Chapter 2

Anesthesia

Pediatric trauma anesthesia varies significantly from adult trauma anesthesia because of the anatomical and physiological differences between adults and children (Table 2-1).

Table 2-1. Anatomical Considerations

Airway Anatomy	Implications
Infants have a large occiput, anterior airway	The traditional sniffing position, which flexes the head downward, is not helpful; place a rolled towel under the shoulders to facilitate intubation
Small airway means small ET tube	Tube can easily become plugged with blood or secretions
Cricoid is the narrowest part of the airway	Ensure leak at 20–25 cm water pressure to avoid edema*
Short trachea	Endobronchial intubation is common; extubation can be caused by small movements of the head or ET tube
Infants have increased airway reactivity	Bronchospasm is common, especially during light anesthesia or if ET tube is near the carina
Infants have an increased dead space/minute ventilation ratio	Increased risk of rebreathing carbon dioxide; avoid adding connectors between ET tube and circuit

ET: endotracheal
*It may be necessary to have a seal of a greater magnitude than 25-cm water pressure when ventilating patients who have significant pulmonary contusions or edema that is a greater immediate threat than the eventual risk of postintubation croup or subglottic stenosis. Ventilating pediatric patients is difficult with field anesthesia machines, which rely on older, manually adjusted bellows. Intensive-care-unit-grade ventilators are more effective at generating exact tidal volumes and can be used with intravenous anesthesia.

Physiological Considerations

Infants and small children are unable to increase their stroke volume, making them dependent on heart rate to maintain cardiac output. In infants < 6 months old, consider using atropine before induction or giving neuromuscular blockade to maintain heart rate during rapid sequence intubation (see Table 2-2 for normal vital signs by age group).

Table 2-2. Normal Vital Signs by Age Group

Age	Weight (kg)*	Respiratory Rate (breaths/min)	Heart Rate (beats/min)	Normal Systolic Blood Pressure (mmHg)†
Premature infant	< 3 kg	40–60	130–170	45–60
Term newborn (< 28 days)	3 kg	35–60	120–160	60–70
Infant (1 mo–1 y)	4–10	25–50	110–150	70–100
Toddler (1–2 y)	10–13	20–30	90–130	75–110
Young child (3–5 y)	13–18	20–30	80–120	80–110
Older child (6–12 y)	18–40	15–25	70–110	90–120
Adolescent (13–18 y)	> 40	12–20	55–100	100–120

*Weight norms based on US children. Expect lower weights in countries where malnutrition is more prevalent.

†For children 1–10 years old, use the following equation: 70 + 2(age) = lowest acceptable systolic pressure for age.

- **Hypoventilation** is the most common cause of cardiac arrest in children
- **Respiratory acidosis**, further exacerbating a metabolic acidosis, is a common occurrence in injured children
- **Hypotension** is a late sign of **hypovolemia** in pediatric patients
  - Blood pressure usually remains normal until > 25% blood volume is lost
  - Poor perfusion, evidenced by cool extremities, delayed capillary refill, and diminished distal pulses, is an early sign of hypovolemia
  - The most common cause of hypotension in pediatric patients is hypovolemia
  - If the patient is not responding to volume resuscitation, medications may be needed to increase blood pressure
    - Phenylephrine **should not** be a first-line choice for treating intraoperative hypotension in children
    - Small doses of epinephrine are a better first-line choice

        - ▹ Start with 1–4 μg and titrate to effect
        - ▹ At low doses, the β effects of epinephrine predominate, increasing heart rate and contractility
    - ▸ Consider a continuous infusion of inotropes or pressors if hypotension persists despite adequate fluid and blood product resuscitation
    - ▸ Dopamine and epinephrine are preferred for pediatric patients

Intubation

- Indications: altered level of consciousness, impending or actual upper airway obstruction, and hemodynamic instability
- Orotracheal intubation is the most reliable means of establishing an airway and ventilating a child
    - The risk of penetrating the cranial vault or injuring the nasopharyngeal soft tissue is a relative contraindication to the use of the nasotracheal route in patients ≤ 12 years old
- In head-injured or comatose patients, intubation should be performed with cervical spinal immobilization
- For chronically malnourished children, consider starting with a slightly smaller tube

Airway Formulas

- Ways to estimate the appropriate endotracheal (ET) tube size:
    - (Age + 16)/4
    - Height (cm)/20
    - Size of child's small finger (fifth digit on hand)
    - Premature infant: 2.5
    - Term infant: 3.0
- Ways to estimate appropriate depth of ET tube (cm):
    - Infant: 6 + weight (kg)
    - Child: 3 × size (inner diameter) of tube
- **NOTE:** These are only estimates; always evaluate clinically

Surgical Airway

In infants and small children, cricothyroidotomy may cause long-term damage to the larynx, so tracheostomy is preferred. Cricothyroidotomy can be safely performed in children ≥ 11 years old.

