**Ventilation Modalities in the NICU**

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**Session Summary**

This presentation provides an overview of current invasive and noninvasive ventilation strategies used to ventilate neonates in the NICU. The benefits and limitations of each strategy are discussed. This overview should provide a broad understanding of the numerous ventilator modalities available to the neonatal clinician, which enable treatment to be tailored to the patient and his/her unique lung disease.

**Session Objectives**

Upon completion of this presentation, the participant will:

- understand the various ventilation strategies/modalities used to support the infant’s respiratory system in the intensive care unit;
- outline the factors that can guide decision making regarding ventilation strategies used in the neonatal intensive care unit (NICU).

**References**


**Session Outline**

See presentation handout on the following pages.
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Early History

Causes

• Disease and PTV, Hi f Nl Vi l i

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1970's

strategies

were developed to

address different pulmonary pathologies

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1980's

Clinical trials and specific strategies developed to address different pulmonary pathologies

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End of the 20th Century

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Use of advanced technologies such as PTV, TVC, PIP


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What Are the Goals of Neonatal Ventilation?

Goals of Neonatal Ventilation

To maintain and achieve adequate pulmonary gas exchange

To minimize lung injury risk

To reduce work of breathing by the patient

To optimize the comfort of the patient

Mechanisms of Lung Injury Caused by Mechanical Ventilation

• Extensive basic investigation added several new concepts of lung injury

Known Mechanisms of Lung Injury

• Barotrauma

• Volutrauma

• Atelectrauma, with chronic lung disease

Newly Discovered Mechanisms of Lung Injury

• Oxidant stress

• Inflammatory mediators

• Infectious agents (“biotrauma”)
There Are 2 Approaches to Neonatal Ventilation

- Neonatal ventilation strategies can be viewed across a continuum of dependency from the infant who only requires oxygen to the fully ventilated infant requiring intensive care.

2 Types of Neonatal Ventilation Strategies

- Invasive
- Noninvasive

There Are Several Types of Invasive Neonatal Mechanical Ventilation

- Pressure Control Continuous Mandatory Ventilation (PC-CMV)
- Pressure Support Ventilation (PSV)
- Synchronized Intermittent Mandatory Ventilation (SIMV)
- High Frequency Oscillation (HFO)
- High Frequency Ventilation (HFV)
- Intermittent Mandatory Ventilation (IMV)
- Intermittent Positive Pressure Ventilation (IPPV)
- Noninvasive Positive Pressure Ventilation (NPPV)
- Noninvasive Continuous Mandatory Ventilation (NCMV)
- Noninvasive Pressure Support Ventilation (NPSV)
- Noninvasive High Frequency Ventilation (NHFO)
- Noninvasive High Frequency Oscillation (NHFO)

Pressure Control Intermittent Mandatory Ventilation (PC-IMV): Definition

- Initial mode used in early trials and for almost 2 decades in the NICU
- The clinician sets the mechanical breathing rate that cycles at regular intervals
- The infant may breathe spontaneously between mechanical breaths

Benefits
- Utilized for patients with impaired respiratory drive
- Indicated for patients with excessive work of breathing

Limitations
- Significant dysynchrony may occur between the ventilator and the infant that may result in:
  - A wide variability in the tidal volumes delivered to the infant
  - Inefficient gas exchange
  - Trapping of gas
  - Air leaks
  - Intraventricular hemorrhage

Synchronized Intermittent Mandatory Ventilation (SIMV): Definition

- The ventilator breaths are synchronized with the infant’s own spontaneous inspiratory effort
  - Delivers a synchronized breath when a change in flow or a pressure drop is detected within the ventilator tubing
  - Has an assist sensitivity control setting to allow the delivery of a ventilator breath when the infant exhibits respiratory effort
Synchronized Intermittent Mandatory Ventilation (SIMV): Benefits and Limitations

Benefits
- The infant can take additional spontaneous breaths between the ventilator-assisted breaths.
- Synchronized breathing increases patient comfort.
- Can be used to wean the ventilator support by reducing the preset rate and pressure over time.
- Can be combined with other ventilator strategies to optimize ventilation based on the infant's specific disease state.

