Nonconventional Ventilation of Pediatric Patients

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9/10/14
Unique characteristics of infant lungs

- The smaller the child, the higher the airway resistance
  - $R_{RS}$ and $R_{AW}$ decrease as height increases
- Possible that lung tissue growth exceeds increases in airway diameter
  - Infants are prone to air trapping and hyperinflation
    - Especially with airway narrowing and increased resistance (bronchioloitis)

Unique characteristics of infant lungs

- Airways exposed to mechanical ventilation are difficult to expand, but easy to collapse
  - Greater resistance to airflow
  - Gas trapping
  - Increased dead space
  - Increased work of breathing
  - Increased chest wall compliance
  - Closing pressure near FRC – more prone to atelectasis

Unique characteristics of infant lungs

• Ventilation changes airway properties
  ▫ Increased tracheal diameter
  ▫ Thinning of cartilage and muscle
  ▫ Disruption of muscle-cartilage junction
  ▫ Focal abrasions of the epithelium

• Neurally Adjusted Ventilatory Assist (NAVA)

• High Frequency Oscillatory Ventilation (HFOV)

• High Frequency Jet Ventilation (HFJV)
Neurally Adjusted Ventilatory Assist (NAVA)
Steps required to trigger ventilator

<table>
<thead>
<tr>
<th>The Patient</th>
<th>The Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central nervous system</td>
<td>Ideal technology</td>
</tr>
<tr>
<td>Phrenic nerve</td>
<td></td>
</tr>
<tr>
<td>Diaphragm excitation</td>
<td>NAVA</td>
</tr>
<tr>
<td>Diaphragm contraction</td>
<td></td>
</tr>
<tr>
<td>Chest wall and lung expansion</td>
<td></td>
</tr>
<tr>
<td>Airway pressure, flow and volume</td>
<td>Conventional technology</td>
</tr>
</tbody>
</table>

Ventilator unit

Problems with conventional ventilation

- Patient-ventilator asynchrony
  - Found in ¼ of patients on assisted ventilation
  - Mismatch between neural output and ventilator inspiratory/expiratory times
  - Associated with longer duration of MV
  - Increased use of sedation, muscle relaxants

- Delivery of excess tidal volume and pressures
  - Increased risk of barotrauma and ventilator induced lung injury (VILI)
  - Can result in ventilator induced diaphragm dysfunction (VIDD)
NAVA device
Overview

- Assist mode of CMV
  - Delivers pressure proportional to the integral of the electrical activity of the diaphragm (EAdi)
  - Reflects neural output of respiratory center
- Vent triggered and cycled off based on EAdi
- $P_{AW} = \text{NAVA level} \times \text{EAdi}$
  - $P_{AW}$ (cm H$_2$O) = Airway Pressure
  - NAVA level (cm H$_2$O/mV) – set by clinician
Mechanics

- Increase in EAdi triggers inspiratory effort
- Decrease in EAdi terminates assistance
  - Delivery pressure is synchronous with diaphragm activity
  - Vt is controlled by output of respiratory center
- Decreases inspiratory trigger delay
  - Caused by PEEP$_i$, poor respiratory effort
- Decreases cycling off delay
  - Time from end of neural diaphragmatic input and end of breath
NAVA monitoring - No synchronization
NAVA-triggered ventilation
Mechanics

- Protects against excess Vt and $P_{AW}$
  - Downregulation of EAdi in response to increasing vent assist levels
  - As you increase EAdi, the patient will downregulate their neural output

- Hering-Breuer reflex
  - Pulmonary stretch receptors trigger action potential in vagus nerve
  - Inhibits respiratory center in the medulla
  - Prolongs expiration
Drawbacks

- Body position, PEEP, and intra-abdominal pressure can alter position of diaphragm
  - Requires adjustment after major changes in vent settings, clinical condition, and positioning
- Setting high NAVA levels can result in unstable breathing patterns
  - High Vt, followed by periods of apnea
- Optimal method for setting EAdi trigger has not been determined
16 ventilated infants

- Age 2 days – 4 yrs (mean 9.7 mos), Mean wt 6.2 kg

Given 30 min of PSV mode ➔ NAVA x 4 hrs

NAVA mode:

- Improved synchrony
- 28% decrease in PIP at 30 min, 31% at 3 hrs
- 11% decrease in MAP, 9% at 3 hrs
- No significant change in pO2, pCO2
Prospective crossover comparison between NAVA and pressure control ventilation in premature neonates less than 1500 grams

5 ventilated neonates, 25-29 wks
NAVA x 4 hrs → PCV x 4 hrs
  ▫ Cycle repeated 3 times
Data collected every 30 min
On NAVA
  ▫ Lower PIP, FiO2, RR, increased Vt
  ▫ Decreased pCO2, increased compliance
  ▫ No difference in MAP
High Frequency Oscillatory Ventilation (HFOV)
Overview

