High-Frequency Oscillatory Ventilation

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Learning Objectives:

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

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(TM)
  - inhalation injuries - burn centers
  - ventilation during airway surgery
  - neonatal ventilation

Click to see patient with Bird VDR ventilator

http://www.percussionaire.com/applications/assets/images/pt6_img12.jpg

High-frequency ventilation types

- High-frequency jet ventilation
  - Bunnell Life Pulse(TM) - 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 PulseTM ventilator
http://www.bunl.com/product-tabs2.html

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.

Definition and Description

- HFOV- AKA CPAP with a wiggle.
  - CPAP- sustained lung inflation for alveolar recruitment
  - Wiggle- alveolar ventilation with oscillating pressure waveform at adjustable frequency (Hz) and amplitude (delta P)

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/7altafrecuencia/vafcriticaremedicipillow.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

Mechanisms for gas transport

- Cardiogenic mixing - heart contractions augments gas mixing
- Simple molecular diffusion
- Active expiration ==>

$VE = f \times TV^2$

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

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Complications

- Hypotension
  - due to decreased venous return
  - responds to fluid bolus
- Pneumothorax
  - sudden onset of hypotension, desaturation
  - decreased chest wiggle
- ETT obstruction
  - hypercapnia, desaturation
  - 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.medscape.com/fullsize/migrated/449/257/ccm449257.fig1.gif

Click to see picture of the SensorMedics flexible circuit
http://www.kumc.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.us/Pages/Hospital/Babylog-VN500.aspx

HFOV Ventilators (US)

- Infant Star 950
  - operates by flow interruption
  - wave form 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.

Ventilator Settings

- 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

Ventilator Settings

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

Ventilator Settings

- Frequency- Measured in Hertz (Hz)
  - 1 Hz = 1/sec
  - 1 Hz = 60/min
- Changing frequency also changes delta P and MAP

Ventilator Settings

- Increased frequency ==> increased
  PaCO2
- Initial frequency settings
  - adults 5-6 Hz
  - recent study supports 10 Hz - rationale was to decrease TV for lung protection

Ventilator Settings

- Initial pediatric frequency settings

1000 g	15 Hz
1000-2000 g	12 Hz
2.0-10.0 kg	10 Hz
13-20 kg	8 Hz
21-30 kg	7 Hz
>30 kg	6 Hz
Meconium aspiration	3-6 Hz

Ventilator Settings

- TI%- proportion of cycle occupied by inspiration
  - initial setting = 33%
  - increased TI% ==> increased TV ==> affects PCO_2
  - increased TI% decreases PCO_2

Ventilator Settings

- Bias flow
  - generates pressure in circuit
  - flushes CO_2
  - Initial settings (usually not changed)
    - 10-15 L/min term neonate
    - 25-40 L/min (adults)

Ventilator Settings

- Bias flow
  - too low- MAP not attained
  - too high- dampens exhalation, increasing PCO_2

Strategies for increased PCO_2

- Permissive hypercapnea
- Deflate tube cuff (adults)
  - permits CO_2 excretion
  - must adjust MAP to compensate for loss

Weaning, transition to CMV

- Criteria
  - resolution of pathology
  - clinical stability
  - tolerance of procedures

Weaning, transition to CMV

- wean FiO_2 <50%
- slowly- decrease MAP in 1 cm H_2O 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.

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%.

ABG: 7.47/34/96.

- 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

- BG worsened. CXR revealed Rt pneumothorax. Post-chest tube ABG: 7.08/85/46.
- 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?

Case Two

- ABG: 7.19/75/45
- What to do about PaO2?
  - MAP increased to 30, observing SPO2 and CXR
- What to do about PaCO2?
  - delta P increased to 36
- ABG: 7.32/52/85

Case Two

- Over two days, BG improves; but small air leak persists.
- FIO2 weaned to 40% with SPO2
- ABG: 7.56/24/213
- Next changes?

Case Two

- Over two days, BG improves; but small air leak persists.
- FIO2 weaned to 40% with SPO2
- ABG: 7.56/24/213
- Next changes?
  - reduce MAP, using SpO2 = 94%
  - reduce delta P to 30 for PaCO2

Summary & Review

- HFV types
- HFOV definitions:
  - high-frequency, with TV < Vd_{AN}
  - CPAP with a wiggle
- HFOV rationale
- Mechanisms for gas transport
- HFOV indications
- HFOV complications
- HFOV relative contraindications

Summary & Review

- Monitoring with HFOV
  - chest wiggle factor (CWF)
  - chest radiographs
- Ventilator control settings
  - MAP
  - amplitude- like TV
  - frequency (Hz)
  - Ti%
  - bias flow

Summary & Review

- strategies for hypercapnia
- weaning from HFOV
- precautionary notes

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