UDK: 616.24-085.816.2-053.31

MECHANICAL VENTILATION IN NEWBORNS

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Abstract

Mechanical ventilation is a commonly used therapy in neonatal intensive care centers and is associated with increased mortality and morbidity.The goals of mechanical ventilation are to enable adequate gas exchange including adequate oxygen delivery and adequate ventilation to remove CO2, to reduce the work of breathing and to minimize the risk of lung injury.Indications for mechanical ventilation are respiratory failure, pulmonary insufficiency, severe apnea and bradycardia, congenital heart disease, diseases of the central nervous system and surgical interventions.The use of mechanical ventilation in newborns is a real challenge due to certain characteristics of the newborn, such as non-compliant lungs, fast irregular breathing rate, short inspiratory time and limited muscle strength.Basic knowledge of the respiratory physiology and pathophysiology of the existing diseases that can lead to respiratory failure is necessary in choosing the optimal ventilation mode and adjusting proper ventilator parameters.This ensures adequate gas exchange and minimal damage to the lungs.Neonatal mechanical ventilation is a very demanding, yet, still developing field. In this text we discuss various models and modalities of ventilation commonly used in neonatology.

Key Words: *mechanical ventilation, newborn, respiratory failure.*

Introduction

Mechanical ventilation is one of the most common therapies in neonatal intensive care units.The primary goal of mechanical ventilation is to ensure adequate gas exchange such asadequate oxygenation and removal of carbon dioxide (CO2).Despite the development of non-invasive ventilation modes, mechanical ventilation remainsa main treatment in the intensive care units.

In a 2010 cohort study, itwas reported that 74% of infants born before 28thgestational week were intubated and received surfactant during hospitalization(1).

Indications for mechanical ventilation include respiratory failure, pulmonary insufficiency, severe apnea and bradycardia, congenital heart disease, central nervous system disorders and surgical interventions.However, mechanical ventilation can also be the cause for lung injury (VILI-Ventilator induced lung injury). In order to reduce the risk of VILI, basic knowledge of respiratory physiology and understanding the pathophysiology of the existing disease leading to respiratory weakness is necessary, along with the selection of the optimal mode of ventilation and appropriate ventilator parameters (3).

Historically, pressure ventilation has been the most commonly used method of ventilation(4). However, recent research suggests that volume-targeted ventilation is the best mode of ventilation for newborns.The improved technology in the field of advanced respirators has allowed the development of ventilation modes that mimic the physiological aspects of spontaneous breathing innewborn in order to reduce VILI.

Basic principles

The primary goal of mechanical ventilation is to achieve satisfactory oxygenation and ventilation. Oxygenation (PaO_2) depends on the fraction of inspired oxygen (FiO_2) and mean airway pressure (MAP). Ventilation (CO_2 clearance) depends on the minute volume [minute volume (MV) = respiratory volume (VT) x number of respirations (RR)].

Mechanical ventilators enable control of oxygenation and ventilation by adjusting certain parameters. Oxygenation can be improved by increasing mean airway pressure (MAP), extendinginspiratory time (Ti) and adjusting FiO_2.Increasing peak inspiratory pressure (PIP) or positive end-expiratory pressure (PEEP) raises MAP, thereby enhancing oxygenation.

Ventilation facilitates CO_2 removal from the lungs.A higher minute volume leads to increased CO_2 removal and consequently reduced $PaCO_2$.This can be achieved by increasing the respiratory rate or increasing the tidal volume.

↑ PaO_2	↑ FiO_2, ↑ Ti ↑ MAP (PIP/PEEP)
↑ ventilation (↓ $PaCO_2$)	↑ TV ↑ RR

Standard modes of ventilation

Standard ventilation modesinclude pressure-controlled, volume-controlled and hybrid ventilation. In pressure-controlled ventilation, the ventilator delivers gas flow until the set pressure is reached while in volume-controlled ventilation the ventilator delivers already set volume (5). In pressure-controlled ventilation, there is a variable respiratory volume (Vt) while the pressure (PIP) remains constant (6).

Pressure-controlled Ventilation

Pressure-controlled ventilation is the most commonly used method for respiratory failure in newborns. An appropriate peak inspiratory pressure (PIP) is set that overcomes the resistance of the airways to achieve the delivery of a specific gas volume (Vt) into the alveoli. The gas volume entering the alveoli depends on the compliance of the lungs, inspiratory pressure, inspiratory time, flow, and synchronization of the ventilator with the newborn's spontaneous respirations (7). Changes in compliance alter the achieved Vt at the same PIP, and can lead to hypoventilation or hyperventilation, thus atelectasis or hyperinflation. In conditions like respiratory distress syndrome (RDS) where surfactant is deficient, the lungs are stiff, poorly expandable and compliance is low. Applying surfactant improves compliance by expanding previously atelectatic lungs. In the case of lungs with areas of hyperinflation, such as bronchopulmonary dysplasia (BPD), they easily expand having a high compliance. Monitoring the gas analysis and following ventilator parameters and curves is necessary for proper adjustment of the already set pressure in order to avoid hypoventilation or hyperventilation.