Initial Ventilator Settings

- Tidal volume: 7–10 mL/kg
- If using pressure control, peak inspiratory pressure (PIP): 20–25 cm H_2O
- Positive end-expiratory pressure (PEEP): 3–5 cm H_2O
- Age-appropriate respiratory rates:
  - Adolescents: 10–15 breaths per minute (bpm)
  - Children: 15–25 bpm
  - Infants: 25–30 bpm
- Fraction of inspired oxygen (FiO_2): 100% initially, then titrate to nontoxic levels as permissible

Pediatric Equipment Sizing

In an emergency, the preferred method of determining equipment size for pediatric patients is using the Broselow Pediatric Measuring Tape (if available). To use the tape, measure the patient from the top of the head to the heels and use the equipment and drug doses indicated on the tape. For central line sizes, refer to Chapter 3, Vascular Access. Otherwise, refer to the equipment table on the inside and front cover of this book.

Pediatric Trauma Resuscitation

Acidosis, hypothermia, and coagulopathy are a deadly triad for patients presenting with major exsanguinating trauma.

- **Hypothermia**
  - Pediatric patients are predisposed because of their large surface-area-to-weight ratio
  - Worsens preexisting acidosis by causing a leftward shift in the oxyhemoglobin dissociation curve, leading to decreased oxygen delivery to the tissues
  - Can cause decreased drug metabolism and, in infants, can lead to apnea and hypoglycemia
  - Aggressive rewarming and normothermia maintenance must be initiated immediately upon arrival of the pediatric trauma patient. Strategies for increasing or maintaining body temperature include, but are not limited to:
    - Increasing the room temperature
    - Using forced-air warmers
    - Preparing and working on one body part at a time while leaving the rest of the child covered

    - Wrapping the child's body and head in plastic bags
  - Fluid-warming devices are helpful; however, the volume of fluid and blood products administered to the pediatric patient must be controlled. One way to do this is to use a syringe at the end of the warming line to administer warm intravenous (IV) fluids and blood products
- Fluid resuscitation
  - In cases where blood products are not the initial therapy of choice, fluid resuscitation should be initiated with a 20 mL/kg bolus of normal saline (NS) or Ringer's lactate
    - The patient should be reassessed after each bolus of NS to evaluate whether or not more fluid or a change to blood is required
    - If IV access is not rapidly achieved (1–3 min), immediately proceed to intraosseous (IO) access
    - Resuscitate through the IO access and then obtain reliable IV access
  - For small IV catheters (22 gauge and 24 gauge), bolusing with a 10–20 mL syringe is the most efficient way to rapidly deliver fluids and blood products (see Table 2-3 for maintenance fluid recommendations)

Table 2-3. Maintenance Fluid Requirements

Weight (kg)	Amount of Normal Saline to Administer
Up to 10	4 mL/kg/h
10–20 kg	40 mL/h + 2 mL/kg/h for each kg > 10
> 20 kg	60 mL/h + 1 mL/kg/h > 20 kg

  - Small children (< 2 years old) can occasionally become hypoglycemic during long operative cases
    - The tendency toward hypoglycemia is usually counterbalanced by the stress response of surgery
    - If potential hypoglycemia is concerning, run a maintenance-only infusion using an infusion pump of D_5 0.45% NS (do not include glucose in any of the resuscitation fluids or the patient will become hyperglycemic)

- Blood therapy
  - See Chapter 5, Transfusion Medicine, for guidance on routine and massive transfusion strategies
  - Hypocalcemia is associated with rapid infusion of colloids, including blood products (particularly fresh frozen plasma and fresh warm whole blood)
    - Severe cardiac depression and hypotension can result from ionized hypocalcemia (potent inhalational agents dramatically exacerbate hypotension)
    - Do not **routinely** transfuse at a rate faster than 1 mL/kg/min
    - Prevention includes limiting the rate of fresh frozen plasma transfusion to less than 1 mL/kg/min and administering calcium chloride (5 mg/kg) or calcium gluconate (15 mg/kg)
  - If a patient is at risk for massive transfusion, packed red blood cells, fresh frozen plasma, and platelet transfusion should be initiated in a 1:1:1 ratio
    - Helps avoid coagulopathy
    - Has been shown in adults to reduce mortality

Burns

In children with unrecognized inhalational injuries, severe airway swelling may occur after fluid resuscitation. If there is uncertainty about whether an inhalational injury has occurred, intubate early.

