

Mechanical Ventilation: High-Frequency Oscillatory Ventilation (Pediatric) – CE

ALERT

Potential complications of high-frequency oscillatory ventilation (HFOV) include hemodynamic compromise, barotrauma, inadequate humidification, endotracheal (ET) tube obstruction, and intraventricular hemorrhage in the neonate.

Asymmetric chest rise may indicate a pneumothorax.

OVERVIEW

Several modes of high-frequency ventilation (HFV) are available. Modes are described by the delivery method and classified by the exhalation mechanism (active or passive). HFOV is the most commonly used mode of HFV.

HFOV delivers a smaller tidal volume (V_T) than conventional ventilation, usually less than or equal to the anatomic dead space volume. This decreased V_T decreases barotrauma and allows for healing of the lung tissue. With HFOV, oxygenation and elimination of carbon dioxide occur as long as the lung is inflated.⁴ Alveolar recruitment continues for several hours after HFOV therapy begins, and arterial partial pressure of carbon dioxide (P_aCO_2) values may initially climb.

Clinical indications for HFOV include:

- Diffuse alveolar disease, including hyaline membrane disease, acute respiratory distress syndrome, systemic inflammatory response syndrome, and pneumonia⁴
- Air leak syndromes, including pulmonary interstitial emphysema and persistent pneumothoraces⁴
- Congenital diaphragmatic hernia and pulmonary hypoplasia
- Focal disease, including meconium aspiration syndrome
- Failure of conventional ventilation to provide adequate ventilatory support

HFOV is used in the treatment of acute lung injury and acute respiratory distress. The goal of HFOV is to provide respiratory support while avoiding the alveoli stretching and barotrauma that occurs with conventional ventilation. HFOV provides lung protection to children with deteriorating gas exchange who require increased ventilatory support.

- HFOV is produced by a piston pump or a diaphragm with ventilation at a frequency of 600 to 900 breaths per minute,⁴ which creates positive and negative pressure swings. HFOV does not produce bulk gas delivery. It uses a continuous gas flow to eliminate carbon dioxide and deliver oxygen to the alveoli.
- Oxygenation is primarily controlled by mean airway pressure (mPaw) and fraction of inspired oxygen (F_{IO_2}) concentration. The mPaw can be adjusted with a change in the bias flow or the mPaw adjust control.
- In HFOV, inspiration and expiration are active. The gas is pushed in and out of the lungs by the piston or oscillating diaphragm.⁴
- During HFOV, the child exhibits a chest wiggle factor. A chest wiggle that extends to the umbilicus for infants, the iliac crest for children, and the midhigh for adolescents is recommended.

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Essential terms include:

- *Frequency (F)*: Mechanical rate measured in hertz (Hz); 10 Hz = 600 breaths/min;² adult settings can be 6 to 8 Hz, and settings in infants and children can be 7 to 10 Hz.³
- *Mean airway pressure (mPaw)*: The average airway pressure over one minute, and is affected by changes in positive end-expiratory pressure (PEEP), peak inspiratory pressure (PIP), inspiratory time and respiratory rate.¹
- *Amplitude*: The circuit-measured change in pressure (ΔP) generated across the mPaw.
- *Anatomic dead space*: Volume of gas in the conducting airways, trachea to terminal bronchioles, where no gas exchange occurs.
- *Inspiratory time (Ti)*: Time spent in the inspiratory phase of the ventilatory cycle.
- *Attenuation*: Reduction of force or magnitude of pressure delivered to child.
- *Bias flow*: Constant stream of gas through airways created by rapid movements of piston diaphragm.³
- *Chest wiggle*: The body wiggle or vibration caused by HFV.
- *Power*: The electrical current control that displaces the diaphragm-sealed piston; as the piston is displaced in a forward and backward square-wave pattern, amplitude fluctuations are superimposed.
- *Tidal volume (VT)*: Volume of gas for each breath
- *Alveolar ventilation*: $(VT) \times (F)$.

