ELSEVIER Clinical Skills

Mechanical Ventilation (Neonatal) - CE

ALERT

Mechanical ventilation may contribute to an acute or a chronic respiratory tract injury, such as atelectrauma, volutrauma, barotrauma, oxygen toxicity, and a pulmonary or systemic inflammatory response to lung trauma.[2]

OVERVIEW

Mechanical ventilation is respiratory support using mechanical assistance.[4] The goals of mechanical ventilation are to facilitate adequate gas exchange and decrease the neonate's work of breathing, while minimizing the risk of lung injury and optimizing comfort.[5]

Neonatal respiratory support is an ever-evolving field. The increased use of improved noninvasive respiratory modalities, which are generally accepted as the preferred modes of support, has resulted in a reduction in the number of neonates receiving invasive mechanical ventilation. Indications for mechanical ventilation are respiratory failure, pulmonary insufficiency, severe apnea and bradycardia, congenital cardiac disease, central nervous system disease, and surgery.

Neonates present unique challenges that complicate the use of mechanical ventilation, including noncompliant lungs; rapid, irregular respiratory rates; short inspiratory times; and limited muscle strength. In addition, the approach to respiratory support and treatment differs based on gestational age.[5]

In positive pressure ventilation, a breath is delivered until a specific pressure or volume is reached. There are four main categories of how pressure or volume of air is delivered:

- Pressure-cycled ventilation
  - Air is delivered to the neonate until a preset pressure is achieved.
  - Inspiratory time ends when the preset pressure is delivered.
  - The volume required to deliver the preset pressure is variable with each breath.
- Time-cycled, pressure-limited, continuous flow ventilation
  - This type of ventilation is similar to pressure-cycled ventilation except that the predetermined pressure is delivered during a set inspiration time.
- Pressure support ventilation
  - The ventilator supports breaths initiated by the neonate.
  - The ventilator delivers mechanical breaths to a preset volume.
  - Variable inspiratory time allows the neonate to achieve synchrony with the ventilator.
  - In many cases, the ventilator is used as a weaning mode of ventilation.
- Volume-cycled ventilation
  - A preset volume is delivered to the neonate.
  - Inspiratory time ends when the preset volume is delivered.
  - The pressure required to deliver the preset volume is variable with each breath.

Positive pressure ventilation measuring volume delivers more stable tidal volume (V_T) and allows the ventilator to adjust to the neonate's lung compliance over time.[3] Volume ventilation has the advantage of automatically reducing inflation pressure when lung compliance improves because the underlying pulmonary condition resolves. Volume ventilation as compared to pressure ventilation is associated with a significant reduction in the incidence of pneumothorax, hypocarbia, intraventricular hemorrhage, periventricular leukomalacia, and the duration of mechanical ventilation.[4,7]

Table 1 Definitions Associated with Ventilation

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Amplitude	Change in pressure generated across the MAP and measured within the circuit Setting used in high-frequency ventilation Mainly used to control carbon dioxide levels
Frequency	Mechanical rate measured in hertz: 1 Hz = 60 breaths/min Setting used in high-frequency ventilation
FRC	The volume of gas that remains in the lungs after normal expiration The normal FRC for a neonate is 30 ml/kg.
I:E ratio	The ratio of time spent in inspiration to time spent in expiration
MAP	The average pressure delivered to the airways throughout an entire respiratory cycle MAP is dependent on ventilator rate, gas flow through the ventilator circuit, PIP, PEEP, and inspiratory time. MAP affects atelectasis, intrapulmonary shunting, and oxygenation.
Mechanical dead space	Gas that fills the ventilator circuit for availability in inspiration, as well as exhaled gas Minimal dead space is desired. Excessive dead space can cause increased retention of carbon dioxide.
PEEP	The amount of constant pressure remaining at end of expiration PEEP helps to maintain FRC to prevent atelectasis. PEEP influences oxygenation but can lead to an increase in P_{CO_2}.
PIP	The amount of pressure used during inspiration PIP influences both oxygenation and ventilation.
Physiologic dead space	Anatomic plus alveolar dead space: Anatomic dead space is the volume of gas within the area of the pulmonary conduction airways that cannot engage in gas exchange. Alveolar dead space is the volume of inspired gas that reaches the alveoli but does not participate in gas exchange because of inadequate perfusion to the alveoli.
V_T	The amount of air that moves into or out of the lungs with each breath at rest The normal V_T for a neonate is 4 to 6 ml/kg.
TLC	The amount of air contained in the lung after a maximal inspiration The normal TLC for a neonate is 63 ml/kg.
VC	The volume of air maximally inspired and maximally expired The normal VC for a neonate is 40 ml/kg.