- In addition to maintenance fluids (see Table 2-3), use the Parkland formula for fluid resuscitation in the first 24 hours after a burn:

4 mL/kg Ringer's lactate × body surface area (BSA) burned

  - Give half in the first 8 hours, half over the next 16 hours
  - **This formula is an estimate only.** The goal is to give enough fluids to maintain urine output of 1 mL/kg/h
- To calculate daily maintenance after the first 24 hours (mL/24 h):

$$[(\%\ \text{total BSA burned} + 35) \times \text{BSA}\ (m^2) \times 24] + 1{,}500\ \text{mL}/m^2$$

[1,500 mL/m^2 = daily maintenance fluid required in a burn patient]

Calculating BSA using a Web-based BSA calculator is easier, but the Mosteller formula can also be used:

$$\textbf{BSA (m}^2\textbf{) = (height (cm) × weight (kg)/3,600)}^{1/2}$$

- Consider pulmonary injury, carbon monoxide poisoning, and chemical exposure, particularly in closed-space burns
- Consider airway burns and edema when patient presents with discolored sputum
- Nutritional support is critical; start tube feedings as soon as possible postoperatively
- Blood loss during burn excision: 3% of blood volume for every 1% of BSA excised
- Blood loss during skin grafting: 2% of blood volume for every 1% of BSA grafted

Preoperative Sedation

Children who require repeated operations after sustaining initial trauma will benefit from preoperative sedation. In children for whom IV access has been established, dose-adjusted preoperative sedation regimens similar to those used in adults are appropriate. For children without IV access, the following are some of the available options:

- Oral: **midazolam** 0.5 mg/kg (maximum dose 10 mg) 20 minutes prior to the procedure
- Rectal: **methohexital** 25–30 mg/kg (indicated for children weighing < 15 kg)
    - Mix 500 mg methohexital with water to a volume of 5 mL
- Intramuscular: 0.2 mg/kg **midazolam** + 1.5–2.0 mg/kg **ketamine** + 5–10 μg/kg **glycopyrrolate** (use 5 mg/mL concentration of midazolam or the volume will be too large)

Postoperative Pain Management

- Use a continuous IV opioid infusion (Table 2-4) if unable to use patient-controlled analgesia (PCA; eg, if patient is < 6 years old or if there is a language barrier)
- PCA is usually suitable for children > 6 years old (Table 2-5)
    - Communication must be sufficient to ensure both patient and parent understand appropriate PCA use
    - Loading dose is the same as for continuous infusion

Table 2-4. Intravenous Narcotics: Continuous Infusion*

Drug	Loading Dose	Continuous Infusion
Morphine	0.05 mg/kg	0.01–0.06 mg/kg/h
Fentanyl	1 μg/kg	0.2–3 μg/kg/h
Hydromorphone	10 μg/kg	0.5–4 μg/kg/h

*Bolus to achieve analgesia and start infusion at a lower rate. If analgesia is inadequate, rebolus with half the first dose, and increase rate by 25%.

Table 2-5. Patient-Controlled Analgesia Dosing*

Drug	Dose	Basal Rate	Lock out
Morphine	10–30 μg/kg	5–30 μg/kg/h	6–12 min
Fentanyl	0.25–1.0 μg/kg	0.25–1.0 μg/kg/h	6–12 min
Hydromorphone	2–6 μg/kg	1–3 μg/kg/h	6–12 min

*Patient-controlled analgesia can be used in a normal cooperative child as young as 6 years old.

