High Frequency Oscillatory Ventilation

Definition

HFOV is a method of mechanical ventilation that employs supra-physiological breathing rates and tidal volumes frequently less than dead space. Because conventional ventilation relies on the production of large pressure changes to induce mass flow of gas in and out of the lungs, it may be associated with deleterious consequences of volume and pressure changes at alveolar level. These include air leaks, such as PIE and pneumothorax, and bronchiolo-alveolar injury leading to chronic lung disease.

In animal models, the use of HFOV results in more uniform lung inflation, improves oxygenation and reduces the severity of lung pathology produced by conventional ventilation\(^1\text{-}^3\). In preterm human infants, over distention of the lung and oxygen toxicity are thought to be important factors in the pathogenesis of CLD\(^4\).

Types of Ventilators

There are different types of ventilators used to achieve HFOV via an oscillatory waveform in the airway. They differ in the mechanisms used to generate the waveform, their settings, the waveform characteristics and power in terms of tidal volume delivery. High frequency oscillators are those which actually produce the sinusoidal waveform by a variety of methods. These are piston pump oscillators (Stephanie infant ventilator), electromagnetic flow generators (Sensor medics) or linear motor generators (Humming). There are also “flow interrupters” which can produce fast rates but are not actual oscillators and are often less powerful. (Draeger Babylog, Infant Star).

Ventilation Strategies

The preferred method used in the application of high frequency ventilation is the High Lung Volume Strategy. This means that with higher mean airway pressure, alveolar recruitment and elimination of atelectasis there is improved oxygenation (High lung volume strategy). Low lung volume strategies should NOT be used.

The table below documents differences between HFOV and Conventional ventilation (CV):
## Differences

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>HFOV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory rates</td>
<td>0-150/min</td>
<td>180 – 900/min</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>0-50 cm H2O</td>
<td>0.1-5 cm H2O</td>
</tr>
<tr>
<td>End expiratory volume</td>
<td>Low</td>
<td>Normalised</td>
</tr>
<tr>
<td>Gas flow</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

### Indications.

The main indication for the use of high frequency ventilation in RPA Newborn Care is on a rescue basis (failure of conventional ventilation) despite a lack of evidence for this practice.

**Indications for rescue HFOV** should be considered on a case by case basis and only in consultation with the staff specialist on call.

### Evidence

There are six published systematic reviews of randomised trials of high frequency ventilation [5-10]. The evidence falls into 2 groups – elective HFOV and rescue HFOV. For term or near term infants HFOV is only used in a rescue situation. For preterm infants the area most studied is the elective use of HFOV with minimal information on rescue HFOV

### Elective HFOV in Preterm Infants

From the most recent systematic reviews there is no difference in the following important outcomes when elective HFOV is used compared with conventional ventilation in the initial treatment of preterm babies [6,8]

- Mortality
- Chronic Lung Disease
- Death or chronic lung disease
- Gross Pulmonary air leak
- Periventricular leukomalacia
- Grade 3 or 4 Intraventricular haemorrhage

Adverse effects on short term neurological outcomes of severe intraventricular haemorrhage and periventricular leukomalacia although not significant overall were observed in studies which did not use a high lung volume strategy [11,12]. These outcomes are dominated by the high incidence of brain injury found in the HiFi trial, the first and largest of these trials [11]. Information about
effects on long term outcome is not adequate overall.

There is some evidence of a reduction in chronic lung disease where HFOV is applied in the following situations:

- Where a lung protective strategy on conventional ventilation is not applied
- Where a high frequency oscillator is used (rather than a flow interrupter)

NB Optimal conventional ventilation strategies can be seen on our ventilation protocol.

Rescue HFOV in Preterm Infants

One small trial\(^\text{13}\) has shown

- No effect on mortality
- No difference in pulmonary interstitial emphysema or gross pulmonary air leak
- Reduction in new pulmonary air leak
- Increased rate of intraventricular haemorrhage

This small trial suggests that the harm may outweigh the benefit.

