

Chapter 39

BASICS OF PEDIATRIC TRAUMA CRITICAL CARE MANAGEMENT

CHRISTOPHER M. WATSON, MD, MPH,* AND DOWNING LU, MPH, MD, MPH†

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*Lieutenant Commander, Medical Corps, US Navy; Pediatric Intensivist, Department of Pediatrics, Walter Reed National Military Medical Center, 8901 Rockville Pike, Bethesda, Maryland 20889

†Lieutenant Colonel, Medical Corps, US Army; Chief of Pediatric Critical Care, Department of Pediatrics, Walter Reed National Military Medical Center, 8901 Rockville Pike, Bethesda, Maryland 20889

INTRODUCTION

Children represent a particularly vulnerable segment of the population and have increasingly become more affected by armed conflict during the last century. As modern warfare technologies advance and armed conflict spreads, the lines between civilians and combatants have blurred such that children often become the victims of displacement, malnourishment, and sexual assault or are the direct targets of violence.¹ It is estimated that more than 2 million children worldwide died as a result of armed conflict during the past decade, and more than 6 million were

permanently injured.² Review of recent military conflicts suggests that in Operations Enduring Freedom and Iraqi Freedom, more than 6,000 children presented to combat support hospitals by late 2009. Of these, more than 75% were admitted with traumatic injuries, primarily gunshot wounds and explosive injuries.³ This chapter will highlight basic observations, understandings, and implications of pediatric critical care to better inform anesthesia providers of the principles of initial trauma resuscitation and stabilization of pediatric casualties.

RECEIVING THE PEDIATRIC CRITICAL CARE PATIENT

Recognizing the many anatomic, physiologic, and developmental differences between adult and pediatric trauma patients is fundamental to caring for children (Table 39-1). These unique characteristics factor significantly into the patterns and pathophysiology of injury and in a patient's response and recovery after trauma and illness. Compensatory mechanisms often obscure the true degree of illness, although both hypotension and bradycardia should be noted as late and ominous findings. Because of the wide variation in size and physiology across the spectrum of pediatric patients, clearly identifying the proper equipment is essential. Vital sign norms and preferred equipment sizes are often best interpreted by age (Table 39-2).

Developmentally appropriate behavior and curiosity make children more apt to explore their environments than adults. When combined with the inability to recognize threats, this curiosity may lead to disastrous outcomes. Psychological response to trauma and illness differ by age and developmental stage, which may require modification of often-used trauma assessment tools such as the Glasgow coma scale that are based on age and developmental stage (Table 39-3).

The handoff of care from the operative setting to the intensive care unit (ICU) represents a vulnerable period during which key information is exchanged that

dictates future care needs (Exhibit 39-1). Teamwork and protocol-driven handoff techniques can minimize communication errors, errors of omission, technical errors, and duration of handoffs.^{4,5} During the transition from the operative to postoperative environment, special attention should be given to preventing undue artificial airway manipulation and unintentional dislodgment of catheters or drainage devices. Once the patient is situated in the ICU and handoff has been completed, the intensivist should repeat a primary and limited secondary survey.⁶ A chest radiograph should be obtained in intubated patients to establish location of the endotracheal tube as well as other indwelling devices. Selective repetition of blood gas tests, complete blood counts, coagulation studies, and chemistries should be considered, particularly if preoperative or intraoperative blood loss was estimated to be greater than complete blood volume. Nearly all medications are weight based; quickly estimating a pediatric patient's dosing weight is necessary to appropriately dose medications. In these instances, a length-based dosing tape, such as the Broselow Pediatric Emergency Tape (Armstrong Medical Industries, Lincolnshire, IL), can help provide a quick estimate of a patient's weight and absolute doses of resuscitation medications as well as estimates of appropriately sized resuscitation equipment.

PULMONARY SUPPORT AND MECHANICAL VENTILATION IN PEDIATRIC TRAUMA PATIENTS

Children may require mechanical ventilation and pulmonary support for a variety of reasons (Exhibit 39-2). Polytrauma, including intrathoracic injury, is also a common precipitant of respiratory distress and failure in pediatric patients; therefore, understanding basic therapeutic pediatric pulmonary strategies is crucial to minimizing morbidity and mortality.

Chest Trauma

Intrathoracic injury, primarily as a result of blunt injury, occurs in 4% to 6% of pediatric traumas.^{3,7} Children tend to tolerate such severe intrathoracic injury poorly because of low functional residual capacity, greater oxygen consumption, and decreased pulmo-

TABLE 39-1

KEY ANATOMIC AND PHYSIOLOGIC DIFFERENCES BETWEEN INFANTS/CHILDREN AND ADULTS

Differences	Importance
General	
Vital signs age- and size-based	Normative values may vary drastically by age and size
Smaller total body mass but increased body surface area compared to mass	Less subcutaneous tissue and fat increases force per unit body area; vital organs are closer together; increased caloric, glycemic, and fluid needs; increased risk of environmental exposure and hypothermia
Proportionally larger heads	Increased risk of head trauma
Fontanelle closure delayed	Anterior fontanelle remains patent until 7–19 months and may assist with volume assessment
Skeletal calcification incomplete	Increased risk of solid organ injury from blunt trauma
Blood volume relatively greater per unit body mass	Increased risk of hypovolemia from seemingly small hemorrhages
Immature renal function	Impaired fluid and electrolyte regulation in infants
Respiratory	
Short neck and chin and larger tongues	Increased risk of upper airway obstruction
Anterior and cephalad larynx (C3/4); airway narrowest at cricoid cartilage	Infants require padding under torso to maintain airway and cervical spine in neutral (“sniffing”) positioning
Shorter trachea (4–9 cm)	Increased predilection for mainstem intubation
Smaller diameter of conducting airways	Disproportionately increased peripheral airway resistance and airway obstruction with minimal edema
Increased alveolar minute ventilation; small thorax in relation to abdomen	Similar tidal volume per kilogram results in increased respiratory rates
Increased chest wall compliance; protuberant abdomen with weak musculature	Inefficient lung expansion during distress evidenced by subcostal retractions/abdominal breathing in infants; increased risk of functional residual capacity loss when sedated because of unopposed elastic recoil; potential for respiratory compromise secondary to abdominal distention
Immature central respiratory drive	Immature respiratory control predisposes neonates to apnea in response to hypoxia
Cardiovascular	
Neonatal myocardium relatively stiff	Relatively fixed cardiac stroke volume requires heart-rate elevation to increase cardiac output
Cardiac index increased 30%–60%	Required to meet high oxygen consumption
Sympathetic nervous system maturation delayed until 4–6 months; parasympathetic system mature at birth	High vagal tone and potent laryngeal reflex with apnea, bradycardia, and laryngospasm

nary but increased chest wall compliance. Pulmonary contusion is relatively common in pediatric thoracic trauma (48%) and it is generally well tolerated.⁸ However, up to a fifth of pediatric patients with pulmonary contusions develop secondary complications, includ-

ing aspiration, infection, and acute respiratory distress syndrome.⁹ Bronchospasm and acute asthma exacerbations may occur subsequent to or independent of chest trauma and require unique diagnostic and therapeutic considerations (Figure 39-1).

TABLE 39-2
PEDIATRIC PARAMETERS AND EQUIPMENT

Age	Neonate	3 mo	6 mo	1 y	2 y	3 y	4 y	6 y	8 y	12 y	14 y
Wt (kg)	3.5	6	8	10	12	14	16	20	25	40	50
~ BSA (m²)	0.24	0.34	0.42	0.49	0.56	0.62	0.68	0.79	0.92	1.3	1.5
HR	80–190	80–160	80–160	80–160	80–130	80–130	80–120	75–115	70–110	65–110	60–105
RR	30–50	24–38	24–38	22–30	22–30	22–30	20–24	20–24	18–24	16–22	14–20
SBP*	60–90	70–110	70–110	70–110	74–110	76–110	78–115	82–115	86–120	94–125	98–130
DBP	35–60	40–60	40–60	40–60	45–60	50–65	50–70	55–75	60–80	60–80	65–85
BP cuff	Neonate	Infant	Small child	Small child	Child	Child	Child	Small adult	Small adult	Adult	Adult
BVM	Infant	Infant	Child	Child	Child	Child	Child	Child	Child/adult	Adult	Adult
Oral airway	Infant 50 mm	Small 60 mm	Small 60 mm	Small 60 mm	Child 70 mm	Child 70 mm	Med 80 mm	Med 90 mm	Med 90 mm	Large 100 mm	Large 100 mm
ETT blade	#0–1	#1	#1	#1	#2	#2	#2	#2	#2–3	#3	#3
ETT size[†]	2.5–3.5	3.5–4.0	3.5–4.0	4.0–4.5	4.0–4.5	4.5–5.0	4.5–5.0	5.0–5.5	5.5–6.5	6.0–7.0	7.0–8.0
Suction cath	6 Fr	8–10 Fr	8–10 Fr	8–10 Fr	10 Fr	10 Fr	10 Fr	10 Fr	10 Fr	12 Fr	14 Fr
NGT	5–8 Fr	5–8 Fr	8–10 Fr	8–10 Fr	10 Fr	10 Fr	10–12 Fr	12–14 Fr	14 Fr	14–18 Fr	14–18 Fr
Foley	6 Fr	8 Fr	8 Fr	8 Fr	8 Fr	8 Fr	8 Fr	10 Fr	12 Fr	14 Fr	14 Fr
IV access	22–24 g	22–24 g	20–24 g	20–24 g	18–22 g	18–22 g	18–22 g	18–20 g	18–20 g	16–20 g	16–20 g
Central line	4 Fr 8 cm	4 Fr 9 cm	4 Fr 12 cm	5 Fr 8 cm	5 Fr 8 cm	5 Fr 12 cm	5 Fr 12 cm	5 Fr 15 cm	5 Fr 15 cm	7 Fr 15 cm	7 Fr 15 cm

*Hypotension = systolic BP $\leq 70 + (2 \times \text{age in years over 1 year})$; < 1 mo SBP ≤ 60 ; 1 mo – 1 y SBP ≤ 70
[†]ETT size = $[\text{age (years)} + 16] / 4$; use cuffed tube for ≥ 6.0 ; ETT depth = $3 \times \text{ETT internal diameter or (age in years} / 2) + 12$
 BP: blood pressure
 BSA: body surface area
 BVM: bag-valve mask
 cath: catheter
 DBP: diastolic blood pressure
 ETT: endotracheal tube
 Fr: French
 HR: heart rate
 IV: intravenous
 NGT: nasogastric tube
 RR: respiratory rate
 SBP: systolic blood pressure
 Wt: weight

Airway Equipment

Pediatric intubation should follow a routine step-wise algorithm (Figure 39-2). Equipment sized for pediatric patients is necessary to safely deliver respiratory support. Appropriately sized bag-valve masks (BVMs) are necessary to administer the proper tidal volumes of positive-pressure ventilation. BVMs with inappropriately small bags pose the risk of insufficient ventilation, whereas use of excessively large BVMs

risks gastric distension and barotrauma. If only adult-sized bags are available, the operator must closely observe chest wall motion to gauge appropriate ventilation. Endotracheal tube internal diameter (ID) can be quickly sized with the following formula:

$$\text{endotracheal size (mm)} = \frac{16 + \text{age (years)}}{4}$$

This size roughly correlates to the child’s fifth finger (the “rule of pinky”). Depth of insertion in centimeters

