Learning Objectives:
- Explain the indications, rationale and monitoring for HFOV.
- Explain the effects of adjusting HFOV ventilator controls.

High-Frequency Oscillatory Ventilation
Arthur Jones EdD, RRT

High Frequency Ventilation
Introductory Information

High-frequency ventilation
- High-frequency ventilation - any form of ventilation with frequency greater than 150/min
- Five basic types

High-frequency ventilation types
- High-frequency positive pressure ventilation - conventional ventilation with high frequencies and low tidal volumes
- High-frequency flow interruption
  - early form of HFV
  - interruption of gas flow from a high pressure source at a high rate

High-frequency ventilation types
- High-frequency percussive ventilation (HFPV)
  - high-frequency pulsations with conventional breaths
  - volumetric diffusive ventilation - Bird VDR 4\textsuperscript{TM}
  - inhalation injuries - burn centers
  - ventilation during airway surgery
  - neonatal ventilation

Click to see patient with Bird VDR ventilator
High-frequency ventilation types

- High-frequency jet ventilation
  - Bunnell Life Pulse™ - currently in use
  - Jet ventilator in tandem with conventional vent
  - Triple-lumen jet tube - pressure monitoring lumen at distal end
  - Frequencies - 240-660/min

Click to see Bunnell Life Pulse™ ventilator

High-frequency ventilation types

- High-frequency oscillatory ventilation
  - First developed by Emerson - 1950s
  - Most common HFV technique for pediatric patients
  - Approved and available for adults

HFOV Rationale, Physiology & Applications

Definition and Description

- Definition - Rapid rate ventilation with small tidal volume (often less than dead space).
- Goal - Oxygenate and ventilate without ventilator-induced lung injury.

Rationale

- HFOV effectively ventilates with intrapulmonary volume changes that are less than conventional ventilation, decreasing volutrauma and ventilator-induced lung injury.
Mechanisms for gas transport

How does HFOV work, when tidal volume is less than dead space?
- Tidal volume is not routinely measured; but, it can be.
- Adult TV = 44 - 209 mL
- Neonatal TV = 2.5 mL/kg BW

Mechanisms for gas transport

Bulk convection, like conventional ventilators, to proximal alveoli
- Pendelluft - collateral exchange between distal units with varying compliance at:
  - airway bifurcations
  - pores of Kohn
  - canals of Lambert

Click for illustration of gas exchange mechanisms
http://www.prematuros.cl/webmayo05/tallervm/7/alairfrecuencia/valcriticaremedicipillow.jpg

Mechanisms for gas transport

Taylor dispersion - turbulence at airway bifurcations speeds diffusion
- Asymmetric velocity profiles - augmented gas mixing due to high energy from the oscillations

Cardiogenic mixing - heart contractions augments gas mixing
- Simple molecular diffusion
- Active expiration =>
VE = f x TV²

General Indications

- Failure of conventional mechanical ventilation (CMV) and before ventilator-induced lung injury (VILI) occurs
- Some studies favor HFOV before frank failure of CMV

Specific Indications

- ARDS/ALI (adults)
- Air leaks:
  - pneumothorax
  - PIE (pulmonary interstitial emphysema)
  - bronchopulmonary fistula
Specific Indications
- Other neonatal indications
  - RDS
  - meconium aspiration
  - persistent pulmonary hypertension
  - pulmonary hemorrhage
  - pulmonary hypoplasia
  - congenital diaphragmatic hernia

Complications
- Hypotension
  - due to decreased venous return
  - responds to fluid bolus

Complications
- Hypotension
  - due to decreased venous return
  - responds to fluid bolus
- Pneumothorax
  - sudden onset of hypotension
  - decreased chest wiggle

Complications
- Intraventricular hemorrhage, due to high MAP
- Neurodevelopmental problems for neonates from noise (unsubstantiated for HFOV)
- Critical illness polyneuropathy, due to:
  - sedation
  - neuromuscular blockers

Relative contraindications
- Increased ICP
- Obstructive lung disease
Research on effectiveness

- Randomized clinical trials:
  - favor conventional ventilation
  - favor HFOV
  - find no difference
- Meta-analyses of RCTs no clear evidence favoring either
- My opinion - HFOV is another tool that requires judicious application on a case-by-case basis.