FRC, functional residual capacity; *I:E,* inspiratory-expiratory; *MAP,* mean airway pressure; *PEEP,* peak end-expiratory pressure; *PIP,* peak inspiratory pressure; P_{CO_2}, partial pressure of carbon dioxide; *TLC,* total lung capacity; *VC,* vital capacity; V_T, tidal volume
(Data from Verklan, M.T., Walden, M. [Eds.]. [2015]. *Core curriculum for neonatal intensive care nursing* [5th ed.]. St. Louis: Saunders.)

There are two modes for how ventilation rates are determined: intermittent mandatory ventilation and patient-triggered ventilation. For patient-triggered ventilation, there are five options available.[4]

- **Intermittent mandatory ventilation:** Ventilator breaths are delivered at a predetermined rate and not synchronized with the neonate's breath.
- **Patient-triggered ventilation:** Ventilator breaths are delivered in response to a signal from the neonate and synchronized with his or her breath. The five types of patient-triggered ventilation are:

- Synchronized intermittent mandatory ventilation
- Assist control (AC) mode of ventilation
- Pressure support ventilation
- Volume-targeted ventilation
- Neurally adjusted ventilatory assist

These various modes of mechanical ventilation are best classified based on how each breath is initiated, how the gas flow controls each breath, and how the breath ends.

Table 2 Classification of Basic Modes of Ventilation

Factors	Definition
How is each breath initiated?	Controlled ventilation: Breath is initiated by a timing mechanism unrelated to the neonate's own inspiratory effort. Synchronized patient triggered: The breath is triggered by the neonate's inspiratory effort.
How is gas flow controlled?	Pressure-controlled: A predetermined pressure is delivered. Volume-controlled: A predetermined tidal volume is delivered.
How is each breath ended?	Time-cycled: The breath is terminated based on predetermined elapsed time. Volume-cycled: The breath is terminated based on cessation of inspiratory flow.

(Data from Gardner, S.L. and others [Eds.]. [2016]. *Merenstein & Gardner's handbook of neonatal intensive care* [8th ed.]. St. Louis: Elsevier.)

In addition to these modes of mechanical ventilation, there are high-frequency ventilation (HFV) modes, which use small V_T at rapid rates. The most common forms of HFV used in the neonate are high-frequency oscillatory ventilation (HFOV) and high-frequency jet ventilation (HFJV).[2,4] The advantage of HFV modes over other modes of mechanical ventilation is the ability to deliver adequate volumes with decreased airway pressure.

Indications for the use of HFV include severe lung disease that is unresponsive to other forms of mechanical ventilation, pulmonary air leaks, and pulmonary hypoplasia. Both HFOV and HFJV deliver gentle ventilation and are very effective with disorders in which carbon dioxide elimination is the major problem. Severe atelectatic disorders (e.g., respiratory distress syndrome) and obstructive disorders (e.g., meconium aspiration syndrome) have been shown to respond to HFJV.[2,4] Determining the appropriate ventilator mode is based on the individual neonate's condition, disease process, and response to previous ventilatory support.

Table 3 Modes of Mechanical Ventilation

Modes of ventilation	Definition
Conventional ventilation	
IMV	A set number of breaths are delivered at a predetermined rate, regardless of where the patient is in the respiratory cycle.
PTV, SIMV	A set number of breaths is delivered and synchronized with the neonate's breath. If a breath is not sensed, the ventilator will deliver a breath at the end of a set time interval. A set PIP and PEEP are delivered.