TABLE 39-3
MODIFIED GLASGOW COMA SCALE

Activity	Infant	Child/Adult	Score
Eye opening	Spontaneous	Spontaneous	4
	To speech	To speech	3
	To pain only	To pain only	2
	No response	No response	1
Verbal response	Coos and babbles	Oriented, appropriate	5
	Irritable cries	Confused	4
	Cries to pain	Inappropriate words	3
	Moans to pain	Incomprehensible sounds	2
Motor response	No response	No response	1
	Moves spontaneously and purposefully	Obeys commands	6
	Withdraws to touch	Localizes painful stimulus	5
	Withdraws to pain	Withdraws in response to pain	4
	Abnormal flexion posture to pain	Flexion in response to pain	3
	Abnormal extension posture to pain	Extension in response to pain	2
	No response	No response	1

when placed orally is estimated by either of the following two rules:

$$\text{endotracheal tube depth (cm)} = (3 \times \text{ID})$$

$$\text{endotracheal tube depth (cm)} = \frac{\text{age (years)} + 12}{2}$$

Placement should be verified by auscultation, end tidal carbon dioxide detection, and radiograph. Given their smaller anatomy, children are at greater risk of mainstem intubation. Cuffed endotracheal tubes are typically half a size lower than that calculated. Cuffed endotracheal tubes are safe and preferred over uncuffed endotracheal tubes in children with significant lung disease; when used appropriately, they can minimize ventilator leak and aid in achieving goal tidal volumes. Cuff pressures should be

EXHIBIT 39-1
ANESTHESIA HANDOFF CHECKLIST

Patient Details

- Name
- Age
- Weight (kg)
- Preoperative diagnosis
- Allergies

Operative Course

- Operation performed
- Anesthesia technique
- Airway classification
- Endotracheal tube and laryngoscope sizes
- Access (type, location, size, placed by)
- Tubes/drains (type, location)
- Problems in OR
- Bleeding issues (preoperative hemoglobin, estimated blood loss [total and mL/kg])
- Blood products given (totals, types, last hemoglobin)
- Crystalloid given
- Urine output

Present Status

- Hemodynamics (rhythm, HR, BP, MAP, CVP, NIRS)
- Ventilation (settings, difficulties, iNO, blood gases)
- Infusions (vasopressors)
- Antibiotics (total dose, last dose)
- Opiates (total dose, last dose)
- Neuromuscular blockade (last dose, reversal)

BP: blood pressure; CVP: central venous pressure; HR: heart rate; iNO: inhaled nitrous oxide; MAP: mean arterial pressure; NIRS: near-infrared spectroscopy; OR: operating room
Data sources: (1) Joy BF, Elliott E, Hardy C, Sullivan C, Backer CL, Kane JM. Standardized multidisciplinary protocol improves handover of cardiac surgery patients to the intensive care unit. *Pediatr Crit Care Med.* 2011;12(3):304–308. (2) Catchpole KR, de Leval MR, McEwan A, et al. Patient handover from surgery to intensive care: using Formula 1 pit-stop and aviation models to improve safety and quality. *Paediatr Anaesth.* 2007;17(5):470–478.

monitored and kept below 20 cm H₂O to avoid mucosal damage, scarring, and subglottic stenosis.

Many adult-type ventilators can be adapted for use in children, provided appropriately sized circuits are used; however, the inconsistent delivery of appropriate tidal volumes at variable peak end expiratory pressures, coupled with inadequate safety alarms, warrants careful review of individual ventilator capabilities and capacities prior to use.¹⁰ For example, the simplified automated ventilator (SAVE) has been used successfully in adult trauma patients; however, the preset factory

EXHIBIT 39-2

INITIAL INTUBATION INDICATIONS FOR MECHANICAL VENTILATION

Cardiorespiratory failure

- Cardiopulmonary benefit (shock, cardiopulmonary resuscitation)
- Inability to oxygenate in the absence of cyanotic heart disease
- Inability to ventilate, acute and unresponsive to intervention
- Neuromuscular weakness (negative inspiratory force > - 20 cm H₂O)

Compromised airway, actual or anticipated

- Absent airway protective reflexes (cough and gag)
- Aspiration of oral secretions
- Complete airway obstruction
- Glasgow coma score ≤ 8

Additional considerations

- Diagnostic or therapeutic intervention (ie, intracranial hypertension)
- Emergency drug administration
- Pulmonary toilet
- Residual anesthetic effect
- Transport stability

Data source: Thompson AE. Pediatric airway management. In: Fuhrman BP, Zimmerman J, eds. *Pediatric Critical Care*. 3rd ed. Philadelphia, PA: Mosby; 2006.

settings do not deliver peak end expiratory pressure and are not adjustable.¹¹ Therefore, the SAVE can result in significant ventilator-induced injury in children.

Ventilatory Management Techniques

Once the decision has been made to provide invasive ventilation, regardless of cause, ongoing mechanical ventilation strategies vary based on the severity of lung disease and coexisting conditions such as intracranial hypertension or cardiac dysfunction. Pressure ventilation is typically selected in patients with lung disease to achieve goal tidal volumes at lower pressures. Synchronized intermittent mandatory ventilation mode with pressure control and pressure support is well tolerated by pediatric patients. Typical starting settings will vary based on individual pathology, but basic initial settings are given in Table 39-4. In certain circumstances, such as cardiac disease and significant restrictive lung disease, a lower peak end expiratory pressure of 3 to 4 cm H₂O may be optimal. General criteria for the extubation of a pediatric patient following surgery are presented in Exhibit 39-3.

As with any mode of ventilation, a number of moni-

toring parameters are recommended to safely deliver mechanical ventilation and minimize barotrauma, atelectrauma, and volutrauma. These include inline capnography, chest radiography, blood-gas sampling (via arterial line), and peak and mean airway pressures. In the absence of acute lung injury, goals of normocapnia and partial pressure of oxygen in arterial blood are 70 to 80 mm Hg (SpO₂ 90%–100%). In the presence of acute lung injury or acute respiratory distress syndrome, management strategies are similar to adult ARDSNet (www.ardsnet.org) strategies targeting permissive hypercapnia and low-tidal volumes¹² (Exhibit 39-4). However, pediatric data are insufficient to completely recommend all-adult protocols. The calculation of an oxygenation index (OI) and PaO₂ to FiO₂ (P/F) ratio may also be helpful, where the OI is defined as:

$$OI = \frac{FiO_2 \times 100 \times MAP}{PaO_2}$$

where FiO₂ is the fraction inspired oxygen, MAP is the mean airway pressure, and PaO₂ is the partial pressure of oxygen. Generally, an OI greater than or equal to 40 and a P/F ratio under 100 are suggestive of failed conventional ventilation.

Figure 39-1 (facing page). Acute management of asthma exacerbation algorithm.

Data source: Gorelick MH, Stevens MW, Schultz TR, Scribano PV. Performance of a novel clinical score, the Pediatric Asthma Severity Score (PASS), in the evaluation of acute asthma. *Acad Emerg Med*. 2004;11(1):10–18.

Airway - Breathing – Circulation
 Continuously monitor vital signs and pulse oximetry
 Administer supplemental oxygen to maintain SpO₂ ≥ 92%
 Obtain brief history (prior admissions, ICU admits, intubations?)
 Conduct focused physical exam (respiratory rate, work of breathing, auscultation, PEF)



Acute Asthma Category:			
Clinical Finding	Mild	Moderate	Severe
Wheezing	None or mild	Moderate	Severe or absent
Air Entry	Good	Fair	Poor or absent
Work of Breathing	Mild	Moderate	Severe
Expiratory Prolongation	Normal or mild	Moderate	Severe
Tachypnea (above mean)	30 %	30 – 50%	> 50% or slow
Mental Status	Normal	Agitated	Drowsy
PEF	> 70%	40 – 69 %	< 40%

Moderate to Severe? **Yes**



Albuterol 2.5 – 5 mg INH q 20 minutes x 3
 AND
Methylprednisolone 2 mg/kg/dose (load) IV/IM x 1 (max dose 80 mg)
 AND
Ipratropium 0.25 – 0.5 mg INH q 6 hours



Continuous nebulized albuterol: 0.5 mg/kg/hour (usual max 20 mg/hr)
 (< 7.5 kg: 2.5 mg/hour INH; 7.5 – 14.9 kg: 5 mg/hour INH;
 15 – 29.9 kg: 10 mg/hour INH; > 30 kg: 20 mg/hour INH)



Magnesium sulfate 75 mg/kg IV x 1 over 20 minutes (max 2000 mg), monitor for hypotension



Terbutaline 10 mcg/kg/dose (load) IV x 1 over 30 minutes,
 followed by and infusion at 0.4 – 6 mcg/kg/min IV
 → Monitor EKG q 24 hours and cardiac enzymes q 6 – 12 hours



Heliox 70/30, monitor for hypoxia



Consider **CPAP/BiPAP**, may use ketamine



Consider **intubation, mechanical ventilation and inhalational anesthetics** as a last resort;
 Initial settings: TV 8-12 mL/kg (peak pressure < 45 cmH₂O), low PEEP, RR 6 – 12, I_{time} 1-1.5s
 (I:E 1:4 – 1:6); Allow permissive hypercapnia; Goal: spontaneous / pressure supported mode

BiPAP: bilevel positive airway pressure
 CPAP: continuous positive airway pressure
 EKG: electrocardiogram
 INH: inhaled
 IV: intravenous
 PEEP: positive end-expiratory pressure
 PEF: peak expiratory flow
 PR: per rectum
 TV: tidal volume

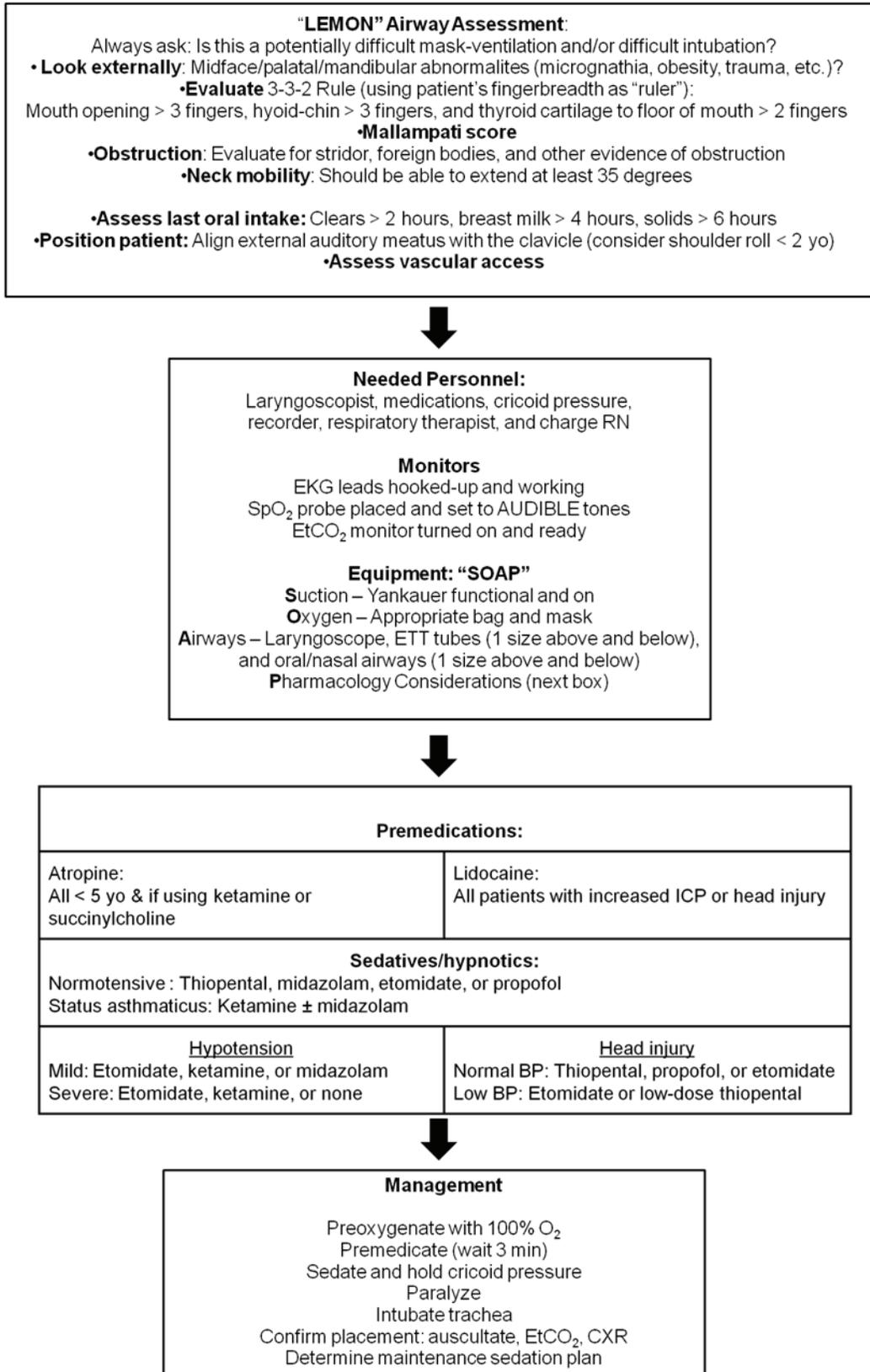


Figure 39-2. Intubation management algorithm. BP: blood pressure. CXR: chest x-ray; EKG: electrocardiogram; ETT: endotracheal tube; ICP: intracranial pressure; RN: registered nurse

