ELSEVIER Clinical Skills

Mechanical Ventilation: Pediatric Volume Mode (Respiratory Therapy)

ALERT

Match the ventilator settings with the challenges of ventilating the child to provide optimal oxygenation and ventilation and minimize the harmful effects of positive pressure in smaller lungs.

OVERVIEW

Conventional modes of mechanical ventilation provide positive pressure ventilation (PPV) to improve oxygenation and ventilation, prevent cardiovascular failure, manage intracranial pressure, protect the airways, and improve oxygen delivery to the tissues. PPV can be used as temporary therapy until the child's condition no longer warrants support or as long-term therapy in children with chronic conditions requiring mechanical ventilation.[4]

To perform this procedure, the respiratory therapist (RT) must be competent in pediatric advanced life support and must be able to identify indications for an artificial airway and other adjuncts used to support ventilation.[2]

The RT must also know this information:

- Lung volumes and capacities
- Differences in lung volumes for infants and children
- Interface between volume and pressure for the thorax, lungs, and chest wall for adults and infants
- Physiologic concepts of lung mechanics that interface with the ventilator
- How and when to make ventilator adjustments to improve oxygenation and ventilation

The RT should also understand these facts about PPV:

- Positive pressure ventilators raise the mean airway pressure above intrapleural pressure, thus reversing the intrathoracic pressure dynamics from spontaneous breathing.[3]
- Normal glottis closure at end exhalation is prevented by an endotracheal (ET) tube; therefore, a minimal amount of positive end-expiratory pressure (PEEP) (approximately 5 cm)[3] maintains physiologic functional residual capacity (FRC) in children.
  - In children with pulmonary disease, PEEP is adjusted according to underlying pathophysiology.[4]
  - One goal for the use of PEEP is to reduce the fraction of inspired oxygen (F_{IO_2}) to maintain an adequate arterial pressure of arterial oxygen (Pa_{O_2}) range.
- Common modes of ventilation include assist control, synchronized intermittent mechanical ventilation (SIMV), and pressure support.
- The potential complications with mechanical ventilation include decreased cardiac output and increased intracranial pressure.
- Mechanical ventilators can be used in a volume or pressure mode as well as hybrid variations that combine aspects of both modes.

Lung protective strategies for a child on PPV include low tidal volume (V_T) (6 ml/kg or range of 5 to 7 ml/kg)[4] controlled plateau pressure of 30 mm Hg or less, and early and aggressive PEEP.[1] Recommended strategies to improve oxygenation use F_{IO_2} and PEEP (Table 1).[1] An open-lung model with a stepwise progression of PEEP to recruit atelectatic lung segments in children with restrictive lung disease, such as acute lung injury, is suggested.

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Table 1 Improvement of Oxygenation with Fraction of Inspired Oxygen and Positive End-Expiratory Pressure

FIO_2	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7
PEEP	5	5	8	8	10	10	12	12
FIO_2	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.0
PEEP	14	14	16	16	18	20	22	24

FIO_2, fraction of inspired oxygen; *PEEP,* positive end-expiratory pressure
Oxygenation goal: Arterial partial pressure of oxygen (PaO_2) 55-80 mm Hg or peripheral oxygen saturation (SpO_2) 88%-95%. Use incremental fraction of inspired oxygen/positive end-expiratory pressure (FIO_2/PEEP) combinations to achieve goal. (Adapted from National Institutes of Health [NIH], National Heart, Lung, and Blood Institute [NHLBI], ARDS Clinical Network. [n.d.]. Mechanical ventilation protocol summary. Retrieved August 20, 2019, from http://www.ardsnet.org/files/ventilator_protocol_2008-07.pdf)

PEEP is based on the child's disease process. For children undergoing ventilation for general physiologic support, a minimal PEEP of 5 mm Hg is considered adequate to replicate FRC.[3,4] At high levels of PEEP, which increase mean airway pressure, the V_T can be reduced for lung protection in many cases.

EDUCATION

- Provide individualized, developmentally appropriate education to the family based on the desire for knowledge, readiness to learn, and overall neurologic and psychosocial state.
- Explain the reasons for and the purpose and risks of PPV therapy.
- Discuss sensory information, including the sounds of the ventilator, the sensation of lung inflation, and coughing.
- Provide the family with descriptions and explanations of the equipment alarms.
- Explain that medications, including local anesthetics, sedatives, and pain medications will be used to minimize the child's pain and anxiety during the procedure.
- Discuss relaxation methods that can be incorporated into the child's care, including reading to him or her, providing quiet distractions, and facilitating rest.
- Identify a method of communication between the child and family and the authorized practitioners.
- Provide assurance that the family can be present and involved in the child's care.
- Discuss the need for suctioning of the ET tube at regular intervals and the expected coughing sensation.
- Encourage questions and answer them as they arise.