- Uses pump-driven diaphragm
- Delivers small volumes at frequencies of 3-15 Hz
- Constant mean airway pressure ($P_{MAW}$)
- High alveolar distention and recruitment
- Limit exposure to high ventilatory pressures
- Exhalation is active

Mechanisms of Gas Exchange

• Different than conventional ventilation

- Normal RR 10-34 BPM
- Panting RR 240-300 BPM
  ▫ 5-6 Hz

Mean Airway Pressure (MAP)
- Constant pressure used to inflate the lung and keep alveoli open
- Reduces injury from alveolar collapse and reopening

Amplitude/Power (ΔP)
- Representation of volume of gas generated by each HF wave
- Volume delivered depends on circuit tubing, humidification, ET tube diameter/length

Inspiratory Time
- Percentage of time in inspiratory phase of waveform
- Normally not increased – will lead to air trapping and fulminant barotrauma

Frequency (Hz)
- Rate of oscillation of the diaphragm
- Range 2-20 Hz (120-1200 BPM)
Initial Settings

• Frequency
  ▫ 15Hz – Premature infant, <2.5 kg
  ▫ 10Hz – Term infant 2.5-6kg
  ▫ 8Hz – Children 6-10kg
  ▫ 6Hz – Children >10kg

• Inspiratory time set to 33% (I:E = 1:2)
  ▫ Time increases with decreasing frequency
  ▫ 15 Hz = 22ms, 8Hz = 41ms, 6Hz = 55ms
SensorMedics High Frequency Ventilator

Use a fixed I.E. ratio 33:67% (1:2)

* Do not increase I.T. above 30-33% because of extreme risk of massive airleak (pneumothorax)

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Alveolar ventilation = (TV)^2 \times \text{frequency}

TV is represented by Amplitude (or Power)

**Frequency Changes**

1. At any given Power, a lower Freq will increase the tidal volume (33% of 1/5 sec > 33% of 1/15 sec) and increase alveolar ventilation.

2. Lower Freq will increase total I.T. and may improve oxygenation.

3. Higher Freq will decrease total I.T. and will minimize flow through an airleak.
Initial Settings

• MAP
  ▫ Neonates: 2-4 cm above MAP on CMV
  ▫ Infants/Children: 4-8 cm above MAP on CMV
  ▫ If using HFOV first: MAP 8-10 cm (neonate) and 15-18 cm (infants/children)

• Amplitude (ΔP)
  ▫ Adjust to vigorous chest wall to thigh wiggle (~24-34 cm)
  ▫ Titrate based on pCO2 (45-60)
Management

• Hypoxia
  ▫ Check CXR to assess lung volume
    • Diaphragm should be @ ribs 9-10
  ▫ Increase MAP until adequate SaO2 achieved or lung is over-inflated
  ▫ Max MAP 40-45 cm
  ▫ If SaO2 is adequate and lungs over inflated
    • Decrease MAP 1-2 cm every 2-4 hrs until volume normal
  ▫ If low SaO2 and over-inflated, can decrease frequency (will increase IT)
SensorMedics High Frequency Ventilator

Use a fixed I:E ratio 33:67% (1:2)

J.M. Klein
University of Iowa

Alveolar ventilation = (TV)^2-frequency
TV is represented by Amplitude (or Power)

Frequency Changes
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* Do not increase I.T. above 30-33% because of extreme risk of massive airleak (pneumothorax)
Management

- **Ventilation (CO₂)**
  - Alveolar ventilation \( (Ve) = Vt^2 \times freq \)
    - CMV: \( Ve = Vt \times RR \)
  - Primary regulation is through \( \Delta P \)
  - If high pCO₂ at high \( \Delta P \)
    - Decrease frequency
    - Creating a cuff leak can enhance CO₂ clearance
  - Increase IT to 50% as last resort
Weaning

• Oxygen
  ▫ Wean FiO2 first until <0.5-0.6 (unless hyperinflated)
  ▫ If FiO2 <0.5-0.6 (or hyperinflated)
    • Decrease MAP by 1 cm q4-q8h
    • If desats, increase MAP by 3-4, then wean more slowly
  ▫ When MAP is 8-16 with FiO2 < 0.4-0.5, can convert to CMV
Weaning

• Carbon Dioxide
  ▫ Decrease $\Delta P$ by 3cm per change until $\Delta P = 11-13$
  ▫ Must maintain chest wall vibration
  ▫ If low PaCO2 on minimal amplitude
    • Decrease frequency to 10Hz and then 6Hz to decrease alveolar ventilation
• Multicenter RCT
• 500 infants randomized to HFOV or SIMV
• VLBW (601-1200g), <4 hrs old, 1 dose surfactant, required ventilation (PEEP 6, FiO2 25%)
• HFOV patients:
  ▫ Extubated earlier
  ▫ 56% survived to 36 wks (vs 47%)
  ▫ No increase in ICH, PVL, other complications
Compiled RCTs comparing HFOV and CV in preterm or LBW infants with pulmonary dysfunction/RDS
- 17 studies, 3652 infants
- No effect on mortality at 28-30d
- Subgroup analysis: Reduced CLD with HFOV, no surfactant, I:E of 1:2 on HFOV
- Increased air leaks, grade III/IV IVH in HFOV group
- Not recommended as initial vent strategy
Trials in CDH