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PTV, AC	A time-cycled, pressure-limited breath is delivered with every spontaneous breath. Each spontaneous breath is supported with set PIP and set PEEP. A background rate is set in the event of apnea.
PTV, pressure-support ventilation	Spontaneous breaths are supported by a preset pressure-support setting. Similar to AC, but breath is terminated when neonate's inspiratory flow declines to a preset threshold. PIP delivered may vary between breaths and is measured above PEEP baseline.
PTV, PC	Similar to SIMV or AC but set pressure is measured above baseline PEEP. Flow is delivered per the neonate's demand.
PSVG	Ventilator provides a set V_T responsive to changes in patient compliance. PIP may vary with each breath based on neonate's V_T.
HFV: A form of mechanical ventilation that uses smaller V_Ts at high rates of at least 150 breaths/min that allows for generation of lower intrathoracic pressure to reduce barotrauma that contributes to chronic lung disease.	
HFJV	Short, rapid, high-velocity pulses are delivered directly. Indications for use are mainly for disorders in which carbon dioxide elimination is the major problem.
HFOV	A small volume of vibrating gas is moved toward and then away from the patient. The amount of gas moved is referred to as amplitude with the resulting push-pull eliminating carbon dioxide buildup and delivering oxygen.

AC, assist control; *HFJV,* high-frequency jet ventilation; *HFOV,* high-frequency oscillatory ventilation; *HFV,* high-frequency ventilation; *IMV*, intermittent mandatory ventilation; *PC,* pressure control; *PEEP,* peak end-expiratory pressure; *PIP,* peak inspiratory pressure; *PSVG,* pressure support, volume-guaranteed; *PTV,* patient-triggered ventilation; *SIMV,* synchronized intermittent mandatory ventilation; V_T, tidal volume
(Data from Verklan, M.T., Walden, M. [Eds.]. [2015]. *Core curriculum for neonatal intensive care nursing* [5th ed.]. St. Louis: Saunders; Berger, T.M., Fontana, M., Stocker, M. [2013]. The journey towards lung protective respiratory support in preterm neonates. *Neonatology, 104*[4], 265-274; Gardner, S.L. and others [Eds.]. [2016]. *Merenstein & Gardner's handbook of neonatal intensive care* [8th ed.]. St. Louis: Elsevier.)

Ensuring the proper placement of the endotracheal (ET) tube is essential during mechanical ventilation. Monitoring exhaled carbon dioxide levels helps determine if the ET tube is in the correct place. End-tidal and side-stream carbon dioxide monitors are available to assess the levels of exhaled carbon dioxide effectively. Failure to detect exhaled carbon dioxide in neonates with adequate cardiac output strongly suggests esophageal intubation.

Because neonates have a limited volume of exhaled gas, in some cases several breaths must be passed through the sensor to detect carbon dioxide. Sometimes poor or absent pulmonary blood flow (e.g., during cardiac arrest) may result in failure to detect exhaled carbon dioxide despite correct tube placement in the trachea. Failure to detect carbon dioxide can lead to the conclusion that the tube is incorrectly placed and thus results in unnecessary extubation and reintubation in these critically ill neonates.[9]

The use of an uncuffed ET tube is preferred in neonates to prevent airway necrosis; however, this type of ET tube is less secure, and unplanned extubations can occur with minimal tube movement. Signs of extubation include sudden deterioration in clinical status, abdominal distention, crying, decreased chest wall movement, breath sounds in the abdomen, agitation, cyanosis, and bradycardia.

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EDUCATION

- Provide individualized, appropriate education to the family based on the desire for knowledge, readiness to learn, and overall psychosocial state.
- Explain the purpose for and complications of mechanical ventilation.
- Provide the family with descriptions and explanations of the equipment and alarms.
- Discuss the need for suctioning and explain the procedure to the family.
- Discuss methods the family may use to interact with and calm the neonate.
- Encourage questions and answer them as they arise.

ASSESSMENT AND PREPARATION

Assessment

1. Perform hand hygiene before patient contact.
2. Introduce yourself to the family, if they are present at the bedside.
3. Verify the correct neonate using two identifiers.
4. Ensure that a manual ventilation bag (MVB), mask, and suction are immediately available and connected at the neonate's bedside.