  - Basal rates are associated with overdoses in adults; monitor closely or avoid if possible
  - Prevent family from pushing PCA button
- Intermittent IV opioid dosing
  - **Morphine**: starting dose is 0.05–0.1 mg/kg IV
    - Repeat dosing every 5–10 minutes until effective analgesia is established
    - Use this as basis for IV q2–4h dosing schedule
  - **Fentanyl**: starting dose is 0.5–1 μg/kg IV
    - Repeat dosing every 5–10 minutes until effective analgesia is established
    - Use this as basis for IV q1–2h dosing schedule
- Oral opioids and other adjuvant medications
  - **Acetaminophen** has opioid-sparing effects
    - Oral load 30 mg/kg, then 10 mg/kg q4h
    - Rectal load 40 mg/kg, then 20 mg/kg q4h
    - Maximum dose is 90–110 mg/kg/day
  - Administer ketorolac 0.5 mg/kg IV q6h for no more than 3 days

- **Tramadol** is a weak μ-agonist
    - Administer 1–2 mg/kg orally q6h
    - Do not exceed 400 mg/day
- **Acetaminophen with codeine** can also be used
    - Codeine dosing is 0.5–1.0 mg/kg/dose orally q4–6h (dose is limited by maximum daily dose of acetaminophen)
    - 25% of patients cannot convert codeine to its active formulation and it will not be effective in these patients
- Administer **oxycodone** 0.05–0.15 mg/kg/dose orally q4–6h (daily dose is limited by maximum dose of acetaminophen if in a combined form)

Regional Anesthesia

Regional anesthesia may be contraindicated by shock or sepsis at initial presentation, but can be effective after initial stabilization and is usually performed while the child is anesthetized (Tables 2-6–2-8).

Table 2-6. Pediatric Drug Dosing for Caudal or Epidural Blocks

Age	Bupivacaine	Ropivacaine	Clonidine	Fentanyl
Single Injection				
< 1 y	0.25%, 1 mL/kg	0.2%, 1.2 mL/kg	1.0–1.5 µg/kg	2 µg/mL
> 1 y	0.25%, 1 mL/kg, max 20 mL	0.2–0.5%, max 20 mL or 3.5 mg/kg	1.0–1.5 µg/kg	2 µg/mL
Continuous Injection				
< 3 mo	0.0625%–0.125%, 0.2 mg/kg/h	0.1%–0.2%, 0.2 mg/kg/h	0.12–0.2 µg/kg/h	1–2 µg/mL
< 1 y	0.125%, 0.3 mg/kg/h	0.1-0.2%, 0.3 mg/kg/h	0.12–0.2 µg/kg/h	1–2 µg/mL
> 1 y	0.125%, 0.3–0.4 mg/kg/h	0.1%–0.2%, 0.4 mg/kg/h	0.12–0.2 µg/kg/h	1–2 µg/mL

Reproduced from: Buckenmaier C, Bleckner L. *Military Advanced Regional Anesthesia and Analgesia Handbook*. Washington, DC: Borden Institute; 2009: Table 30-2.

Table 2-7. Pediatric Spinal Dosing

Age	Bupivacaine (mg/kg)	Tetracaine* (mg/kg)	Ropivacaine (mg/kg)
Infants	0.5–1.0	0.5–1.0	0.5–1.0
1–7 y†	0.3–0.5	0.3–0.5	0.5
> 7 y†	0.2–0.3	0.3	0.3–0.4

*With tetracaine, use epinephrine wash (epinephrine aspirated from vial and then fully expelled from the syringe prior to drawing up local anesthetic) to increase duration up to 120 minutes.
†Additives: clonidine 1–2 μg/kg for children > 1 year of age.
Reproduced from: Buckenmaier C, Bleckner L. *Military Advanced Regional Anesthesia and Analgesia Handbook.* Washington, DC: Borden Institute; 2009: Table 30-3.

Table 2-8. Drug Dosing for Pediactric Single-Injection Peripheral Nerve Block*

Block	Dose Range (mL/kg)	Midrange Dose (mL/kg)	Maximum Volume (mL)
Parascalene	0.2–1.0	0.5	20
Infraclavicular	0.2–1.0	0.5	20
Axillary	0.2–0.5	0.3	20
Paravertebral	0.5–1.0	0.7	5
Femoral	0.2–0.6	0.4	17
Proximal sciatic	0.3–1.0	0.5	20
Popliteal	0.2–0.4	0.3	15
Lumbar plexus	0.3–1.0	0.5	20

*Children < 8 y: 0.2% ropivacaine or 0.25% bupivacaine. Children > 8 y: 0.5% ropivacaine or 0.5% bupivacaine. **Do not exceed maximum recommended doses of local anesthetic.**
Reproduced from: Buckenmaier C, Bleckner L. *Military Advanced Regional Anesthesia and Analgesia Handbook.* Washington, DC: Borden Institute; 2009: Table 30-4.

Further Reading

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