounced as to be mistaken for a pathologic condition. Image courtesy of Swaminatha V Mahadevan, MD, Stanford University.*

The most prominent abnormality in pediatric cervical spine films is the physiologic pseudosubluxation of the C2 on C3 vertebral body (Fig. 4).²⁵ Physiologic pseudosubluxation may occur at several levels between C2 to C5. There may be up to four millimeters of subluxation at the C2 to C3 junction as part of normal variation in children up to the age of 16 years.²⁵ This pseudosubluxation pattern is unusual beyond the age of 16. Use of the spinolaminar line (also known as the posterior cervical line) as a reference may be helpful in differentiating acute injuries from normal anatomical variants. The spinolaminar line junction of the C2 vertebral segment should be within two millimeters of a line drawn between the C1 and C3 spinolaminar line junction.²⁶ If the C2 spinolaminar line junction is offset by two or more millimeters, the radiograph should be interpreted as abnormal and suspicious for an injury.^{26,27} The spinolaminar line should only be applied in cases where anterior displacement of the C2 on C3 vertebral body exists. When the C2 and C3 vertebral bodies are in a neutral or extended position, an offset of two millimeters or more of the C2 spinolaminar line may be a normal finding.

Emergency radiologic evaluation of the pediatric cervical spine can be challenging because of the confusing appearance of synchondroses, normal anatomic variants, and injuries that are unique to children. Due to unique pediatric anatomy, cervical spine injuries are usually seen in the upper cervical spine. The synchondrosis at the junction of the dens and body of C2 is often the site of injury. The most prominent abnormality in pediatric cervical spine films is the physiologic pseudosubluxation of the C2 on C3 vertebral body, which may be mistaken for pathologic motion.

The synchondrosis at the junction of the dens and body of C2 is often the site of injury.^{28,29} The dens and body of the axis synchondrosis may remain unfused up to the age of seven, mimicking a dens fracture. Any anterior angulation of the dens should be viewed as suspicious for injury.²⁷ The anterior vertebral bodies of C3, C4, and C5 will often have a wedged appearance mimicking wedge compression fractures (Fig. 5). As their ossification sites fully calcify, they will take on the appearance of adult vertebral bodies. Small calcifications may sometimes be seen inferior to the cervical vertebral bodies. These represent normal ring epiphyses. Looking for any subluxation, soft-tissue swelling, or any clinical evidence of injury at those levels is helpful in deciding whether any radiographic abnormalities in those regions represent acute injuries. Children suffer a disproportionate number of high cervical spine injuries.¹⁸ Children are also still vulnerable to lower cervical spine injuries, although injury in this location is not as common.¹⁸



Figure 5. Wedge-shaped appearance of vertebral bodies, most prominent at C3, should not be confused with compression fractures. The vertebrae take on a more rectangular appearance with age. Image courtesy of Swaminatha V. Mahadevan, MD, Stanford University.

Spinal cord injury without radiographic abnormality (SCIWORA) is a post-traumatic myelopathy that results from acute spinal cord or nerve root injury and results in some combination of sensory and motor deficit.³⁰ Spinal cord injury without radiographic abnormality is defined as a post-traumatic myelopathy that occurs without radiographic evidence of fracture or dislocation on plain radiography and computed tomography (CT) scan evaluation. Anatomic differences of the pediatric spine allow for significant intersegmental spinal movement without bony column disruption. The spinal cord does not share the same degree of elasticity as the spinal column. This explains why, despite the lack of radiographic evidence of spinal column disruption, spinal cord injury may still occur. In a recent meta-analysis of pediatric studies describing SCIWORA syndrome, 27 percent of patients (24/88) experienced delayed onset of symptoms.³⁰ Paralysis developed hours to days after patients' initial injuries. The prognosis of patients with SCIWORA syndrome is better than patients with similar neurologic deficits who exhibit radiographic evidence of bony column disruption. Nevertheless, patients with complete cord syndromes or severe deficits on initial examination generally do not recover.³¹ In more recent studies, SCIWORA syndrome has been documented in adult patients as well.³⁰

Spinal cord injury without radiographic abnormality is defined as a post-traumatic myelopathy that occurs without radiographic evidence of fracture or dislocation on plain radiography and CT scan evaluation.

Trauma victims who complain of either transient or persistent symptoms potentially attributable to a spinal cord injury should be assumed to have an unstable spinal column until proven otherwise. Radiographic evaluation often involves plain radiography and CT. High-dose glucocorticosteroid (i.e., methylprednisolone) therapy was the standard of care in adult patients with blunt trauma and clinical evidence of spinal cord injury. That was largely based on the results of the National Acute Spinal Cord Injury Study (NASCIS) II trial, which have since been called into question.³² This trial did not include any patient age 12 or younger. There are no published trials that support administering high-dose methylprednisolone in children age 12 and younger with spinal cord injuries. The benefits of administering high-dose glucocorticosteroids following blunt spinal cord injury has been refuted by many experts who feel the practice is of no value and possibly harmful.³³

There are no published trials that support administration of high-dose methylprednisolone in children age 12 and younger with spinal cord injuries.

Skeletal and Body Surface Area

Due to incomplete calcification and multiple unfused growth plates, the skeleton of a child is more pliable than an adult skeleton. As a result, significant internal organ injury can occur in children without notable overlying skeletal findings.^{34,35} For example, pulmonary contusions commonly occur in children, without associated rib fractures. Conversely, rib fractures denote significant trauma and are commonly associated with underlying injuries.^{34,35} Thus, when a rib or central bony structure is fractured, a diligent search for underlying internal organ injuries should follow, irrespective of how hemodynamically stable the child initially appears. The head is another area where a skull fracture may not occur, but there can be significant underlying cerebral pathology.³⁶ Skin surface-area-to-body-volume ratio is highest at birth and decreases with age.³⁷ As a result, heat transfer occurs much more rapidly in smaller children. Therefore, injured children are prone to hypothermia and must be evaluated and monitored vigilantly.

The skeleton of a child is more pliable than an adult skeleton. As a result, significant internal organ injury can occur without notable overlying skeletal injuries.

AGE (YEARS)	WEIGHT (KG)	RESPIRATORY RATE	PULSE
Less than 1	3	40 to 60	130 to 150
1 to 5	10 to 20	20 to 40	110 to 130
6 to 10	20 to 35	12 to 20	75 to 100
11 to 18	35 to 70	12 to 20	70

Table 2. *Physiologic parameters for respiratory rate and pulse rates in children.*

Physiology

Vital Signs and Other Physiologic Parameters

Normal respiratory and pulse rates vary with age as is described in Table 2. The definition of hypotension (less than fifth percentile) according to systolic blood pressure is less than 70 mm Hg for infants, less than $70 \text{ mm Hg} + 2 \times (\text{age in years})$ for children one to 10 years of age, and for children older than 10 years of age, it is less than 90 mm Hg.³⁸ Children also have a smaller circulating blood volume than adults. Using 80 milliliters of blood volume per kilogram of body weight will allow for an accurate estimation of a child's intravascular blood volume. For example, the calculated intravascular blood volume for a five-kilogram infant would be 400 milliliters.

The definition of hypotension according to systolic blood pressure for infants is less than 70 mm Hg, for children one to 10 years of age is less than $70 \text{ mm Hg} + 2 \times (\text{age in years})$, and for children older than 10 years of age is less than 90 mm Hg.

Normal intracranial pressure (ICP) in a child is similar to an adult and ranges between five to 15 mm Hg in the supine position with the exception of infants with an open fontanel where the ICP will be slightly lower. Similar to adults, the standard goal is to maintain ICP less than 20 mm Hg.³⁹ The threshold to treat low cerebral perfusion pressure (CPP), defined by mean arterial pressure minus ICP, in children is dependent upon their age. In general, CPP should be maintained greater than 40 mm Hg for children under two years of age, greater than 50 mm Hg for those two to six years of age, greater than 60 mm Hg for those six to 12, and greater than 70 mm Hg for patients older than 13 years of age.³⁹

Normal central venous pressures in children range between three to five mm Hg. Since children rarely have diastolic dysfunction, the central venous pressure is a relatively accurate measure of intravascular volume. For patients requiring positive-pressure mechanical ventilation, the intrapulmonary pressure that is transmitted to the intrapleural space will elevate the measured central venous pressure.⁴⁰ The amount of central venous pressure elevation will be dependent upon the degree of compliance of the lungs, with increased lung compliance causing less transmission of pressure and therefore less effect on the measured central venous pressure.⁴¹ Intraabdominal pressure in children can be approximated with any device that measures urinary bladder pressure or intragastric pressure as is done in adults. Normal intraabdominal pressure in children is less than 10 mm Hg and typically three to five mm Hg, which is similar to adults, and in critically ill children requiring mechanical ventilation without signs of abdominal compartment syndrome, normal intraabdominal pressures were reported to be 7 ± 3 mm Hg.⁴²

Abdominal compartment syndrome has been loosely defined in children, as in adults, by an intraabdominal pressure greater than 20 mm Hg.⁴³ Children may develop abdominal compartment syndrome at lower pressures compared to adults.⁴³ Splanchnic perfusion pressure, defined as mean arterial pressure minus intraabdominal pressure, may also be calculated. Splanchnic perfusion pressure is as a more accurate marker of splanchnic blood flow, and a decrease in splanchnic perfusion pressure may be the most sensitive early finding of abdominal compartment syndrome.⁴⁴ Aggressive volume resuscitation in combination with inflammatory processes that promote capillary leak syndrome increases the risk of abdominal compartment syndrome, which can manifest as renal failure, decreased pulmonary compliance, and multiorgan failure.⁴³

Aggressive volume resuscitation in combination with inflammatory processes that promote capillary leak syndrome increases the risk of abdominal compartment syndrome, which can manifest as renal failure, decreased pulmonary compliance, and multiple organ system failure.

Due to higher metabolic rates, oxygen consumption is increased in infants and younger children compared to adolescents and adults.⁴⁵ A significant related consequence is that younger children will become hypoxemic more rapidly during rapid sequence intubation. Methods to monitor the relationship between oxygen delivery and consumption in children are similar to what is practiced in adults. Blood gas analysis of arterial partial pressure of oxygen, base deficit or lactate concentrations, central venous oxygen saturations, and systemic arterial and cerebral tissue oxygen saturation monitoring are all used to directly or indirectly measure oxygen delivery, consumption, and cardiac output.

WEIGHT (KG)	HOURLY RATE OF FLUIDS
3 to 10	4 milliliters (ml) per kilogram per hour
11 to 20	40 ml per hour + 2 ml per kilogram per hour
20 to 70	60 ml per hour + 1 ml per kilogram per hour

e.g., for weight of 13 kg, maintenance fluid requirement is 40 ml/hr + 2(3) ml/hr = 46 ml/hr

e.g., for weight of 37 kg, maintenance fluid requirement is 60 ml/hr + 1(17) ml/hr = 77 ml/hr

The exception is day 1 to day 2 of life in full-term neonates. Day 1 use = 60 to 80 ml per kilogram per day. Day 2 use = 80 to 100 ml per kilogram per day.

Table 3. *Daily maintenance fluid requirement for pediatric patients, based on weight.*

Higher oxygen consumption in infants and young children combined with decreased functional residual capacity compared to adults causes children to become hypoxemic more rapidly during rapid sequence intubation.

Fluids, Electrolytes, Nutrition, and Glucose Metabolism

Daily fluid requirements in children are dependent upon their weight (Table 3).⁴⁶ For children who present with intravascular volume depletion due to fluid losses, these deficits should be replaced with non-dextrose containing isotonic saline rapidly if the child is hemodynamically compromised and more gradually (e.g., over 24 hours) if the losses have been subacute and the child is hemodynamically stable.

Determining intravascular volume in pediatric patients is difficult since there is no direct method to measure it. Patient vital signs, physical exam findings, urine output, hemodynamic parameters, and laboratory values must be collectively evaluated to estimate the patient's intravascular volume status. When intravenous fluids are used, close attention needs to be paid to the child's electrolyte status. Critical illness in children increases antidiuretic hormone production, which increases free water retention. The risk of hyponatremic seizures increases with the use of hypotonic saline such as one-quarter normal saline (0.22 percent NaCl).⁴⁷ Therefore, one-half normal saline (0.45 percent NaCl) to isotonic fluids such as

normal saline (0.9 percent NaCl) or lactated Ringer’s solution should be used to provide maintenance fluids in critically ill children. This is a change from classical teaching that stressed the use of hypotonic fluids. Recent literature shows that the use of hypotonic fluids provides too much free water and should be abandoned.⁴⁷

Intravascular volume depletion should be rapidly reversed with non-dextrose containing isotonic saline if the child is hemodynamically unstable, and more gradually reversed if the fluid deficit is subacute and the child is hemodynamically stable.

Potassium daily requirements are 1 to 2 milliequivalents (mEq) per kilogram per day.⁴⁸ In children less than one month of age this can be achieved with the addition of 10 mEq per liter of potassium chloride and in children greater than three months of age by adding 20 mEq per liter of potassium chloride to their intravenous fluid solution. The standard maximum potassium chloride concentrations suggested for peripheral intravenous (IV) solution is 80 mEq per liter and is 200 mEq per liter for central line administration.⁴⁸ In non-immediately life-threatening scenarios, the maximum IV rate of potassium-containing solutions is 0.5 mEq per kilogram per hour with a maximum of 40 mEq per hour for children weighing greater than 40 kilograms.⁴⁹ To minimize the risk of significant electrolyte disturbances, serum electrolytes should be monitored at least daily in all children requiring intravascular fluids.

Children in areas of combat operations are often malnourished. Consequently, nutritional deficiencies are common, which increases the risk of many nutritional comorbid disorders such as sepsis and poor wound healing.^{50,51} A major difference between children and adults is caloric requirements. Daily caloric resting energy requirements decrease with age (Table 4). The standard caloric requirement or resting energy expenditure for an infant is 90 to 120 kilocalories (kcal) per kilogram per day compared to 25 to 30 kcal per kilogram per day in adults.⁴⁶ There is no one simple formula that can be used to calculate critically ill patients’ total caloric requirements. This requires direct calorimetry, which will not typically be available at Combat Support Hospitals. Alterations in energy expenditure as a result of critical illness in children cannot be estimated accurately, therefore nutritional support should be provided according to measurement of resting energy expenditure to avoid the consequences of overfeeding or malnutrition.⁵²

AGE (YEARS)	KCAL/KG
0 to 1	90 to 120
1 to 7	75 to 90
7 to 12	60 to 75
12 to 18	30 to 60
Greater than 18	25 to 30

Table 4. Daily maintenance caloric requirements in children. Note the decrease of caloric requirements associated with age.

Enteral feeding compared to parenteral is preferred since it preserves gastrointestinal function and has been associated with decreased infections and length of hospital stay in critically ill children.⁵³ Enteral feeds are indicated early in the course of critical illness as soon as enteric peristalsis is established, unless there is a medical or surgical contraindication. Post-pyloric feeds are advantageous due to less gastric distention and decreased risk of gastroesophageal reflux compared to gastric feeding.⁵³ Nasoduodenal tubes can often be placed blindly 30 minutes after the administration of a prokinetic agent with the child in the right lateral decubitus position. Promotility agents can be used to improve gastric motility, and non-narcotic agents can be used for sedation to decrease the risk of ileus.⁵⁴

Children in areas of combat operations are often malnourished, which increases the risk of many comorbid disorders such as sepsis and poor wound healing. Enteral feeding is preferred to parenteral feeding since it preserves gastrointestinal function and has been associated with decreased infections and length of hospital stay in critically ill children.