Potential complications of HFOV include:

- Hemodynamic compromise
- Barotrauma from excessive air trapping
- Inadequate humidification
- Intraventricular hemorrhage in the neonate
- ET tube obstruction

EDUCATION

- Provide individualized, developmentally appropriate education to the family and child based on the desire for knowledge, readiness to learn, and overall neurologic and psychosocial state.
- Explain that HFOV offers respiratory support and lung protection by providing small breaths at a very fast rate while the child's lungs are kept open to a constant airway pressure; that the practitioner can adjust oxygenation or ventilation; and that this procedure carries some risks, including the possibility of lung overdistention.
- Explain the assessments necessary during HFOV.
- Provide the family with descriptions and explanations of equipment alarms.
- Explain that the procedure frequently results in discomfort for the child and that analgesic and sedative medications may be used to minimize the child's pain and anxiety during the procedure.
- Encourage questions and answer them as they arise.

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ASSESSMENT AND PREPARATION

Child and Family 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. Assess the child's developmental level and ability to interact.
5. Assess the child's and family's understanding of the reasons for and the risks and benefits of the procedure.
6. Assess the child's vital signs, respiratory status, and cardiovascular stability, including intravascular volume.
7. Assess the child's level of consciousness.
8. Assess the child's skin integrity.
9. Observe the child for signs of pain and anxiety.

Preparation

1. Note the baseline arterial blood gas (ABG) values before the initiation of HFOV.
2. Ensure that a chest radiograph has been evaluated before the initiation of HFOV.

PROCEDURE

1. Perform hand hygiene and don gloves.
2. Verify the correct child using two identifiers.
3. Explain the procedure to the child and family and ensure that they agree to treatment.
4. Obtain the correct ventilator based on the child's size, as determined by the practitioner and respiratory therapist.
5. Ensure that the child is connected to cardiopulmonary, peripheral oxygen saturation (SpO₂), and transcutaneous carbon dioxide (TcCO₂) monitors.

Rationale: Monitoring indicates the adequacy of ventilation and signs and symptoms of complications and allows the nurse to respond immediately to changes in carbon dioxide and oxygenation levels.

6. Review the prescribed ventilator settings and compare them with the appropriate guidelines for HFOV.
7. Suction the child's ET tube to ensure tube patency before starting therapy.
8. Administer the prescribed analgesic, sedative, and neuromuscular blockade medications.

Rationale: Analgesia, sedation, and neuromuscular blockade should be adjusted to adequate levels before the start of HFOV.

Administer the minimal dose of paralytic agent necessary to achieve the desired effect.

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9. Reassess the child's pain status, allowing for sufficient onset of action per medication, route, and the child's condition.
10. Calibrate the circuit and complete performance verification.

Rationale: Proper function of the ventilator must be demonstrated before initiation.

11. Establish ventilator settings as prescribed.

- a. Activate the oscillator by pushing the Start-Stop button.

Watch for a green light-emitting diode (LED), which signifies that the oscillator is enabled.

- b. Set the bias flow.

Rationale: Bias flow provides fresh gas to the circuit and enhances carbon dioxide clearance. Bias flow works interchangeably with the mPaw; the knob should be adjusted to establish the set mPaw.

Readjust the mPaw after changes in bias flow to prevent inadequate or impeded clearance.

Rationale: If the bias flow is less than the oscillatory flow, carbon dioxide clearance will be inadequate, reducing the ventilation effect while increasing the pressure differential to high levels (amplitude). If bias flow is greater than oscillatory flow, carbon dioxide clearance may be impeded.

- c. Set the mPaw and increase it as prescribed until an adequate SpO₂ value is achieved.

Rationale: The goal is maximum alveolar recruitment without overdistention of the lungs. The mPaw is adjusted to maintain optimal lung volume. The mPaw can fluctuate with temperature and humidity changes. Lung volumes reach equilibrium slowly in response to changes in ventilator pressure.

- d. Set the frequency.

Rationale: Frequency is the secondary control for ventilation, and it depends on the child's weight.