Limitations
- Expiratory asynchrony may occur if the infant's inspiratory time is shorter than the ventilator's inspiratory time (T1).
- The only ventilator support is positive end expiratory pressure (PEEP).

Assist/Control (Patient-Triggered) Ventilation: Definition

Assist
- The ventilator is triggered to deliver a breath or assist the infant's breath at a set pressure and T1 each time the infant starts to breathe.
- The delivered and recorded rate is determined by the infant.

Control
- The ventilator will deliver the set backup rate if the infant does not trigger a breath.
- As long as the patient's spontaneous breathing rate exceeds the set backup rate, the control rate is not used.

Pressure-Support Ventilation (PSV): Definition

- Ventilator breaths set to a predetermined pressure supports the infant's breathing efforts.
- Assists the infant's own breath by pressurizing the breath to the set pressure support level and does not supply a backup rate.
- Primarily used to decrease the work of breathing needed to overcome the resistance of the ET during spontaneous breaths.
- Used in conjunction with other ventilator modes, like SIMV:
  - Ensures that every spontaneous breath is supported by the ventilator at a set percentage pressure.
  - Is useful during weaning as a gradual step down once the backup rate on SIMV is reduced.

Volume Targeted Ventilation (VTV): Definition

- VTV is also referred to as Target Tidal Volume or Volume Guarantee ventilation.
- VTV can be used with SIMV, PTV, or Assist/Control Ventilation.
- The desired VT limit to be delivered by the ventilator is set by the clinician so that the lowest possible PIP necessary to reach the set volume is used.
  - As the lung compliance changes the measured PIP is likely to vary with each breath.

Optimum
- Optimum
- Due to the fact that the only parameters that can be set are PIP and PEEP, it can be used to wean infants from mechanical ventilation.
- Optimum backup rate allows the clinician to support the infant's own respiratory efforts.
- Allows the infant to take control of his own breathing over time.

Benefits
- Reduces barotrauma by allowing the patient to self-regulate.
- Ideal for infants who are obviously uncomfortable during mechanical ventilation.
- Optimum backup rate allows the clinician to support the infant's own respiratory efforts.
- Allows the infant to take control of his own breathing over time.

Limitations
- Prolonged use can cause diaphragmatic muscle atrophy.
- Diaphragmatic muscle atrophy may offset improvements in compliance thereby leading to difficulty in weaning.
- Due to the fact that the only parameters weaned by the clinician are the peak inspiratory pressure (PIP) and PEEP, weaning can be difficult.
- Because all of the infant's spontaneous breaths are supported, wearing the rate does not affect CO2 or O2 levels.

PIP and inspiratory pressure.

VTV: Volume Targeted Ventilation.
Volume Targeted Ventilation (VTV): Setting the Volume Target

**Deteriorating Lung Conditions**
- It is may be difficult to deliver the set \( V_t \) in deteriorating lung conditions
- It is important that an appropriate maximum pressure limit is set

**Improving Lung Conditions**
- As lung compliance improves, PIP will decrease
- It becomes easier for the desired volume to be delivered at lower pressures
- Improving lung conditions and readiness for weaning is signaled when the PIP needed to generate the desired \( V_t \) decreases

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Volume Targeted Ventilation (VTV): Benefits and Limitations

**Benefits**
- Can show changes in lung compliance
- Infant receives a consistent \( V_t \) independent of lung compliance
- Volutrauma is avoided with volume-limited breaths
- Combining VTV with other modes can facilitate weaning

**Limitations**
- The clinician must be aware of the smallest tidal volume the ventilator can deliver
- Infants who require smaller endotracheal tube (ETT, 2.5-3.0mm) may have difficulty triggering breaths (particularly if pressure-triggered)
- Airway leaks may cause a loss in baseline pressure

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High-Frequency Ventilation (HFV): Definition

- Neonatal units began utilizing HFV in the early 1980s
- Delivers tidal volumes at a very high rate (4-11 Hz) that are smaller than the anatomical dead space

2 Types of High-Frequency Ventilation

- Passive Exhalation-Based HFV: High Frequency Jet Ventilation
- Active Exhalation-Based HFV: High Frequency Oscillatory Ventilation

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High-Frequency Ventilation (HFV): How Does HFV Work?