Hypoglycemia is a significant risk in young children if glucose is not provided (in some form) early after initial resuscitation. This is due to decreased hepatic stores of glycogen and increased metabolism in children.⁵⁵ For neonates it is standard to provide 10 percent dextrose (D10) when parenteral fluids are required and 5 percent dextrose (D5) for all other ages until adolescence.⁴⁸ Clinical signs and symptoms of hypoglycemia may not be easily recognized in sedated and mechanically ventilated children. The risk of hypoglycemia makes it necessary to evaluate serum glucose values at least once a day if not more frequently in these critically ill children. Adolescent age children have larger glucose stores and are able to temporarily tolerate maintenance fluids without dextrose, similar to adults. Table 5 summarizes the range of acceptable choices of solutions, with dextrose concentrations and additives. For the treatment of symptomatic hypoglycemia in neonates and infants, it is preferred to give 4 ml per kilogram of D10 solution by intravenous bolus infusion and to check the glucose concentration within 15 to 30 minutes. The use of D25 and D50 solutions should be avoided in neonates and infants due to the theoretical risk of intraventricular hemorrhage following the rapid infusion of a hyperosmotic agent and the risk of infiltration and tissue injury when administered into a peripheral vein.⁴⁸

AGE	DEXTROSE (PERCENT)	SOLUTION	POTASSIUM CHLORIDE (KCl)
0 to 2 Days	10	Water + 2 mEq/kg NaCl + 1 mEq/kg KCl	
3 Days to 1 Month	5 or 10	0.45 Normal Saline	10 mEq per liter
1 Month to 1 Year	5	0.45 to 0.9 Normal Saline or LR	20 mEq per liter*
1 to 8 Years	5	0.45 to 0.9 Normal Saline or LR	20 mEq per liter*
8 to 18 Years	0 or 5	0.45 to 0.9 Normal Saline or LR	20 mEq per liter*

*Potassium chloride should not empirically be added to lactated Ringer's (LR) solution if not required.

Table 5. *Appropriate range of fluid solutions and additives in children.*

Hypoglycemia is a significant risk in young children if glucose is not provided in some form early after initial resuscitation. The use of D25 and D50 solutions should be avoided in neonates and infants due to the theoretical risk of intraventricular hemorrhage with the rapid use of a hyperosmotic agent and the risk of infiltration and tissue injury when used within a peripheral vein.

Respiratory System

While there are age-dependent changes in pulmonary compliance and resistance and chest wall compliance, in children as compared to adults, these differences have minimal effect on the treatment of respiratory failure once it has occurred in children.⁵⁶ Increased resistance due to smaller airways and increased metabolic rates and lower functional residual capacities may increase the risk of respiratory failure in

young children. Once a child is intubated, the same open-lung or low-lung tidal volume strategies that are applied in adults should also be applied in children (e.g., 5 ml per kilogram as an initial tidal volume). Principles of permissive hypercapnia and permissive hypoxemia to prevent ventilator-associated lung injury are also practiced in children.⁵⁷ Complications of hypercapnia are minimal as long as the pH of the blood is medically controlled at a pH of 7.1 or above.

Once a child is intubated, the same open-lung or low-lung tidal volume strategies that are applied in adults should also be applied. Principles of permissive hypercapnia and permissive hypoxemia to prevent ventilator-associated lung injury are also applied to children.

Pharmacology

The dosing of most, if not all, medications for children is weight-based. Multiple references for appropriate dosing and how to adjust for renal and hepatic impairment in addition to contraindications and adverse reactions are available and must be used for the safe and appropriate use of medications in children. The Harriet Lane Handbook is a small soft-cover book that is an invaluable resource for pediatric medication dosing and adjustment.⁵⁸ All Combat Support Hospitals should have this reference available.

The Harriet Lane Handbook is a small soft-cover book that is an invaluable resource for pediatric medication dosing and adjustment.⁵⁸ Level III care facilities should have this reference available.

Succinylcholine and propofol are two pharmaceutical agents that are commonly used for patients with traumatic injuries that have added risks or considerations in children compared to adults.⁵⁹ Succinylcholine has historically been the paralytic of choice for true rapid sequence induction due to its rapid onset of action (30 seconds) and brief duration of action (five to six minutes).⁸ This was undoubtedly true, especially when there were no other similar profile agents. The increased risks associated with succinylcholine in children must be recognized and alternative choices should at least be considered. The major risk associated with its use is life-threatening hyperkalemia, which is increased when used in children with undiagnosed neuromuscular disorders, massive multiorgan trauma, widespread intestinal ischemia, and subacute burn injuries.⁵⁹ In addition, risks associated with succinylcholine use include malignant hyperthermia, masseter spasm, increased intracranial, intraocular, and gastric pressure, sinus bradycardia with hypotension, and pulmonary edema.⁵⁹ Several methods of blunting the transient rise of ICP directly resulting from succinylcholine administrations have been studied. The use of lidocaine (1 to 1.5 milligrams [mg] per kilogram) IV has shown mixed results in the literature; the studies demonstrating benefit required a minimum of three minutes of time to pass prior to administering succinylcholine.⁶⁰ The administration of a defasciculating dose (0.01 mg per kilogram) of a nondepolarizing paralytic agent such as pancuronium has been shown to decrease succinylcholine-associated rises in ICP.⁵⁹ Administration of atropine will eliminate the risk of bradycardia with laryngoscopy.⁵⁹ The use of these premedication agents often negates the rapid onset of action of succinylcholine since it takes time for these agents to be administered and take effect. If succinylcholine is used in pediatric patients, infants may require 2 to 3 mg per kilogram and children 1 to 2 mg per kilogram of succinylcholine compared to the adult intravenous dose of 1 to 1.5 mg per kilogram.⁵⁹

An alternative agent that has near similar onset of action that should be considered in children is rocuronium. Rocuronium at a dose of 0.6 mg per kilogram typically produces paralysis at 50 to 80 seconds, and using an increased dose of 0.8 mg per kilogram will decrease the average time to 30 seconds.⁵⁹ The duration of action

in children is typically 30 to 40 minutes, which is much longer than succinylcholine since it is an intermediate-acting nondepolarizing paralytic.⁵⁹ Hence, careproviders will need to provide airway and breathing support for this extended period of time if endotracheal intubation is unsuccessful. Hemodynamic effects include mild increase in heart rate. It is metabolized primarily by the liver and excreted by the kidneys. Since there are now suitable alternatives to succinylcholine, many in the pediatric emergency medicine and critical care communities discourage its use and support the alternative use of agents such as rocuronium.⁵⁹

Succinylcholine has historically been the paralytic of choice for true rapid sequence induction due to its rapid onset of action and brief duration of action. An alternative agent that has near similar onset of action that should be considered in children is rocuronium.

Propofol is an intravenous anesthetic agent that gained wide acceptance for long-term sedation in adult intensive care units as a result of its potent anesthetic properties, fast-onset, and short duration of action. Propofol's attractive rapid-onset and rapid-offset pharmacologic profile has resulted in extending its use to critically ill pediatric patients (e.g., enabling near-term neurologic exams in patients with head injuries). Short-term use of propofol for procedural sedation and operative cases has not been shown to be a problem, but the use of propofol for prolonged sedation in the critical care setting has raised concerns. A fatal metabolic acidosis syndrome associated with prolonged use of propofol has been described. The mechanism is unclear, but duration of therapy and higher doses are the most commonly cited factors associated with the syndrome. Notably, children have been reported to develop a rapidly fatal metabolic acidosis syndrome when higher doses of propofol have been used for sedation for more than two to three days.^{61,62,63,64} While this has also been reported in adults, it has been more commonly associated with pediatric use (specifically in brain injury and burn patients), hence the black box warning for long-term use in children.⁶⁵

Propofol has an attractive rapid-onset and rapid-offset pharmacologic profile, which has resulted in extending its use to critically ill pediatric patients. The use of propofol for prolonged sedation in the critical care setting has raised concerns. With prolonged sedation of more than two to three days, a fatal metabolic acidosis syndrome, also known as propofol infusion syndrome, can occur.

Fatal metabolic acidosis, also known as propofol infusion syndrome, can present with the following signs and symptoms: lactic acidosis, rhabdomyolysis, elevated hepatic enzymes, and fatal dysrhythmias. Discontinuation of propofol and supportive care is the only treatment.^{61,62,63,64} Since there are alternative agents that can produce adequate deep sedation such as fentanyl, remifentanyl, midazolam, ketamine, barbiturates, and dexmedetomidine, the use of propofol for greater than 24 hours must be carefully considered. If propofol is used for long-term sedation, patients should be carefully monitored for the development of propofol infusion syndrome.

Patient Monitoring Considerations

Standard monitoring of vital signs in children includes continuous end-tidal carbon dioxide monitoring for children who are intubated.⁶⁶ A main benefit of continuous end-tidal carbon dioxide monitoring is the rapid recognition that the ETT has been displaced out of the airway. Children, due to their shorter tracheas and difficulty in maintaining adequate sedation, are at increased risk of accidental extubations (Fig. 6). Immediate recognition of ETT displacement before the child becomes hypoxicemic will minimize adverse outcomes. Continuous end-tidal carbon dioxide waveform analysis monitoring improves the recognition



Figure 6. *A pediatric victim of an IED blast undergoing mechanical ventilation with cardiac and respiratory monitoring in place.*

of obstructive airway disease, whether it is from reactive airways or mucus plugging.⁶⁶ It is also beneficial for the child with severe traumatic brain injury where the goal is to keep the arterial partial pressure of carbon dioxide (PCO_2) within a certain range and can also be used to estimate pulmonary dead space.⁶⁶ Once correlated with the arterial PCO_2 , the end-tidal carbon dioxide can be used to titrate ventilation and has the potential to minimize phlebotomy.

Because children are at increased risk of accidental extubations, standard monitoring should include continuous end-tidal carbon dioxide monitoring, which may aid in rapid recognition of a displaced ETT.

The use of intracranial ventriculostomy catheters for patients with severe traumatic brain injury is standard practice in children.³⁹ Diagnostic benefits include the monitoring of ICP, while therapeutic benefits include the ability to drain cerebrospinal fluid (CSF) via the catheters when intracranial pressures become elevated. Compared to intraparenchymal pressure monitoring devices, there is an increased infection risk with the use of ventriculostomy catheters, but this risk is still very low and the therapeutic benefits outweigh the risks.³⁹

Resuscitation

General Considerations

Advanced Trauma Life Support (ATLS) course principles all apply for children. The Broselow® tape is a commonly used and helpful method to standardize the approach to the resuscitation of children (Fig. 7).¹⁰ It provides a valuable reference source for the appropriate sizing of pediatric resuscitation equipment and dosing of medications.

Airway and Breathing

For the conscious child with an obstructed airway, back blows or the Heimlich maneuver should be performed to dislodge any foreign body.³⁸ Attempts



Figure 7. Pediatric resuscitation of a host nation casualty cared for at a Level III facility. By measuring the patient's body length, the Broselow® tape allows careproviders to rapidly determine appropriate resuscitation equipment and medication dosing.

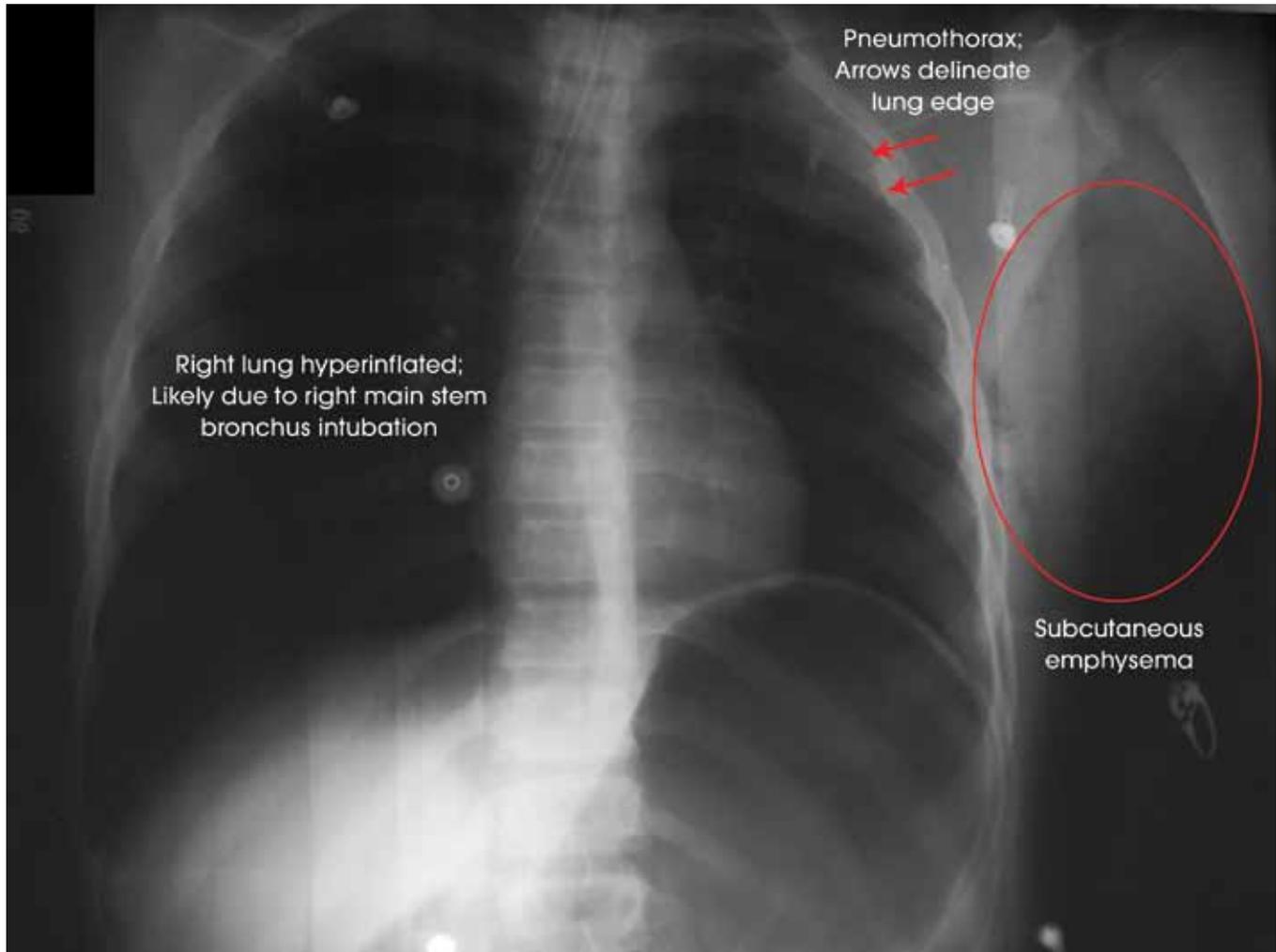


Figure 8. A pediatric patient who sustained multiple traumatic injuries. A right mainstem intubation is noted, with hyperinflation of the right lung.

to manually remove the obstruction should only occur if a foreign body is visible.³⁸ In cases where positive-pressure ventilation is indicated, the use of an oral airway will greatly improve the ability to bag-valve-mask ventilate a young child since the tongue often obstructs a child's airway. The use of a Miller blade and the Sellick maneuver will often improve your ability to visualize the larynx in a young child.

Always consider ETT misplacement (e.g., right mainstem bronchus intubation) if it is difficult to increase a child's arterial oxygen saturations or if the peak inspiratory pressures are higher than expected. The trachea of a child is much shorter than it is in an adult and it is easy to mistakenly advance the ETT into the right mainstem bronchus (Fig 8). The proximal airways in an intubated child obstruct very easily due to their small size. Nebulized hypertonic saline, respiratory vibratory and percussive therapy, and the use of mucolytics (nebulized or instilled) can be considered and have been used with mixed results to minimize airway obstruction in a variety of conditions.^{67,68,69}

The trachea of a child is much shorter than it is in an adult, and it is easy to mistakenly advance the ETT into the right mainstem bronchus. Always consider ETT misplacement (e.g., right mainstem bronchus intubation) if it is difficult to increase a child's arterial oxygen saturations or if the peak inspiratory pressures are higher than expected.