TABLE 39-4
INITIAL PEDIATRIC VENTILATOR SETTINGS*

Parameter	Setting
PIP	20 cm H ₂ O
TV	6–10 mL/kg [†]
PEEP	5 cm H ₂ O
I _t	0.3–1.2 sec [‡]
Rate	Age appropriate [§]
PS	10 cm H ₂ O
FiO ₂	Begin at 1.0; rapidly wean to < 0.6

*Preferred mode is synchronized intermittent mandatory ventilation using either pressure or volume control.

[†]Decrease TV if measured PIPs > 30–35 or if there is excessive chest rise.

[‡]Inspiratory time should be no less down than 0.3 seconds for infants and up to 1.2 seconds for adolescents.

[§]Begin with a rate of 30 for infants to 15 for adult-sized adolescents.

FiO₂: fraction of inspired oxygen

I_t: inspiratory time

PEEP: peak end expiratory pressure

PIP: peak inspiratory pressure

PS: pressure support

TV: tidal volume

If peak pressures cannot be maintained below 30 to 35 cm H₂O, alternative ventilation strategies should be considered, namely high-frequency oscillatory ventilation, to avoid the risk of further barotrauma. Extracorporeal membrane oxygenation is typically used as rescue therapy for failed conventional and high-frequency ventilation at some medical facilities. The use of this modality as rescue therapy in field military medicine is still in its infancy and, thus, unlikely to be a modality offered to children in theater.

Pediatric ventilator-associated pneumonia has been independently linked with longer duration of ventilation, use of gastric tubes, and sedation or analgesia, and

EXHIBIT 39-3

RECOMMENDED EXTUBATION CRITERIA*

- Resolution of etiology of respiratory failure
- Oxygen saturation adequate with FiO₂ ≤ 0.4
- PEEP ≤ 5 cm H₂O
- PIP ≤ 25 cm H₂O
- pH > 7.35
- PaCO₂ < 60 mm Hg
- Stable hemodynamics (heart rate and blood pressure normal for age)
- Adequate hemostasis
- Spontaneously breathing
- Airway protective reflexes intact
- Easily arousable to verbal stimuli/light touch

Consider spontaneous breathing trial with minimal pressure support for 30 minutes to 2 hours prior to extubation. Minimal pressure support is determined to overcome the resistance of the endotracheal tube (eg, for endotracheal tube size 3.0 to 3.5 mm, use 10 cm H₂O pressure support; for 4.0 to 4.5 mm, 8 cm H₂O; for > 5.0 mm, use 6 cm H₂O).

FiO₂: fraction of inspired oxygen

PaCO₂: partial pressure of carbon dioxide in blood

PEEP: positive end-expiratory pressure

PIP: positive inspiratory pressure

pH: percent of hydrogen

is the second most common nosocomial infection and most common cause for antibiotics in the pediatric ICU (PICU).^{13,14} A ventilator-associated pneumonia prevention bundle has been shown in children and adults to decrease the likelihood of ventilator-associated pneumonia (Exhibit 39-5).^{15,16} Appropriate sedation and analgesia with daily wake-up tests, as hemodynamics allow, are also useful in decreasing the number of days a patient remains on a ventilator and reducing the risk of ventilator-associated pneumonia.

PEDIATRIC HEMODYNAMIC PRINCIPLES IN TRAUMA

Shock in a patient of any age is characterized by compromised tissue oxygenation, substrate delivery, and metabolite removal. Primary etiologies can be hypovolemic, distributive, and cardiogenic, although hypovolemia from hemorrhage is more likely in early trauma critical care, including during the postoperative period. Shock is a life-threatening emergency that must be quickly recognized and treated. Shock may be differentiated into compensated, decompensated, and irreversible. Early compensated shock is clinically recognizable and characterized by tachypnea, tachy-

cardia, altered mental status, hypothermia or hyperthermia, cool extremities (cold shock), or peripheral vasodilation (warm shock) and decreased urine output in conjunction with progressive metabolic acidosis and rising serum lactate levels. This phase of shock is most optimal for response to rescue therapy. Hypotension is the defining characteristic of decompensated shock and is a late finding in shock, evident only once 15% to 20% blood loss has occurred. In pediatric patients, hypotension is defined as a systolic blood pressure of less than the fifth percentile for age. Blood pressure for

EXHIBIT 39-4

RECOMMENDATIONS FOR THE MANAGEMENT OF PEDIATRIC ALI AND ARDS

Recommended

- Avoid hypoglycemia and hyperglycemia
- Avoid tidal volumes ≥ 10 mL/kg
- Hemoglobin target ≥ 10 g/dL, if unstable
- Hemoglobin target ≥ 7 g/dL, if stable
- Keep plateau pressures < 30 cm H₂O
- PaO₂ goal 60–80 mm Hg (SpO₂ $\geq 90\%$)
- pH goal 7.3–7.45
- Sedation and analgesia
- Include stress-ulcer prophylaxis

Consider

- 4–6 mL/kg tidal volume protocol
- Corticosteroids for lung inflammation
- Endotracheal surfactant
- Extubation readiness testing
- Noninvasive lung ventilation (ie, BiPAP)
- Restrictive fluid management

Not Recommended

- High-flow nasal cannula
- Inhaled bronchodilators
- Inhaled nitric oxide
- Prone positioning
- Tight glycemic control

ALI: account lung injury
 ARDS: acute respiratory distress syndrome
 PaO₂: partial pressure of oxygen in blood
 SpO₂: saturation of peripheral oxygen
 Data source: Randolph AG. Management of acute lung injury and acute respiratory distress syndrome in children. *Crit Care Med.* 2009;37(8):2448–2454.

children 1 to 10 years of age is calculated as:

$$\text{systolic blood pressure (mm Hg)} = 70 + (2 \times \text{age in years})$$

Hypotension is blood pressure lower than this calculated value. Early goal-directed therapy, similar to that practiced with adults, is the preferred therapeutic management strategy for shock and has been associated with improved outcomes among pediatric patients.^{17–19}

Vascular Access

Vascular access is essential for rapidly correcting shock states. Large-bore, peripheral intravenous (IV)

EXHIBIT 39-5

KEY ELEMENTS OF A RECOMMENDED PEDIATRIC VENTILATOR-ASSOCIATED PNEUMONIA BUNDLE

- Perform routine oral care every 4 hours
- Rinse oral suction devices following use
- Store oral suction devices in non-sealed plastic bags at bedside when not in use
- Wash hands before and after contact with ventilator circuits
- Drain condensate from ventilator circuit at least every 2–4 hours
- Change ventilator circuits and inline suction catheters only when visibly soiled
- Elevate head of bed to 30°–45° unless contraindicated
- Always drain ventilator circuit prior to patient repositioning
- For patients > 12 years of age, use a cuffed endotracheal tube with dorsal lumen above the cuff to help keep secretions off of the cuff
- Always wear a gown before providing patient care when soiling from respiratory secretions is expected

Data source: Bigham MT, Amato R, Bondurant P, et al. Ventilator-associated pneumonia in the pediatric intensive care unit: characterizing the problem and implementing a sustainable solution. *J Pediatr.* 2009;154(4):582–587.e2. Epub 2008 Dec 3.

access may not be feasible if significant volume loss has occurred. As a general rule, if IV placement is unsuccessful after three attempts or 90 seconds, intraosseus (IO) needle placement is recommended for rapid fluid resuscitation. The preferred insertion site for IO access is the anteromedial aspect of the tibia 1 to 2 finger breadths below the tibial tuberosity, taking care to avoid the physal growth plate (Figure 39-3). This site may generally be used up to 6 to 8 years of age. Alternate sites include the distal femur, sternum, lateral and medial malleoli, iliac crest, and proximal humerus. IO needles should not be placed distal to an injury site. Subsequent attempts at IO needle placement may be made in the same limb, provided each attempt is made proximal to the last attempt. Styleted bone marrow biopsy needles (16 and 18 gauge) may be placed manually; however, the EZ-IO (Vidacare, Shavano Park, TX) and the Bone Injection Gun (WaisMed, Houston, TX) offer automated alternatives with options for pediatric-appropriate needle size and depths (Figures 39-4 and 39-5). The commonly available FAST1 IO (Pyng Medical, Vancouver, Canada) should not be used in children younger than 12 years



Figure 39-3. Intraosseous insertion site in children. Reproduced with permission from: Vidacare, Shavano Park, TX. Copyright 2012 Vidacare.

of age because the length of the catheter could traverse the sternal cartilage and enter the mediastinum. If marrow is available by aspiration, blood laboratory evaluation may be done. Like a central venous catheter, an IO needle can be used to deliver medications and fluids. Once placed, an IO needle should be removed after 24 hours to avoid infection. After a period of



Figure 39-4. Intraosseous insertion device for pediatric patients: The EZ-IO. Reproduced with permission from: Vidacare, Shavano Park, TX. Copyright 2012 Vidacare.



Figure 39-5. Intraosseous insertion device for pediatric patients: the pediatric bone injection gun (BIG). Reproduced with permission from: WaisMed, Houston, TX.

TABLE 39-5
VASOACTIVE AGENTS USED IN PEDIATRICS

Drug	Dose
Dobutamine	2–20 µg/kg/min IV/IO
Dopamine	2–20 µg/kg/min IV/IO; begin 5 µg/kg/min
Epinephrine	0.03–1 µg/kg/min IV/IO
Milrinone	Infusion: 0.25–1 µg/kg/min IV/IO
Norepinephrine	0.05–1 µg/kg/min IV/IO
Phenylephrine	0.1–4 µg/kg/min IV/IO
Vasopressin	0.3–2 mU/kg/min (18–120 mU/kg/h) IV/IO

IO: intraosseous; IV: intravenous

fluid resuscitation and relative hemodynamic stability, longer-term access methods, such as placement of a central venous catheter, can be used.

Resuscitation

Resuscitation fluids of choice are isotonic crystalloids, either lactated Ringer or 0.9% normal saline (NS). Both are administered in 20 mL/kg rapid IV boluses. In small infants, this may amount to administering prepackaged 10-mL NS IV flushes for ease of delivery. If there is ongoing blood loss, packed red blood cells in a similar amount may be substituted. If no physiologic response has been observed after a total of 60 mL/kg (three 20-mL/kg boluses) have been administered over 15 to 20 minutes, a vasopressor is indicated for additional hemodynamic support (Table 39-5). Typical vasopressors include dopamine, norepinephrine for warm shock, and epinephrine for cold shock. Vasopressor support via a peripheral IV is generally safe prior

to obtaining central venous access, provided the site is monitored for distal perfusion.

