Chapter 4

Mechanical Ventilation

Equipment

When providing mechanical ventilation for pediatric casualties, it is important to select the appropriately sized bag-valve mask or endotracheal (ET) tube. The appropriately sized bag-valve mask will cover the child's mouth and nose and will sit below the eyes, across the bridge of the nose (Tables 4-1 and 4-2).

Table 4-1. Bag-Valve Mask Sizes

Age	Size
Infant	500 cc
1–3 y	1 L
> 3 y	3 L

Table 4-2. Artificial Airways

Age	ET Tube Size	Tracheostomy Tube Size*
Newborn	3.0–3.5	3.0–3.5
6 mo	3.5	4.0
18 mo	3.5–4.0	4.0
24 mo	4.0–4.5	5.0
2–4 y	4.5–5.0	5.5
4–7 y	5.0–6.0	6.0
7–10 y	6.0–6.5	6–8
10–12 y	7.0	8

ET: endotracheal
*Tracheostomy tube should typically be a half size larger than the appropriately sized ET tube.

Safety

All ventilated patients should have an appropriately sized bag, mask, replacement ET tube, or tracheostomy tube available at the bedside. Wall suction and a Yankauer airway suction catheter should also be available at the bedside at all times.

Most modern ventilators are capable of safely, effectively, mechanically ventilating infants and small children. A knowledgeable respiratory therapist should be able to adjust for these patients' special needs during setup.

Settings for Getting Started

- Volume Ventilation Mode: Synchronized Intermittent Mechanical Ventilation/Volume Control
  - Fraction of inspired oxygen (FiO_2): 50%; if patient is hypoxemic, use 100%; wean rapidly to FiO_2 < 50% if possible
  - Inspiratory time ("I time") should be no less than 0.5 seconds, ranging up to 1 second in older children
  - Intermittent mandatory ventilation (IMV) rate should be appropriate for the patient's age (ie, 30 [for infants] down to 15 [for adult-sized patients]) to start
  - **Tidal volume** (Vt) should initially equal 10 mL/kg, rounding down
    - Look at chest rise, listen for breath sounds, and check peak inspiratory pressure (PIP)
    - **Decrease Vt** if examination reveals excessive chest rise, large air entry, and higher-than-expected PIPs (< 30–35 cm H_2O)
      - Elevated PIPs may result from right main stem ET tube placement, mucous plugging, excessive Vt, or poor lung compliance (ie, 1° pulmonary disease)
      - Goal Vt for patients with acute lung injury or acute respiratory distress syndrome (ARDS) should be around 6 mL/kg (as it is for adults)
      - Strongly consider switching to pressure-control (PC)–style ventilation for severe lung disease
    - **Increase Vt** if examination reveals poor chest rise, minimal air entry, and lower-than-expected PIPs (< 15 cm H_2O)
      - Adult-sized ventilator circuits may consume large amounts of volume each breath (2–3 cc for every centimeter H_2O pressure difference between PIP and positive end expiratory pressure [PEEP])
      - If this occurs, increase Vt or change to a PC-style breath

  - **PEEP** should be 4 cm, or higher if functional residual capacity is compromised by atalectasis, abdominal distension, or severe lung disease
    - Increase in increments of 2 cm H_2O
    - Volume recruitment with PEEP takes hours but can be lost in minutes
  - If available, start **pressure support** (PS) for spontaneously breathing patients at 10 cm H_2O
  - Measure arterial blood gases to accurately access ventilation status
  - Use chest radiographs to confirm the adequacy of the ET tube placement and chest expansion
  - Use end-tidal carbon dioxide monitors if available
- Pressure Ventilation Mode: Synchronized Intermittent Mechanical Ventilation/Pressure Control
  - Same initial settings as volume control for FiO_2, I time, IMV rate, PEEP, and PS
  - Pressure-style ventilation offers advantages by allowing effective Vt at lower PIP and improves oxygenation for any given Vt
  - Strongly consider pressure ventilation (if available) for large air leaks due to small ET tube size, ineffective ventilation (eg, 2° adult ventilator circuit on infant or small child), or poor lung compliance
  - Set PC to give effective chest rise and adequate air entry
    - Expect PIPs between 18 and 22 cm H_2O in patients with healthy lungs, between 23 and 27 cm H_2O for those with moderate lung disease, and between 28 and 35 cm H_2O in those with more severe lung disease
  - Once PC is established, use machine-measured inspiratory and expiratory volumes as an estimate of the patient's lung compliance (volumes should be $\leq$ 10 mL/kg to avoid overstretch)

Problem Solving

- When a ventilated patient **acutely deteriorates**, don't be a **DOPE**

  Dislodged ET tube: check for equal breath sounds. Is end-tidal carbon dioxide waveform present?