> Rationale: Emergency equipment is necessary for sudden changes in the neonate's condition or in the event of ventilator failure.[4]

5. Assess the family's understanding of the reasons for and the risks and benefits of the procedure.

Preparation

1. Inspect the ventilator equipment and settings.

a. Parameters to review when using conventional ventilation include fraction of inspired oxygen (F_{IO_2}), ventilator rate, positive inspiratory pressure (PIP), positive end-expiratory pressure (PEEP), V_T, inspiration-to-expiration ratio (I:E ratio), flow rate, and mean airway pressure (MAP).
b. Parameters to review when using HFV include F_{IO_2}, amplitude, frequency, and MAP.

2. Assess the ventilator alarm status.

PROCEDURE

1. Perform hand hygiene and don gloves.
2. Verify the correct neonate using two identifiers.
3. Explain the procedure to the family (if they are present at the bedside) and ensure that they agree to treatment.
4. Administer the prescribed sedatives and pain medications and reassess the neonate's pain status regularly.

> Rationale: Early identification of the neonate's comfort level allows immediate attention to problems. Sedation may be necessary to achieve ventilator synchrony but should be used with caution.[6,10]

5. Assess the neonate's vital signs and cardiopulmonary stability, including spontaneous respiratory rate, chest expansion (in conventional ventilation) or vibration (in HFV), and response to mechanical ventilator cycling.

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6. Auscultate the neonate's breath sounds, including upper and lower lung fields and differences in left and right lung fields. Include the equality of aeration and the presence of crackles or other abnormal lung sounds.
7. Assess chest wall vibration when using HFV.

> Rationale: Chest wall vibration is an indicator of lung compliance, airway patency, and effectiveness of ventilator settings. An increase in chest wall vibration accompanied by an increase in partial pressure of arterial oxygen (PaO_2) and a decrease in arterial partial pressure of carbon dioxide ($PaCO_2$) is an indication to consider weaning the ventilator settings. A sudden decrease in chest wall vibration may indicate a plugged or displaced ET tube or a pneumothorax. Unless ventilation is stopped, assessing the neonate's breath sounds during HFV is impossible.[4]

8. Assess ET tube stability and centimeter marking at the gumline once per shift and as needed.
9. Assess the neonate for signs of ventilatory failure, including increased $PaCO_2$, decreased arterial oxygen saturation (SaO_2), increased work of breathing, tachypnea, and increased retractions.
10. Assess the neonate for signs of hypoxemia, including decreased SaO_2, pale or cyanotic color, tachycardia or bradycardia, tachypnea, agitation, increased work of breathing, increased retractions, and acidosis.
11. Assess radiographic findings, blood gas analysis, and the neonate's clinical status for indications that weaning from the ventilator can be initiated.
12. Ensure that the head of the bed is slightly elevated, unless contraindicated.[1]

> Rationale: Elevating the head of the bed reduces the incidence of aspiration and is a recommended practice in the prevention of ventilator-associated pneumonia.[8]

13. Assess the need for suctioning. Signs that may indicate a need for suctioning include:

a. Visible secretions in the ET tube
b. Coarse or decreased breath sounds
c. Changes in vital signs
d. Decreased oxygen saturation
e. Increased partial pressure of transcutaneous carbon dioxide ($PtCCO_2$) readings
f. Decreased chest wall movement
g. Decreased chest wall vibration for neonates on HFV

14. Suction as needed.

> **Suctioning is not a benign procedure. Suction only as needed to maintain airway patency and remove secretions. Carefully assess the neonate's conditions that require ET tube suctioning.**

a. Suction the ET tube using the shallow or measured technique, preferably with a closed, inline suction device.
b. Notice and document the characteristics of secretions.

15. Respond immediately to ventilator alarms, and watch for changes and fluctuations in prescribed settings, which may indicate water in the tubing or the need for suctioning.

> Rationale: An alarm may be associated with the need for suctioning or the need to drain water from the tubing, or it may indicate that the ventilator tubing has been disconnected.
>
> **Report to the practitioner any inappropriate sounding of alarms.**

16. Adjust ventilator settings (as ordered) in collaboration with the practitioner and respiratory therapist on the basis of treatment strategies and the neonate's response. Wean the neonate from the ventilator as soon as possible to minimize lung injury.