Volume-controlled Ventilation

Modern ventilators are equipped with microprocessors capable of measuring and delivering low gasvolumes which is very important for premature newborns. Usually, respiratory volume is set between 4-5ml/kg. In volume-controlled ventilation, the ventilator automatically adjusts the peak inspiratory pressure (PIP), achieving the already given respiratory volume based on changes in compliance and resistance in the airways. This reduces the risk of hypoventilation and hyperventilation, thereby minimizing the risk of ventilator-induced lung injury (VILI). Therefore, this invasive ventilation mode is the greatest for premature newborns. In comparison to pressure-controlled ventilation, the use of volume-targeted ventilation shows a reduction in mortality, lower cases of bronchopulmonary dysplasia, less days on mechanical ventilation, less cases of pneumothorax, hypocarbia and severe intraventricular hemorrhage (8). It is crucial to note that volume controlled ventilation relies on precise measurement of the flow and it is not a choice in the presence of a significant leak (>50%) around the endotracheal tube.

Hybrid Ventilation Modes

Hybrid ventilation modes are combination of different modes aimed to create ventilation that is more physiological, thus reducing the risk of lung injury.

Other ventilation modes

The fast technological development and appearance of new and advanced ventilation modes for newborns allows various options for mechanical ventilation to be chosen from. Despite the existence of different types of ventilators, the basic principles apply to all. The most commonly used ventilation modes in the treatment of newborns are pressure-controlled (assist-control [A.C.] and synchronized intermittent mechanical ventilation [SIMV]), volume controlledand high-frequency ventilation. Muscle relaxants are usually not used in newborns while on mechanical ventilation, allowing them to have their own respirations. Therefore, synchronized ventilation models are often used, where the ventilator coordinatesthe delivered respirations with the spontaneous breaths of the newborn. Those spontaneous respirations are detected by the flow sensor located between the endotracheal tube and the Y-connector. The sensor detects minimal changes in flow initiated by spontaneous inspiratory respirations, triggering the ventilator to provide support during inhalation. This enables synchronization of the newborns breathing with the ventilator in achieving the pre-set pressure or volume. The sensitivity of the flow sensor can be adjusted if necessary. Sometimes, fluid in the ventilator system can mimic changes in flow, causing auto-triggeringas in spontaneous breathing.

Basic Synchronized Ventilation Modes

Three basic synchronized ventilation modes are assist/control (AC), synchronized intermittent mandatory ventilation (SIMV) and pressure support ventilation (PSV).

Assist/control (AC)

In AC ventilation, the newborn triggers and initiates the inspiratory phase but the ventilator completes it, thereby reducing the work of breathing. In AC ventilation, pressures (PIP and PEEP) and inspiratory time are controlled. During weaning, PIP needs to decrease as the respiratory frequency is primarily controlled by the newborn. Inspiratory time is fixed, which results in very short expiratory time at high breathing frequencies, leading to air trapping (autoPEEP).

Synchronized Intermittent Mandatory Ventilation (SIMV)

SIMV is a ventilation mode where the ventilator delivers predetermined respiratory volume and respiratory frequency which is synchronized with the newborns inspirations and strong enough to trigger the ventilator. Spontaneous respirations overcoming respiratory frequency are supported only by PEEP. Lowering the pre-set frequency reduces ventilator support for spontaneous respirations. This increases the work of breathing and results in unsuccessful weaning.

Both synchronized modes (AC, SIMV) can have an additional mode of volume-guaranteed ventilation.

Pressure Support Ventilation (PSV)

PSV is a mode of spontaneous breathing where the patient triggers respiration and the ventilator provides inspiratory support with a pre-set inspiratory pressure (pressure support). The inspiratory phase ends when the inspiratory flow decreases to a previously set threshold, usually 10-15% of the peak flow. At this point, the gas flow stops, and passive expiration begins. The patient determines the respiratory frequency, respiratory volume and inspiratory time. PSV reduces the work of breathing and allows synchronization between the patient and the ventilator, avoiding prolonged inspiration. However, this can lead to very short inspiratory time (Ti) and a rapid respiratory frequency in newborns in their first few days of life. Short Ti results in a relatively low mean airway pressure (MAP), therefore adequate PEEP must be used to prevent atelectasis (9). This ventilation mode is very useful in assessing the newborn weaning which should be stopped if there is apnea even when minimal backup respiratory frequency is set to be delivered by the ventilator.

High-Frequency Ventilation (HFV)

HFV is a special type of ventilation where a rapid respiratory frequency and respiratory volumes smaller than the anatomical dead space are set, reducing the possibility of lung injury by reducing PIP. The advantage of this ventilation compared to standard ventilation modes is the ability to provide adequate alveolar ventilation and arterial oxygenation at low PIP and small respiratory volumes, thereby preventing barotrauma (10).