ASSESSMENT AND PREPARATION

Assessment

1. Perform hand hygiene before patient contact.
2. Introduce yourself to the child and family.
3. Verify the correct child using two identifiers.
4. If able, assess the child's developmental level and ability to interact.
5. Assess the family's understanding of the reasons for and the risks and benefits of conventional modes of mechanical ventilation.
6. Assess the child's vital signs.
7. Assess the child for signs and symptoms of ventilatory failure, including increased arterial partial pressure of carbon dioxide ($PaCO_2$) and symptoms of hypercarbia, such as respiratory acidosis, decreased mental status, tachycardia, hypertension, and dilated pupils.

8. Assess the child for signs and symptoms of hypoxemia, including decreased arterial oxygen saturation, pale or cyanotic color, tachycardia or bradycardia, tachypnea, agitation or decreased mental status, and increased work of breathing.
9. Assess the child's cardiovascular stability.

Preparation

1. Ensure that all necessary equipment and supplies have been collected and that the equipment is working properly.
2. Ensure that a manual ventilation bag, a mask, and suction are immediately available and connected at the child's bedside.

PROCEDURE

1. Perform hand hygiene and don gloves, gown, mask, and eye protection as indicated.
2. Verify the correct child using two identifiers.
3. Explain the procedure to the family and ensure that they agree to treatment.
4. Ensure that end-tidal carbon dioxide ($ETCO_2$) and peripheral oxygen saturation (SpO_2) monitoring are in place, if indicated.
5. Select the mode of ventilation.

Rationale: The choice of mode must be individualized to the child.

6. Set the initial V_T; observe chest excursion and auscultate lung sounds to ensure that the child has adequate aeration.

Rationale: The V_T is individualized to the child and disease state.

7. Set the cycle mechanism (volume, time, or flow). Children with hypoxemia may benefit from a longer controlled inspiratory time, and the time-cycled mode may be preferred over the flow- or volume-cycled mode.[3]

Rationale: The cycle mechanism is individualized to the child and the capabilities of the ventilator and determines when inspiration terminates.

8. Set the ventilator rate.

a. An initial rate setting should be based on age and the size of the neonate, infant, or child.
b. The rate may be adjusted on the basis of $PaCO_2$ with the assumption that the V_T is held constant.
c. Initially, V_T can be estimated. For complete control, the calculated rate is used.

$$\text{New rate} = \frac{PaCO_2\ (\text{child}) \times (\text{set})}{\text{Desired } PaCO_2}$$

d. For spontaneous breathing, a lower rate is chosen and then adjusted based on the $PaCO_2$.
e. When permissive hypercapnia is desired for lung protection, pH (rather than $PaCO_2$) drives changes in the rate.[3]

Rationale: The rate is set to achieve appropriate minute ventilation, where minute ventilation = V_T × respiratory rate. The rate setting depends on how much mandatory ventilation is desired.

9. Set the inspiratory:expiratory (I:E) ratio; typically, it is 1:2.[1]

a. In children with restrictive lung disease, a longer inspiratory time may be beneficial.
b. In children with obstructive disease, a longer expiratory time may be necessary.[3]

Rationale: Inspiratory time influences oxygenation, and expiratory time influences ventilation.

10. Select the PEEP.

Rationale: The PEEP is based on the child's lung function and disease process.

Do not interrupt the ventilator circuit (e.g., during suctioning) for children on higher levels of PEEP; doing so may cause a significant loss of FRC.

11. Adjust the trigger sensitivity to reduce the effort the child must make to access flow from the circuit.

a. For a child who has just started mechanical ventilation, adjust the sensitivity to provide complete comfort and rest.
b. The ventilator is triggered when either a pressure sensor or a flow sensor recognizes the child's effort.

12. Tailor the flow rate and pattern to meet the child's needs. The circuit may provide continuous flow or demand flow.
13. Set the appropriate alarms and limits.

Rationale: High- and low-pressure alarms, inspiratory time, and V_T limits are always set, and the values are based on the cycling mechanism chosen. Low-pressure alarms are used to detect disconnection in the system. High-pressure alarms are used for notification of increased pressure in the system.

In the volume-controlled mode, the child's lung compliance may cause variable PIP. Set the high-pressure alarm per the organization's practice above the child's PIP to protect the lungs from sudden changes in resistance or compliance.

14. Set the pressure-support ventilation (PSV), if required. With the initiation of PSV, consider comfort and a target V_T. PSV is used with or without SIMV.

a. Set a pressure level that provides enough support to achieve a targeted V_T.
b. Some children may need higher initial PSV levels, depending on their disease and their strength.[3]

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15. Discard supplies, remove personal protective equipment (PPE), and perform hand hygiene.
16. Document the procedure in the child's record.

MONITORING AND CARE

1. Monitor cardiopulmonary status including vital signs and indicators of oxygenation and ventilation.
2. Monitor physiologic stability, including cardiac function and hemodynamic changes (heart sounds, heart rate, blood pressure, and perfusion).

> Rationale: Increased intrathoracic positive pressure may reduce venous return and cardiac output. Likewise, positive pressure may cause pneumothorax, which may also decrease cardiac output.

3. Observe the child for child-ventilator synchrony.

> Rationale: Asynchrony causes increased work of breathing and distress. Asynchrony in a small child is commonly associated with flow regulation; access to flow and speed of delivery influence the child's ability to breathe comfortably.