- Forced oscillations experiments have shown that adult lungs have a resonant frequency of 4-8 Hz

**Inhalation**
- At resonance, the energy supplied by gas momentum promotes lung expansion
- Outside force is only required to overcome airway resistance
- At resonant frequency less pressure is needed to move gas in and out of the lungs

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High Frequency Jet Ventilation (HFJV): Definition

- Used in conjunction with a conventional ventilator
- The conventional ventilator:
  - Delivers PEEP
  - Entrains gas
  - Provides intermittent sighs
- Small pulses of gas under pressure are introduced into the airway at a very fast rate (240-660 breaths/minute or 4-11 Hz) for a brief duration (T, of about 0.02 seconds)
  - Uses very small \( V_t \) (<1 ml/kg) creating lower distal airway and alveolar pressures than conventional mechanical ventilation

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Pattern of Gas Flow During High-Frequency Jet Ventilation

**Inspiratory Gas Flow**
- Gas is actively pulled into the lungs through the ETT

**Expiratory Gas Flow**
- As incoming gas travels down the center of the ETT, CO2 passively spirals up and around the jet of gas to exit the lungs

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[References and citations are included in the text boxes for each section.]

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A2b: VENTILATION MODALITIES IN THE NICU
High Frequency Jet Ventilation (HFJV): Benefits and Limitations

**Benefits**
- Uses lower pressure amplitude than conventional ventilation
- Very effective elimination of CO₂
- Provides rapid resolution of air leaks
- High PEEP can be used safely
- Lung volume recruitment and maintenance is effective with the background sigh
- Venous return hemodynamics are improved
- Secretions and aspirated material are mobilized
- Reduced risk of developing BPD

**Limitations**
- The necessity for two machines mean that other forms of high frequency ventilation may be more suitable

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High Frequency Oscillatory Ventilation (HFOV): Definition

- More commonly used than HFJV
- Allows even smaller V̇ₐ than HFJV and active exhalation
  - Rates of 480-900 breaths/minute (common range in NICU 8-15 Hz)
- True negative pressure is generated during the exhalation phase by a piston pump or an oscillating electromagnetic membrane
- Pressure “oscillates” around a constant distending pressure that is comparable to PEEP and equal to MAP

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Pattern of Gas Flow During High-Frequency Oscillatory Ventilation

**Inspiratory Gas Flow**
Gas is actively pushed into the lungs through the ETT

**Expiratory Gas Flow**
CO₂ is actively drawn out of the lungs through the ETT

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Overview of High Frequency Oscillatory Ventilation Settings

**Pressure Amplitude (Delta P)**
- The “power” setting that determines the strength of the oscillations (the degree of “chestwiggle” in the infant)
  - An increase in the chest wiggle is accomplished by increasing the Delta P
  - Controls the volume entering the lungs and so controls CO₂ elimination

**Hertz**
- The Hertz measurement sets the frequency of oscillations (60 breaths in 5 Hz)
  - Common Hertz settings range from 8-15

**MAP**
- MAP is adjusted to control oxygenation
- MAP is usually set above the MAP given for conventional modes

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High Frequency Oscillatory Ventilation (HFOV): Benefits and Limitations

**Benefits**
- Allows for independent adjustments for oxygenation and ventilation
- Ventilation is improved at lower pressure and volume swings in the lung
- Use of high peak airway pressures to maintain ventilation is avoided
- Accomplishes more uniform lung inflation
- Air leaks are reduced

**Limitations**
- Compromised cardiac output, acute lung injury and decreased venous return can result from increasing mean lung volumes
- It is crucial to optimally define mean lung volume for safe use

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Neurally Adjusted Ventilatory Assist (NAVA): Definition