Beyond heart rate and blood pressure, central venous pressure, differential skin temperature, and capillary refill (normally less than 2 seconds) are useful clinical measures for evaluating therapy response. Serial laboratory assessment monitoring, including serum lactate levels, blood gas determination, and mixed central venous oxygen saturation measurement further augment characterization of the resuscitation response. Hydrocortisone therapy should be considered for patients with catecholamine-resistant shock at risk of absolute adrenal insufficiency. Broad-spectrum antibiotics should be administered during the first hour of resuscitation for all patients presenting with septic shock, though the routine use of antibiotics in burn patients presenting in shock is discouraged because it promotes antimicrobial resistance. Ideally, blood cultures should be obtained and sent to a laboratory before antibiotics are administered.

POSTOPERATIVE FLUID MANAGEMENT AND NUTRITION

Maintenance Fluids and Electrolytes

The classic teaching in pediatric fluid management emphasizes meticulous attention to balancing inputs and outputs. A child’s postoperative hourly fluid requirements are based on weight (Table 39-6). Fluid

selection is based on the dextrose and sodium needs of the child. Children have fewer glycogen stores than adults and typically need additional dextrose to maintain a supply to their glucose-dependent organs. This is usually achieved by providing 10% dextrose to infants less than 1 year of age and 5% dextrose to children older than 1 year, in addition to the requisite electrolytes, at a maintenance rate. Typical daily sodium requirements in children range from 2 to 5 mEq/kg/day, but may increase due to ongoing losses. Though either lactated Ringer’s or 0.9% NS alone are used as isotonic crystalloid for fluid resuscitation, 0.45% NS is usually preferred as the postoperative maintenance fluid in conjunction with either 5% or 10% dextrose for pediatric patients. Potassium chloride is typically added to saline-containing IV fluids, provided there is evidence of adequate renal function (ie, urine output). To meet the daily need of 2 to 3 mEq/kg/day, a standard 20 to 40 mEq/L is generally added, though caution must be taken in severely burned or crushed children.

TABLE 39-6
MAINTENANCE FLUID REQUIREMENTS FOR INFANTS AND CHILDREN

Based on Holliday-Segar Formula	
Weight	Daily Total Volume
0–10 kg	100 mL/kg
11–20 kg	1,000 mL plus 50 mL for each kg over 10 kg
≥ 20 kg	1,500 mL plus 20 mL for each kg over 20 kg
Examples: for 15 kg, 1,250 mL/24 h; for 25 kg, 1,600 mL/24 h	
Based on “4-2-1” Rule	
Weight	Hourly Rate
0–10 kg	4 mL/kg/h
11–20 kg	40 mL/h plus 2 mL/h for each kg over 10 kg
≥ 20 kg	60 mL/h plus 1 mL/h for each kg over 20 kg
Examples: for 15 kg, 50 mL/h; for 25 kg, 65 mL/h	

Sodium and Fluid Disturbances

Typically, adequate urine output is considered to be more than 1 mL/kg/h, though in fluid-restricted states, smaller output can be expected. An indwelling urinary catheter during the acute phase of illness can be instrumental in accurately measuring urine output. Weighing diapers is another method of estimating urine output in children, though this can be compli-

cated by the addition of stool in the diaper. Given a significant amount of stress, one should expect an antidiuretic hormone surge and a state of relative antidiuresis during the first 24 to 48 hours following trauma, operation, or onset of a critical illness. Decreased urine output must be considered in the context of the child's hemodynamics and physical examination to avoid unnecessary fluid overload. Early clues to compromised preload include decreased perfusion, altered mental status, and elevated heart rate. Laboratory data, such as serum lactate and bicarbonate, may help as well. Sustained urine output in excess of 4 mL/kg/h with rising serum sodium may indicate diabetes insipidus. Elevated urine output with low or normal serum sodium may also be indicative of cerebral salt wasting in children with traumatic brain injury. Brisk urine output can also be seen in healthy patients after

receiving significant amounts of fluid resuscitation or after the period of antidiuresis has resolved.

Nutrition

Appropriate nutrition is necessary to prevent catabolism and encourage wound healing. Critical illness results in a neuroendocrine stress response. In general, a critically ill child receiving mechanical ventilation will need fewer calories than an active child, though the hypermetabolic state may lead to increased protein need (Table 39-7).

Early enteral nutrition may decrease ICU length of stay and promote healing while addressing nutritional energy deficit.²⁰⁻²² Trophic feeds (1–5 mL/h) may also assist in the preservation of gut function, preferably postpyloric if intubated versus nasogastric feeds.^{23,24}

TABLE 39-7
MACRONUTRIENT REQUIREMENTS AND DISTRIBUTIONS*

Age	Total Water (L/day)	Total (g/day)	Fat		Protein (g/day)	Carbohy- drates (g/day)	Carbo- hydrates (% total kcal)	Protein (% total kcal)	Fat (% total kcal)
			n-6 Polyun- saturated Fatty Acids Linoleic acid (g/day)	n-3 Polyun- saturated Fatty Acids α-lino- lenic acid (g/day)					
0–6 mo	0.7	31	4.4	0.5	9.1	60	ND	ND	ND
7–12 mo	0.8	30	4.6	0.5	11	95	ND	ND	ND
1–3 y	1.3	ND	7	0.7	13	130	45–65	5–20	30–40
4–8 y	1.7	ND	10	0.9	19	130	45–65	10–30	25–35
9–13 y	2.1 (female), 2.4 (male)	ND	10 (female), 12 (male)	1 (female), 1.2 (male)	34	130	45–65	10–35	20–35
14–18 y	2.3 (female), 3.3 (male)	ND	11 (female), 16 (male)	1.1 (female), 1.6 (male)	46 (female), 52 (male)	130	45–65	10–35	20–35
Adults	2.7 (female), 3.7 (male)	ND	12 (female), 17 (male)	1.1 (female), 1.6 (male)	46 (female), 56 (male)	130	45–65	10–35	20–35

*Estimated energy requirement for critically ill patients is unlikely to be significantly more than the basal energy expenditure (BEE). As such, the following equations can be utilized to estimate energy requirement:
 For boys: BEE (kcal/d) = 68 – [43.3 × age (yr)] + [712 × height (m)] + [19.2 × weight (kg)]
 For girls: BEE (kcal/d) = 189 – [17.6 × age (yr)] + [625 × height (m)] + [7.9 × weight (kg)]
 When insufficient data is available to develop recommended daily allowance (RDA), both RDAs and estimated adequate intake are used for individual intake goals.
 ND: not determined
 Data sources: (1) Institute of Medicine (US) Panel on Macronutrients; Institute of Medicine (US) Standing Committee on the Scientific Evaluation of Dietary Reference Intakes. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*. Washington, DC: National Academies Press; 2005. (2) Otten JJ, Hellwig JP, Meyers LD, eds. *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements*. Washington, DC: National Academies Press; 2006.

Radiographic verification of feeding-tube placement prior to use is generally recommended given the known risk of malpositioning and complication.²⁵ Goal rate for continuous enteral feeds depends upon the desired caloric need and fluid volume (Table 39-8). Although postpyloric feeds must be administered on a continuous basis, for infants and young children gastric feeds may be condensed to six to eight feeds per day as tolerated. For older children, feeds may be further condensed to three to six per day. Overfeeding, particularly in the form of excess carbohydrates, can create additional carbon dioxide and pose ventilatory difficulties.

Most commercially available infant formulas were developed to mimic human breast milk. In infants with lactating mothers, human breast milk (20 kcal/oz) is the preferred option, provided the infant is able to latch appropriately onto the breast or a breast pump is available so the mother can express breast milk. Other enteral formulas vary in composition depending on the age of the patient. Full-term infant formulas typically consist of 20 kcal/oz and are acceptable for use in children up to 1 year of age. Premature infant formulas consist of 22 to 24 kcal/oz and are also used in children up to 1 year of age. Pediatric formulas are indicated for children 1 to 10 years of age and typically have 30 kcal/oz. Adult-type formulas (eg, Boost [Nestle, Vevey, Switzerland]; Ensure, Promote, Osmolite [all made by Abbott Nutrition, Columbus, OH]) typically have between 30 and 60 kcal/oz. Standard adult formulations may be used in children older than 1 year to meet minimum caloric intake, though renal function must be closely monitored because the protein load is 1.5 to 2 times that of pediatric products. If a powder formulation is available, ensure the formula is prepared

TABLE 39-8
GUIDELINES FOR INITIATING AND ADVANCING CONTINUOUS ENTERAL FEEDING*

Age (y)	Initial Infusion	Incremental Advances
0–1	1–2 mL/kg/h	10–20 mL/kg/day
1–6	1 mL/kg/h	1 mL/kg q 2–8 h
> 7	10–25 mL/h	20–25 mL q 2–8 h

*Hourly infusion increases incrementally until goal calories are achieved.

Reproduced from: Fuenfer MM, Creamer KM, eds. *Pediatric Surgery and Medicine for Hostile Environments*. Washington, DC: Borden Institute; 2011.

according to published guidelines with potable water.

Parenteral nutrition may or may not be available (based on resource availability) and requires staff skilled in the sterile and accurate preparation, administration, and monitoring of total parenteral nutrition. Depending on patient acuity, parenteral nutrition may be the only method possible to deliver nutrition (Tables 39-9 and 39-10). Depending on ongoing losses from illness or injury, daily requirements may be higher. The addition of multivitamins and trace elements, such as zinc, copper, manganese, chromium, and selenium, is also essential for wound healing. In the setting of cholestasis, decrease the amount of copper by 50% and discontinue manganese. Patients with renal insufficiency should also be given limited amounts of chromium and selenium. Consider daily electrolyte monitoring to adjust electrolytes.

TABLE 39-9
INITIATION AND ADVANCEMENT OF PARENTERAL NUTRITION*

Dose	Glucose infusion rate (mg/kg/min)	Dextrose (%)	Protein (g/kg/day)	Fat [†] (g/kg/day)
Initial	5–8 (neonate–child), 3–5 (adolescent)	5 (neonate), 10 (infant and older)	2.5 (neonate), 1.5 (infant and older)	1
Advance	1–3	2.5 (neonate), 5–10 (infant and older)	0.5 (neonate), 1 (infant and older)	1
Maximum	11–12 (neonate–child), 5–8 (adolescent)	12.5% peripheral, 25% central	3.5 (neonate), 2 (infant and older)	3–4 (neonate), 2–4 (infant and older)

*Recommended osmolarity should not exceed 900–1,050 Osm/L.

[†]Parenteral lipid emulsion should be run over 24 hours; 20% concentration is preferred.

Data source: Freeman BK, Hampsey J. Nutrition and Growth. In: Tschudy MM, Arcara KM, eds. *The Harriet Lane Handbook: A Manual for Pediatric House Officers*. 19th ed. Philadelphia, PA: Mosby; 2012.

TABLE 39-10
RECOMMENDATIONS FOR PARENTERAL NUTRITION COMPONENTS*

Component	Infants & Toddler	Children	Adolescents
Sodium	2–4 mEq/kg/day	2–4 mEq/kg/day	60–150 mEq/day
Potassium	2–4 mEq/kg/day	2–4 mEq/kg/day	70–180 mEq/day
Calcium (20 mg/mEq)	0.45–4 mEq/kg/day	0.45–3.15 mEq/kg/day	10–40 mEq/day
Phosphorous (31 mg/mmol)	0.5–2 mmol/kg/day	0.5–2 mmol/kg/day	9–30 mmol/day
Magnesium (125 mg/mEq)	0.25–1 mEq/kg/day	0.25–1 mEq/kg/day	8–32 mEq/day
Multivitamin	5 mL/day, pediatric	5 mL/day, pediatric	10 mL/day, adult
Trace elements [†]	0.2 mL/kg/day	0.2 mL/kg/day	5 mL/day

*Consider adding acetate (1–2 mEq/kg/day) if serum bicarbonate is less than 20 or chloride is greater than 115. For parenteral nutrition given via central venous catheter, use heparinization (0.25–0.5 units/mL).