4. Perform a ventilator check including F_{IO_2}, PIP, V_T, PEEP, mean airway pressure, and other relevant settings, such as the temperature of the inspired gas.

> Rationale: Changes in oxygen flow may occur from the oxygen source; auto-PEEP may also occur. Body temperature can be significantly altered by the temperature of inspired gas.

5. Confirm the activation of all alarms during each shift.
6. Provide additional ventilatory support, including manual breaths and adjustments in mechanical ventilation as indicated by the signs of hypoxemia, hypercarbia, and hemodynamic instability.

> Rationale: Early intervention when inadequate ventilator support and hemodynamic instability occur may prevent further clinical deterioration.

7. Monitor and adjust the ventilator's settings according to treatment strategies.

> Rationale: Changes in lung compliance may change the PIP or V_T.

8. Monitor the ventilator's alarms and watch for changes from prescribed settings, including an increased PIP or a change in V_T.

> Rationale: An alarm indicating an increase in PIP or change in V_T may be associated with a need for suctioning or an airway obstruction. A low-pressure alarm may indicate that the ventilator tubing has been disconnected.[3]

9. Ensure that the ET tube is secure and stabilized.

a. Consider attaching the circuit to the bed or device to ensure security while allowing the child to move.

Rationale: Attaching the circuit to the bed or device eliminates undue pressure on the child's skin from the ET tube and tubing.

b. Replace loosened tape quickly.

10. Suction the ET tube as indicated and observe the characteristics of secretions.

Rationale: Suctioning the ET tube maintains airway patency and removes secretions.

11. Minimize sources of infection by limiting interruptions of the circuit and by emptying condensation from the tubing.

Rationale: Ventilator-associated pneumonia (VAP) is a significant cause of morbidity in children undergoing ventilation.

12. Encourage daily drug holidays or neurostimulation monitors if the child is undergoing paralytic therapy.

Rationale: Sedation and neuromuscular blockade may be necessary to achieve ventilator synchrony, but paralytics mask the child's underlying neurologic state. Early identification of the child's discomfort allows immediate attention to problems.

13. Consider keeping the head of the bed elevated.

Rationale: Elevating the head of the bed reduces the incidence of aspiration.

14. Observe the child for signs and symptoms of pain. If pain is suspected, report it to the authorized practitioner.

EXPECTED OUTCOMES

- Adequate oxygenation and ventilation
- Maintenance of adequate pH and $PaCO_2$
- Decreased work of breathing
- Ventilation without lung injury
- Hemodynamic stability
- Maintenance of skin integrity
- Airway in correct position
- No infection
- Mobilization and removal of secretions
- Adequate airway humidification
- Adequate pain control during the procedure

UNEXPECTED OUTCOMES

- Inadequate ventilation and oxygenation (hypoxemia, hypercarbia, acidosis, alkalosis)

- Lung overinflation, air-leak syndrome (pneumothorax, pneumomediastinum, pneumoperitoneum, subcutaneous emphysema)
- Acute lung injury (volutrauma or progression of lung disease)
- Hemodynamic instability
- Skin breakdown or pressure injury
- Unplanned extubation or malpositioned ET tube
- VAP
- Tenacious sputum
- ET tube obstruction
- Infection
- Inadequately managed pain or anxiety

DOCUMENTATION

- Cardiopulmonary assessment before and after procedure, including vital signs, lung sounds, work of breathing, arterial blood gas analysis, pulse oximetry, and ET_{CO_2} monitoring
- ET tube size: cuffed or uncuffed
- ET tube marking at the teeth or gums for correct placement
- Date and time of initiation of ventilator assistance
- Record of ventilator settings, including F_{IO_2}, mode, V_T, PIP, rate, and PEEP
- Record of ventilator checks as indicated, including F_{IO_2}, mode, V_T, PIP, rate, and PEEP
- Timing of suctioning and characteristics of ET tube secretions
- Pain assessment and specific interventions provided
- Child's response to the procedure
- Child and family education
- Unexpected outcomes and related interventions

REFERENCES

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*In these skills, a "classic" reference is a widely cited, standard work of established excellence that significantly affects current practice and may also represent the foundational research for practice.

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Elsevier Skills Levels of Evidence

- Level I - Systematic review of all relevant randomized controlled trials
- Level II - At least one well-designed randomized controlled trial
- Level III - Well-designed controlled trials without randomization
- Level IV - Well-designed case-controlled or cohort studies
- Level V - Descriptive or qualitative studies
- Level VI - Single descriptive or qualitative study
- Level VII - Authority opinion or expert committee reports

Supplies

- Air source
- ET tube and airway box at bedside
- Appropriate-size mask (to provide PPV as needed via bag-mask ventilation in the event of unplanned extubation or planned extubation with subsequent respiratory distress)
- Cardiopulmonary monitor
- Invasive or noninvasive mechanical ventilator
- $ETCO_2$ monitor
- Manual ventilation device (i.e., flow-inflating or self-inflating bag)
- Oxygen source
- PPE (gloves, mask, gown, and eye protection, as indicated)
- Pulse oximeter
- Suction source and catheter(s)

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