Frequency usually needs no adjustment after the rate has been established.

Rationale: Frequency is not weaned as in conventional ventilation. A decrease in frequency causes an increase in volume displacement, which would decrease the

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PaCO₂ level. Too high a frequency may cause an elevated PaCO₂ because of small volume displacement (less than anatomic dead space).

e. Set the power control and adjust it as prescribed while observing amplitude and chest wiggle.

Rationale: Adjusting the power control changes the piston displacement, which in turn affects the amplitude. Amplitude is the primary control for ventilation.³

Look for an adequate chest wiggle to establish the appropriate amplitude.

Rationale: Attenuation varies according to the size of the ET tube.³

f. Set the inspiratory time using an inspiratory-to-expiratory (I:E) ratio of 1:2.³

Rationale: Using an I:E ratio of 1:2 has been shown to minimize the risk of air trapping.³

g. Set the FIO₂ as low as possible. Once the FIO₂ has been decreased, reevaluate lung volume to determine whether mPaw can be decreased.

Rationale: Adjusting the FIO₂ to the lowest possible level is the goal of therapy. Permissive hypoxemia may be acceptable in some children with certain conditions.

The inability to wean FIO₂ after stable ventilator settings have been established may indicate poor lung expansion or HFOV failure.

h. Set the humidification to achieve the desired proximal airway temperature.

Rationale: The use of heat and humidity with mechanical ventilation is necessary to prevent damage to the mucosa of the respiratory system. Adequate humidification keeps secretions from becoming thick and sticky.

i. Set the ventilator alarms.

Rationale: Ventilator alarms protect the child from injury and prevent equipment damage.

Set pulse oximeter alarms at a narrow range.

Rationale: Loss of pressure in the circuit causes an audible and visual alarm.

12. Position the child and the circuit to avoid pressure areas, prevent pulling on tubing, and promote ventilator function.

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Rationale: Proper positioning reduces the risk of skin breakdown from immobilization and promotes airway stability.

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

MONITORING AND CARE

1. Ensure that a chest radiograph is obtained and evaluated at prescribed intervals. Do not stop the piston during the radiograph.

Rationale: Reviewing chest radiographs assists in the evaluation of lung volume. Inadequate lung volume inhibits optimal gas exchange.

Reportable condition: Inadequate lung volume as evidenced by chest radiograph

2. Monitor and adjust ventilator settings on the basis of treatment strategies.

Rationale: Maintaining appropriate ventilator support assists in the evaluation of lung volume.

Reportable condition: Significant changes in mPaw

3. Evaluate chest wiggle, especially after each change in the child's position.

Rationale: Evaluation of chest wiggle alerts the nurse or respiratory therapist to changes in the child's lung compliance. Changes in chest wiggle may indicate mucus plugging, dislocation of the ET tube, or pneumothorax.

Reportable condition: Significant changes in chest wiggle

4. Monitor cardiac function, including heart sounds, heart rate, blood pressure, and perfusion. To complete an adequate assessment of heart sounds, stop the piston by pressing the Start-Stop button.

Rationale: The child is especially at risk for hypotension when mPaw is high and hypovolemia or cardiac dysfunction is present.

Reportable conditions: Tachycardia; hypotension; poor perfusion, including cool extremities and changes in skin color

5. Monitor respiratory status, including work of breathing and chest auscultation, to assess the symmetry of breath sounds. Note the intensity of the piston.

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Rationale: Changes in the symmetry of the chest or intensity of the piston could indicate changes in lung compliance, mucus plugging, ET tube dislodgment, or pneumothorax.

Reportable conditions: Tachycardia, increased work of breathing, cyanosis, asymmetric chest movement, decreased SpO₂ level, significant change in breath sounds, significant change in intensity of piston

6. Evaluate ABG values at prescribed intervals and as needed with changes in clinical condition or ventilator parameters.

Rationale: The ABG analysis provides quantitative measurements of carbon dioxide and oxygen levels.

