How does HFOV work?

John F Mills
MBBS, FRACP, M Med Sc, PhD
Neonatologist
Royal Children’s Hospital

Synopsis

• Definition of an oscillator
• Historical perspective
• Differences between HFOV and CMV
• Determinants of gas exchange
  • Oxygenation
  • CO₂ removal
Definitions

• High frequency oscillatory ventilation
  • A type of artificial ventilation in which an oscillatory flow with clearly defined inspiratory and expiratory phases is generated in the lung at a frequency greater than 2 Hz

  Chang 1984
Definitions

• High frequency oscillator
  • A machine which generates an oscillatory waveform at the airway opening, with the following characteristics:
    • Frequency above 2 Hz (usually 5-15 Hz)
    • Active inspiration and expiration
    • Tidal volumes less than anatomic dead-space
  • Frequently characterised by the method of exhalation

Historical perspective

• Scotter et al (1967): diffusion of oxygen through a cylinder augmented by application of an oscillatory waveform to one end
• Lunkenheimer et al (1972): CO\textsubscript{2} transport in apnoeic dogs improved if lung exposed to an oscillatory waveform
• Bohn et al (1980): prolonged normocarbia in five beagles using a rudimentary oscillator (possible despite tidal volume 40% of anatomic dead-space
• Butler et al (1980): first report in humans. Four healthy volunteers, and subsequently 12 patients (three days to 74 years) ’oscillated’ for one hour. CO\textsubscript{2} clearance easily achieved, oxygenation stable and pulmonary shunt decreased
### HFOV vs IPPV

#### Fundamental differences

<table>
<thead>
<tr>
<th></th>
<th>IPPV</th>
<th>HFOV</th>
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<tbody>
<tr>
<td>Rate</td>
<td>0-150</td>
<td>180-900</td>
</tr>
<tr>
<td>Tidal volume</td>
<td>4-20 mL/kg</td>
<td>0.1-3 mL/kg</td>
</tr>
<tr>
<td>Alveolar pressure</td>
<td>0-&gt;50 cm H₂O</td>
<td>0.1-5 cm H₂O</td>
</tr>
<tr>
<td>EELV</td>
<td>Low</td>
<td>Normal</td>
</tr>
<tr>
<td>Gas flow</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
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#### Differences in ventilator waveforms

![Airway pressure waveforms: HFOV vs IPPV](image)

Gerstman et al
Determinants of gas exchange during HFOV Oxygenation

Determinants of gas exchange
CMV vs HFOV

CMV
- Rate/Frequency
- Tidal Volume/PIP
- PEEP
- I-Time
- FIO₂

HFOV
- Frequency
- Amplitude
- I-Time %
- Mean Airway Pressure
- FIO₂
Determinants of oxygenation
Mean airway pressure

- Oxygenation is determined by lung volume
- The mean airway pressure (P_{aw}) setting is used to determine lung volume by recruiting atelectatic lung units and optimising the alveolar surface area for gas exchange
Determinants of oxygenation
Volume history

- Successful application of HFOV is dependent upon ventilation with the lung recruited (open lung strategy, high lung volume strategy)
- Alveolar recruitment manoeuvres are required on initiation of HFOV, and after disconnection/suction
- Regular re-assessment of $P_{aw}$ to ensure continuous ventilation at optimum lung volume
Determinants of oxygenation
Impact of $P_{aw}$ on PVR

PVR is increased with:
- Atelectasis - loss of support for extra-alveolar vessels
- Overdistension - compression of alveolar capillary bed

Determinants of gas exchange during HFOV
Carbon dioxide removal
Determinants of CO$_2$ removal

CMV vs HFOV

- Alveolar ventilation during CMV is defined as: $f \times V_T$
- Alveolar ventilation during HFOV is defined as: $f \times V_T^2$
- During HFOV, $V_T$ is determined by stroke volume of the ventilator

Determinants of CO$_2$ removal

Stroke volume

- The stroke volume will increase if
  - The amplitude increases
  - The frequency decreases (longer cycle time)
Determinants of CO₂ removal

Amplitude

- The amplitude is created by the distance that the piston/diaphragm moves. This movement results in a gas volume displacement and a visual chest wiggle.
- It may also be described as the peak-to-trough swing around the $P_{aw}$

Determinants of CO₂ removal

Frequency

- Secondary control of CO₂ is provided by the frequency
- If the amplitude controls the ‘force’ with which the piston moves, the frequency controls the time allowed for the piston to move
  - The lower the frequency setting, the greater the volume displacement
  - The higher the frequency setting, the smaller the volume displacement
**Determinants of CO$_2$ removal**

**Frequency**

- The frequency is generally set according to the size of the patient, and the type of lung disease
- Frequency may need to be adjusted from the initial setting
- Frequency is not weaned in the same way as it is during CMV
  - decreasing frequency with HFOV actually *increases* ventilatory support
- Effect of resonant frequency

**Determinants of CO$_2$ removal**

**Inspiratory time**

- Allows more time for piston travel resulting in larger tidal volume
- More pronounced at lower frequencies
Determinants of CO₂ removal

Bias flow

- The ventilator bias flow produces the $P_{aw}$ of the system, and also helps to flush the CO₂ that accumulates in the circuit during the expiratory phase
- If ventilation is problematic, increasing or decreasing flow may be helpful

Questions