Mechanical Ventilation in the NICU

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BCHO MORNING LECTURE
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History

• Commonly used in neonates in the 1960s
• Reduced mortality
  • Improved gas exchange (recruits lung, improves VQ matching)
  • Decreased work of breathing
  • Guarantees minute ventilation
• But increased morbidity (chronic lung disease)
  • Volutrauma
  • Barotrauma
Who Needs Mechanical Ventilation?

- Failed non-invasive support
- Inadequate ventilation
- Inadequate oxygenation
- Persistent apnea
Conventional Mechanical Ventilation

- Intermittent exchange of bulk volumes of gas
- Minute ventilation = frequency of breaths (rate) x tidal volume
  - Normal respiratory rate in neonates 30-50
  - Normal tidal volume in neonates: 4-6 ml/kg
- Breath can be ventilator or patient triggered
  - Breaths can be volume, time, or flow regulated
- The tidal volume can be regulated by pressure or volume
High Frequency Ventilation

• Delivers small volumes (~ equal to the anatomic dead space) at a very rapid rate
• Minute ventilation = frequency of breaths x tidal volume$^2$
• Also applies a continuous distending pressure to maintain expansion (mean airway pressure)
• Two modes:
  • High frequency oscillatory ventilation (HFOV)
  • High Frequency jet ventilation (HFJV)
Conventional Ventilation: Modes

• Time-cycled, pressure-limited (TCPL) Ventilation
  • Provides a continuous flow of heated, humidified gas, allowing the patient to breathe spontaneously at any time
  • IMV: Intermittent mandatory ventilation
  • SIMV: Synchronized intermittent mandatory ventilation
    • breaths delivered at a given rate in synchrony with the patient
    • Patient can breathe above this rate for unsupported

• Pressure Control/Pressure Support

• Automode

• Volume Guarantee
Conventional Ventilation: Modes

- Patient-triggered ventilation
  - Breaths are delivered in response to a sensor that detects airflow, airway pressure, or chest wall movement.
  - Improves patient comfort
  - Ventilates with lower mean airway pressure (MAP)
  - Reduces the need for sedatives
- But does not reduce mortality or incidence of BPD
  - Or rate of air leak, severe IVF, or extubation failure
- Shorter duration of ventilation with synchronized vs conventional ventilation
  - Which could benefit the extremely preterm infants most susceptible to mechanical ventilatory lung injury

Greenough et al, Cochrane Review, 2016
Ventilator Settings

- Peak Inspiratory Pressure (PIP): highest pressure delivered during inspiration
  - Excessive PIP can lead to air leaks, chronic lung disease, barotrauma, decreased venous return $\rightarrow$ decreased cardiac output

- Tidal Volume: the volume of air exchanged between unforced inhalation and exhalation
  - Affects both oxygenation and ventilation
  - Increased by increasing PIP or decreasing PEEP
  - Goal volumes are 4-6 ml/kg
  - Too large a tidal volume can cause damage to the alveoli, pulmonary edema, endothelial injury, inflammation
Ventilator Settings

• Positive End Expiratory Pressure (PEEP)
  • Maintains functional residual capacity
  • Recruits alveoli for gas exchange
  • Improves compliance
  • Improves V/Q mismatch
  • Physiologic PEEP is 2cm H$_2$O
  • Usually set PEEP on vent ~ 5-6
Ventilator Settings

• Inspiratory: Expiratory Ratio (I:E ratio): ratio between time spent in inspiration and exhalation
  • Physiologic I:E = 1:2 or 1:3
  • Longer expiratory times may improve ventilation and decrease air trapping

• Mean Airway Pressure: average distending pressure throughout a complete respiratory cycle
  • Major determinant of oxygenation
  • Affected by changes in PEEP, PIP, and I:E ratio
  • Too much mean airway pressure can cause barotrauma
Terminology

• SIMV: breaths delivered at a given rate in synchrony with the patient
  • Patient can breathe above this rate for unsupported breaths

• Pressure Control (AC): breaths delivered when the patient’s inspiratory effort exceeds a preset threshold
  • Set iTime, PIP or TV, minimum mandatory vent rate if patient goes apneic

• Pressure support ventilation (PSV): breaths delivered when spontaneous breaths exceed a preset trigger, but support ends when inspiratory gas flow falls a certain percentage below peak flow (often 20%)
  • Patient determines rate and I:E ratio
  • Provides support against the resistance of the ETT
  • Often used in combination with SIMV
Modality

• Pressure limited
  • Set the PIP, iTime
  • TV varies as a function of lung compliance and resistance
  • Advantages: avoid barotrauma
  • Disadvantages: variation in tidal volume
    • TV > target in 25% of breaths (causing volutrauma) and < target in 36% of breaths (causing atelectotrauma)¹

• Volume targeted
  • Set TV, PEEP, and rate
  • PIP varies as a function of lung compliance
  • Advantage: avoid volutrauma and atelectotrauma
    • Decreases combined outcome of death and BPD with NNT 8, pneumothorax with NNT 17, ventilation days by 2.36 days, hypocarbia with NNT 4, and grade 3 or 4 IVH/PVL with NNT 11²
  • Disadvantage: some machines only measure TV delivered, which does not account for leaks around ETTs; to avoid this, you need to measure the exhaled TV

¹ Keszler et al, Pediatr Pulmonol, 2004
² Wheeler et al, Cochrane Database Syst Rev, 2010
High Frequency Oscillatory Ventilator

• Delivers small volumes about equal to the anatomic dead space (amplitude) at a very rapid rate (frequency)
  • Typical frequencies are 8-15 Hz (480-900 breaths per minute)
  • Amplitude set to obtain good chest wiggle bilaterally, and titrated per CO$_2$

• Also applies a continuous distending pressure to maintain expansion (mean airway pressure)

• Expiration is active with HFOV
High Frequency Jet Ventilator

- Used in parallel with a conventional ventilator
- High frequency jet breaths are delivered through an adapter
- Set a PIP, PEEP, and frequency for jet breaths
- Set PIP, PEEP, and low rate (2-10 breaths per minute) as sigh breaths on the conventional vent
- Expiration is passive
When To Use What

• Conventional Vent

• High Frequency
  • Severe hypercarbia
  • Restrictive lung disease
  • Air leak
  • Unable to achieve adequate oxygenation on max conventional vent settings
  • High pressures on conventional vent