[†]Trace elements include zinc, copper, manganese, and chromium.

Data source: Parenteral nutrition. In: Kleinman, RE, ed. *Pediatric Nutrition Handbook*. 6th ed. Elk Grove Village, IL: American Academy of Pediatrics; 2009.

Refeeding Syndrome

In chronically malnourished children, rapid initiation of full feeds (either total parenteral nutrition or enteral nutrition) can result in a life-threatening depletion of phosphorous, magnesium, and potassium, leading to cardiac arrhythmias, cardiac arrest, and even death. Rapid glucose initiation can also up-regulate insulin

secretion, precipitating hypoglycemia. To initiate nutrition in chronically malnourished children, administer 25% to 50% of estimated caloric needs on days 1 and 2 and increase by 20% each day until the patient has attained goal feeds by day 4 or 5. Monitor serum electrolytes and glucose and replace accordingly. Daily weight checks and weekly serum albumin, prealbumin, and triglycerides are useful in monitoring progress.

PEDIATRIC PAIN AND SEDATION MANAGEMENT

Critically ill children who experience pain often have real and underestimated psychological and physiological responses. Therefore, pain is rightfully recognized as the fifth vital sign, and pain relief is a basic right of all patients. The aims of sedation and analgesia, particularly in a mechanically ventilated child, are manifold: to compassionately provide comfort to injured and ill children, facilitate compliance and tolerance of routine care that can be noxious at times, and preserve calories for the healing process. Three primary approaches have been used to measure pain in pediatric patients: (1) self-report, (2) observational, and (3) physiological.²⁶ The Faces Pain Scale (revised) is an easy-to-use visual identification scale for self-reporting pain in patients over the age of 4 years.^{27,28} In the case of comatose or preverbal children, self-reported pain intensity measures have limited utility. The CRIES neonatal pain score or FLACC score may be of greater utility for these patients.²⁹ When monitoring and titrating sedation, the State Behavioral Scale, COMFORT-Behavioral Scale, or Ramsay Score are also commonly used.^{30–33}

Many agents used for sedation and analgesia in adults can be used safely in children; however, most have never been studied directly in pediatric patients. Propofol is a classic example of how altered patient-drug interactions may differ in children. Although relatively safe for short-term procedural use, prolonged use (greater than 12 hours) of propofol in children has been associated with propofol infusion syndrome, which is characterized by intractable metabolic acidosis, rhabdomyolysis, renal failure, cardiac failure, and death.

Adequate analgesia is often best offered through strategies focused on prevention, with the integration of preemptive and multimodal therapies.²⁹ Non-opioid and opioid-derived analgesics remain an integral component of any strategy (Table 39-11); however, weight-based dosing is necessary, and known toxicities can be expected if weight-based maximum total and daily doses are exceeded. Among opioids, the μ -receptor agonists, particularly fentanyl and morphine, remain the most common drugs used in the PICU. Repeated exposure to an agent predisposes a child to tolerance

TABLE 39-11
COMMONLY USED ANALGESICS IN PEDIATRICS

Nonopioid	
Acetaminophen	10–15 mg/kg/dose (max 1,000 mg) PO/PR q 4–6 h PRN; PO/PR max 90 mg/kg/day up to 4,000 mg/day; 15 mg/kg IV q 6 h or 12.5 mg/kg q 4 h PRN; IV max 75 mg/kg/day
Ibuprofen	10 mg/kg/dose PO q 4–6 h PRN (max dose 40 mg/kg/day)
Ketorolac	0.5 mg/kg/dose IV/IM (max 30 mg) q 6 h × 72 h (do not exceed 5 days)
Trisalicylate	7.5–15 mg/kg/dose (max 1.5 g) PO q 6–8 h PRN
Opioid*	
Fentanyl	0.5–2 µg/kg/dose IV/IO q 1–2 h PRN
Hydromorphone	0.015 mg/kg/dose IV/IO q 4–6 h PRN
Morphine	0.05–0.1 mg/kg/dose IV/IO q 2 h PRN
Oxycodone	0.05–0.15 mg/kg/dose (max 5 mg) PO q 4–6 h PRN

*morphine 0.1 mg = methadone 0.1 mg = hydromorphone 0.02 mg = fentanyl 0.001 mg

PO: per os (by mouth); PR: per rectum; PRN: pro re nata (as needed); max: maximum; IM: intramuscular; IO: intraosseous; IV: intravenous; q: quaque (every)

at that particular dose, as occurs in adults. Titration in amounts of 20% to 50% of the baseline dose is usually well tolerated and, depending on the duration of sedation, the absolute administered dose may reach high levels. When used in the neonate, caution must be taken because hepatic biotransformation and clearance

may be altered and significantly delayed due to the immaturity of the P450 enzyme system. Also, it should be noted that despite historical anecdotes, oral sucrose is likely ineffective and wholly inadequate as an analgesic strategy.³⁴ Both patient-controlled analgesia and local anesthesia are viable and important parts of the analgesic strategy as well (Table 39-12). When opioids are used as sedatives in the PICU, a second class of drugs, such as benzodiazepines or ketamine, should also be considered to provide amnesia as needed, which may also potentiate the opiate effect, resulting in a lower total opiate dose.

Even though children have sleep-wake cycles that differ in structure from adults, disrupted sleep architecture in conjunction with anxiety and fear also predispose children to ICU psychosis.^{35,36} Commonly used sedatives in the PICU include benzodiazepines, barbiturates, dexmedetomidine, ketamine, and propofol, with the latter used largely for procedural sedation (Table 39-13). The utility of intermittent versus continuous infusion is provider dependent, with the benefit of hemodynamic stability offered via continuous infusion weighed against accelerated tolerance. With repeated use of lorazepam, progressive metabolic acidosis and osmolar gap secondary to polyethylene glycol may develop. Given its catechol-dependent metabolism, ketamine is particularly useful for sedating children with congenital heart disease or asthma.

The use of neuromuscular blockade agents in the PICU is driven by clinical necessity, potential adverse effects, and provider preference. The most commonly used neuromuscular blockade agents in the PICU are pancuronium and vecuronium, though other non-depolarizing agents such as cisatracurium are also often used safely.³⁷ The key considerations are limiting paralysis to the shortest period possible at the lowest possible dosing and selection of an agent based on renal and hepatic function.

TABLE 39-12
PEDIATRIC PATIENT-CONTROLLED ANALGESIA*

Drug	Bolus	Basal	Max Dose [†]
Fentanyl	0.25–1 µg/kg/dose	0.25–1 µg/kg/h	3 doses/h; lock out every 10 min
Hydromorphone	0.003–0.006 mg/kg/dose	0.003–0.006 mg/kg/h	5 doses/h; lock out every 7–15 min
Morphine	0.01–0.03 mg/kg/dose	0.01–0.03 mg/kg/h	5 doses/h; lock out every 7–15 min

*Child should be 5 years or older and able to understand the PCA concept. Start low and titrate to effect. Use of basal may improve overall analgesia steady state, including sleep pattern. Consider low-dose naloxone infusion (1–2.5 µg/kg/h) for side-effect alleviation.

[†]Recommended bolus max dose: 0–5 doses/h
max: maximum

TABLE 39-13
COMMONLY USED PEDIATRIC SEDATIVES

Drug	Load/PRN	Infusion
Chloral hydrate	25–100 mg/kg/dose PO/PR; max 1 g/dose	N/A
Dexmedetomidine	Load: 0.5 µg/kg/dose IV × 1	0.2–2 µg/kg/h IV
Ketamine	0.5–2 mg/kg/dose IV every 1–2 h	0.5–2 mg/kg/h IV
Midazolam	0.05–0.1 mg/kg/dose IV every 1–2 h	0.05–0.1 mg/kg/h IV
Pentobarbital	1–3 mg/kg/dose IV or 2–6 mg/kg/dose PO/PR/IM every 2–4 h (max 150 mg)	1–2 mg/kg/h IV
Propofol	1–3 mg/kg/dose IV for induction*	75–300 µg/kg/min IV
Opioid	Infusion†	
Fentanyl	1–6 µg/kg/h IV	
Hydromorphone	0.010–0.015 mg/kg/h IV	
Morphine	0.05–0.2 mg/kg/hour IV	
Remifentanyl	Load: 0.5–1 µg/kg/dose IV × 1; Infusion: 0.05–0.5 µg/kg/min IV	
Adjuncts	Dose	
Clonidine	5 µg/kg/day topical patch (in 50 µg intervals up to 300 µg patch); consider enteral load: 2.5 µg/kg/dose PO every 12 h × 4 doses	
Diphenhydramine	0.5–1 mg/kg/dose (max 50 mg) IV/PO every 6 h	
Lorazepam	0.05–0.1 mg/kg/dose IV/PO every 4–8 h PRN	
Methadone	0.1 mg/kg/dose IV/PO every 4 h × 3 doses, then every 6–12 h (max dose 10 mg)	

*Limit infusion to less than 12 h in children under 18 y because of the association with propofol infusion syndrome.

†To alleviate side effects of continuous opiate infusions, consider antipruritic dosing of naloxone (0.25–1 µg/kg/h IV).
IV: intravenous; max: maximum; N/A: not applicable; PO: per os (by mouth); PRN: pro re nata (as needed)

HEAD AND SPINAL CORD TRAUMA IN CHILDREN

Neurological system failure and brain injury are the most common proximate causes of death in the PICU.³⁸ For those who survive to discharge, long-term sequelae such as motor deficits, visual deficits, speech and language abnormalities, seizures, and behavioral problems are common.³⁹ Thus, although pediatric traumatic brain injury management varies with injury severity and elements of it are common to adult algorithms, understanding and instituting appropriate neuroprotective management strategies is fundamental to the PICU plan of care (Figure 39-6).⁴⁰ In patients who cannot protect their airways, typically those with Glasgow coma scale scores less than or equal to 8, a secure airway must be established. Induction agents should be selected with a consideration toward minimizing spikes in intracranial pressure, particularly through the use of adjuncts such as lidocaine and induction with agents such as thiopental or alternatives such as etomidate (Table 39-14). Careful cervical spine precau-

tions must be taken to maintain neutral positioning, even in the presence of apparently normal cervical spine radiographs, given the frequent occurrence of spinal cord injury without radiographic abnormality among children. Once intubated, the patient should be adequately sedated with continuous infusions and placed on mechanical ventilation to avoid hypoxia and hypercapnia and minimize intracranial hypertension. Goal cerebral perfusion pressures (CPPs) vary by age and are defined as:

$$\text{CPP} = \text{MAP} - \text{ICP}$$

where MAP is the mean arterial pressure and ICP is the intracranial pressure. In the absence of an ICP measurement, MAP is used as a proxy for CPP.