Current pediatric standards taught in the Pediatric Advanced Life Support (PALS) course advise the use of cuffed endotracheal tubes to optimize oxygenation and ventilation in all children. The primary benefit is to secure the tube and prevent significant air leaks around the ETT. With the use of cuffed ETT tubes comes the responsibility of maintaining the appropriate ETT cuff pressure (less than 25 cm H₂O). This will minimize the risk of subglottic stenosis that may occur from ischemic injury to this area from over inflated endotracheal cuffs.⁷⁰ The short length of the trachea especially in infants can make it very difficult to keep the ETT in proper midtracheal position. To minimize the risk of accidental extubations it is wise to: (1) keep the infant and young child well-sedated; (2) ensure the ETT is securely taped; (3) immediately change the tape if it loosens (e.g., due to oropharyngeal secretions); (4) obtain daily chest radiographs to determine the position of the ETT; and (5) always use continuous end-tidal carbon dioxide monitoring to enable immediate recognition of ETT dislodgment. In circumstances where it is difficult to maintain an orally-placed ETT in proper position, considerations should be given to performing nasotracheal intubation.

Rapid Sequence Intubation

Careproviders need to consider multiple important factors when performing rapid sequence intubation in young children. Atropine should be strongly considered as a premedication prior to intubation in infants and young children. Infants have a strong vagal response to laryngoscopy and can develop significant bradycardia as a result.⁷⁰ Oropharyngeal secretions in young children can make airway visualization difficult during laryngoscopy. This is especially true with the use of ketamine, which is a potent sialogogue. Atropine has been shown to decrease oral secretions and may also reduce the risk of vomiting during recovery from ketamine use.⁷¹ Interestingly, while glycopyrrolate and atropine have been traditionally used to minimize secretions, recent studies have found that neither drug has been shown to decrease serious adverse respiratory events associated with ketamine use.^{72,73}

Infants and young children have a strong vagal response to laryngoscopy and can develop significant bradycardia as a result. Atropine should be strongly considered as a premedication prior to intubation of infants and young children.

Due to increased metabolic rates and decreased functional residual capacity compared to adults, children will undergo arterial oxygen desaturation more quickly with rapid sequence intubation.⁷⁴ This is especially true for children with nutritional deficiencies and decreased muscular strength and those with distended abdomens either from malnutrition or hepatic enlargement. For children who require bag-valve-mask ventilation prior to intubation, intragastric air can increase intraabdominal pressure significantly enough to decrease pulmonary compliance and make it more difficult to maintain adequate oxygenation (Fig. 9). To minimize increased intragastric air accumulation, the Sellick maneuver should be used during bag-valve-mask ventilation once the child is sedated. If gastric distension still occurs, the placement of a nasogastric tube to decompress the stomach should also be considered.



Figure 9. For children who require bag-valve-mask ventilation prior to intubation, intragastric air can increase intraabdominal pressure significantly enough to decrease pulmonary compliance and make it more difficult to maintain adequate oxygenation. In such cases, prompt nasogastric tube decompression is warranted.

Vascular Access

Rapid resuscitation of a child is best accomplished through the largest peripheral intravascular access that can be obtained. If a child is in need of immediate intravascular access and standard peripheral or central intravenous access cannot be rapidly established, an intraosseous (IO) needle should be inserted.⁷⁰

Intraosseous needles can be inserted by hand or with the use of a tool such as the EZ-IO® (Fig. 10).⁷⁵ The preferred landmark for IO line placement is two centimeters inferior to the tibial tuberosity and perpendicular to the medial flat surface of the tibia. Local anesthetic (e.g., lidocaine) injected at the site of needle insertion several minutes prior to needle insertion will minimize procedural discomfort. Alternative sites include the distal tibia, distal femur, and proximal humerus (Fig. 11). All resuscitative medications and blood products that can be given intravenously can be administered via an IO needle.⁷⁰ Marrow sinusoids drain into venous channels, which lead into nutrient and emissary veins, which in turn, drain into the systemic venous system. Medications infused via intraosseous lines can reach the central circulation rapidly and in a similar timeframe compared to peripheral injections, even in hypoperfused states. Pressure bags or manual syringe infusion are the recommended methods for attaining adequate infusion rates. Passive flow rates (i.e., gravity infusion of hanging saline bags) are suboptimal. Blood can also be sampled from an IO needle for laboratory analysis.⁷⁶



Figure 10. *Vascular access in this patient includes bilateral proximal tibia IO lines. All resuscitative medications and blood products that can be given intravenously can be administered via an IO needle.*

If a child is in need of immediate intravascular access and standard peripheral or central intravenous access cannot be rapidly established, an IO needle should be inserted. All resuscitative medications and blood products that can be given intravenously can be administered via an IO needle. Pressure bags or manual syringe infusion are the recommended methods for attaining adequate flow rates, as passive flow rates are suboptimal.

Complications of IO lines include subcutaneous extravasation of infusate, extremity compartment syndrome, tibial fracture, and osteomyelitis.⁷⁵ Intraosseus line utilization should be regarded as temporary vascular access and should be replaced with traditional IV access within 24 hours. This is due to the concern that there is an increased risk of osteomyelitis with prolonged IO access.⁷⁷ Close monitoring for extravasation of fluid is crucial. Early recognition of a malfunctioning IO line will minimize the risk of compartment syndromes at IO infusion sites.

Circulation

Damage control or hemostatic resuscitation principles can be applied to children in hemorrhagic shock.⁷⁸ There is no contraindication to the use of appropriately cross-matched whole blood for children who

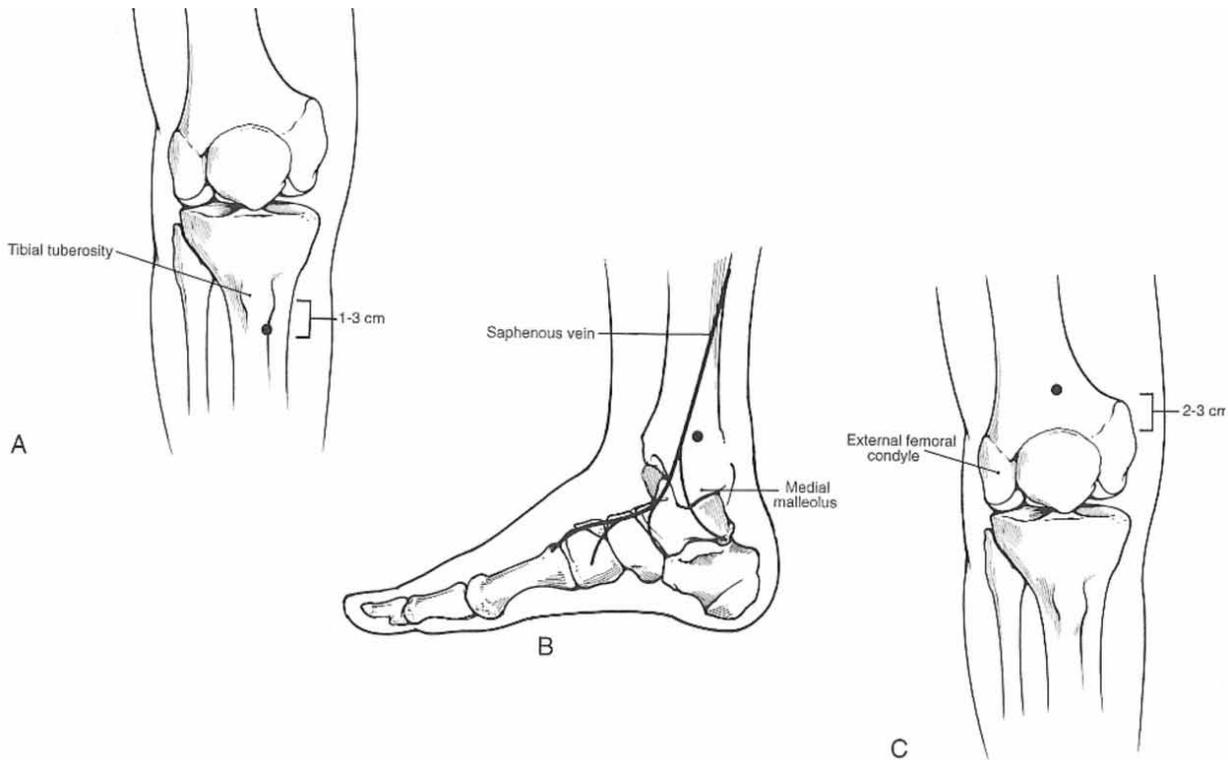


Figure 11. Sites for IO line placement. The preferred landmark for IO line placement is two centimeters inferior to the tibial tuberosity and perpendicular to the medial flat surface of the tibia. Alternative sites include the distal tibia, distal femur, and proximal humerus. Image courtesy of Elsevier. In: Roberts JR and Hedges JR. *Clinical Procedures in Emergency Medicine*. 4th ed. Philadelphia (PA): WB Saunders; 1998.

present in hemorrhagic shock. In fact, the only randomized controlled trial of whole blood was performed in children after cardiac surgery.⁷⁹ In this study, whole blood was transfused in both the operating room and intensive care unit, and outcomes were statistically adjusted. The results indicated that whole blood transfusion compared to blood product components decreased postoperative blood loss.⁷⁹ This study is often compared to another that reported increased length of stay with the use of whole blood compared to components.⁸⁰ It is important to realize that in this study by Mou et al., whole blood was only transfused in the operating room, and the analysis did not adjust for other factors associated with length of stay.⁸⁰ The use of type O whole blood should only be considered when there is no other alternative, and the child is in immediate risk of death. Every effort should be made to use type-specific whole blood when it is indicated. All vasoactive agents used in adults to increase cardiac output can be used in children, including vasopressin.^{81,82} Relative adrenal insufficiency is common in critically ill children.⁸³ Hydrocortisone is used for its treatment with reported dosing that varies from 2 mg per kilogram IV every 4 hours to a 50 mg per day continuous infusion.⁸⁴ Of note, the benefit of low-dose hydrocortisone in critically ill children in septic shock remains poorly defined. The recognition of low ionized calcium concentrations and its treatment in hypotensive children is important since correction improves myocardial contractility and vasomotor tone.⁸¹

Damage control or hemostatic resuscitation principles can be applied to children in hemorrhagic shock, as in adults. Standard volumes for red blood cell, fresh frozen plasma, and platelet transfusions range from 10 to 15 ml per kilogram. For children requiring massive transfusion, which is typically defined as more than one blood volume (70 to 80 ml per kilogram) in 24 hours, hypothermia, hyperkalemia, and hypocalcemia are all risks.

Blood Product Transfusion

Standard volumes for red blood cell, fresh frozen plasma (FFP), and platelet transfusions range from 10 to 15 ml per kilogram. Cryoprecipitate dose is 1 to 2 units per 10 kilograms bodyweight.⁸⁵ For children requiring massive transfusion, which is typically defined as more than one blood volume (70 to 80 ml per kilogram) in 24 hours, hypothermia, hyperkalemia, and hypocalcemia are all risks.⁸⁶ As a result, the use of a blood warmer should be strongly considered, and frequent electrolyte monitoring is required. The treatment of hypocalcemia is important for patients with coagulopathy since calcium is required for optimal coagulation factor function.⁸⁶ This is critical in the patient requiring massive transfusion. The large citrate load in packed red blood cells binds calcium, increasing the risk of hypocalcemia.⁸⁶ If left uncorrected, this will lead to decreased cardiac function.⁸⁷ In addition, for children requiring massive transfusion, the treatment of acidosis with alkaline solutions with either sodium bicarbonate or THAM (tromethamine) can be considered.⁸⁶ Adjunctive pro-hemostatic agents such as recombinant factor VIIa (rFVIIa) and antifibrinolytics can also be considered.^{78,86} If rFVIIa is given, anecdotal experience and preliminary data indicate that it works best when used in conjunction with cryoprecipitate.⁸⁸ If thromboelastography is available, it can be used to direct hemostatic resuscitation and specifically determine if rFVIIa or antifibrinolytics are indicated.⁷⁸ For children who are hemodynamically stable without active bleeding, a hemoglobin concentration below 7 grams per deciliter is an appropriate red blood cell transfusion trigger.⁸⁹

Specific Medical Condition Management

Acute Respiratory Distress Syndrome (ARDS)

Acute respiratory distress syndrome (ARDS) in children is defined as it is in adults: (1) Partial pressure of oxygen in arterial blood (PaO_2)/fraction of inspired oxygen (FiO_2) ratio less than 200 mm Hg; (2) presence of bilateral lung infiltrates on the chest radiograph; (3) no clinical evidence of heart failure; and (4) absence of COPD or other chronic pulmonary disorders. Principles practiced in adults regarding ventilator (e.g., permissive hypercapnia) and fluid management are also used for children.⁵⁷ Goals include keeping peak inspiratory pressures less than 30 cm H_2O with the use of tidal volumes between 4 to 6 ml per kilogram bodyweight.⁵⁷ In addition, judicious fluid administration is recommended to prevent an excessive fluid balance since it has been associated with worse outcomes in adults with ARDS.⁹⁰ There is no limit to the amount of positive end-expiratory pressure that can be used to support oxygenation, and the prone position is also commonly used to attempt to improve oxygenation indices.⁵⁷ Nonconventional modes of ventilation, such as alternating pressure release ventilation (APRV) and high-frequency oscillation ventilation (HFOV), and alternative therapies, such as nitric oxide and surfactant therapy, are not currently available at Combat Support Hospitals.

Acute respiratory distress syndrome in children is defined as it is in adults. Principles practiced in adults regarding ventilator (e.g., permissive hypercapnia) and fluid management are also used for children. Nonconventional modes of ventilation are not currently available at Combat Support Hospitals.

Severe Sepsis and Septic Shock

Children respond differently hemodynamically to sepsis than adults.⁸¹ Children typically have decreased

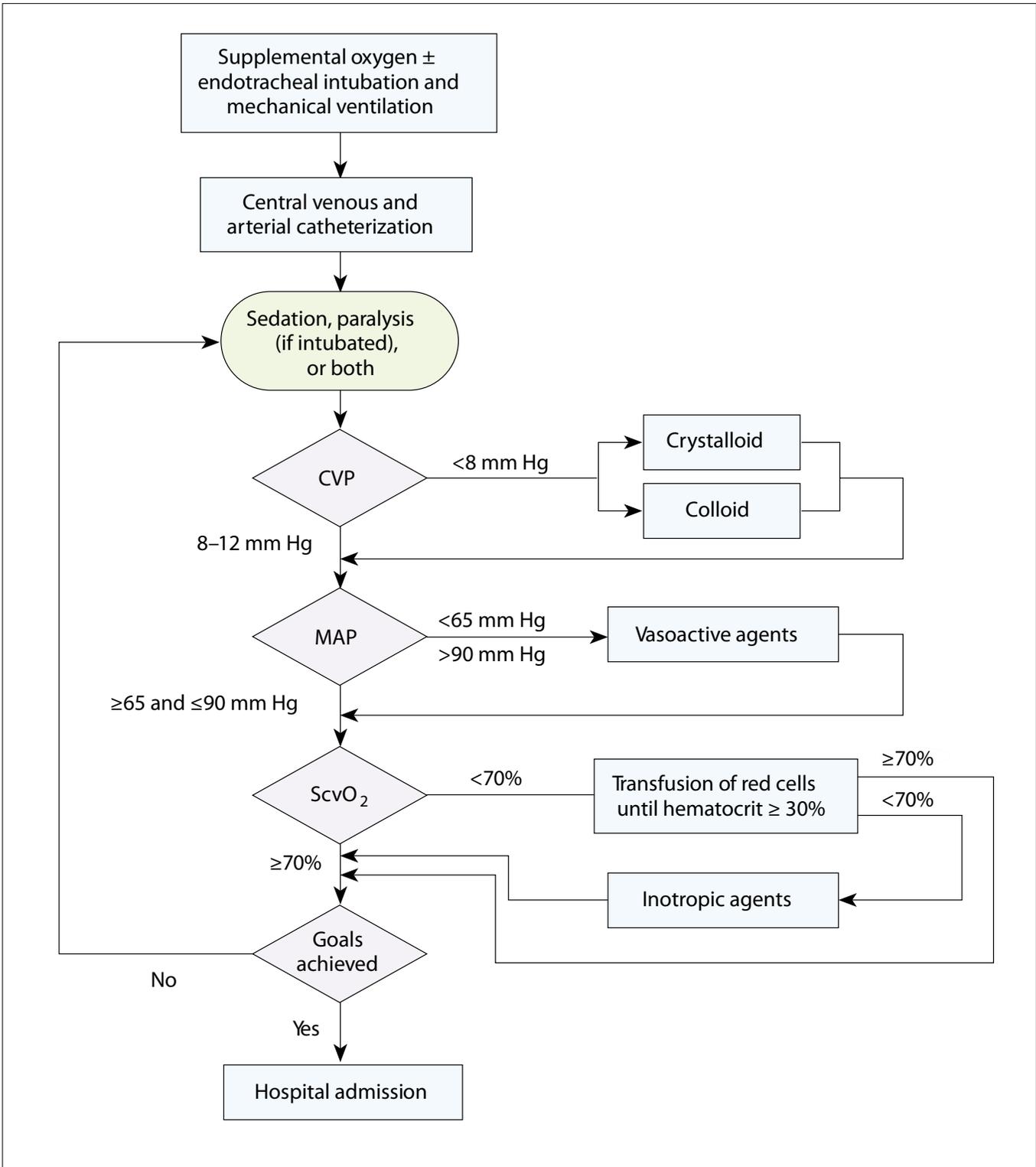


Figure 12. Protocol for early goal-directed therapy.⁹¹ CVP denotes central venous pressure, MAP mean arterial pressure, and ScvO₂ central venous oxygen saturation. Image courtesy of Massachusetts Medical Society.