Reportable condition: Significant changes from previous ABG levels

7. Monitor continuous noninvasive respiratory values, including SpO₂ and Tcco₂.

Rationale: Noninvasive monitoring provides continuous evaluation of oxygenation and ventilation. Weaning the FIO₂ is often based on the SpO₂.

Reportable condition: Significant changes in Tcco₂ and SpO₂

8. Suction the ET tube. Stop the piston during the procedure and then restart.

Rationale: Inline suctioning (without breaking into the circuit to cause derecruitment) establishes airway patency, ET tube patency, and lung recruitment and removes secretions.

Do not disconnect the child from the HFOV to perform open suctioning.

Reportable conditions: Inability to clear secretions, deteriorating respiratory status

9. Assess, treat, and reassess pain.

10. Reposition the child as tolerated.

Rationale: Children are at risk for developing skin breakdown from immobilization.

Reportable condition: Breakdown of skin integrity

11. Monitor humidity to ensure adequate airway humidification.

Rationale: Adequate humidification is necessary to prevent mucosal damage. Inadequate humidification can cause problems with mucus plugging and decreased chest wiggle, which decrease ventilation.

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Reportable condition: Mucus plugs that result in decreased ventilation

EXPECTED OUTCOMES

- Adequate ventilation and oxygenation
- Improved alveolar recruitment as evidenced by improved lung expansion
- Improved respiratory function
- Hemodynamic stability
- No infection
- Adequate airway humidification
- HFOV instituted without injury to airway, lungs, or skin
- Intact skin integrity

UNEXPECTED OUTCOMES

- Inadequate ventilation and oxygenation
- Lung overinflation or air leak syndrome: pneumothorax, pneumomediastinum, pneumoperitoneum, subcutaneous emphysema
- Intraventricular hemorrhage (in a neonate)
- Hemodynamic instability
- Ventilator-associated pneumonia
- Tenacious sputum
- ET tube obstruction
- Barotrauma
- Alteration in skin integrity

DOCUMENTATION

- Cardiopulmonary assessment, including vital signs, chest sounds, and TccO₂ and ABG values
- Date and time HFOV initiated
- Ventilator settings, including FIO₂, mode, frequency, mPaw, power, amplitude, Ti, and bias flow
- Assessment of chest wiggle
- Characteristics of ET tube secretions
- Child's response to the procedure
- Pain assessment and specific interventions provided
- Unexpected outcomes and related nursing interventions
- Child and family education

REFERENCES

1. Chipman, D.W. (2017). Chapter 53: Neonatal and pediatric respiratory care. In R.M. Kacmarek, J.K. Stoller, A.J. Heuer (Eds.), *Egan's fundamentals of respiratory care* (11th ed., pp. 1216-1246). St. Louis: Elsevier.

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2. Felmet, K. (2017). Chapter 55: Critical care medicine. In P.J. Davis, F.P. Cladis (Eds.), *Smith's anesthesia for infants and children* (9th ed., pp. 1282-1300). Philadelphia, Elsevier.
3. Hupp, S.R., Turner, D.A., Rehder, K.J. (2015). Is there still a role for high-frequency oscillatory ventilation in neonates, children and adults? *Expert Review of Respiratory Medicine*, 9(5), 603-618. doi:10.1586/17476348.2015.1077119
4. Kornecki, A., Singh, R.N. (2019). Chapter 38: Acute respiratory distress syndrome. In R.W. Wilmott and others (Eds.), *Kendig's disorders of the respiratory tract in children* (9th ed., pp. 606-614). Philadelphia: Elsevier.

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

- PPE (gloves, mask, eye protection, and gown, as indicated)
- Cardiopulmonary monitor
- Humidifier and sterile water
- Manual ventilation device: flow or self-inflating with appropriate-size mask
- Medication: analgesia, sedation, and neuromuscular blockade, as indicated
- Oxygen and air source
- Pulse oximeter monitor
- Rubber stopper
- Suction head, canister, tubing, and catheter
- TcCO₂ monitor
- Ventilator circuit, appropriate size

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Published: February 2020