Rescue HFOV in Term Infants

Despite a lack of evidence the main situation where HFOV is used is for severe respiratory disease in near term or term babies as in individual babies it occasionally works where other strategies have failed. One trial has shown\(^\text{14}\)

- No effect on mortality
- No difference in failed therapy
- No difference in requirement for extracorporeal membrane oxygenation, days on a ventilator, days in oxygen or days in hospital.

Principles of HFOV.

The use of high frequency ventilation at low tidal volume allows the primary goals of ventilation, oxygenation and CO2 removal, to be achieved without the costs of pressure-induced lung injury.

HFOV has been described as "CPAP with wobbles". This reflects the two physical goals:

- "CPAP": Sustained inflation and recruitment of lung volume by the application of distending pressure (mean airway pressure (MAP)) to achieve oxygenation
- "Wobbles": Alveolar ventilation and CO2 removal by the imposition of an oscillating pressure waveform on the MAP at an adjustable frequency (Hz) and an adjustable
amplitude (dP or % on the Draeger Babylog 8000).

The ‘art’ of HFOV relates to achieving and maintaining optimal lung inflation. Optimal oxygenation is achieved by gradual increments in MAP to recruit lung volume and monitoring the effects on arterial oxygenation. The aim is to achieve maximum alveolar recruitment without causing over-distension of the lungs.

**Optimising lung inflation with MAP:** It is useful to conceptualise HFOV as like taking the lung around one sustained pressure volume hysteresis loop, figure 2

- **Point A in figure:** Under-inflation: At this point the lung is under-inflated, PVR will be high and relatively large amplitude will produce only small changes in volume. Clinically this manifests as a high oxygen requirement with limited chest vibration.
- **Point B in figure:** Optimal recruitment inflation: Once the lung has opened up with higher MAP, the PVR will fall and a smaller amplitude will produce a larger change in volume. Clinically this manifests as falling oxygen requirements and good chest vibration.
- **Point C in figure:** Over-inflation: Again more amplitude will be needed to
produce volume changes and over inflated lung will compromise the systemic circulation. This is the most dangerous point in HFOV and is to be avoided at all costs. It is difficult to pick clinically because the oxygen requirement stays low, although they will eventually rise and the reduced chest vibration is easy to miss. Chest X-ray is currently the best diagnostic tool for this see below.

- **Point D in figure:** Optimal inflation: The goal should be to move the babies lungs from point B to point D avoiding point C (as shown on the arrow marked *** in Figure 2). Having achieved optimal lung inflation by slowly reducing MAP it should be possible to maintain the same lung inflation and ventilation at a low MAP. If MAP is lowered too far oxygen requirements will start to rise.

---

**Optimising ventilation.**

- This is controlled mainly by adjusting amplitude to achieve optimal pCO2 (40-50 mmHg). Although the amplitude of each breath appears large by comparison to conventional ventilation pressures, the attenuation of oscillation through the endotracheal tube (ETT) means that the transmitted amplitude at the level of the alveolus is very small. Higher amplitude (% on the Draegar) will increase tidal volume and hence CO2 removal. With increasing ventilator frequency, lung impedance and airway resistance increases so the tidal volume delivered to the alveoli decreases. This leads to the apparent paradox that increasing ventilator frequency may reduce CO2 elimination, leading to raised PaCO2 and vica-versa.

---

**Practical Management.**

There are two ways of delivering HFOV in RPA Newborn care via the Draegar Babylog 8000 or the Stephanie.

It is worth noting that the Draegar is a “flow interrupter” and not a high frequency oscillator and that HFOV delivered by the Draegar Babylog 8000 is only likely to be effective in babies whose birth weight is less than 1.5 kg.

**Preparation pre HFOV**

1. If there is any significant leak around the ET tube consider insertion of a larger one.
2. Transcutaneous pO2, CO2 and oxygen saturation monitoring should be commenced and invasive BP monitoring established.
3. A pre-oscillation x-ray should be taken to exclude other pathologies.
4. Blood pressure and systemic blood flow should be optimised; any volume replacement contemplated should be completed and inotropes commenced if necessary.
5. Correction of metabolic acidosis
6. If nitric oxide is to be commenced start prior to HFOV
7. Muscle relaxants are not indicated unless the baby’s respiratory effort is interfering with ventilation.
8. Analgesia with opiates is indicated in line with current policy if the baby is in discomfort.
9. If using the Draegar change to a low volume humidifier and consider changing to low compliance tubing.
Lung Recruitment Manoeuvres

Some trials that used a high lung volume strategy also used specific lung recruitment measures to open the lung. Strategies to do this vary considerably and recognition of good lung recruitment is difficult at the bedside. The safety of this is yet to be proven.