myocardial function and compensate with increased systemic vascular resistance commonly referred to as “cold shock.” This is in contrast to adults who conversely first develop loss of vasomotor tone and compensate with increased cardiac function or what has been termed “warm shock.”⁸¹

Adhering to principles of goal-directed therapy for treatment of patients with severe sepsis and septic shock is warranted (Fig. 12).^{91,92} Therefore, the standard approach to septic shock in children is early administration of antibiotics and volume resuscitation, while correcting hypoglycemia and low ionized calcium concentrations. Correcting hypocalcemia is important since cardiac contractility is dependent upon normal serum ionized calcium concentrations. These interventions are coupled with infection source control (e.g., debridement of infected tissue). Either dopamine or epinephrine is appropriate as the initial inotrope.⁸² If cold shock persists and intravascular volume is adequate (determined primarily by a central venous pressure of greater than 8 mm Hg), the use of an afterload reducing agent, either dobutamine or milrinone, is appropriate. If warm shock develops, norepinephrine, phenylephrine, or vasopressin is appropriate. Hydrocortisone should be used for patients with catecholamine-resistant shock.⁸² Pulmonary artery catheters and other methods of determining cardiac output are not usually available at Combat Support Hospitals.



Figure 13. Careproviders reviewing a CT scan of the brain demonstrating an epidural hematoma.

Adhering to principles of goal-directed therapy for treatment of patients with severe sepsis and septic shock is warranted. The standard approach to septic shock in children is early administration of antibiotics and volume resuscitation while correcting hypoglycemia and low ionized calcium concentrations.

Cerebral Herniation Syndromes

Several immediate interventions are indicated when a child has signs and symptoms of impending cerebral herniation (hypertension, bradycardia, abnormal breathing pattern, and posturing). These include hyperventilation by manual bag-valve-mask as a temporizing measure while initiating additional interventions. Additional measures include elevation of the head of the bed to approximately 30 degrees, and the rapid administration of an osmotic agent. Mannitol or hypertonic saline can be used as osmotic agents.³⁹ If the patient is hypovolemic and volume resuscitation is problematic, mannitol should not be used since it will often have a diuretic effect several hours after infusion. The decrease in mean arterial pressure from diuresis will translate into decreased cerebral perfusion pressure.⁹³ Hypertonic saline may be a better choice in hypovolemic pediatric patients. The dose of 3% hypertonic saline is 10 ml per kilogram IV (maximum dose 250 ml per bolus) and should be given as a fast intravenous push for impending herniation. Pediatric dosage handbooks mention it is preferable to use a central line with hypertonic saline since there is a risk of thrombophlebitis when used peripherally.⁴⁹ This risk has also been noted with mannitol.⁹⁴ Therefore, the safest approach may be to use either agent with a central line.

If a child displays evidence of impending cerebral herniation, hyperventilation, elevation of the head of the bed, and infusion of mannitol or hypertonic saline are indicated.

Concurrent efforts (cranial computed tomography scanning) should be made to determine whether a neurosurgically treatable intracranial lesion exists (e.g., epidural hematoma) (Fig. 13). Prompt neurosurgical consultation will also enable placement of intracranial ventriculostomy tubes, which can real-time monitor intracranial pressures and provide a method to decrease intracranial pressure through the removal of CSF.³⁹

Seizure Management

The etiology of seizures in children that are evacuated to a Combat Support Hospital after an acute injury is likely to be related to traumatic brain injury or a consequence of hypoxic ischemic injury (Fig. 14). Hypoglycemia, hyponatremia, and other electrolyte disturbances should always be immediately ruled out as the cause of seizure. The differential diagnosis should also include meningitis, epilepsy, hypertension, and drug ingestion.

After determining that the patient's airway is patent and breathing and circulation are adequate, oxygen should be applied and vascular access obtained. A rapid-acting benzodiazepine such as lorazepam (0.1 mg per kilogram) or diazepam (0.2 mg per kilogram) should be administered intravenously as a first-line therapeutic agent if continued tonic-clonic seizure activity persists beyond one minute. If the seizure persists beyond several minutes, repeat dosing of rapid-onset benzodiazepines is indicated. Alternative routes of benzodiazepine administration include intraosseous, intranasal, buccal, and rectal administrations. If seizures recur or persist in the minutes that follow infusion of first-line agents (benzodiazepines), second-line therapy is indicated. Second-line agents include intravenous administration of phenytoin (18 to 20



Figure 14. A critically ill head-injured child at high risk for seizure activity.

mg per kilogram) or fosphenytoin (15 to 20 mg phenytoin equivalents per kilogram).⁹⁵ If phenytoin is administered, the rate should not exceed 1 mg per kilogram per minute (maximum infusion rate 50 mg per minute) due to the risk of fatal dysrhythmias.⁹⁵ Fosphenytoin has become the preferred second-line agent for the acute management of seizures in children for several reasons. While fosphenytoin will not work any faster than phenytoin and is more expensive, it does not have the serious risk of tissue necrosis that phenytoin possesses upon extravasation into soft tissues and can be administered intramuscularly or intravenously.⁹⁶ Phenobarbital (15 to 20 mg per kilogram) can be used in children instead of phenytoin or fosphenytoin as a second-line antiepileptic agent. Phenobarbital carries a profound respiratory depressant effect and can also cause hypotension upon intravenous administration.⁹⁵ Careproviders must be prepared to treat hypotension and/or apnea subsequent to infusion of barbiturates or multiple doses of benzodiazepines to control seizure activity.

The etiology of seizures in children that are evacuated to a Combat Support Hospital after an acute injury is likely to be related to traumatic brain injury or hypoxic ischemic injury. A rapid-acting benzodiazepine such as lorazepam (0.1 mg per kilogram) or diazepam (0.2 mg per kilogram) should be administered intravenously as a first-line therapeutic agent if continued tonic-clonic seizure activity persists beyond one minute.

Pediatric Advanced Life Support (PALS)

The Pediatric Advanced Life Support (PALS) course concepts have been developed to improve the recognition and treatment of cardiopulmonary failure in children. Early recognition of respiratory or cardiac failure and its reversal is obviously optimal. However, if a child arrests and cardiopulmonary resuscitation (CPR) is initiated, the following principles should be applied: the rate of cardiac compression should be 100 per minute, and full elastic recoil should occur with compressions to improve venous return into the thoracic cavity. Efficacy of CPR can be most effectively assessed by evaluating the diastolic pressure on the invasive arterial blood pressure monitor. The respiratory rate should not exceed 12 breaths per minute as hyperventilation will decrease venous return.⁷⁰ The differential diagnosis for all nonperfusing, bradycardic, and tachycardic rhythms include: hypoxemia, hypovolemia, hypothermia, hyper/hypokalemia, acidosis, tamponade physiology, tension pneumothorax, drug overdose, trauma, and thromboembolism.

For a pediatric cardiac arrest, the cardiac compression rate should be 100 compressions per minute. Full elastic recoil of the chest should occur between compressions to improve venous return to the thoracic cavity. The respiratory rate should not exceed 12 breaths per minute as hyperventilation will decrease venous return.

Cardiac Rhythm Disturbances

Treatment of cardiac rhythm disturbances must occur with the clinical context of the patient in mind. The treatment of pulseless electrical activity in the setting of hypovolemic shock due to traumatic hemorrhage will be futile unless concurrent efforts to restore blood volume and stop ongoing hemorrhage are undertaken. However, CCC providers should be familiar with standard therapies for the more commonly encountered cardiac rhythm

disturbances encountered in critically ill children. In reality, many cases will involve immediately initiating cardiac rhythm disturbance treatments while identifying and treating concurrent contributory medical conditions. It is important to note that the QRS complex is age-dependent. A wide QRS complex is defined as greater than or equal to 80 milliseconds in infants and young children up to age three years; greater than 80 milliseconds in children ages four to nine years; greater than 90 milliseconds between ages nine and 11 years; and greater than 100 milliseconds in children age 12 and above (Table 6).^{97,98}

AGE (YEARS)	TIME
Infants to 3	≥ 80 milliseconds
4 to 9	> 80 milliseconds
9 to 11	> 90 milliseconds
12 and above	> 100 milliseconds

Table 6. *Definition of wide QRS complex based on patient's age.*

Combat casualty care providers should be familiar with standard therapies for the more commonly encountered cardiac rhythm disturbances encountered in critically ill children.

Asystole and Pulseless Electrical Activity

Rapid initiation of CPR should occur followed by 0.1 ml per kilogram of epinephrine (1:10,000) or 0.01 mg per kilogram of epinephrine IV injection every three to five minutes while attempting to reverse the cause of the arrest.⁷⁰

Pulseless Ventricular Tachycardia and Ventricular Fibrillation

Standard treatment includes the rapid initiation of CPR, then defibrillation at 2 joules per kilogram, another five cycles of CPR, defibrillation at 4 joules per kilogram, then epinephrine (1:10,000) 0.1 ml per kilogram IV, five cycles of CPR, defibrillate at 4 joules per kilogram, then amiodarone (5 mg per kilogram) IV, while attempting to identify and reverse the cause of the arrest.⁷⁰

Bradycardia with Poor Perfusion

Cardiopulmonary resuscitation should be initiated for a pulse rate less than 60 with poor perfusion, then epinephrine, atropine, and cardiac pacing should be considered while attempting to identify and reverse the cause of the arrest. Keep in mind that bradycardia is a very common manifestation of hypoxemia in children.⁷⁰ Conversely, bradycardia with good perfusion occurs with severe traumatic brain injury and herniation syndrome.

Bradycardia is a very common manifestation of hypoxemia in children.

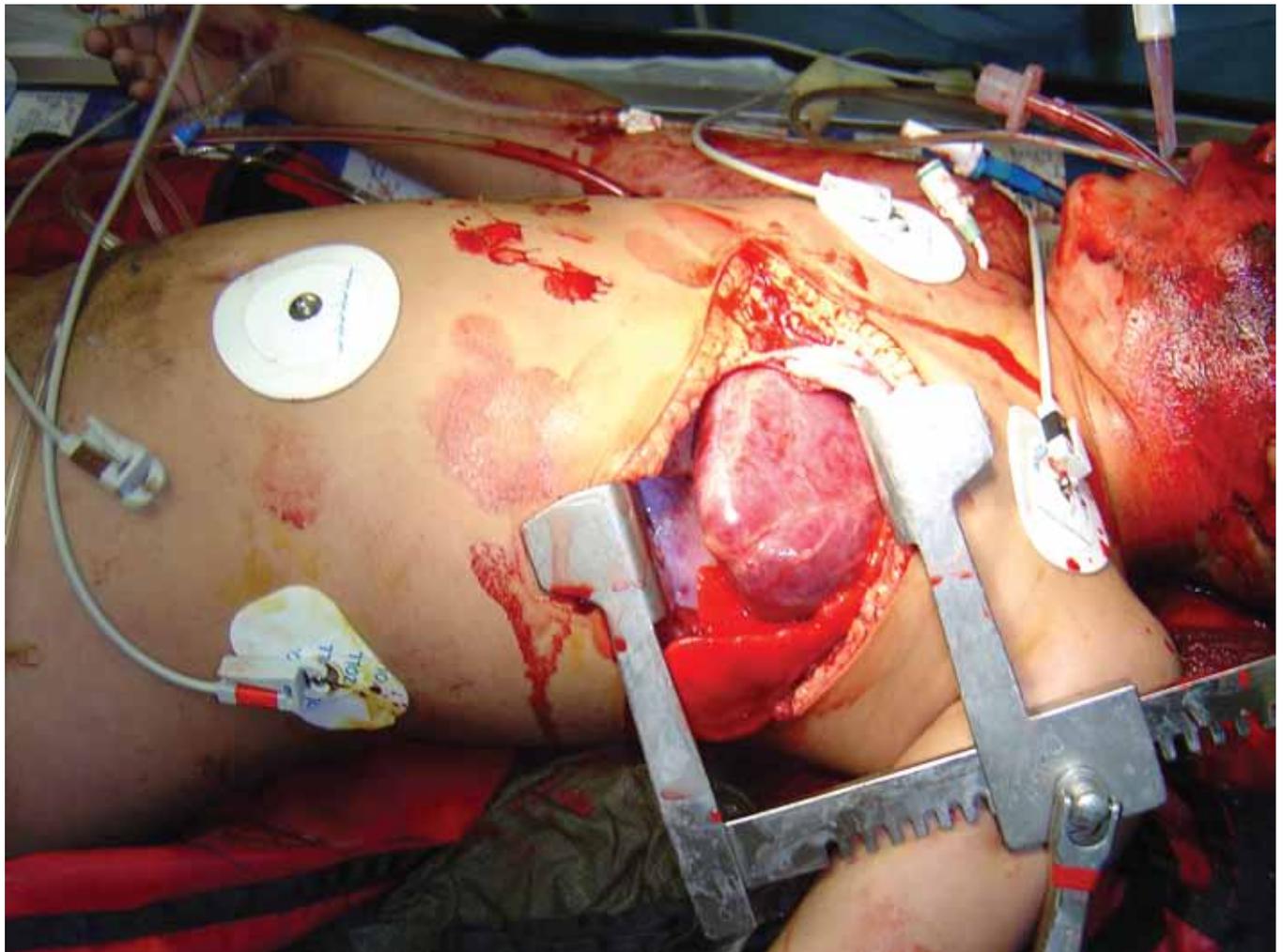


Figure 15. The left anterior fifth intercostal space is used as the standard approach for resuscitative thoracotomies in pediatric patients, as in adults. Image courtesy of J. Christian Fox, MD, University of California, Irvine.