Regardless of the patient's age, a target intracranial pressure of less than 20 mm Hg is generally accepted. Serum osmolarity, sodium, and glucose should be monitored frequently. Osmolarity between 290 and

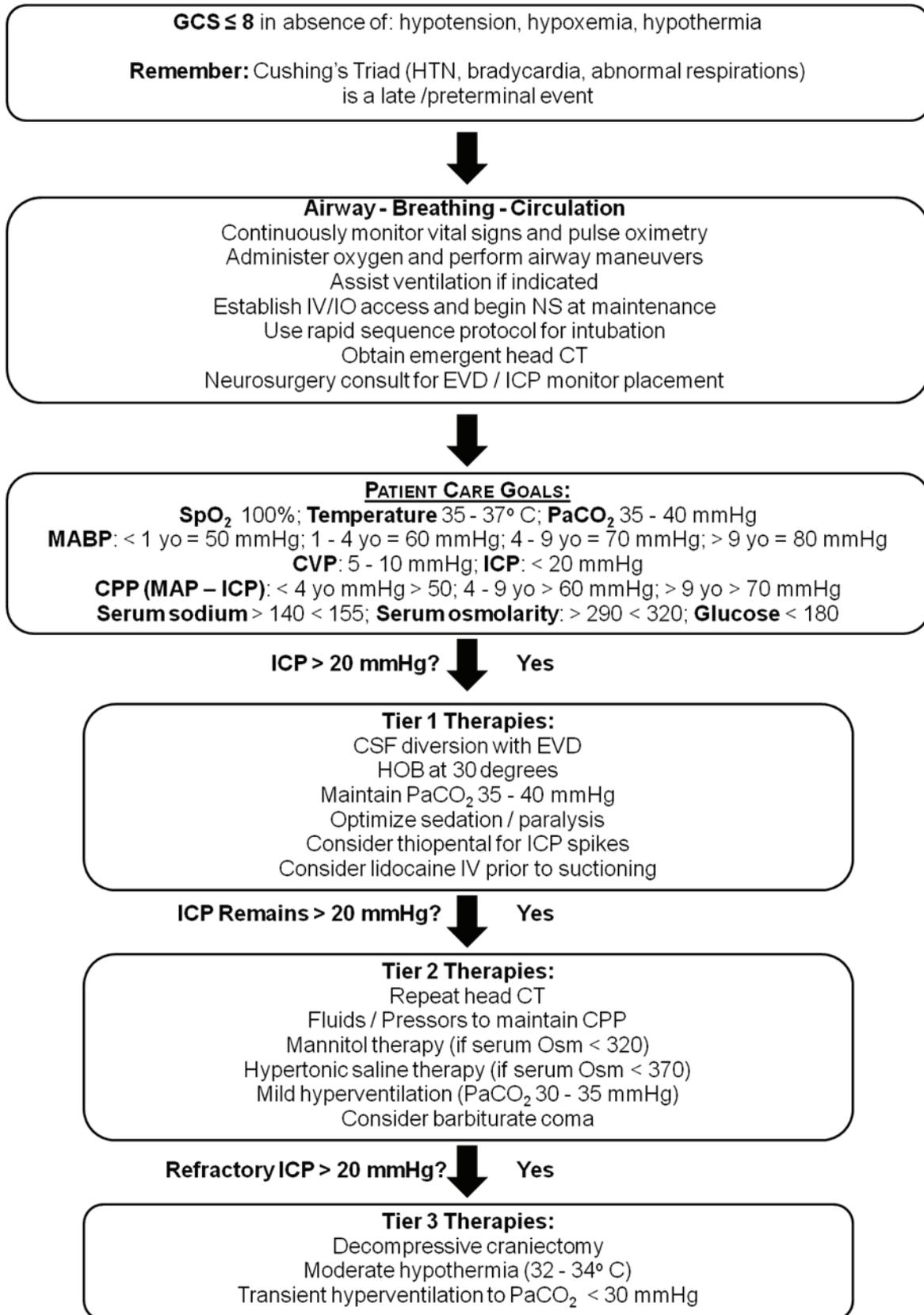


Figure 39-6 (facing page). Acute management of increased intracranial pressure algorithm.

CPP: cerebral perfusion pressure; CSF: cerebrospinal fluid; CT: computed tomography; CVP: central venous pressure; GCS: Glasgow coma scale; EVD: estimated blood volume; HOB: head of bed; HTN: hypertension; ICP: intracranial pressure; IO: introsseous; IV: intravenous; MAP: mean arterial pressure

Data source: Adelson PD, Bratton SL, Carney NA, et al. Guidelines for the acute medical management of severe traumatic brain injury in infants, children and adolescents. *Pediatr Crit Care Med.* 2003;4(3 suppl).

320 mOsm/L, serum sodium between 140 and 155 mEq/L, and normoglycemia are the optimum goals. During periods of increased intracranial hypertension, hypertonic saline can be administered in a 1- to 2-mL/kg dose of 3% saline, ideally via central line, although it can be administered peripherally with proper site monitoring. Mannitol has also been recommended, although its use has become less common as experience with hypertonic saline increases. As a diuretic, mannitol use risks depleting intravascular volume and decreasing mean arterial pressure and cerebral perfusion pressure. If the blood-brain barrier has been disrupted, mannitol may further contribute to cerebral

edema. Mannitol is dosed at 0.25 to 1 g/kg IV. Inducing hyperventilation during the acute period may be an option to reduce cerebral perfusion, although usually only until end tidal carbon dioxide reaches 30 mm Hg. Sustained hyperventilation has been associated with increased morbidity and should be avoided. If an intraventricular catheter has been placed, it may be possible to directly drain cerebrospinal fluid. Data are currently inconclusive regarding the use of therapeutic hypothermia in pediatric brain injury; however, the importance of avoiding hyperthermia is well established.^{41,42} Steroids are not routinely recommended for treating pediatric traumatic brain injury.

FEVER AND INFECTION

Fever in a child, particularly a neonate, can be an ominous sign of occult bacteremia and impending sepsis. In neonates up to 30 days old, fever is defined as a core temperature of 38°C or higher (100.4°F). Temperature is most reliable when obtained via the rectal route. Given their immature immune systems, neonates require full sepsis evaluation for neonatal fever, including blood, urine, and cerebrospinal fluid cultures, and initiation of empiric, broad-spectrum antibiotics pending results.⁴³ Empiric antibiotics in this age range are selected to target perinatally acquired infections such as *Listeria*, Group B streptococcus, *Klebsiella*, *Enterobacter*, and *Pneumococcus* species. Such antibiotics include the combination of ampicillin (200 mg/kg/day IV divided every 6 hours) and cefotaxime (200 mg/kg/day IV divided every 6 hours). Ceftriaxone is not routinely used in this age group because of concerns about cholestasis. If risk factors are significant for herpes simplex virus infection (ie, maternal disease), consider treatment with acyclovir 20 mg/kg/dose every 8 hours IV for 21 days or until a herpes simplex virus polymerase chain reaction test, if available, is negative. In older infants and children,

cerebrospinal fluid studies are recommended based on clinical examination and index of suspicion for meningitis. Because occult urinary tract infection remains the most common cause of serious bacterial infection in infants and young children, blood and urine studies and cultures and empiric antibiotics should still be initiated if the level of clinical suspicion is high. Empiric antibiotic selection for older infants is the same as for neonates. For older children, ceftriaxone (100 mg/kg IV every 24 hours) is the recommended initial therapy. If clinical history indicates concern for methicillin-resistant *Staphylococcus aureus*, the addition of vancomycin (20 mg/kg IV every 8 hours) may be appropriate, with appropriate drug-level monitoring at steady state (prior to the fourth dose).

In the first 48 hours following operative intervention, fever may be common in pediatric patients, as it is in adults, and is a poor predictor of serious infection.⁴⁴ In this setting, blood-culture yield in particular may be low.⁴⁵ In addition to bacteremia and urinary tract infections, wound infection and pneumonia are common causes of serious infection in postoperative patients and should be considered and evaluated.

HEMATOLOGIC ISSUES

Children with significant traumatic injury may require massive transfusion as part of their resuscitation, increasing the risk for metabolic and coagulation derangement. In adults, massive transfusion is defined

as greater than one blood volume loss in 24 hours, 50% in 3 hours, or 150 mL/h. In pediatrics, all blood volume loss and replacement estimates are calculated based on weight (Tables 39-15 and 39-16). To prevent dilutional

TABLE 39-14
**MEDICATIONS COMMONLY USED FOR PEDI-
ATRIC RAPID SEQUENCE INTUBATION**

Drug	Dose
<i>Adjuncts</i>	
Atropine	0.01–0.02 mg/kg/dose IV/IO for < 5 y to blunt vagal reflex; min dose 0.1 mg, max dose child 0.5 mg, max dose adolescent 1 mg
Lidocaine	1 mg/kg/dose IV/IO for patients at risk for increased ICP
<i>Induction</i>	
Etomidate	0.3 mg/kg/dose IV/IO
Fentanyl	2–5 µg/kg/dose IV/IO/IM
Ketamine	1–2 mg/kg/dose IV/IO; 2–4 mg/kg/dose IM
Midazolam	0.1–0.3 mg/kg/dose IV/IO (max 4 mg)
Propofol	2 mg/kg/dose IV/IO
Thiopental	4–7 mg/kg/dose IV/IO if normotensive; 2–4 mg/kg/dose IV/IO if hypotensive
<i>Paralytics–Intubation</i>	
Rocuronium	0.6–1.2 mg/kg/dose IV/IO
Succinylcholine	1–2 mg/kg/dose IV/IO; 2–4 mg/kg/dose IM (premedicate with atropine for < 5 y)
Vecuronium	0.1–0.2 mg/kg/dose IV/IO
<i>Paralytics–Maintenance</i>	
Cisatracurium	0.1–0.2 mg/kg/h IV/IO
Pancuronium	0.1 mg/kg/h IV/IO
Vecuronium	0.1 mg/kg/h IV/IO

ICP: intracranial pressure; IM: intramuscular; IO: intraosseous; IV: intravenous; max: maximum; min: minimum

coagulopathy during massive transfusion, consider a transfusion ratio of 1:1:1 for packed red blood cells to fresh frozen plasma to platelets for children weighing more than 30 kg, and a 30:20:20 milliliter-to-kilogram ratio for children weighing less than 30 kg until hemostasis has been achieved.⁴⁶ Activated factor VIIa (90 µg/kg IV) has also been used successfully to help restore hemostasis in trauma patients.

To conserve such limited resources, when transfusing products in small children, it is useful to have the blood bank split products into aliquots and save them for future use. If possible, a warmer should be

TABLE 39-15
PEDIATRIC ESTIMATED BLOOD VOLUMES

Age	EBV (mL/kg)
Preterm newborn	100
Term newborn	90
1–12 months	75
≥ 12 months	70–75

EBV: estimated blood volume

TABLE 39-16
**PEDIATRIC BLOOD PRODUCT DOSING
GUIDELINES**

Blood product	Dose	Notes
PRBCs	10–15 mL/kg	Transfusion of 10 mL/kg will increase Hgb by ~ 3 gm/dL and Hct by ~ 10%. Give over 4 hours, no faster than 3–5 mL/kg/h*
Platelets	1 unit/10 kg	Increases platelet count by 30,000–50,000/µL; transfuse over 15–30 min
FFP	10 mL/kg	Increases clotting factors by 10%–20%
Cryo-precipitate	1 bag/5 kg	Raises levels by 40% with greater amount of fibrinogen, factor VIII, vWF, and factor XIII

*In severe compensated anemia (Hgb ≤ 5), transfuse X mL/kg (where X = the patient’s Hgb) and transfuse over 4 hours, no faster than 1 to 2 mL/kg/h.