Other than optimal application of a high lung volume strategy, recruitment manoeuvres should only be performed with a staff specialist present.

Switching the Draegar Babylog 8000 from CMV to HFOV: Initial settings.

1. Leave FiO2 at that on CMV.
3. Press “Vent Option” – “HFOV”.
4. Move the cursor to “Frequ” with the arrow key and adjust to 10Hz using the “+” “-” keys.
5. Move the cursor to “Ampl” with the arrow key and adjust to 50% using the “+” “-” keys.
6. Press “on” and HFOV will commence.
7. Adjust MAP using the “PEEP/CPAP” rotary knob. Start at 2 cmsH2O above the MAP during previous CMV.

Commencing the Stephanie Ventilator

1. Dial PEEP to 2-3 cms above current MAP – as ordered by Dr
2. Turn ventilator mode to CPAP
3. Before turning HFO on, check that Hz is set at 10 & amplitude is set at 0-1
4. MO to increase amplitude until chest wiggle is adequate

After HFOV has started ASAP the nurse is to:

1. Turn temperature to +2.5 that is temperature will leave humidifier at 39.50C & drop to 37oC at airway
2. Insert chain on expiratory block to close safety valve- this will allow the generation
3. Turn PIP to at least 30cms H2O above MAP / CPAP setting
4. Turn “pop up” valve to maximum
5. Press alarm option x 2 to reset alarms
HFOV adjustments

Oxygenation and ventilation are best considered separately, however adjusting the ventilator for one parameter will also alter other settings and so after making a change always check the other settings.

1. Ventilation: Changes in pCO2 may be effected by changing the amplitude of oscillation or occasionally the frequency. Ventilation may be increased by raising the amplitude of oscillation and vice versa.
   - Start at an amplitude of 50% and then adjust the amplitude in increments of 10% until the chest wall is seen to “bounce” and a tidal volume of about 2 ml/kg is achieved. Be cautious as tidal volumes of more than 2 ml/kg are potentially harmful. Aim for a pCO2 between 40 and 50 mmHg.
   - The optimal frequency of oscillation may be different in different disease states. Small infants with RDS may be managed at 15 Hz, term infants are often best managed at 10 Hz, although with very non-compliant (stiff) lungs lower frequencies may be necessary.
   - NOTE: If adjustment of frequency is needed, decreasing the frequency increases CO2 removal (opposite to CMV). Always discuss this option with the consultant.

2. Oxygenation is controlled by adjusting the MAP and FiO2. The goal is the high volume strategy. This allows the use of low FiO2 levels (<35%) and the MAP should be adjusted to achieve this.
   - For air leak: A low volume strategy may help. Reduce MAP 1-2 cm H2O below MAP on CMV and tolerate a higher FiO2.
   - For rescue HFOV: Starting MAP should be 2 cm H2O above that used on CMV.
   - For prophylactic HFOV: Starting MAP will need to be guided by an empirical assessment of lung disease severity derived during resuscitation. Generally start at 6-8 cm H2O. But use 10-12 cm H2O if the lungs seem unusually stiff.
   - MAP should be increased in 1 cm H2O increments every 5 minutes until the FiO2 is less than 0.3. Generally it is unusual to need MAP >20 cm H2O. (Moving from point A to point B in figure 2.)
   - Overinflation (Point C) can be assessed clinically or by X-ray. Arrange for a chest X-ray when gases are stable to assess lung volume (see below) - usually after 1-2 hours.
   - Normal inflation should allow the right hemi-diaphragm to be at the 8th or 9th rib. It may be necessary to perform Chest X-rays 6-12 hourly if difficulties are encountered.
   - Over-inflation is occurring if: diaphragm is at 10+ ribs, intercostal bulging of lungs present or sub-cardiac air is visible as a crescent under the apex. Under-inflation is indicated by a high diaphragm. When managing RDS there will also be clearing of the lung fields as atelectasis resolves.
   - Once the baby is stable in an FiO2 <0.3, the MAP should be cautiously reduced in 1 cm H2O as allowed by the oxygenation. (to get to point D) FiO2 rising above 0.3 suggests you have dropped MAP too much.