Narrow Complex (Supraventricular) Tachycardia

If good perfusion is noted, administer adenosine 0.1 mg per kilogram IV as a fast-push infusion. Since the half-life of adenosine is five seconds, the use of a three-way stopcock with another syringe in-line for a flush allows for rapid bolus administration. A repeat dose of adenosine at 0.2 mg per kilogram IV can be given if needed.⁷⁰ Amiodarone 5 mg per kilogram over 20 to 60 minutes can be used as a second-line agent in refractory cases. If poor perfusion is noted, synchronized cardioversion with 0.5 to 1 joules per kilogram is indicated followed by adenosine and amiodarone administration as indicated.⁷⁰

Wide Complex (Ventricular) Tachycardia

If good perfusion is noted, amiodarone, 5 mg per kilogram IV over 20 minutes should be administered. Administration of adenosine, 0.1 mg per kilogram IV fast-push can be considered in patients with adequate perfusion who are suspected of having supraventricular dysrhythmias with associated bundle branch block(s) resulting in wide complex QRS rhythms. If poor perfusion is noted, synchronized cardioversion of the patient with 0.5 to 1 joules per kilogram is indicated. This is followed by administration of amiodarone, and then adenosine as indicated.⁷⁰

Surgical Considerations

Thoracic Interventions

Resuscitative thoracotomies are best done for penetrating trauma when vital signs have been present within minutes of patient arrival to the trauma suite (Fig. 15).⁹⁹ Resuscitative thoracotomies for blunt trauma are almost uniformly unsuccessful when vital signs have been lost prior to arrival in the trauma suite.¹⁰⁰ A left anterior fifth intercostal space is the approach most commonly employed during emergency resuscitative thoracotomy. Advantages of this approach include ease of access to the heart and great vessels. The disadvantage is that access to the lower lobes of the lung becomes more difficult. Regardless of the approach, Rummel tourniquets should be available on all resuscitative thoracotomy trays for children and infants (Fig. 16). This obviates the concern about the appropriate-sized vascular clamp. The other point unique to children is that pneumonectomies in the very young will lead to scoliosis and lack of chest wall development on that side (post-pneumonectomy syndrome).¹⁰¹ Thus, trauma pneumonectomy should be considered only as a last resort. As in adults, the vast majority of chest trauma can be managed with either observation or tube thoracostomy alone.¹⁰²

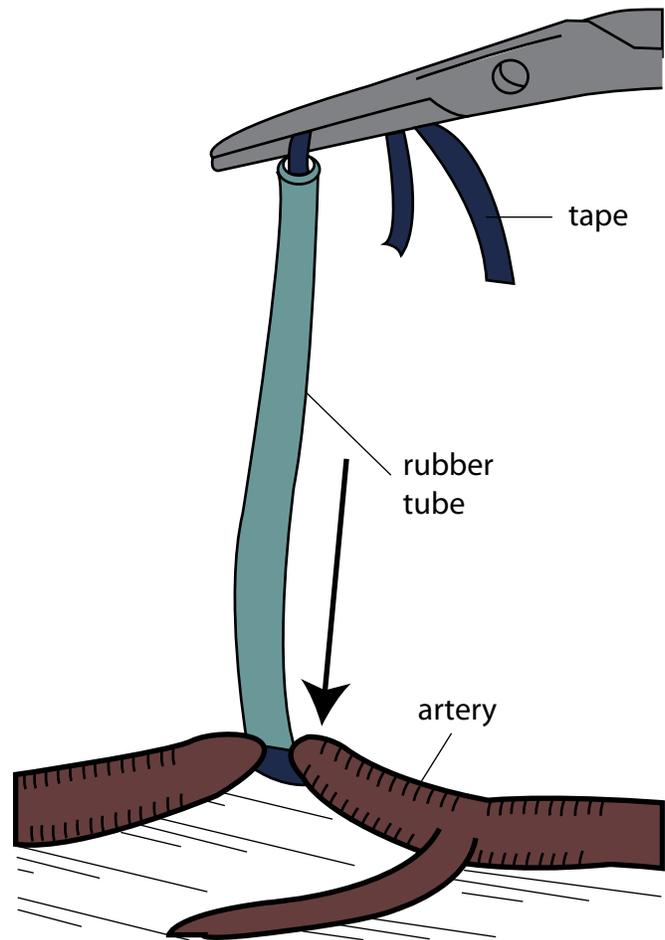


Figure 16. Appropriately-sized vascular clamps are not always available in combat settings. As an alternative, Rummel tourniquets may be used for vascular control. A tourniquet is fashioned by passing umbilical tape around a vessel, threading both ends through a short rubber catheter, and securing with a perpendicularly placed hemostat.

Resuscitative thoracotomies for penetrating trauma are most successful when vital signs have been present within minutes of patient arrival to the trauma suite. Resuscitative thoracotomies for blunt trauma are almost uniformly unsuccessful in patients arriving without signs of life.

Abdominal Interventions

For children less than two years of age, a transverse laparotomy is thought to provide adequate exposure to the entire abdomen, has a lower dehiscence rate, and is generally the accepted approach for elective operations.¹⁰³ While this is true for elective operative cases, many surgeons would argue for an alternative incisional approach in the case of traumatic injury.¹⁰⁴ A midline laparotomy allows for supraceliac aortic control as well as iliac control with minimal changes in retraction (Fig. 17).¹⁰⁴ The approach should be dependent upon the mechanism and severity of the injury, as well as the hemodynamic instability of the patient.

Pediatric surgeons favor splenic salvage whenever possible. An important point in splenic preservation is complete mobilization of the spleen prior to addressing the hilum. The goal is to spare at least 30 percent of the spleen for immunologic function, as less than that will not yield a benefit.¹⁰⁵ Also, it is important to

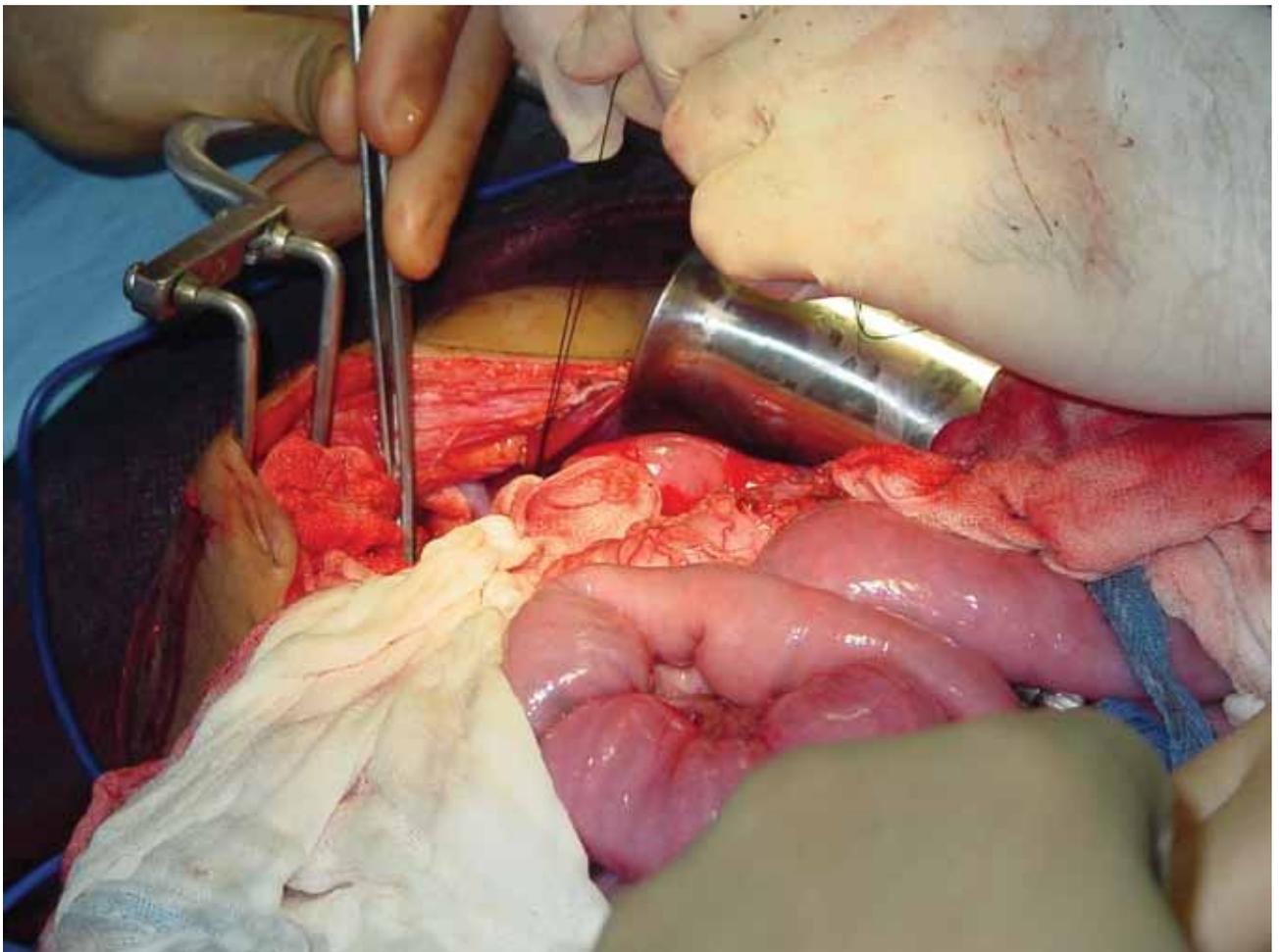


Figure 17. Laparotomy in a 5-year-old male performed through a midline incision. A midline laparotomy allows for supraceliac aortic control as well as iliac control with minimal changes in retraction. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.

remember that associated injuries (especially head) represent relative contraindications to attempting nonoperative splenic preservation.

When dealing with a liver injury, the decision whether to pack or repair the injury is critical. Some advocate that this decision should be delayed until the liver has been fully mobilized. This requires division of both triangular ligaments as well as the falciform ligament from their respective diaphragmatic attachments. Only then can adequate compression be applied and the decision to pack versus repair be made. However, others are in favor of preserving ligamentous attachments to achieve more effective packing. If repair is attempted, blood flow to the liver needs to be temporarily controlled in order to prevent overwhelming blood loss.¹⁰⁶ The correct size of vascular clamps is not always available in the pediatric-aged population, thus Rummel tourniquets are extremely helpful to control the portal hilum as well as the hepatic veins, retrohepatic cava, and inferior vena cava in order to achieve complete vascular isolation of the liver.

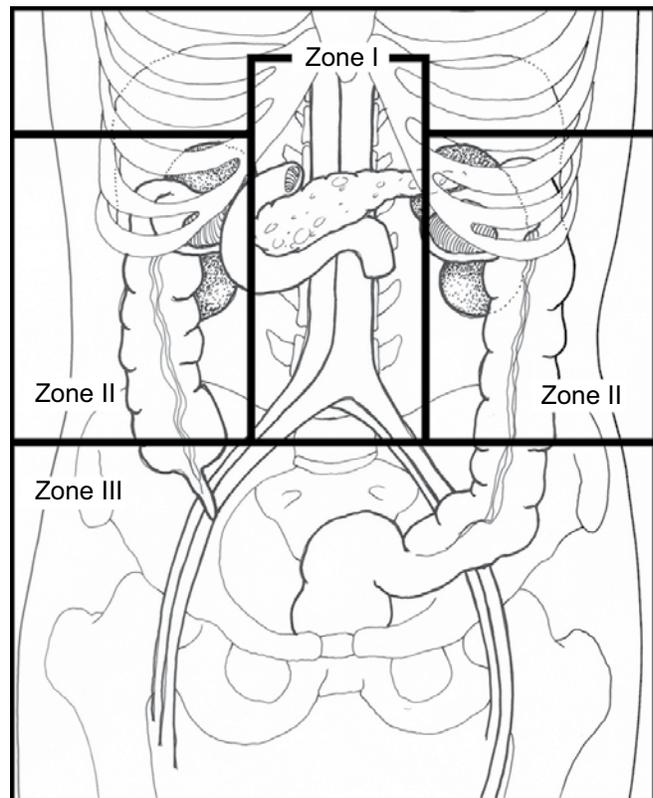


Figure 18. *Zones of the retroperitoneum. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.*

While the surgical approach to retroperitoneal injuries (pancreas, duodenum, aorta) represents a chapter in and of itself, the following principles hold true. Prior to entering a zone I (central) retroperitoneal hematoma, vascular control of the aorta and vena cava, respectively, needs to be achieved (Fig. 18). For any central hematoma involving the duodenum or pancreas, a full Kocher maneuver to elevate the head of the pancreas and to inspect the posterior duodenum needs to be performed. This will assist in vascular control and allow for complete inspection of the head of the pancreas and duodenum. Finally, for all injuries requiring surgery for the pancreas and/or duodenum, wide drainage should be employed before closing the abdomen.

For traumatic injuries of the pancreas involving ductal disruption, there has been support for a nonoperative approach.¹⁰⁷ Operative intervention will necessitate full hospital and ancillary support (e.g., parenteral nutrition), prolonged hospitalization, and interventional radiology support to address complications.¹⁰⁸ If resources are at a premium, major pancreatic ductal disruptions need to be surgically corrected either with distal pancreatectomy or a Whipple procedure depending upon injury location. There has been a recent case report of a minimally invasive splenic preserving approach to pancreatic injury.¹⁰⁹ It is the authors' opinion that splenic preservation and a minimally invasive approach are not part of the algorithm for the operative management of severe pancreatic traumatic disruptions in a combat environment. The limited resources in most CCC environments make nonoperative management of such injuries difficult.

In the case of major penetrating duodenal injury, there is paucity in the literature of long-term outcomes or even large series in children. It is generally accepted that children tolerate primary duodenal repair better

than their adult counterparts, and this needs to be considered if the head of the pancreas is spared in the face of a duodenal injury. This approach will decrease the operative time and eliminate the need for future intervention. However in the authors' opinion, when in a combat theater where total parenteral nutrition, intensive unit care, blood products, and preoperative factors such as the nutritional status and immunologic status of the patients are questionable, primary repair should either be avoided or performed in carefully selected patients. In the event of significant additional injuries (e.g., burns) that may affect healing, primary repair may give way to a more complex approach that involves isolation, exclusion, and drainage maneuvers that are well developed in adults.¹¹⁰ These include pyloric exclusion proximal to a duodenal repair and gastrojejunostomy or tube externalization of the duodenum, t-tube decompression of the biliary system, gastrostomy, and jejunostomy with or without antrectomy and establishment of gastrointestinal continuity.¹¹¹

When encountering intestinal perforations, the decision to exteriorize the injury or primarily repair it has its evidence-based background embedded in military history. Once again, there is a lack of evidence-based literature in children, so our practice relies on the adult experience. The state of the art has gone from initial primary repair, to exteriorization of all colon injuries, to a physiologic basis for our operative decisions.¹¹² The decision to perform colostomies or small intestinal stomas should be based upon the degree of hemodynamic instability, shock, and the presence of other injuries, rather than the degree of destruction of the colon or small intestine.¹¹³

Finally, the single most important decision when performing a trauma laparotomy is when and how to close. Deciding that any procedure is only for "damage control" is best done within the first 20 minutes of the procedure.^{114,115} Children, like adults, do not tolerate abdominal compartment syndrome. Unlike adults, the physiologic response in children is not one of gradual and progressive hemodynamic compromise (i.e., decreased urine output, development of hypotension, response to volume and pressors, and then continued deterioration). Children often develop increased intraabdominal pressure with less overt signs and symptoms and then unexpectedly suffer a major cardiorespiratory event.¹¹⁶ This may be due to the fact that abdominal compartment syndrome is underrecognized in children.

Monitoring of intraabdominal pressure and following a calculated splanchnic perfusion pressure has been useful in managing other models of abdominal compartment syndrome, specifically gastroschisis.⁴⁴ The placement of silon sheeting has been the traditional approach to this problem in congenital anomalies.¹¹⁷ This is suboptimal in a traumatic situation where drainage and monitoring of the intraabdominal fluid has both diagnostic and therapeutic value. The development and use of the wound vacuum-assisted closure (V.A.C.®) devices or "trauma vac" have become a useful adjunct to control fascial contraction, allow for abdominal wall expansion, monitor for bleeding, manage fluids, and allow instant access for reoperation (Fig. 19).¹¹⁸ In addition, the concern of increased morbidity

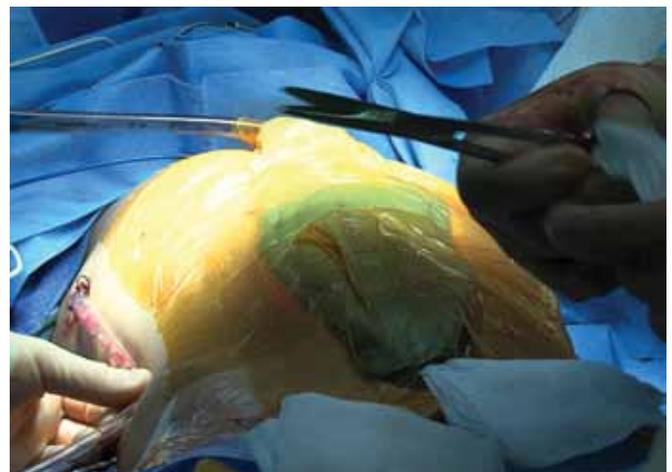


Figure 19. Pediatric damage control laparotomy following fragmentation injuries from an IED blast. Given the susceptibility of children to abdominal compartment syndrome, the abdominal wall was left open and covered with a wound V.A.C.®

from bowel fistulization has not been born out in the recent literature.¹¹⁹ In the authors' opinion, use of this system alleviates the need for constant intraabdominal pressure monitoring and should be employed liberally as part of the damage control procedure in children. In addition, one can achieve a V.A.C.®-like closure with any sterile adhesive plastic drape, sponges, sterile plastic sheets, and a suction apparatus. These materials are typically available in a Combat Support Hospital.