HFOV Ventilators & Management

HFOV Ventilators (US)
- SensorMedics
  - 3100a - neonates and small children
  - 3100b - large children (> 35 kg) and adults

SensorMedics 3100a
Courtesy of Cardinal Health

HFOV Ventilators (US)
- SensorMedics operation
  - electronically powered and controlled piston-diaphragm oscillator
  - PAW = 3 - 45 cm H2O (b = 5 - 55)
  - f = 3 - 15 Hz
  - amplitude = 8 - 110 cm H2O (b = 8 - 130)

HFOV Ventilators (US)
- SensorMedics ventilator circuit
  - very low volume and compliance
  - strict motion limitation
  - ventilator requires calibration (later)

Click to see diagram of the SensorMedics circuit
http://img.medscapel.com/fullsize/migrated/449/257/ccm449257.fig1.gif
Click to see picture of the SensorMedics flexible circuit
http://www.bu.edu/SAH/resp_care/flexcir2.jpg

HFOV Ventilators
- Drager Babylog
  - oscillation produced by expiratory valve switch
  - provides active exhalation

Image used with permission from Drager Medical

FYI - Link to Drager Babylog VN500
http://www.draeger.com/Pages/Hospital/Babylog-VN500.aspx
HFOV Ventilators (US)
- Infant Star 950
  - operates by flow interruption
  - waveform same as other oscillators

Monitoring
- Arterial line
  - blood pressure
  - blood gas analysis
- SPO2
- Endotracheal tube leak

Monitoring
- Chest Wiggle factor (CWF)
  - absent or diminished- airway obstruction
  - asymmetric- endobronchial intubation
  - check, especially after patient repositioning

Monitoring
- Chest radiograph
  - Initially- should be frequent
  - 8.5-9.0 ribs should be visible- infants and adults
  - monitor for appropriate expansion

Ventilator Settings
- Mean airway pressure (MAP)
  - In conjunction with FIO2, used to adjust oxygenation
  - Initial settings
    - 2-5 cm H2O greater than MAP for CMV (high volume strategy)
    - 2 cm H2O less than CMV for air leak syndromes (low volume strategy)

Ventilator Settings
- Mean airway pressure (MAP)
  - Adjusted in 1-2 cm H2O increments, as determined by:
    - CXR
    - Oxygenation- PaO2, SPO2
    - FiO2- MAP used to reduce FiO2
Ventilator Settings

- **Amplitude (delta P)**
  - SensorMedics - power control adjusts the piston displacement
  - Adjusted for chest wiggle factor (CWF)
    - neonates from nipple line to umbilicus
    - adults from clavicles to mid-thigh.

**Amplitude (delta P)**

- Initially set at:
  - neonates - 2 cm H2O
  - adults 6-7 cm H2O
- Changed in 1-2 cm increments
- Similar to TV adjustment
- For HFOV, VE = f x TV^2

**Amplitude (delta P)**

- Increased delta P ==> decreased PaCO2- used to change PaCO2
- When amplitude changed, MAP requires change

**Frequency- Measured in Hertz (Hz)**

- 1 Hz = 1/sec
- 1 Hz = 60/min
- Changing frequency also changes delta P and MAP

**Increased frequency ==> increased PaCO2**

**Initial frequency settings**

- adults 5-6 Hz
- recent study supports 10 Hz - rationale was to decrease TV for lung protection

**Initial pediatric frequency settings**

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<thead>
<tr>
<th>Weight Range</th>
<th>Frequency</th>
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<tr>
<td>1000 g</td>
<td>15 Hz</td>
</tr>
<tr>
<td>1000-2000 g</td>
<td>12 Hz</td>
</tr>
<tr>
<td>2.0-10.0 kg</td>
<td>10 Hz</td>
</tr>
<tr>
<td>13-20 kg</td>
<td>8 Hz</td>
</tr>
<tr>
<td>21-30 kg</td>
<td>7 Hz</td>
</tr>
<tr>
<td>&gt;30 kg</td>
<td>6 Hz</td>
</tr>
<tr>
<td>Meconium aspiration</td>
<td>3-6 Hz</td>
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</tbody>
</table>
**Ventilator Settings**

- **TI%** - proportion of cycle occupied by inspiration
  - Initial setting = 33%
  - Increased TI% => increased TV
  - Increased TI% decreases PCO2