Variables set in HFV include frequency (Hz), mean airway pressure (MAP), amplitude, inspiratory time, and FiO2. Increasing MAP causes greater lung recruitment, allowing better oxygenation. Increasing FiO2 increases the diffusion gradient, thus improving oxygenation. CO2 removal is achieved through high-frequency oscillations of small volumes in and out. CO2 removal is determined by amplitude and frequency. Increasing the amplitude reduces PaCO2, while increasing the frequency increases PaCO2.

HFV is used in severe lung conditions where standard ventilation modes are inadequate due to the need for high PIP and FiO2, which potentially leads to barotrauma. When transitioning a newborn from standard ventilation to HFV, it is recommended to increase MAP by 2-3cmH2O above the previous value. Other parameters are adjusted based on oxygen requirements and appropriate lung expansion, with the diaphragm positioned at the 8-9th posterior rib as diagnosed on X-ray.

Table 1. HFOV parameter adjustments.

	Condition			
	Poor oxygenation	**Over oxygenation**	**Under ventilation**	**Over ventilation**
1st	↑↑ FiO_2	↓↓ FiO_2	↑↑ Amplitude	↓↓ Amplitude

	Condition			
	Poor oxygenation	**Over oxygenation**	**Under ventilation**	**Over ventilation**
choice				
2nd choice	↑↑ MAP (1–2 cmH_20) if CXR shows high diaphragm position	↓↓ MAP (1–2 cmH_20) if CXR shows low diaphragm position	↓↓ Frequency (1–2 Hz) if Amplitude maximal, or if Air Leak present	↑↑ Frequency (1–2 Hz) if Amplitude minimal

NAVA (Neurally Adjusted Ventilatory Assist)

NAVA is a ventilation mode that utilizes an electrical signal from the newborn's diaphragm to synchronize the ventilator with spontaneous respirations.

Ventilator parameter settings [NICE (The National Institute for Health and Care Excellence) Guidance - https://www.nice.org.uk/guidance/ng124]:

Preterm infants with Respiratory Distress Syndrome

- PC-AC with VG → Rate 40-50, Ti 0.3, PEEP 5, VT 4ml/kg (Pmax 28)
- Pressure limit: 20-22cmH2O for newborns and 25-28 cmH2O for babies
- To avoid hypocarbia (pCO2 < 4.5)
- Gas analysis in the first hour, and VT adjustment based on the results.

Terminal infants with a pulmonary disease

- PC-AC with or without VG → Rate 50, Ti 0.4-0.45, PEEP 5-6, set PIP to achieve VT 4-5ml/kg
- HFOV if high pressure is needed (PIP > 28-30)

The minute volume at the beginning of ventilation should be set at 0.15-0.35ml/kg. If the delivered respiratory volume is too high or too low, the ventilator should alarm. The gas analyses should also be checked.To enable synchronization and measurement of respiratory volume, the proper functioning of the flow sensor with an alarm is essential.

NICE recommends the use of SIMV with PLV (pressure-limited ventilation) if VG or HFOV is not suitable. With PC-AC, more frequent respirations are set at higher pressure which can damage the lungs. SIMV with PLV provides greater control over the number of respirations set with high pressure, thereby minimizing lung damage.

Mismatch between ventilation and perfusion due to atelectasis and hypoventilation causes hypoxemia. Depending on the current oxygenation, an appropriate PEEP is set. The use of high PEEP can lead to hyperinflation of the lungs, pneumothorax, reduced venous return and increased PaCO2. Low PEEP can lead to hypo-inflation, lung collapse and an increased need for FiO2. It is recommended to start with a PEEP of 5-6cmH2O. If FiO2 needs to get higher than 30% or there is inadequate lung expansion with the diaphragm positioned at the 8-9th posterior rib diagnosed on X-ray, PEEP need to be increased to 8cmH2O.

Ventilator settings should be set according to the individual needs of each patient.

Weaning

The decision to wean from the ventilator is based on gas analyses and saturation levels. Initially, FiO2 is reduced to 30% while SpO2 ranges from 91% to 95%. Depending on the PaCO2 levels, both Vt and respiratory frequency can be decreased. With improved oxygenation, PEEP is also reduced. Extubatingshould be performed when the newborn exhibits good spontaneous respirations, minimal pressure support (PIP < 18) and favorable gas analyses.

Conclusion

There is no ideal mode of mechanical ventilation for newborns. A great understanding of the physiology and pathophysiology of newborns,along with knowledge fordifferent ventilation modes, is essential in their treatment using mechanical ventilation. It is crucial to monitor the dynamics of changes in ventilation and adjust parameters or ventilation modes accordingly. This approach minimizes the risk of lung injury.

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