The single most important decision when performing a trauma laparotomy is when and how to close the abdomen. Deciding that any procedure is only for damage control is best done within the first 20 minutes of the procedure.

Burn Care

Differences in burn care for children versus adults are minimal and predominantly involve fluid and nutritional management (Fig. 20). For children less than 30 kg, glucose should be added to the intravenous maintenance fluids that are in addition to the amount of fluid replacement calculated based upon the Parkland or any other formula that is used.¹²⁰ The body surface area burned is based upon second- and third-degree burns and can be estimated according to age-based charts.¹²⁰ In general, the size of the child's palm is equal to one percent of body surface area.¹²¹



Figure 20. *Pediatric burn patient with injuries sustained from a civilian motor vehicle accident. The patient developed capillary leak syndrome, acute respiratory distress syndrome, and abdominal compartment syndrome.*

Both hyper- and hypoglycemia should be avoided. There is always a risk of over-resuscitating a patient with burn injuries when algorithmic fluid infusion and urine output alone are used to guide fluid replacement. Vital signs and hemodynamic parameters should also be utilized to determine the patient's intravascular volume status. The development of conditions associated with over-resuscitation such as acute respiratory distress syndrome or abdominal compartment syndrome should be closely monitored. It is critical to avoid over-resuscitation in a combat environment while remembering that most burns encountered in a combat environment are almost always associated with blast injuries. Thus underlying muscle damage causing myolysis and eventual renal failure are accentuated with low urine output states. Early excision and grafting for all nonviable skin are recommended. When dealing with large volume surface area burns, care must be taken to preserve all viable skin surface. The availability of artificial skin barriers and temporary skin coverage may be limited and the only viable grafting material may be the patient's surviving skin. Finally, transfer to a burn unit, while always the first option, may not be possible or available; thus, a clean environment needs to be established for the acute and chronic care of these patients.

Differences in burn care for children versus adults are minimal and predominantly involve fluid and nutritional management. There is always a risk of over-resuscitating a patient with burn injuries when algorithmic fluid infusion and urine output alone are used to guide fluid replacement. Vital signs and hemodynamic parameters should also be utilized to determine the patient's intravascular volume status.

Neurosurgical Interventions

Forward Neurosurgical Care by Non-Neurosurgical Careproviders

Non-neurosurgical providers are increasingly tasked with the care of neurotrauma patients in a CCC environment. Unconventional warfare places children in harm's way, where the combination of their natural curiosity, disproportionate head size, and lack of protective equipment can lead to tragic results. Local geography, weather, tactical considerations, medical rules of engagement, and limited subspecialty availability often conspire to bring these casualties to the door of facilities staffed with non-neurosurgical careproviders. Caring for these patients is resource intensive and emotionally taxing for all members of the health care team. It requires both a clear understanding of coalition and host nation medical capabilities and advanced preparation on the part of providers and facilities.

While a complete review of forward neurosurgical care is beyond the scope of this chapter, careproviders should acquire technical and decision-making skills in neurotrauma prior to deployment. The training of non-neurosurgical personnel for this task is not a new concept, but surprisingly little progress has been made in this area since World War I.¹²² However, past successes in civilian settings both in the United States and elsewhere speak to the potential of this approach.^{123,124} Resources include formal courses, informal courses by local neurosurgical providers, and self-education through literature review.^{125,126} While deployment may require a careprovider to reach into the periphery of clinical comfort zones, some lines are better not crossed. Each careprovider should carefully assess his or her ability to perform select critical neurosurgical interventions in a forward environment. Critical interventions include: (1) scalp closure; (2) ICP monitoring; and (3) limited craniectomy for extradural hemorrhage. Individual non-neurosurgical careproviders will need to decide whether they are competent to perform such procedures when clinically indicated in a forward environment. Palliative care remains a viable option for patients with devastating neurological injuries and is often the prudent course of action in a CCC environment with limited resources.

Non-neurosurgical providers are increasingly tasked with the care of neurotrauma patients in a CCC environment. Careproviders should acquire technical and decision-making skills in neurotrauma prior to deployment. Critical interventions include: (1) scalp closure; (2) ICP monitoring; and (3) limited craniectomy for extradural hemorrhage.

ADDITIONAL INSTRUMENTS	SUGGESTED DISPOSABLES
<ul style="list-style-type: none">• Raney clip applier• Hudson brace• Disposable perforator bit (Codman®)• Penfield dissectors #1, #4• Leksell rongeur, large• Kerrison rongeur, 3 mm or greater• Adson cerebellar retractor• Bipolar cautery unit (if available)	<ul style="list-style-type: none">• Raney clips• Gelfoam®• Thrombin™• Surgicel®• Bone wax• 35 cm-ventricular catheter with trochar• Lumbar drain catheter• ICP monitor system

Table 7. Instruments typically available for neurosurgical interventions at a Level III facility.

Local facility considerations are of paramount importance (Table 7). Medical rules of engagement, equipment availability, careprovider skill sets, imaging capabilities, and coalition and host nation medical assets all influence medical decision making in a deployed environment. Pediatric neurotrauma patients are particularly problematic from a disposition standpoint, as many resource-constrained nations are not equipped to provide supportive care for patients whose needs exceed the limited holding capabilities of deployed medical facilities. It is the responsibility of facility leadership to address these issues, prospectively if possible, and to ensure that care delivery does not place unsustainable burdens on host nation medical facilities. This may involve difficult ethical decisions that are among the most challenging aspects of deployment medical care.

Surgical Management of Head Injuries

The principles of caring for adult and pediatric neurotrauma patients are more similar than different. However, the assessment and management of pediatric neurotrauma patients do provide unique challenges in the delivery of care.

Triage and Initial Assessment

Good triage requires the timely consideration of pertinent clinical information about multiple casualties within the framework of resources available. In a deployed environment, this may result in decisions to delay or even withhold treatment that would be readily offered in a civilian environment. As host nation citizens, pediatric casualties must be treated with the intention to return them to host nation medical facilities within a timeframe that is compatible with the treating facility's holding capacity and mission.

Presenting neurologic status is consistently cited as a valuable tool in predicting outcome from both closed and penetrating head injuries.^{127,128} A complete, concise neurologic assessment is therefore invaluable to the triage officer in evaluating salvageability of casualties in a deployed environment. In the authors' opinion, the presenting exam is the most valuable information available for determining prognosis of a casualty. For the exam to be valid, it must be obtained following appropriate resuscitation and in the absence of confounding medications including sedatives, hypnotics, analgesics, and muscle relaxants. This requires resuscitation to normotension, normothermia, and restoration of physiologic arterial oxygen and carbon dioxide pressures.

Presenting neurologic status is consistently cited as a valuable tool in predicting outcomes following head injuries. For the exam to be valid, it must be obtained following appropriate resuscitation and in the absence of confounding medications including sedatives, hypnotics, analgesics, and muscle relaxants.

On occasion, some patients may require administration of appropriate weight-based medication reversal agents and twitch-monitor assessment to ensure pre-facility medications do not interfere with a baseline exam (Table 8). Reversal of medications with antiepileptic properties (e.g., benzodiazepines) in the setting of head injury may precipitate seizure activity, which would further secondary brain injury. Alternative approaches include providing supportive care pending metabolism and elimination of confounding medications.

Pupillary exam is an important indicator of outcome in civilian closed and penetrating head injuries. In the setting of epidural hematoma, latency to treatment exceeding 90 minutes after the development of

WEIGHT-BASED DOSING OF REVERSAL AGENTS

- Neostigmine (50 micrograms [mcg] per kilogram)
- Glycopyrrolate (10 mcg per kilogram)
- Naloxone (0.1 mg per kilogram)
- Flumazenil (10 mcg per kilogram)

Table 8. *Weight-based dosing of agents to assist with pharmacologic reversal of sedation/paralysis.*

	GCS	PEDIATRIC GCS	INFANT FACE SCALE
Eyes			
1	No opening	No opening	No opening
2	Open to pain	Open to pain	Open to pain
3	Open to voice	Open to voice	Open to voice
4	Spontaneous	Spontaneous	Spontaneous
Verbal			
1	No response	No response	No facial expression to pain
2	Incomplete sounds	Inconsolable, agitated	Grimaces to pain
3	Inappropriate words	Inconsistently inconsolable	Cries to deep pain only
4	Confused	Cries, consolable	Cries to minor pain, alternating with sleep
5	Oriented	Smiles, tracks appropriately	Cries to minor pain, alternating with wakefulness
Motor			
1	No response	No response	Flaccid
2	Decerebrate	Decerebrate	Decerebrate
3	Decorticate	Decorticate	Abnormal rhythmic movements (seizure-like)
4	Flexion withdrawal	Withdraws to pain	Nonspecific movements to deep pain
5	Localization	Withdraws to touch	Hypoactive spontaneous movements
6	Follows commands	Purposeful	Normal spontaneous movements

Table 9. *Modified scales of neurologic assessment in pediatric patients.*

anisocoria has been shown to correlate with dramatic increase in mortality.¹²⁹ In penetrating injury, bilaterally fixed and dilated pupils have been shown to be highly predictive of mortality.¹³⁰ Pupil responsiveness is an objective finding that is easily assessed regardless of patient age. A common misconception by careproviders is that muscle relaxants and paralytic medications (e.g., pancuronium) impair pupil responsiveness. They do not. Among medications frequently used during resuscitation in children, atropine and epinephrine are likely to impair pupillary responsiveness, with effects varying from minutes to several hours.¹³¹

Pupillary responsiveness is an objective finding that is easily assessed regardless of patient age and is an important indicator of outcome. Muscle relaxants and paralytic medications (e.g., pancuronium) do not impair pupillary responsiveness.

The Glasgow Coma Scale (GCS) is a highly effective tool in the assessment of neurotrauma patients. Developed to improve communication about the neurologic state of comatose patients, the GCS is an excellent predictor of neurologic outcome in head-injured patients.^{132,133} Glasgow Coma Scale scores in preverbal children are more problematic due to immature motor pathways and limited or absent verbal skills on an age-related continuum. Alternative grading scales such as the pediatric GCS or Infant FACE Scale should be utilized in these patients (Table 9).¹³⁴

Glasgow Coma Scale scores in pre-verbal children are problematic due to immature motor pathways and limited verbal skills. Alternative grading scales include the pediatric GCS or Infant FACE scales.

Neuroimaging, when available, is another valuable tool for patient triage. Computed tomography (CT) scanners are currently available at Level III facilities in both Afghanistan and Iraq (Fig. 21). Reliable forward imaging technology has been a major advance of the past decade. The Traumatic Data Coma Bank Classification Scale identified two findings that were consistently predictive of worsened neurologic outcome: compression or absence of patent basal cisterns and degree of midline shift (Fig. 22).¹³⁵ Additional anatomic information regarding relative distribution (lateralized versus diffuse pathology), location (intradural versus extradural and frontal/temporal/parietal), and reversibility of injuries can also be determined for both adult and pediatric patients by cranial CT. In the clinically unstable patient, ICP monitoring can also be used as a triage tool. Uncontrolled intracranial hypertension has been associated with a high rate of mortality and poor neurologic outcome.¹³⁶ Unstable patients undergoing emergent laparotomy/thoracotomy with suspected severe head injuries can undergo simultaneous ICP monitor placement, facilitating decisions on cessation of clinical efforts for overwhelming injuries. The authors employed the following algorithm in the management of pediatric head trauma patients in 2007 at a Level III facility with neurosurgical support and a two-week patient holding capacity (Table 10).



Figure 21. CT scanners are currently available at Level III facilities in both Afghanistan and Iraq.

Repair of Scalp Injuries

Early and aggressive treatment of scalp injuries is perhaps the most important technical skill for careproviders to acquire in the management of the forward head-injured patient (Fig. 23). Adequate exposure of injuries is essential, and aggressive shaving of the scalp is often required to fully identify what are frequently multiple injuries (Fig. 24). The value of routine practice of shaving scalp wounds has been questioned, and civilian studies have linked routine preoperative skin shaving with increased infection

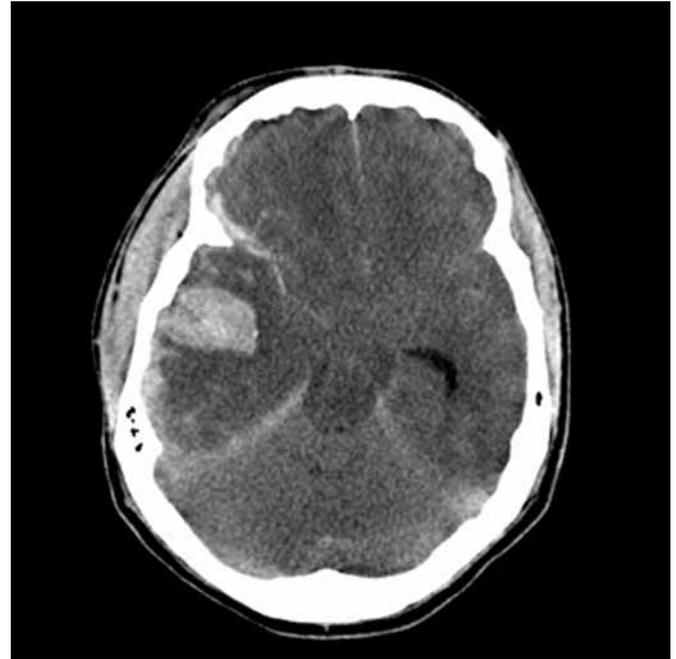
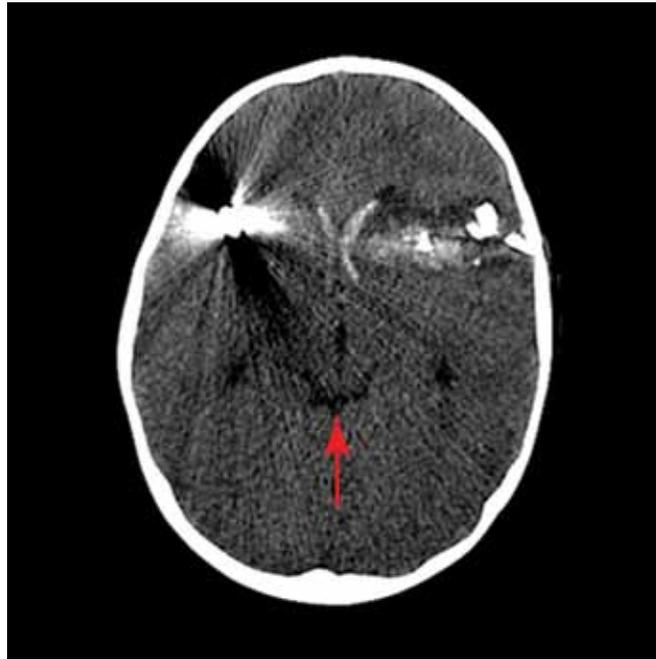
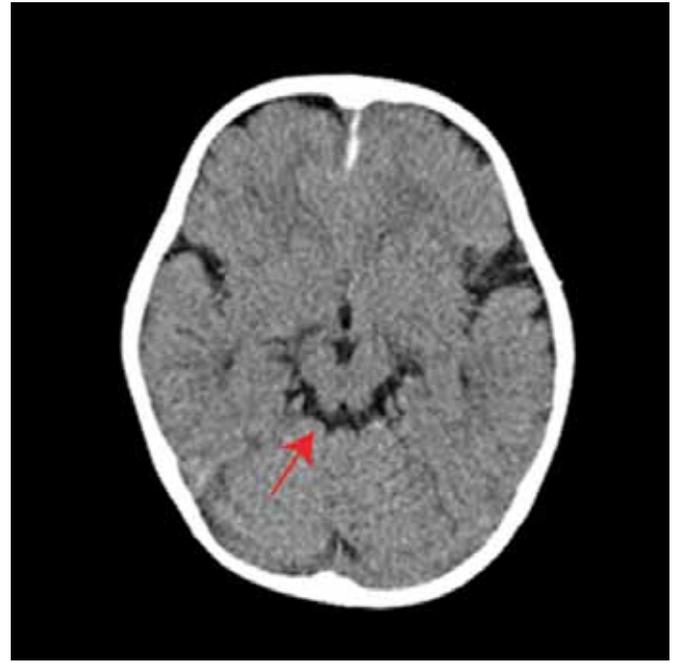


Figure 22. (Top Left) Axial image demonstrating the pentagon-shaped suprasellar cistern. (Top Right) Axial image demonstrating the 'smile'-shaped quadrigeminal plate cistern. Normal head CT demonstrating patency of basal cisterns in the setting of normal ICP. These small-volume spinal fluid spaces are excellent indirect markers of ICP. (Bottom Left) Despite trajectory of fragment across the midline and ventricular system, no midline shift is present and the basal cisterns remain patent. The patient required limited debridement only and was discharged from the hospital on post-injury day four. (Bottom Right) In this patient who suffered a blast-related injury, marked midline shift is present with effaced basal cisterns. Palliative care was elected, and the patient expired.