Obstructed: suction mucous plug
Pneumothorax: check for equal breath sounds; use needle decompression or chest radiograph depending on relative urgency
Equipment failure: disconnect from circuit, hand bag, confirm 100% oxygen is flowing

- **Moderate to severe hypoxemia:** goal is to wean to FiO_2 < 50%
  - Minimize air leak by placing a larger ET tube, repositioning head, or changing to pressure mode
  - Increase PEEP in increments of 2 cm H_2O to increase functional residual capacity (aerated lung volume); consider paralytics for PEEP > 10
  - Increase I time to improve oxygenation by increasing mean airway pressure
  - Increase rate, especially if partial pressure of carbon dioxide (PCO_2) is also elevated and minute ventilation needs to be increased
  - Changing to PC will result in improved oxygenation for the same volume delivered
  - Once the appropriate Vt is established, avoid changing volumes; in ARDS, ventilator-induced lung injury is associated with Vt > 8–10 mL/kg
- **High peak pressures**: > 35 cm H_2O or **plateau pressure** > 30 cm H_2O
  - Suction ET tube
  - Check tube position with chest radiograph
  - Consider administering inhaled bronchodilators, especially if the patient exhibits wheezing, prolonged expiratory phase, or develops auto-PEEP
  - Changing to PC will result in lower peak pressure for the same Vt
  - Consider adopting a permissive hypercapnia strategy if lung compliance and oxygenation are poor in the face of high peak pressures
    - Limit delivered Vt to roughly 6 mL/kg of ideal body weight
    - Accept higher PCO_2 and lower saturations (85%)
    - Use higher PEEP and longer I time for recruitment and

oxygenation
- Most pediatric patients will tolerate a pH of ≥ 7.2
- Treat or minimize metabolic acidosis

Sedation Strategies for Ventilated Pediatric Patients

- **Postoperative short-term ventilation.** If the patient will be extubated in 6–12 hours, use:
  - Intermittent opioids, because pain will be the primary problem
  - Intermittent benzodiazepines as needed for sedation
  - A propofol drip can be considered for short-term sedation because it is titratable
  - Long-term propofol use in pediatrics is discouraged given the concern for fatal metabolic acidosis
- For **postoperative long-term ventilation,** use:
  - Continuous opioids to treat pain
  - Intermittent or continuous-drip benzodiazepines as needed for sedation
- For **medical short-term ventilation,** use:
  - Intermittent benzodiazepines because sedation is the primary requirement for ET tube tolerance
  - Intermittent opioids may be needed
- For **medical long-term ventilation,** use:
  - Continuous midazolam
  - Continuous or intermittent opioids if needed for pain

Remember, if the patient–ventilator synchrony is poor and adjustments to the ventilator are insufficient to make the patient comfortable, more sedation may be required.

Medications for Sedation

- **Midazolam:** starting dose is 0.05–0.1 mg/kg intravenous (IV); may repeat every 5–10 minutes until effective sedation is reached
  - Use this as basis for a dosing schedule of IV q1–2h
  - If effective intermittent regimen cannot be easily established, consider continuous drip at (0.05–0.1 mg/kg/h); watch for respiratory depression and hypotension
- **Lorazepam:** starting dose is 0.05–0.1 mg/kg IV
  - May repeat in 5–10 minutes until effective sedation is reached

  - Use this as a basis for IV q2–4h dosing schedule
- **Morphine:** starting dose is 0.05–0.1 mg/kg IV
  - Repeat dosing every 5–10 minutes until effective analgesia established
  - Use this as basis for IV q2–4h dosing schedule
  - If effective intermittent regimen cannot be easily established, consider continuous drip
- **Fentanyl:** starting dose is 0.5–1 μg/kg IV
  - Repeat dosing every 5–10 minutes until effective analgesia is established
  - Use this as a basis for IV q1–2h dosing schedule (see Chapter 2, Anesthesia, Table 2-4)

Considerations for Extubation

- Has lung disease improved? Use **SOAP** memory aid:
  Secretions/sedation/spontaneous Vt (> 5 mL/kg): What is the minimal suction frequency? Is the patient awake enough to breathe and protect airway?
  Oxygenation: FiO_2 < 35%
  Airway: If a child has been ventilated for more than 48 hours or has been intubated several times, there is a significant risk of airway edema that may compromise a successful extubation. The presence of an audible air leak around the ET tube can be reassuring. Otherwise, consider starting airway dosing of dexamethasone 0.5 mg/kg/dose, at least 12 hours prior to planned extubation and continue q6h for 4 doses
  Pressures: PIP < 25, PEEP < 5

Predictors of Extubation Failure

If a patient displays postextubation stridor, consider nebulized racemic epinephrine, heliox (if available), and steroids (Table 4-3).

Table 4-3. Predictors of Extubation Failure

Variable	Low Risk (< 10%)	High Risk (> 25%)
Vt (spontaneous)	> 6.5 mL/kg	< 3.5 mL/kg
FiO_2	< 0.30	> 0.40
PIP	< 25 cm H_2O	> 30 cm H_2O

FiO_2: fraction of inspired oxygen PIP: peak inspiratory pressure Vt: tidal volume