FFP: fresh frozen plasma; Hct: hematocrit; Hgb: hemoglobin
PRBC: packed red blood cell
vWF: von Willebrand factor

Data source: Children’s Hospital Boston. *The Medical-Surgical Intensive Care Unit Handbook*. Boston, MA: 2007.

used prior to administering blood products to prevent hypothermia, although chemical blankets and other blankets may also be used. Hypocalcemia is well recognized in children who have received large amounts of blood products because of the citrate binding of ionized calcium. Because calcium is a key inotrope, particularly in the developing heart, transfusion-related hypocalcemia can go unrecognized and result in cardiac dysfunction and arrest. Typical replacement doses of calcium include calcium chloride 20 mg/kg or calcium gluconate 50 to 100 mg/kg, ideally administered via slow IV push into a central line or

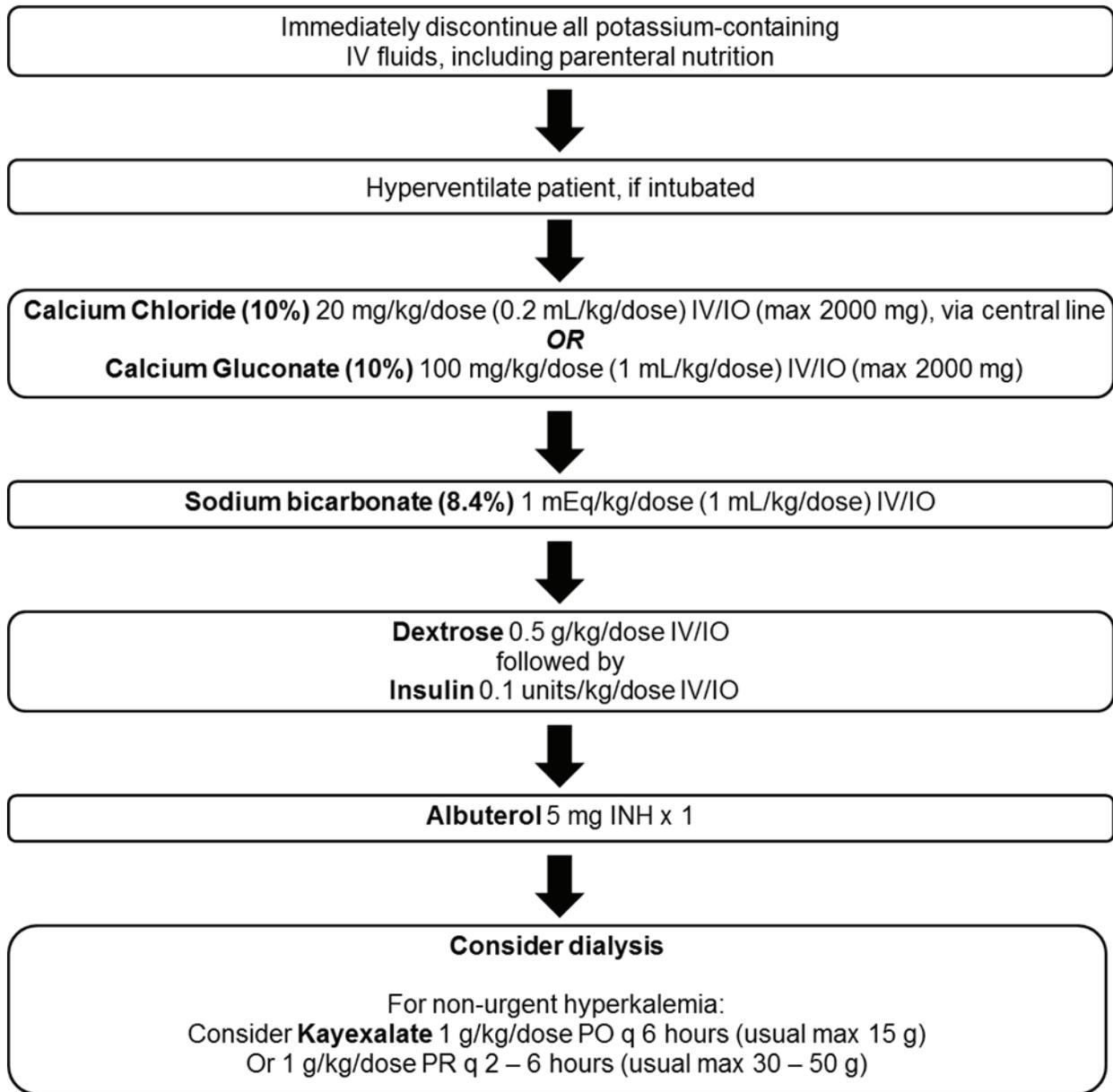


Figure 39-7. Acute management of hyperkalemia algorithm. INH: inhaled; IO: intraosseous; IV; intravenous; PR: per rectum

large-bore peripheral IV. Potassium is released as red blood cells lyse. Older units of packed red cells typically have increased amounts of potassium relative to fresher units. In children with particularly high serum

potassium levels due to crush injuries, burns, or renal failure, the addition of potassium could increase serum potassium to clinically significant levels that require treatment (Figure 39-7).

PEDIATRIC BURN CARE

Retrospective review of military operations from the early 2000s suggests that pediatric burn patients comprised nearly 15% of all pediatric injuries cared for by military physicians in Afghanistan.³ Most

burned children who present to a local combat support hospital must receive their medical care in place. The initial approach and treatment of pediatric burn patients does not differ from that of adults; stopping

the burning process and avoiding extension of primary and subsequent secondary injuries is paramount.⁴⁷ Determining the extent of injury as a proportion of total body surface area varies based on the age of the child (Figure 39-8).

Airway

In an already-at-baseline, smaller-than-adult airway, inhalational exposure to heat and smoke can quickly lead to significant amounts of supraglottic airway edema and obstruction, exacerbated by required fluid resuscitation. A definitive airway should be placed early, particularly if the child presents with facial burns, has noticeable soot in the nares or oropharynx, or presents with stridor. A nasotracheal tube is often easier to secure in the long run, facilitates mouth care, and, during the rehabilitation phase, allows the child to communicate by mouthing words

more effectively. Alar necrosis is a concern in a child who is nasally intubated. If significant portions of the oropharynx and nares are affected by burns, early tracheostomy may be the preferred option.

Breathing

Because children have increased minute ventilation relative to adults, airway exposure to toxic by-products of combustion and higher temperatures is increased manifold. Tissue injury can lead to denuded tissue sloughing and endotracheal tube clogging. This can be avoided with frequent pulmonary toilet and administration of humidified air and mucolytics. Depending on the severity of the injuries, both inhalational injury and extrapulmonary burns may result in acute lung injury and acute respiratory distress syndrome. Carbon monoxide exposure during a burn or inhalation injury is particularly concerning.

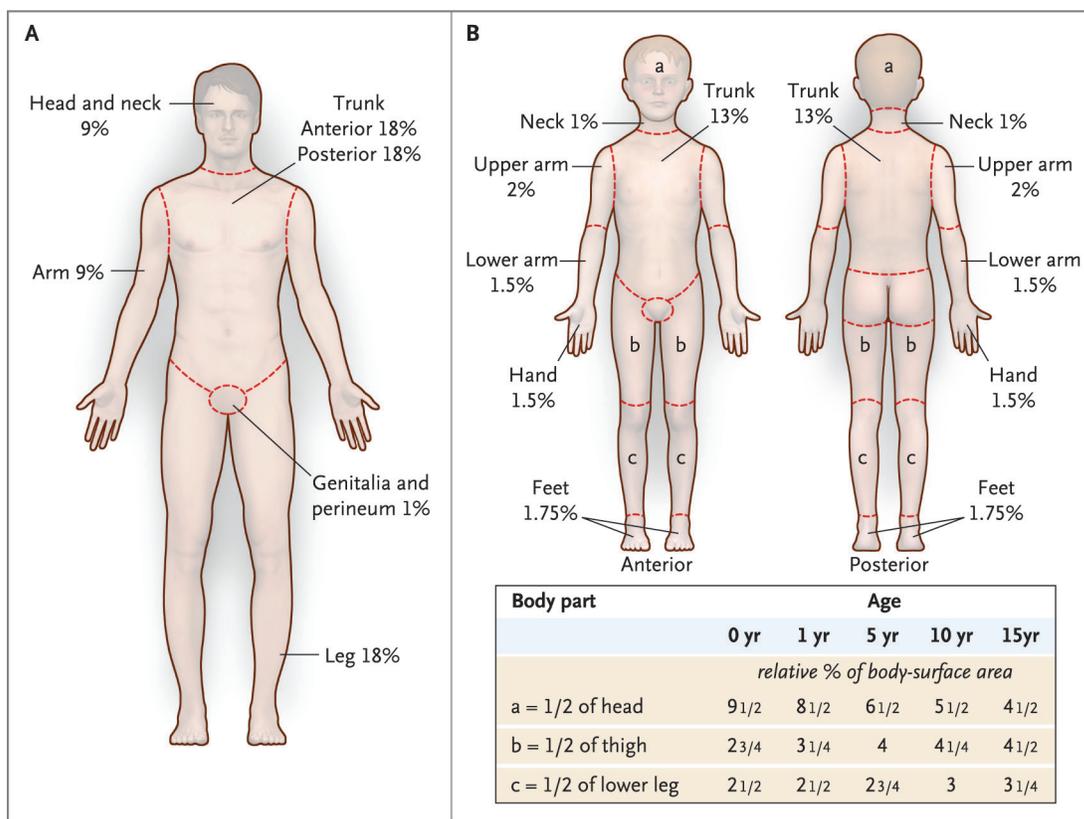


Figure 39-8. The rule of nines and Lund-Browder charts. The rule of nines is often used to determine the extent of total body surface area (TBSA) burn injury in adults. Though less exact, this rule may be adjusted for pediatric patients by considering the head and neck as 18% and the lower extremities as 14%. The Lund-Browder chart allows for more formalized and accurate burn estimation in pediatric patients. In the absence of formal estimation tools, a quick estimate may also be performed by using the patient’s palm to represent approximately 1% TBSA. Reproduced with permission from: Orgill DP. Excision and skin grafting of thermal burns. *N Engl J Med.* 2009;360:893–901.

Carbon monoxide has an affinity for the hemoglobin molecule that is over 200 times higher than that of oxygen, which results in a shift of the oxyhemoglobin curve to the left and to decreased oxygen delivery, leading to cellular hypoxia and tissue acidosis. Direct measurements of carbon monoxide hemoglobin (HbCO) and oxyhemoglobin are necessary to determine injury severity. Administering 100% oxygen at high flows displaces carbon monoxide from HbCO and decreases the half-life of HbCO at room air from 4 to 6 hours to 40 to 60 minutes. This is important because hyperbaric oxygen therapy is unlikely to be available in the field.

Circulation

Reliable IV access is necessary for fluid resuscitation and to administer sedation and analgesia in extensively burned patients. Placing an IO needle for immediate resuscitation can be lifesaving, provided it can be placed in a non-burned site. Placing a urinary catheter is also necessary to monitor ongoing fluid balance. Initial fluid resuscitation aims at restoring burn-related fluid losses in addition to providing ongoing fluid requirements. Exclusive focus on urine outputs as an indication of overall fluid status during this time can result in significant fluid overload, although generally 1 mL/kg/h is adequate. The modified Parkland formula is one common formula for burn resuscitation. In addition to calculated maintenance fluid, the amount of resuscitation fluid over the first 24 hours is determined by the following:

Parkland formula: $4 \text{ mL} \times \text{weight (kg)} \times \% \text{ total body surface area}$

The first half of this fluid is given in the first 8 hours after burn injury and the remaining half is given over the following 16 hours. Lactated Ringer solution is an appropriate resuscitation fluid, although in infants and young children, dextrose should be used in maintenance fluids (dextrose 5% in lactated Ringer or dextrose 5% in NS). Because burned tissue releases potassium into the extracellular space, no potassium is necessary during the first 24 hours. Following initial injury, potassium can be added to fluids, but serum potassium must be closely monitored.