1. Assess Pupils

- Palliative care if *bilateral fixed and dilated pupils* or *unilateral fixed and dilated pupils* documented for greater than 90 minutes without signs of direct trauma to the globe

2. Perform GCS Score or Age-Equivalent Assessment

- GCS scores 9 to 15 mandate aggressive intervention
- GCS scores 6 to 8 consider intervention based on available resources. Imaging helpful in identifying favorable prognosis
- GCS scores 3 to 5 indicate palliative care

3. Review imaging if available

- Favorable prognosis: Basal cisterns patent, less than 1 centimeter midline shift, focal extraaxial mass lesion
- Unfavorable prognosis: Basal cisterns effaced, greater than 1 centimeter midline shift, intraaxial hemorrhage, diffuse injury pattern

Table 10. Suggested algorithm for neurosurgical triage at Level III facilities.



Figure 23. Local advancement flaps to address scalp defect: (Left) One-year-old female with midfrontal penetrating fragment head injury. (Right) Opposing advancement flap closure of scalp defect performed after wide local shaving, exposure, and management of intracranial injury.

rates.^{137,138,139,140,141} In civilian practice, routine scalp shaving has given way to clipping, cutting hair with scissors, or using lubricant gel to congeal and move hair away from wound margins. The complex wound patterns seen in combat and difficulty identifying multiple scalp injuries are cited as reasons for shaving of the scalp to enable better wound bed visualization.

Early and aggressive treatment of scalp injuries is perhaps the most important technical skill for careproviders to acquire in the management of the forward head-injured patient.



Figure 24. Aggressive shaving of the scalp allows for identification and exposure of all injuries and is essential in the management of wartime penetrating head injuries.

Judicious debridement techniques, identifying vascular pedicles, simple rotational and advancement flap techniques, and two-layer closure techniques (galea and skin) can be rapidly learned by all clinicians with even limited surgical skill. Excellent reviews of these techniques are readily available in the literature.¹⁴² Scalp closure alone, as opposed to more extensive cranial operative intervention, is often the primary surgical intervention required to manage patients with low-velocity, fragmentary (e.g., shrapnel) penetrating head injuries.¹⁴³ For example, Taha et al. found that 32 such patients with a GCS score of 10 or higher, entry wounds less than two centimeters in size, and treated within six hours of injury who had negative CT scans for intracranial bleeding, did well with scalp wound closure alone in the emergency department.¹⁴³

Pediatric patients with limited circulating blood volume are highly susceptible to hypovolemic shock from scalp injuries. Beyond common-sense measures such as the application of pressure, management of scalp lacerations associated with closed head injuries can be facilitated by the use of local vasoconstricting agents such as Xylocaine® (0.5% lidocaine with epinephrine 1:100,000), with

weight-based lidocaine with epinephrine dosing not to exceed 7.5 mg per kilogram. Use of lidocaine in penetrating head injuries should be tempered by the potential for subarachnoid infusion with seizure induction. Simple hemostatic devices can also be utilized. Raney clips are widely available within surgical sets at Level III facilities (Fig. 25). They are of lower utility in infants and toddlers due to limited scalp thickness in these patients. Another technique is the application of Dandy clamps (hemostats) along the galea with the application of upward traction or reflection of the clamps outward.

With smaller circulating blood volumes, pediatric patients are highly susceptible to hypovolemic shock from scalp injuries.



Figure 25. Application of Raney clips to the scalp and galea is a valuable technique for hemostasis in the surgical management of head injuries.



Figure 26. Intracranial pressure monitoring systems can readily be inserted in an austere environment to assist with the diagnosis and management of the head-injured patient.

Intracranial Pressure Monitoring

Intracranial pressure monitors and intraventricular drainage catheters are powerful tools that provide valuable diagnostic information and therapeutic benefits for head-injured patients. Both parenchymal and fluid-coupled systems are currently available in the US military medical supply system (Fig. 26). The Codman® ICP EXPRESS (Codman, USA) is the standard intraparenchymal monitoring system utilized, while several vendors have 35-centimeter ventricular catheters with trochars available. Insertion techniques for these systems are easily taught to careproviders with basic surgical skills, and relative complication rates for insertion are low.¹⁴⁴ In the authors' experience, infection rates for intraventricular catheters placed in a field environment are high, and the choice for insertion of these catheters over parenchymal monitors should be weighed carefully. Appropriate indications for intraventricular catheter placement include management of refractory intracranial hypertension and spinal fluid leak.³⁹

Intracranial pressure monitors and intraventricular drainage catheters are powerful tools that provide valuable diagnostic information and therapeutic benefits for head-injured patients. Insertion techniques for these systems are easily taught to careproviders with basic surgical skills, and relative complication rates for insertion are low.

While anatomic landmarks for insertion are identical to those used for adult patients, differences in scale between the two populations can lead to errors in the choice of insertion site resulting in preventable complications. The coronal suture is readily palpable in infants and toddlers. It is essential that the monitor or catheter be placed at or in front of this landmark and a minimum of two centimeters off of the midline to avoid the motor cortex and superior sagittal sinus, respectively (Fig. 27). The lateral edge of the anterior fontanelle is an acceptable point of entry in very young children. Regardless of patient age, parenchymal monitors should be placed to a depth of one to two centimeters. Ventricular catheters are inserted to depths along an age-based continuum: three to four centimeters in infants, four to five centimeters in toddlers, and five to six centimeters in older children and adults. When used for CSF drainage, replacing the volume removed (5 to 10 ml per hour on average) with 0.9% NaCl + 20 mEq KCl per liter to avoid hyponatremia and hypokalemia from solute loss in CSF has been recommended.¹⁴⁵

Landmarks for ICP monitor placement

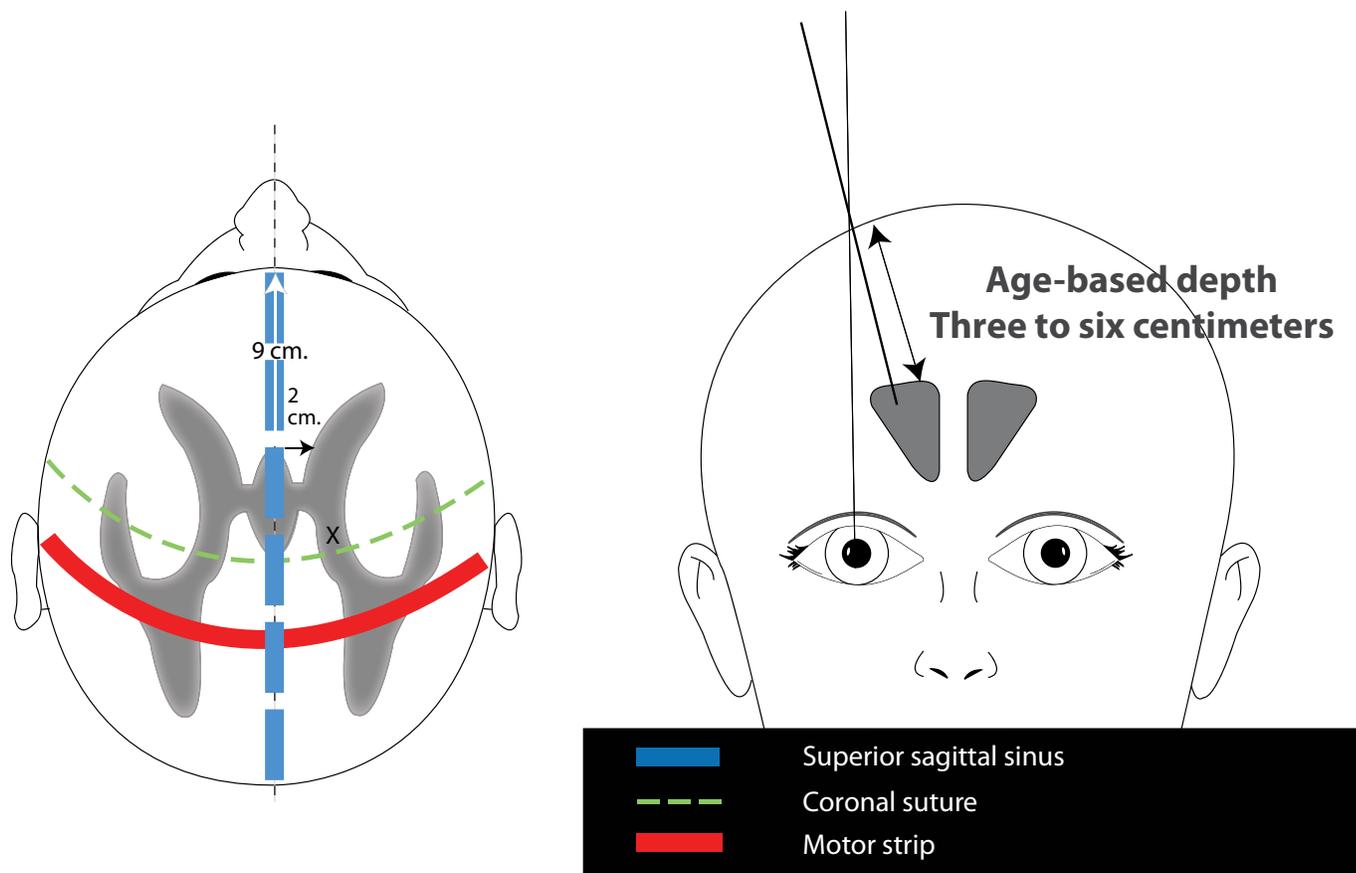


Figure 27. Landmarks for insertion of intracranial monitoring systems. The drill hole should be placed two centimeters off of midline, just anterior to the coronal suture, to avoid the superior sagittal sinus and motor strip. In children over the age of five, the average distance posterior to the nasion is nine centimeters.

Management of Skull Fractures

Treatment of fractures along the skull convexity in a forward environment is limited to the care of associated injuries. Closed skull fractures without significant neurologic impairment such as so called ping-pong fractures in infants or minimally depressed fractures do not require specific treatment in a CCC environment (Fig. 28). Closed fractures are often encountered in combination with underlying intradural and extradural hemorrhage. Under those circumstances, surgical management may be appropriate as discussed later (see Management of Intradural and Extradural Hemorrhage).

Open skull fractures require irrigation and judicious debridement to remove devitalized tissue and reduce risks of infection. In the current environment of counterinsurgency warfare (OEF and OIF), most of these injuries are the result of low-velocity projectiles. Aggressive debridement and watertight dural closure were advocated in the past.¹⁴⁶ This form of management is unnecessary for most low-velocity projectile injuries encountered in OEF and OIF. Long-term follow-up of patients who underwent wide margin, aggressive debridement of embedded bone fragments has not been demonstrated to reduce infection and is technically more challenging for non-neurosurgical providers.¹⁴⁷ Attempts at watertight



Figure 28. (Left) *Linear skull fracture.* (Right) *Ping-pong fracture.*

dural closure can add significant time to the surgical intervention, and in the authors' opinion, is not required for supratentorial injuries. Onlay dural substitutes (DuraGen® Dural Graft Matrix, Integra Neurosciences) are widely available for the coverage of these injuries. Complete coverage of any dural defect with this material followed by meticulous scalp closure is acceptable in such patients.

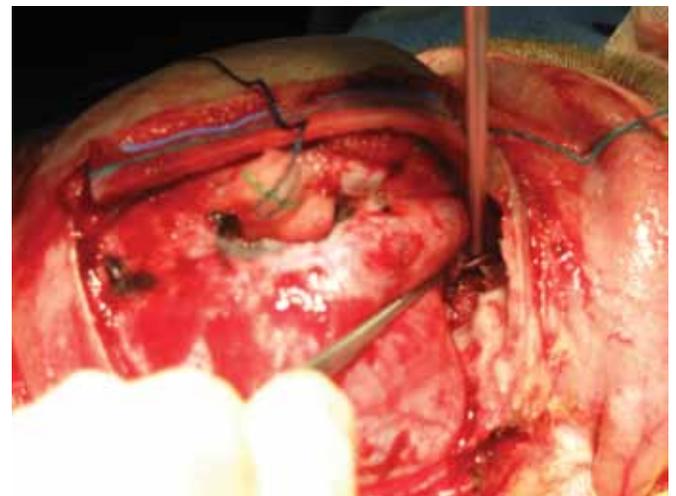
Open skull fractures require irrigation and judicious debridement to remove devitalized tissue and reduce infection risk. Antibiotic administration following open fractures with embedded fragments is controversial, and no standard guidelines regarding either choice or duration of antibiotic therapy exist.

Antibiotic coverage for open fractures with embedded fragments is controversial. No standard guidelines regarding either choice or duration of antibiotic therapy exist.¹³⁰ The presence of both gram-positive and gram-negative organisms in abscesses resulting from penetrating head injuries has resulted in widespread use of broad-spectrum coverage for three days to two weeks by some practitioners.¹⁴⁸ Single agent gram-positive antibiotic therapy has been shown to be effective in reducing wound infection rates following open skull fractures.¹⁴³ In the authors' experience, patients receiving prompt care with debridement and layered closure without subsequent CSF leakage did well with a single dose of an appropriately selected antibiotic (based on local resistance patterns) against skin flora.

Fractures or penetration of the anterior or lateral skull base carry additional risks of spinal fluid leakage and subsequent infection (Fig. 29).¹⁴⁹ Pediatric patients harbor a lower risk of spinal fluid leakage from



Figure 29. Penetrating injuries involving the anterior skull base: (Top Left) Vertex view of the scalp in a child impaled with rebar rod. Note the site of penetration and mild proptosis of the right eye. (Top Right) Coronal CT reconstruction demonstrating penetrating injury extending through the right frontal bone, orbital roof, and maxilla. (Bottom Right) Intraoperative photograph following right frontal craniotomy demonstrating penetration of the floor of the anterior cranial fossa.



injuries to the anterior cranial fossa due to age-related pneumatization of the paranasal sinuses, which is complete by the mid-teens.¹⁵⁰ When CSF leaks do occur, conservative management through head elevation is advocated. Inflammation following the initial injury may result in closure of a persistent CSF fistula; therefore, time may be all that is needed in this circumstance. In the authors' opinion, prophylactic antibiotics for spinal leaks should be avoided, since it may increase the risk of selecting out resistant organisms without any known benefit. Refractory spinal fluid leaks in pediatric patients are not acute medical issues and require subspecialty consultation for management with a trial of lumbar drainage or surgical management by craniotomy and/or sinus exenteration. While leptomeningeal cysts or growing

skull fractures can result from open fractures with dural disruption in infants and toddlers, they are a more chronic concern that is beyond the scope of deployed medical elements.¹⁵¹

Fracture or penetration of the anterior or lateral skull base carries an additional risk of CSF leakage and subsequent infection. Cerebrospinal fluid leaks are conservatively managed. Refractory CSF leaks in pediatric patients are not acute medical issues and require subspecialty consultation for management with a trial of lumbar drainage or surgical management by craniotomy and/or sinus exenteration.