> Rationale: Changes in lung compliance may occur, resulting in the need for more or less ventilator support.[4]

17. Discard supplies, remove gloves, and perform hand hygiene.
18. Document the procedure in the neonate's record.

MONITORING AND CARE

1. Review the ventilator settings at the beginning of each shift and with every vital sign assessment.
2. At the beginning of each shift, confirm that all alarms are activated.
3. Auscultate breath sounds and monitor chest excursion, spontaneous effort, air entry, and the neonate's color as his or her condition warrants. Monitor chest vibrations when the neonate is undergoing HFV.
4. Suction as indicated, preferably using a closed, inline suctioning method.

> Rationale: Closed, inline suctioning devices allow suctioning while ventilation continues, which minimizes the fluctuations in oxygenation, changes in cerebral blood flow, and other hemodynamic changes. Closed, inline suctioning also decreases the risk of infection by decreasing the potential for contamination of the ET tube and suction catheter.

5. Monitor signs of changes in oxygenation and ventilation, including lung sounds and aeration of lung segments, vital signs, oxygen saturation, $PtcCO_2$ and partial pressure of transcutaneous oxygen ($PtcO_2$) as appropriate, arterial or capillary blood gases, cyanosis, work of breathing, adequacy of chest excursion, and chest radiography findings.
6. Monitor and document SaO_2 values as needed or more frequently if warranted.
7. Monitor and document $PtcCO_2$ and $PtcO_2$ values (when applicable) as ordered or as the neonate's condition warrants.
8. Monitor and document site changes and correlate values with blood gases as indicated. Change the site and calibrate the electrode based on the manufacturer's calibration directions and the organization's practice, and as the neonate's condition warrants.
9. Monitor blood gases as indicated, typically after initiation of assisted ventilation, after significant changes in ventilation settings, and with changes in the neonate's condition.
10. Monitor gastric insufflations and remove air from stomach as indicated.
11. Provide oral care as needed when performing hands-on care.
12. Monitor for signs of unplanned extubation, including the sudden deterioration in clinical status, decreased oxygen saturation or $PtcO_2$ readings, abdominal distention, crying,

decreased chest wall movement, breath sounds in the abdomen, agitation, cyanosis, or bradycardia.
13. Assess, treat, and reassess pain.

EXPECTED OUTCOMES

- Adequate oxygenation and ventilation
- Oxygenation and ventilation without lung injury
- Hemodynamic stability
- Proper placement of ET tube
- Absence of infection
- Mobilization and removal of secretions
- Discontinuation of mechanical ventilation as soon as neonate is physiologically ready
- Adequate management of pain and agitation for neonate

UNEXPECTED OUTCOMES

- Inadequate ventilation or oxygenation (e.g., hypoxemia, hypercarbia, acidosis, alkalosis)
- Lung overinflation
- Air-leak syndrome
- Acute lung injury: barotrauma, volutrauma, or progression of lung disease
- Atelectasis
- Hemodynamic instability
- Unplanned extubation or malposition of ET tube
- Ventilator-associated pneumonia
- ET tube obstruction
- Inadequately managed pain and agitation due to presence of ET tube or hypoxemia

DOCUMENTATION

- Cardiopulmonary assessment, including vital signs, lung sounds, work of breathing, chest excursion and symmetry if neonate is on conventional ventilation, chest vibration if neonate is on HFV, capillary or arterial blood gases, pulse oximetry, and $PtCCO_2$ and $PtCO_2$
- Date, time, and response to the initiation of ventilator assistance
- Conventional ventilator settings, if appropriate, including FIO_2, mode, V_T, intermittent mandatory ventilation, PIP, ventilator rate, and PEEP
- HFV settings, if appropriate, including FIO_2, amplitude, frequency, and MAP
- Timing of suctioning, characteristics of ET tube secretions, neonate's response to suctioning, and assessment of breath sounds after suctioning
- Additional interventions and neonate's response
- Comfort assessment
- Family education
- Unexpected outcomes and related nursing interventions

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ADDITIONAL READINGS

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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

- Gloves
- Conventional mechanical or HFV
- Pulse oximetry monitor

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- $PtCCO_2$ monitor (optional)
- $PtCO_2$ monitor (optional)
- End-tidal carbon dioxide detector
- Cardiopulmonary monitor
- Suction source
- Suction catheters
- Oxygen and air sources
- Manual ventilation device: flow or self-inflating bag with appropriate-size mask

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