High Frequency Oscillatory Ventilation

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This Presentation is Approved for
1 CRCE Credit Hour

Learning Objectives

- Explain the indications, rationale & 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 & 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™
  - Inhalation injuries - burn centers
  - Ventilation during airway surgery
  - Neonatal ventilation

See link below to view the VDR

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

See link below to view Bunnell Life Pulse™ ventilator

High Frequency Ventilation Types

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

HFOV Rationale, Physiology, & Applications

Definition & Description

- Definition: rapid rate ventilation with small tidal volume (often less than dead space)
- Goal: oxygenate & ventilate without ventilator-induced lung injury

Definition & 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) & amplitude (ΔP)

Rationale

- HFOV effectively ventilates with intrapulmonary volume changes that are less than conventional ventilation, decreasing volutrauma & 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

See link below for illustration of gas exchange mechanisms

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) & 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

See link below for abstract on HFOV & ARDS/ALI in adults

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 & small children
  - 3100b - large children (> 35 kg) & adults

SensorMedics 3100a Courtesy of Cardinal Health

HFOV Ventilators (US)

- SensorMedics operation
  - Electronically powered & controlled piston-diaphragm oscillator
    - PAW = 3 - 45 cm H_2O (b = 5 - 55)
    - f = 3 - 15 Hz
    - Amplitude = 8 - 110 cm H_2O (b = 5 - 130)

HFOV Ventilators (US)

- SensorMedics ventilator circuit
  - Very low volume & compliance
  - Strict motion limitation
  - Ventilator requires calibration (later)

See links below for diagram of the SensorMedics circuit

Up next: Video of the SensorMedics flexible circuit assembly

HFOV Ventilators (US)

- Dräger Babylog
  - Oscillation produced by expiratory valve switch
  - Provides active exhalation

Image used with permission from Dräger Medical

FYI see link below for Dräger ventilators

HFOV Ventilators (US)

- Infant Star 950
  - Operates by flow interruption
  - Wave form same as other oscillators

Monitoring

- Arterial line
  - Blood pressure
  - Blood gas analysis
- SPO_2
- 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 & adults
  - Monitor for appropriate expansion

Ventilator Settings

- Mean airway pressure (MAP)
  - In conjunction with FiO_2, used to adjust oxygenation
  - Initial settings
    - 2-5 cm H_2O greater than MAP for CMV (high volume strategy)
    - 2 cm H_2O less than CMV for air leak syndromes (low volume strategy)

Ventilator Settings

- Mean airway pressure (MAP)
  - Adjusted in 1-2 cm H_2O increments, as determined by
    - CXR
    - Oxygenation - PaO_2, SPO_2
    - FiO_2 - MAP used to reduce FiO_2

Ventilator Settings

- Amplitude (ΔP)
  - 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 (ΔP)
  - Initially set at
    - Neonates: 2 cm H_2O
    - Adults: 6-7 cm H_2O
  - Changed in 1-2 cm increments
  - Similar to TV adjustment
  - For HFOV, VE = f x TV^2

Ventilator Settings

- Amplitude (ΔP)
  - Increased ΔP → decreased $PaCO_2$ - used to change $PaCO_2$
  - 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 ΔP & MAP

Ventilator Settings

- Increased frequency → increased $PaCO_2$
- 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

1,000 g	15 Hz
1,000 - 2,000 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)

Up next: video of successful calibration of the SensorMedics

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 1,095g BB delivered to 32 YO G2P1 mom. Initial pH = 6.90, Apgars = 6; 4
- BB intubated & hand-bagged; ABG 7.38/37/111
- BB placed on ventilator @ f = 40, PIP = 26, FiO_2 = 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, FiO_2 = 1.0, PEEP = 5 (MAP = 22); ABG 7.22/54/46

Case One

- BB placed on HFOV, settings f = 12 Hz, MAP = 24, ΔP = 42; ABG 7.28/62/174; CXR shows hyperinflation (10th rib) with flattened diaphragms
- What to do about PCO_2
- What to do about hyperinflation

Case One

- What to do about PCO_2
  - Leave it; the pH = 7.28 or
  - Increase ΔP or decrease frequency
- What to do about hyperinflation
  - MAP weaned to 22 cm, monitoring SpO_2 & CXR
- ABG 7.34/48/125

Case One

- Over 2 D, FiO_2 weaned to 40%, maintaining SpO_2 > 94%, MAP weaned to 15, ΔP weaned to 20
- BB changed to PCV 25/5 (MAP = 14 cm H_2O), f = 30/min, FiO_2 = 40%; ABG 7.47/34/96
- Conventional settings successfully weaned over next two days & BB extubated without sequelae

Case Two

- BG is 39 wk, 3,400 g infant vaginally delivered to 27 YO G1P0 mom with complete prenatal care
- At delivery, amniotic fluid is meconium stained & BG is distressed

Case Two

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

Case Two

- BG lavaged with Survanta & placed on SIMV, f = 40, PIP = 25, PEEP = 5, FiO_2 = 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, ΔP = 32, MAP = 26; ABG 7.19/75/45
- What to do about PaO_2
- What to do about $PaCO_2$

Case Two

- ABG 7.19/75/45
- What to do about PaO_2
  - MAP increased to 30, observing SPO_2 & CXR
- What to do about PaCO2
  - ΔP increased to 36
- ABG 7.32/52/85

Case Two

- Over two days, BG improves, but small air leak persists
- FiO_2 weaned to 40% with SPO_2
- ABG 7.56/24/213
- Next changes?

Case Two

- Over two days, BG improves, but small air leak persists
- FiO_2 weaned to 40% with SPO_2
- ABG 7.56/24/213
- Next changes
  - Reduce MAP, using SpO_2 = 94%
  - Reduce ΔP to 30 for $PaCO_2$

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 (ΔP)- like TV
  - Frequency (Hz)
  - Ti%
  - Bias flow

Summary & Review

- Strategies for hypercapnia
- Weaning from HFOV
- Precautionary notes

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