Assessing failure on HFOV:

- Do not be too quick to consider a trial of HFOV to have failed if you have difficulty obtaining adequate blood gases.
- At the very least arrange to get an urgent Chest X-ray to assess the state of inflation and assess the circulation carefully.
- A short period of hand ventilation may be of value in assessing the lung compliance and to help decide the CMV settings after a failed trial of HFOV.
• Discuss any difficulties with the consultant-in-charge earlier rather than later.

Weaning from HFOV:

Lung volume should be maintained during the weaning process. If steps are unsuccessful please discuss with the consultant. Wean parameters in the following order:

i. decrease FiO2 to <30%
ii. decrease MAP in 1 cm H2O steps as allowed by the blood gases
iii. At a MAP of 8 cm H2O either:
   o extubate to head box or CPAP (infant flow driver), or
   o change to PTV/SIMV

CMV may be a valuable step if there are particular problems with secretions requiring vigorous physiotherapy and suction.

Troubleshooting during HFOV

Low \( \text{PaO}_2 \): Consider:

• ET tube patency
• check for chest movement and breath sounds
• check there is no water in the ETT/T-piece
• Air leak/pneumothorax
• chest moving symmetrically?
• transilluminate
• urgent chest x-ray
• Sub-optimal lung volume recruitment
• increment MAP
• consider chest x-ray
• Over-inflated lung
• check blood pressure
• reduce MAP; does oxygenation improve?
• consider chest x-ray

High \( \text{PaCO}_2 \): Consider:

• ET tube patency and air leaks (as above)
• Insufficient alveolar ventilation
• Increase amplitude, does chest wall movement increase?
• Increased airway resistance (MAS, BPD) or non-homogenous lung disease: Is HFOV appropriate?
• Under-inflated lungs, amplitude being delivered on non compliant part of the pressure volume curve ie point A in figure 2
• Over-inflated lungs, amplitude being delivered on non compliant part of the pressure volume curve ie point C in figure 2
• If all the above seem OK try reducing oscillator frequency; lung impedance and airway resistance fall, leading to increased \( V_T \).
**Persisting acidosis/hypotension:** Consider:

- Over-distension
- reduce MAP; does oxygenation improve?
- consider chest x-ray

---

**Key Points**

<table>
<thead>
<tr>
<th>Statement</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>There is no proven benefit on mortality for elective HFOV compared with Conventional Ventilation in preterm babies</td>
<td>⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>If a lung protective strategy of CV is used there is no difference in chronic lung disease between HFOV and CV</td>
<td>⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Low volume strategies for HFOV are not recommended</td>
<td>⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Great care must be taken to avoid over expansion of the lungs. Signs of this should be assessed clinically and with regular 12 hourly X rays</td>
<td>⭐</td>
</tr>
<tr>
<td>There is no RCT evidence to support the use of rescue HFOV in term or near term infants</td>
<td>⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>“It ain’t what you do it’s the way that you do it!”</td>
<td>⭐⭐⭐⭐⭐</td>
</tr>
</tbody>
</table>

---

**References**


6. Henderson-Smart DJ, Bhuta T, Cools F, Offringa M: Elective high frequency oscillatory ventilation versus conventional ventilation for acute pulmonary dysfunction in preterm infants (Cochrane Review). *Cochrane Database of Systematic Reviews* 2005

7. Bhuta T, Henderson-Smart DJ: Elective high frequency jet ventilation versus conventional ventilation for respiratory distress syndrome in preterm infants (Cochrane Review). *Cochrane Database of Systematic Reviews* 2005


14. T Bhuta, RH Clark, DJ Henderson-Smart: Rescue high frequency oscillatory ventilation vs conventional ventilation for infants with severe pulmonary dysfunction born at or near term (Cochrane Review). *Cochrane Database of Systematic Reviews* 2005

Last Updated: December, 2006