Management of Intradural and Extradural Hemorrhage

Indications for performance of a limited craniotomy or craniectomy by a non-neurosurgical provider on a pediatric patient in a deployed environment are limited. The treatment of intradural injuries (e.g., subdural hematoma and intraparenchymal hemorrhage) requires advanced surgical training and clinical experience (Fig. 30). The surgical management of such injuries is beyond the scope of practice of forward non-neurosurgical CCC providers. On occasion, events may conspire to place a well-prepared careprovider in the presence of an acutely deteriorating patient with clinical or radiologic findings supportive of an underlying epidural hematoma (Fig. 31). A clinically significant extradural hemorrhage is one form of injury likely to benefit from surgical intervention by non-neurosurgical careproviders under these circumstances.¹⁵²



Figure 30. *Intradural neurotrauma surgery poses significant operative challenges to the inexperienced careprovider.*

Techniques for expedient craniotomy/craniectomy are similar between pediatric and adult patients. Patients are positioned supine with a bolster under the ipsilateral shoulder and hip with the head in a gel roll or equivalent. Generous hair removal assists with visualization of landmarks. Scalp opening should be well controlled and minimized to reduce blood loss. In the case of image confirmed epidural hemorrhage, placement of a burr hole over the site of injury followed by enlargement with rongeurs is both technically easier to accomplish and more expedient than turning a bone flap (Fig. 32). Exploratory burr holes can be performed with enlargement if a bloodclot is identified at the operative site. Complete removal of the hemorrhage is not essential; decompression of the hemorrhage is usually sufficient to resolve acute neurologic changes. Use of a Hemovac® or Jackson-Pratt® drain under the scalp is useful to prevent blood reaccumulation.

Spinal Injuries

Closed Injuries

Management of closed pediatric spinal injuries in a deployed environment is primarily nonoperative. While spinal instrumentation and intraoperative fluoroscopy are available at select deployed facilities,

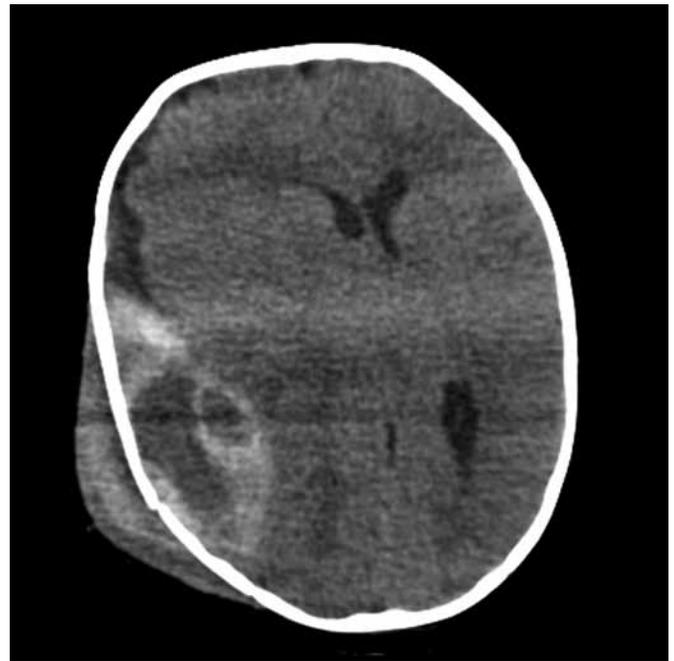


Figure 31. *Epidural hematoma: (Top Left) In the patient harboring an epidural hematoma, impaired neurologic examination including pupillary asymmetry and GCS of 9 or less are independent predictors of poor outcomes. (Top Right) CT scan demonstrating a large right parietal epidural hematoma in a toddler. Note the mixed density of the collection indicative of active hemorrhage and marked midline shift. (Bottom Left) Intraoperative image demonstrating a large epidural hematoma following removal of the overlying calvarial bone.*

most injuries can be managed locally with more modest resources. The majority of closed spinal column injuries are biomechanically stable. In a neurologically intact patient, upright and weight-bearing films can establish the stable nature of these injuries. For the patient with neurologic impairment or unstable fracture, forward facilities are poorly equipped to deal with short- or long-term issues faced by these patients. Realistic goals include restoration of anatomic alignment and immobilization.

Management of closed pediatric spinal injuries in a deployed environment is primarily nonoperative. Forward facilities are poorly equipped to deal with short- or long-term issues faced by patients with neurologic impairment or unstable fractures. Realistic goals include restoration of anatomic alignment and immobilization.

Gardner-Wells tongs are available in surgical sets for Level III facilities; they are a low-cost means of obtaining or maintaining alignment in the cervical spine (Fig. 33). In children older than two years of age, application is identical to adult patients. When utilized appropriately, torque application should not result in penetration of the skull in these patients.¹⁵³ In the authors' experience, less weight is generally required to achieve reduction: two pounds (lbs) per level compared to five to 10 lbs in adult patients. Immobilization can be achieved with bedrest for thoracolumbar fractures, or with appropriately-sized commercial collars for cervical spine fractures. In the absence of appropriate collar sizes, field-expedient

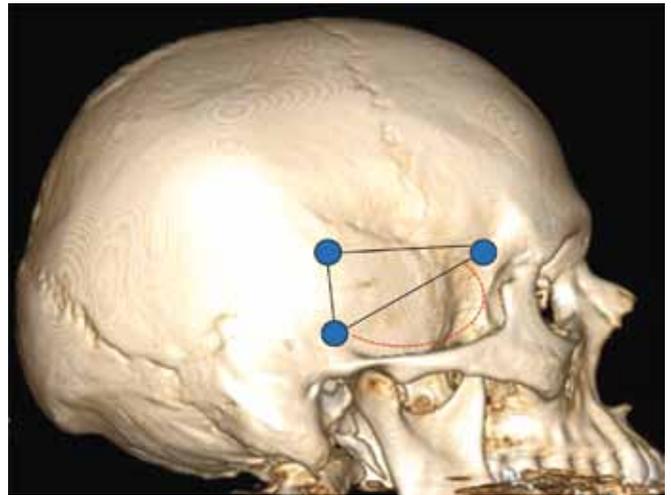
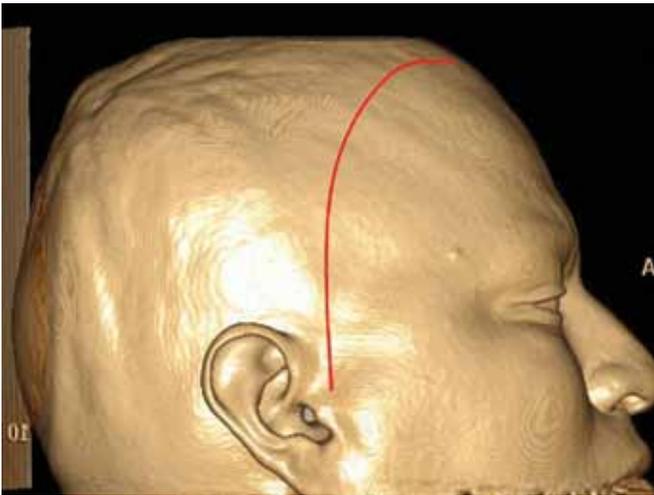
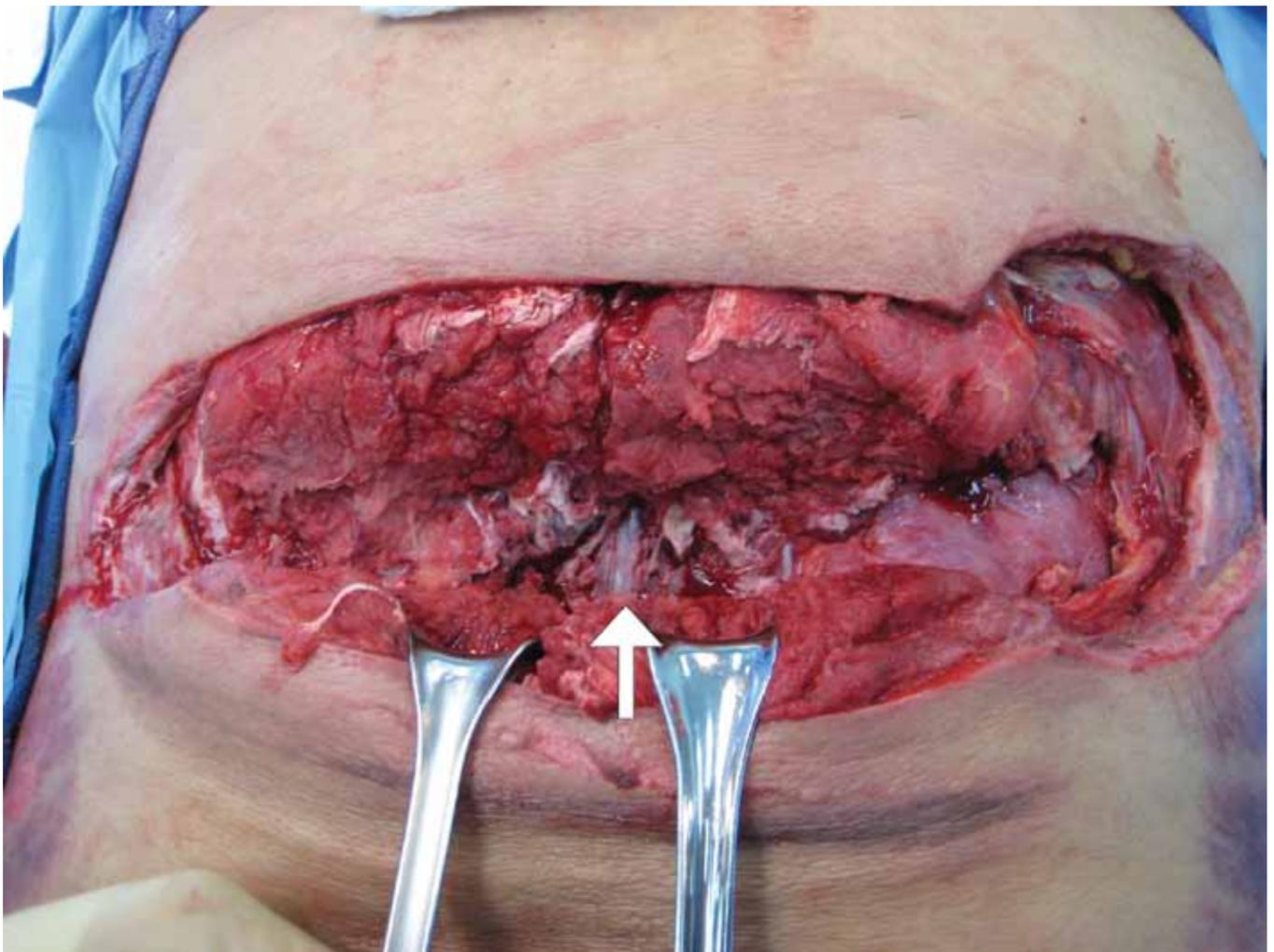


Figure 32. *Damage control craniectomy. Extradural hemorrhage localized or extending into the middle cranial fossa is an ideal indication for this procedure. (Top Left) The scalp incision extends from the root of the zygoma toward the frontal hairline. The incision extends through the underlying temporalis fascia to expose the lateral surface of the middle cranial fossa. (Top Right) Schematic of burr hole sites for middle fossa craniectomy. Note location of posterior-inferior burr hole immediately above the zygomatic root. Craniectomy proceeds between burr holes and extends anteriorly along the greater wing of the sphenoid as indicated. (Bottom Left) Burr hole placed by a non-neurosurgical provider. Note fracture line that resulted in underlying intracranial injury. (Bottom Right) Image following completion of craniectomy and evacuation of local epidural hemorrhage. This craniectomy is ideally located low in the middle cranial fossa resulting in relief of brainstem compression along the medial aspect of the affected temporal lobe.*



Figure 33. (Left) Gardner-Wells tongs are a simple device capable of assisting with the stabilization and reduction of cervical spinal column injuries.

Figure 34. (Below) Thecal sac ligation following penetrating injuries to the spine. Blast injuries can result in massive tissue loss with devastating injuries to the spinal axis and thecal sac. In this case, an IED blast caused extensive destruction of the dorsal elements of the lumbar spine and dura. The ventral surface of the dura is indicated by the arrow. A staged, collaborative surgical approach allowed for ligation of the thecal sac to prevent spinal fluid leak, staged debridement, and spinal stabilization and flap-assisted wound closure.



collars can be custom contoured with SAM® SPLINTS or other materials. Pediatric-sized halo vests are rarely available in a deployed environment. In the exceptional case that an appropriately-sized vest is available, application differs from adult patients in the number of pins used and torque applied.¹⁵⁴ Six to eight pins with an applied torque of four inch-pounds (in-lbs) are sufficient to secure the halo ring in children aged two through eight years of age. Adult application guidelines can be used in children age nine and above.

Penetrating (Open) Injuries

The acute management of penetrating injuries of the spine mirrors that of adult patients with these injuries. Depending on the trajectory of the projectile, abdominal and thoracic injuries are addressed first. Antibiotic therapy is tailored to the individual needs of injuries in these adjacent compartments. Penetrating injuries rarely produce acute spinal instability; however, children with neurologic impairment are at high risk for developing late spinal deformity.^{155,156} Such concerns are beyond the capabilities of forward CCC providers.

The acute management of penetrating injuries of the spine mirrors that of adult patients with similar injuries. Depending on the trajectory of the projectile, abdominal and thoracic injuries are addressed first. Penetrating injuries rarely produce acute spinal instability. Local debridement and wound closure are appropriate at the time of presentation. Massive injuries with extensive tissue loss and spinal cord avulsion are best managed through ligation of the thecal sac.

Local debridement and wound closure are appropriate at the time of presentation. Cerebrospinal fluid fistulae, either externally or into adjacent cavities such as the thorax, are infrequent but challenging problems. Massive injuries with extensive tissue loss and spinal cord avulsion are best managed through ligation of the thecal sac (Fig. 34). In injuries with less tissue destruction, visualization of the leak is more limited. It is the authors' opinion and experience that local tissue patch with external spinal fluid diversion is a rapid and technically less demanding option for these patients. Lumbar drainage systems are available through the military supply system and are an invaluable adjunct for such patients. Catheters can be placed at the time of exploration, or percutaneously by anesthesia providers at the L4 to L5 interspace when the fistula is recognized in patients as young as two years of age. It is the authors' opinion and experience that height-controlled drainage of 10 to 15 ml per hour is usually sufficient to stop the flow of spinal fluid with closure of the fistula within 72 hours in most cases.

End-of-Life Care

While children are very resilient, there are times when enough is enough and it is more appropriate to halt the resuscitation or to recognize that certain wounds are not treatable and further care is futile. In these circumstances, treatment should be focused on providing the appropriate level of pain relief and comfort. It is often very hard for practitioners to recognize when care is futile in children since the death of a child is a very emotional event. The medical team needs to remain objective and truly balance the benefits and risks of treating certain injuries with providing comfort care if the wounds are lethal or severely neurologically debilitating. Balancing what you can do for a child with what can be handled medically in the host nation is a very difficult task, but this dichotomy must be recognized.

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