Continued electrolyte and blood-count monitoring is prudent, particularly given that approximately 3% of a child's blood volume is lost with every 1% of body surface area excised. With grafting, approximately 2% is lost for every 1% of body surface area grafted.⁴⁸ Prophylactic antimicrobial therapy is not indicated in burned children because it predisposes the patient to developing multidrug-resistant organisms. Topical antimicrobial therapy in the form of silver-containing products is often necessary for ongoing wound care. The antimicrobial spectrum of silver-containing substances extends to *Staphylococcus aureus*, *Enterobacteriaceae*, *Escherichia coli*, and *Candida albicans*. Such agents include 1% silver sulfadiazine mesh gauze. Ongoing care also requires particular attention to nutritional needs given a patient's hypermetabolic state following burn injury. As with most critical illnesses, initiation of early enteral nutrition is associated with improved outcomes.

PEDIATRIC TRANSPORT PRINCIPLES

Pediatric and neonatal transport to higher levels of care can be lifesaving. Subspecialty pediatric critical care transport teams have been shown to improve outcomes.⁴⁹ In the absence of such a team in theater, proper planning and team selection is essential to ensure safe and timely transport. Personnel skilled in providing critical care, including airway and vascular access, should accompany the patient and be provided with the appropriate equipment and medication to address any contingencies enroute. All catheters, wires, and tubes need to be properly secured prior to movement. Nasogastric tubes, ostomy bags, and chest tubes should remain vented and monitored frequently during transport. Any air-filled device (eg, cuffed endo-

tracheal tube, gastrostomy tube balloon) must be filled with sterile water or pressure monitored, particularly during takeoff and landing. Limbs with circumferential casts at risk of developing compartment syndrome should be bivalved. Given the significant amounts of noise and vibration stressors enroute, adequate sedation and analgesia is necessary to ensure smooth transport with minimal complications. Hearing protection should be considered for patients. If the patient is small enough (ie, less than 10 kg) a flight-approved neonatal isolette provides a quieter environment that preserves ambient heat and humidity. Joint family movement should also be considered, particularly for pediatric patients.

SUMMARY

As a result of unique anatomical, physiological, and psychological characteristics, children represent a

particularly vulnerable segment of the population affected by armed conflict. This chapter has highlighted

basic observations, understandings, and implications surrounding the care of pediatric trauma patients, reinforcing the axiom that “children are not just small adults.” It has provided military anesthesia providers

with the necessary knowledge and resources to be better equipped during the initial trauma resuscitation and subsequent stabilization of a critically ill pediatric patient.

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ATTACHMENT 1: COMMON PEDIATRIC EMERGENCY RESUSCITATION DOSING

Drug	Dose
Adenosine	0.1 mg/kg/dose (max 6 mg) rapid bolus IV/IO; if no effect, repeat 0.2 mg/kg/dose (max 12 mg) rapid IV/IO
Amiodarone	5 mg/kg/dose IV/IO bolus (max 300 mg) if pulseless arrest (VF/pulseless VT); if pulse present, give over 20–60 min (max 300 mg); may repeat to daily max 15 mg/kg (or 2.2 g)
Atropine	0.02 mg/kg/dose IV/IO or 0.04–0.06 mg/kg/dose ETT; min dose 0.1 mg, max dose child 0.5 mg, max dose adolescent 1 mg; repeat every 5 min to max total dose 1 mg child, 2 mg adolescent
Calcium chloride (10%)	20 mg/kg/dose (0.2 mL/kg/dose) IV/IO slow push during arrest (max 2,000 mg); central line preferred
Calcium gluconate (10%)	100 mg/kg/dose (1 mL/kg/dose) IV/IO slow push during arrest (max 2,000 mg)
Dextrose	0.5 to 1 g/kg/dose IV/IO; D ₁₀ 5–10 mL/kg for < 2 mo; D ₂₅ 2–4 mL/kg for 2 mo–2 y; D ₅₀ 1–2 mL/kg for > 2 y
Epinephrine	Pulseless arrest, bradycardia (symptomatic): <ul style="list-style-type: none"> • 0.01 mg/kg/dose (0.1 mL/kg/dose) 1:10,000 IV/IO every 3–5 min (max 1 mg; 10 mL) • 0.1 mg/kg/dose (0.1 mL/kg/dose) 1:1,000 ETT every 3–5 min Anaphylaxis: <ul style="list-style-type: none"> • 0.01 mg/kg/dose (0.01 mL/kg/dose) 1:1,000 IM (max 0.5 mg) • autoinjector 0.3 mg/dose (wt ≥ 30 kg) or Autoinjector Junior 0.15 mg/dose (wt 10–30 kg) IM
Insulin (hyperkalemia)	0.1 units/kg/dose IV/IO following 0.5 g/kg/dose of dextrose
Lidocaine (1%)	1 mg/kg/dose IV/IO, 2–3 mg/kg/dose ETT
Magnesium sulfate	25–50 mg/kg/dose IV/IO bolus (pulseless VT) or over 10–20 minutes (VT with pulses)
Sodium bicarbonate (8.4%)	1 mEq/kg/dose (1 mL/kg/dose) IV/IO; dilute 1:1 with sterile water for neonates
Vasopressin	0.5 units/kg/dose (max 40 units) IV/IO push for pulseless arrest
Cardioversion/Defibrillation	
SVT or VT w/ pulse	Cardiovert: 0.5–1 joules/kg synchronized × 1; if no response, 1–2 joules/kg synchronized
VF or Pulseless VT	Defibrillate: 2 joules/kg × 1, 4 joules/kg × 2; adult: monophasic 360 joules, biphasic 200 joules
Reversal	
Naloxone	Respiratory depression: 0.001 mg/kg/dose IV/IO/IM/SQ every 1–2 minutes until adequate respirations; respiratory arrest / full reversal: 0.1 mg/kg/dose IV/IO/IM/SQ (max 2 mg/dose)
Flumazenil	0.01 mg/kg/dose (max dose 0.2 mg) IV/IO; repeat every 1 min to max total dose 0.05 mg/kg/dose or 1 mg as necessary
D ₁₀ : dextrose 10%	IV: intravenous
D ₂₅ : dextrose 25%	max: maximum
D ₅₀ : dextrose 50%	SQ: subcutaneous
ETT: endotracheal tube	SVT: supraventricular tachycardia
IM: intramuscular	VF: ventricular fibrillation
IO: intraosseous	VT: ventricular tachycardia

ATTACHMENT 2. PEDIATRIC DOSING FOR SELECTED CATEGORIES OF COMMONLY USED MEDICATIONS

Antihypertensives	
Amlodipine	0.1 mg/kg/dose (usual max 10 mg) PO daily to BID
Esmolol	Load: 500 µg/kg IV × 1; infusion: 25–300 µg/kg/min IV, repeat load as needed
Hydralazine	0.1–0.5 mg/kg/dose (max 20 mg) IV/IM every 4–6 hours PRN
Labetolol	0.25–1 mg/kg/dose (usual max 20 mg) IV every 10 min PRN; infusion: 0.25–1 mg/kg/hour IV
Nicardipine	0.5–5 µg/kg/min IV
Nitroglycerin	0.5–5 µg/kg/min IV
Nitroprusside	0.5–10 µg/kg/min IV; monitor cyanide and thiocyanate for > 4 µg/kg/min
Diuretics	
Bumetanide	≤ 6 mo: 0.01–0.05 mg/kg/dose (max 1 mg) IV/PO daily; > 6 mo: 0.02–0.1 mg/kg/dose (max 10 mg) IV/PO daily; Adult: 2 mg IV/PO daily to BID
Chlorothiazide	10–20 mg/kg/dose IV/PO every 12 h (max IV 500 mg/dose; max PO 188 mg/dose for < 2 yo; max PO 1,000 mg/dose for > 2 yo)
Furosemide	1–2 mg/kg/dose IV/PO every 6–24 h (usual starting max 20 mg); Infusion: 0.05–0.3 mg/kg/h
Spirolactone	1 mg/kg/dose (max 100 mg) PO every 12 h
Endocrine / Metabolic*	
Dexamethasone	Airway edema: 0.1–0.6 mg/kg/dose (max dose 10 mg) IV every 6 h × 4–6 doses; croup: 0.6 mg/kg IM/PO × 1
Hydrocortisone	Stress dose: 50 mg/m ² /dose (usual max 100 mg) IV × 1, then 25 mg/m ² /dose (usual max 75 mg) IV every 6 h; maintenance dose: 5 mg/m ² /dose (usual max 10 mg) IV every 8 h
Methylprednisolone	Loading dose for asthma: 2 mg/kg/dose IV × 1; maintenance: 0.5–1 mg/kg/dose (usual max 60 mg) IV every 6–12 h
Vasopressin	0.5–3 milliunits/kg/h; titrate to maintain UOP < 2 mL/kg/h
Neurologic/Seizure/Cerebral Edema	
Diazepam	0.1–0.2 mg/kg/dose IV/IO every 15–30 min PRN; < 5 yo: 0.5 mg/kg/dose PR every 2 h PRN; 6–11 yo: 0.3 mg/kg/dose PR every 2 h PRN; ≥ 12 yo: 0.2 mg/kg/dose PR every 2 h PRN
Hypertonic saline (2% or 3% NaCl)	3 mL/kg IV over 30 min. Note: 1 mL/kg of 3% NaCl will increase serum sodium ~1 mEq/L
Fosphenytoin	Load: 20 mg PE/kg/dose IV × 1; maintenance: 2 mg PE/kg/dose IV every 8 h; max infusion rate 3 mg PE/kg/min up to 150 mg PE/min
Lorazepam	0.05–0.1 mg/kg/dose (usual max 4 mg) every 15 min PRN
Mannitol	0.25 g/kg/dose IV over 20–30 min PRN × 1
Phenobarbital	Load: 20 mg/kg/dose IV × 1; maintenance: 2.5 mg/kg/dose IV/PO every 12 h

Respiratory

Albuterol	2.5 mg/dose in 3 mL NS nebulized; may repeat every 20 minutes \times 3 or continuous; continuous: 0.5 mg/kg/h (usual max 20 mg/h); < 7.5 kg: 2.5 mg/h INH; 7.5–4.9 kg: 5 mg/h INH; 15–29.9 kg: 10 mg/h INH; > 30 kg: 20 mg/h INH
Epinephrine	0.01 mg/kg (0.01 mL/kg) 1:1,000 SQ/IM (max 0.5 mg)
Ipratropium	0.25–0.5 mg/dose INH every 4–6 h
Magnesium sulfate	75 mg/kg/dose IV \times 1 over 15–20 min (max 2000 mg); monitor for hypotension
Terbutaline	Load: 10 μ g/kg/dose IV \times 1 over 30 min; infusion: 0.4–6 μ g/kg/min IV

Miscellaneous

Albumin	0.5 g/kg/dose (5% = 10 mL/kg; 25% = 2 mL/kg)
Heparin (DVT treatment)	Load: 75 units/kg IV \times 1; infusion: for < 1yo: 28 units/kg/h; for \geq 1 yo: 20 U/kg/h; check coagulation panel 4–6 h after change. Adjust dose to give PTT 1.5–2.5 \times control

*Glucocorticoid effect (ratio of antiinflammatory potency of hydrocortisone per mg vs the antiinflammatory potency of the other steroid preparations): hydrocortisone, 1:1; prednisone, 4:1; methylprednisone, 5:1; dexamethasone, 30:1.

Mineralocorticoid effect (ratio of potency of hydrocortisone per mg vs the potency of the other steroid preparations): hydrocortisone, 1:1; prednisone, 0.25:1; methylprednisone, 0.4:1; dexamethasone, 0:1.

BID: twice a day (bis in die)

DVT: deep vein thrombosis

h: hour

IM: intramuscular

INH: inhaled

IV: intravenous

max: maximum

min: minute

mo: month

NaCl: sodium chloride

NS: normal saline

PE: phenytoin sodium equivalents

PO: per os (by mouth)

PR: per rectum

PRN: pro re nata (as needed)

PTT: partial thromboplastin time

SQ: subcutaneous

UOP: urine output

yo: years old