- **Bias flow**
  - Generates pressure in circuit
  - Flushes CO2
  - Initial settings (usually not changed)
    - 10-15 L/min term neonate
    - 25-40 L/min (adults)

**Strategies for increased PCO2**

- **Permissive hypercapnea**
  - Deflate tube cuff (adults)
    - Permits CO2 excretion
    - Must adjust MAP to compensate for loss

**Weaning, transition to CMV**

- **Criteria**
  - Resolution of pathology
  - Clinical stability
  - Tolerance of procedures

- **Wean FiO2 <50%**
- **Slowly decrease MAP in 1 cm H2O decrements**
- **When MAP <25, consider:**
  - CMV with optimal TV
  - PCV with optimal TV
  - APRV
  - SIMV (Infant Star)
**Practical notes**
- Competency-based training required for all personnel before they use HFOV
- Patients will require sedation, paralysis
- Ventilator is not transportable
- SensorMedics requires calibration (see link below)

Click to view video of successful calibration of the SensorMedics (5 min.)
http://www.youtube.com/watch?v=O2TaDyzxQAY

**Precautionary notes**
- Pneumatic nebulizer may not be used with HFOV
- Limit disconnects, suctioning, bronchoscopies
- Consider recruitment maneuvers after disconnects, suctioning.

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**Case Examples**

**Case One**
- 27 wk GA 1095g BB delivered to 32 YO G2P1 mom. Initial pH = 6.90.
  - Apgars = 6;4
  - BB intubated and hand-bagged. ABG: 7.38/37/111
  - BB placed on ventilator @ f = 40; PIP = 26; FIO2 = 1.0; PEEP = 5.
  - 4.3 ml Survanta given via ETT adapter.
  - ABG: 7.43/37/58

**Case One**
- BB worsened over next 4 H; vent settings advanced to: f = 60; PIP = 36; FIO2 = 1.0; PEEP = 5. (MAP = 22)
  - ABG: 7.22/54/46.

**Case One**
- BB placed on HFO, settings: f = 12 Hz; MAP = 24; delta P = 42.
  - ABG: 7.28/62/174. CXR shows hyperinflation (10th rib) with flattened diaphragms.
  - What to do about PCO2?
  - What to do about hyperinflation?
Case One

- What to do about PCO2?
  - leave it; the pH = 7.28 or
  - increase delta P or decrease frequency

- What to do about hyperinflation?
  - MAP weaned to 22 cm, monitoring SpO2 and CXR.
  - ABG: 7.34/48/125.

Case One

- over 2 D, FIO2 weaned to 40%, maintaining SpO2 > 94%. MAP weaned to 15; delta P weaned to 20.
- BB changed to PCV 25/5 (MAP = 14 cm H2O); f = 30/min; FIO2 = 40%.
- Conventional settings successfully weaned over next two days and BB extubated without sequelae.

Case Two

- BG is 39 wk, 3400 g infant vaginally delivered to 27 YO G1P0 mom with complete prenatal care.
- At delivery, amniotic fluid is meconium stained and BG is distressed.

Case Two

- Direct laryngoscopy reveals thick meconium in airways.
- BG intubated with 3.5 mm ETT and suctioned with meconium aspirator for thick meconium.

Case Two

- BG lavaged with Survanta and placed on SIMV: f = 40; PIP = 25; PEEP = 5; FIO2 = 1.0
- ABG: 7.21/78/73
- Over several hours, f increased to 60; PIP increased to 40.

Case Two

- HFO initiated. f = 5 Hz; delta P = 32; MAP = 26.
- ABG: 7.19/75/45
- What to do about PaO2?
- What to do about PaCO2?
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<tr>
<td>ABG: 7.19/75/45</td>
<td>Over two days, BG improves; but small air leak persists.</td>
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<td>What to do about PaO2?</td>
<td>FIO2 weaned to 40% with SPO2</td>
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<td>MAP increased to 30, observing SPO2 and CXR</td>
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<td>Next changes?</td>
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<td>delta P increased to 36</td>
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<td>ABG: 7.32/52/85</td>
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<td>reduce delta P to 30 for PaCO2</td>
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References

- Czervinske, MP, Barnhart SL. Perinatal and Pediatric Respiratory Care, 2nd Ed. Ch. 21. 2003. WB Saunders; St. Louis.

References