- Improved survival and lower incidence of CLD
- Better oxygenation and higher MAP with less barotrauma
- May decrease need for ECMO
- Study by CDH registry on pts with initial HFOV
  - Increased rate of mortality and BPD
Prospective, multicenter RCT

Enrollment criteria
- Age > 34 weeks, antenatal diagnosis
- No genetic/cardiac/renal/skeletal/CNS anomalies
- Randomized to HFOV or CMV at birth

Primary endpoints: BPD/death within 28 days

Secondary Endpoints:
- Overall mortality, severity of BPD, days on ventilator, VILI, pulmonary HTN, need for ECMO
High Frequency Jet Ventilation (HFJV)
Overview

- Developed in the 1970s for gas exchange during tracheal procedures
- Flow interrupter – uses a pinch valve to generate a stream of high frequency pulses
- Gas propelled into lungs at high velocity
  - Sends gas via laminar and transitional flow down core of the bronchial tree
  - Minimizes effect of dead space
- Requires conventional vent in tandem
  - Generates PEEP and sigh breaths

Overview

- Flow mechanics similar to HFOV
- Exhalation is passive
- **Peak Inspiratory Pressure (PIP)**: Max pressure of delivered gas by the jet
- **PEEP**: Set by attached conventional vent
- **ΔP**: PIP - PEEP
- **Rate**: Set at intervals of 60, range 240-660 BPM (~4-11Hz)
- **Inspiratory Time (IT)**: Set at 20ms (0.02 sec), increase can cause gas trapping and pneumothorax
- **I:E Ratio**: Dependent on frequency
  - At IT of 20ms:
    - Rate 660 – I:E 1:3.5
    - Rate 420 – I:E 1:6
    - Rate 240 – I:E 1:12
Initial Settings

- Rate
  - 420 BPM (7Hz) usual starting frequency in infants
  - 360 BPM (6Hz) if air leaks/trapping
- IT
  - Set at 20ms (0.02 sec)
Initial Settings

- **PEEP**
  - Set by conventional vent
  - 2-4 cm below MAP on CMV/HFOV
  - 8 cm if starting on HFJV
  - Titrate PEEP based on ability to oxygenate

- **PIP**
  - Start at 2 cm below PIP on CMV
  - MAP should equal that of CMV
Initial Settings

• Sigh breaths (on conventional ventilator)
  ▫ For alveolar recruitment
  ▫ Attach HFJV to conventional vent
  ▫ Rate of 3-4 BPM with PIP 6 above PEEP
Management

<table>
<thead>
<tr>
<th></th>
<th>Oxygenation</th>
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<tbody>
<tr>
<td></td>
<td>Inadequate or Poor (Increase FiO₂)</td>
</tr>
<tr>
<td>Over Ventilated</td>
<td>↑ PEEP, Same PIP</td>
</tr>
<tr>
<td>CO₂ is too Low</td>
<td>↑ MAP</td>
</tr>
<tr>
<td></td>
<td>↓ ΔP</td>
</tr>
<tr>
<td>Appropriate Ventilation</td>
<td>↑ PIP, ↑ PEEP</td>
</tr>
<tr>
<td>CO₂ is Adequate</td>
<td>↑ MAP</td>
</tr>
<tr>
<td>Under Ventilated</td>
<td>Same PIP, Same/↑ PEEP</td>
</tr>
<tr>
<td>CO₂ is too High</td>
<td>↑ MAP</td>
</tr>
<tr>
<td></td>
<td>↑ ΔP</td>
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Important differences

- Active vs passive exhalation
  - Increased RR on HFJV increases CO2 clearance
  - Increased frequency on HFOV decreases CO2 clearance
- MAP can be controlled by
  - Changing PEEP or PIP
- Oxygenation can be adjusted via
  - PEEP
  - MAP
  - FiO2
- IT is fixed, and I:E changes with RR

- Multicenter RCT of 130 preterm infants
  - 700 to 1500g
  - All received surfactant
- No difference in mortality, ROP, air leak, severe IVH
- HFJV group less likely to need O2 at 36 weeks PMA or at discharge

- RCT of 73 preterm infants
  - 500g-2000g, 95% received surfactant
- No difference in air leak, need for O2 at 36 weeks PMA, duration of O2 therapy, LOS
- HFJV group more likely to have grade IV IVH, PVL, death (17 vs 7%)
Future Advances

• Computer-directed closed loop systems for weaning
  ▫ Current extubation failure rate 14-24%
  ▫ NAVA may have a role in decreasing this


Questions?