- A novel ventilation modality that reduces asynchrony between the ventilator and the infant
- A diaphragmatic electromyogram (EMG) signal triggers, controls and cycles gas delivery from the ventilator
  - Uses a specially designed nasogastric tube with EMG electrodes that cross the diaphragm to enable the ventilator to detect changes in EMG
- Preliminary data suggest that NAVA have improved ventilator-patient synchrony
- Studies with a larger number of neonates with lung diseases are needed to assess the outcomes where NAVA is the standard NIV modality

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References

Ventilation Modalities in the NICU

Noninvasive Neonatal Mechanical Ventilation Strategies

Continuous Positive Airway Pressure (CPAP): Definition
- According to LaPlace’s law, it is easier to expand a partially inflated alveolus than a fully collapsed one.
- Using this law, CPAP prevents a complete collapse of the alveolus by applying continuous distending pressure throughout the respiratory cycle.
- By utilizing continuous distending pressure to the alveoli throughout the respiratory cycle, CPAP maintains a degree of alveolar inflation during expiration.

Nasal Application
- Infants are obligate nose breathers.
- CPAP can be applied nasally and in turn the mouth can be used to relieve any excess pressure.

Pressure Support Mechanics in a Continuous Positive–Airway Pressure System

Continuous Positive Airway Pressure (CPAP): Benefits and Limitations

Benefits
- Can inflate collapsed alveoli and progress alveolar recruitment.
- Increases volume in the lung, including the functional residual capacity (FRC).
- As gas exchange improves, PaO₂ increases and PaCO₂ decreases as FRC increases.
- Surfactant release may be enhanced in respiratory distress syndrome (RDS).
- Increases the likelihood of successful extubation.
- Produces a more regular breathing pattern.
- Reduces airway occlusion.

Limitations
- Abdominal distention.
- Nasal prongs can cause nasal septum irritation and excoriation.
- Air leaks can occur.
- CO₂ retention.
- Venous return and cardiac output can be impaired.
Bubble CPAP (BCPAP): Definition
- The expiratory limb of the CPAP tubing is immersed in an underwater chamber to achieve the prescribed cm H2O CPAP level1
- Bubbling in the chamber is created by the flow of gas through the system1
- BCPAP may mimic HFOV2

Conclusions of the Study
- No significant difference between nCPAP and BCPAP as a requirement of intubation within 72 hours of non-invasive support (primary outcome)
- No differences between the nCPAP and BCPAP arms with regards to:
  - The duration of oxygen supplementation
  - The prevalence of BPD diagnosis
  - Oxygen requirement upon discharge from the hospital

The Safety of NIPPV Is Comparable to nCPAP in Infants Requiring Respiratory Support
- In a large multicenter study, 1009 infants were randomly assigned to one of two forms of noninvasive respiratory support, NIPPV or nCPAP, at the time of the first use during the first 28 days of life:
  - Study subjects had a birth weight <1000g and gestational age <30 weeks
  - The primary outcome was a composite of death <36 weeks of postmenstrual age (PMA) or survival with BPD at 36 weeks of postmenstrual age

Nasal Intermittent Positive Pressure Ventilation (NIPPV): Definition and Benefits of Use
- A method of assisted ventilation without use of an ETT
  - Continues nCPAP and NIPPV
  - NIPPV is usually delivered at pressures similar to those used during conventional ventilation
  - 2 modes of gas delivery:
    - Synchronized: delivered in synchrony with the infant’s inspiration
    - Non-synchronized: delivered independently of the infant’s breathing effort
  - Both modes have been shown to be superior to nCPAP in keeping infants extubated
  - May be useful as a mode of primary respiratory support

Summary
- Mechanical ventilation technology has significantly evolved over the past 30 years
- Today there are numerous ventilator modalities available to the neonatal clinician
- These choices in modalities offer the clinician strategies that can be customized to the individual patient and their unique lung disease
- The future of neonatal ventilation appears promising particularly in the development and implementation of non-invasive technologies
- More studies are required to validate new methodologies to help translate new innovations to the bedside