Guideline

Women and Babies: High Frequency Oscillatory Ventilation of the Newborn

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Functional Sub-Group: Clinical Governance
Corporate Governance

Summary: Describes the use of high frequency oscillatory ventilation in the NICU.

National Standard: Standard 1 Governance for Safety and Quality in Health Service Organisations
Recognising and Responding to Clinical Deterioration in Acute Health Care

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Previous Review Dates: March 2007
High Frequency Oscillatory Ventilation of the Newborn

**INTRODUCTION**
High frequency oscillatory ventilation (HFOV) is a method of mechanical ventilation that employs supra-physiological breathing rates and tidal volumes that are frequently less than dead space.

**The risks addressed by this guideline:**
Risk of not performing high frequency oscillatory ventilation properly

**The aims / expected outcome of this guideline:**
That infants needing high frequency oscillatory ventilation will be managed properly

**GUIDELINE STATEMENT**
The goal of this guideline is to familiarise staff with the evidence, indications and practical management of an infant on high frequency oscillatory ventilation.

**PRINCIPLES / GUIDELINES**
**Definition**
High frequency oscillatory ventilation (HFOV) is a method of mechanical ventilation that employs supra-physiological breathing rates and tidal volumes that are 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 (CLD).

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 ventilation1-3. In preterm human infants, over-distension of the lung and oxygen toxicity are thought to be important factors in the pathogenesis of CLD.4

**TYPES OF VENTILATORS**
Different types of ventilators use different technologies 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 (Sensormedics) or linear motor generators (Humming). At RPA Newborn Care, we deliver HFOV with the Draeger VN500 which a frequency ejector which uses the Venturi principle to generate pressure oscillations. The VN500 HFOV is powerful enough to ventilate across the weight range seen in NICU.
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):

<table>
<thead>
<tr>
<th>Differences</th>
<th>Conventional</th>
<th>HFOV</th>
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</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 m/lkg</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>Normalised</td>
<td>Low</td>
</tr>
<tr>
<td>Gas flow</td>
<td>Low</td>
<td>High</td>
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Indications.

The main indication for the use of high frequency oscillatory ventilation in RPA Newborn Care is on a rescue basis. This will usually mean persisting hypoxic respiratory failure despite high pressure conventional ventilation. Despite the lack of clinical trial evidence of benefit for rescue HFOV, on an individualised basis, HFOV can improve respiratory status in situations where conventional ventilation is failing.

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

1.1. Evidence

There are several published systematic reviews of randomised trials of HFOV. The evidence falls into 2 groups, elective HFOV and rescue HFOV. For term or near term infants, HFOV is only used in rescue situations. For preterm infants, the area most studied is the elective use of HFOV with minimal information on rescue HFOV.

**Elective HFOV in Preterm Infants**

Systematic review of trials of elective HFOV vs CV involving over 4000 babies shows a small reduction in chronic lung disease at 36 weeks with HFOV. The authors of the Cochrane review conclude that the evidence in relation to chronic lung disease is weakened by inconsistency of effect across the trials and an increased risk of air leak with HFOV.5 Long term neurodevelopmental outcomes are similar but there is some evidence from one of the trials that respiratory function testing at 12-13 years was better in those randomised to HFOV.6 There is not strong evidence of either benefit or harm from elective use of HFOV in preterm babies.

**Rescue HFOV in Preterm Infants**

A systematic review of one trial has shown no effect on mortality but a reduction in new pulmonary air leak but an increased rate of intraventricular haemorrhage.7
This trial was published in 1993 so its findings may not be generalisable to current NICU settings. This small trial suggests that the harm may outweigh the benefit.

Rescue HFOV in Term Infants

Systematic review includes two trials in term and near term babies, one trial had rescue recruitment criteria, the other trial was more elective.8 There were no differences in outcomes. 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.

1.2 PRINCIPLES OF HFOV.

In theory, the use of HFOV at low tidal volume allows the primary goals of ventilation, oxygenation and CO2 removal, to be achieved with less cost in terms 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.

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 which needs to be monitored with regular chest x-rays.
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 2: Under-inflation**: At this point the lung is under-inflated, compliance will be low 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 2: Optimal recruitment inflation**: Once the lung has opened up with higher MAP, the compliance will improve 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 2: 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. 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 2: 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 small.
- Higher amplitude 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.

1.3 PRACTICAL MANAGEMENT OF HFOV.

At RPA Newborn Care, we deliver HFOV with the Draegar VN500 ventilator.

Preparation before changing to HFOV

1. If there is any significant leak around the ET tube, consider insertion of a larger one.
2. Optimize the ventilator circuit by removing the soft extension piece at the end of the inspiratory limb of the Fisher & Paykel Evaqua 2 circuit. Once this is done, you should do a breathing circuit check before commencing HFOV mode.
3. It is preferable to have an arterial line for BP monitoring and consider transcutaneous oxygen and carbon dioxide monitoring.
4. A pre-oscillation x-ray should be taken to exclude other pathologies and to establish a baseline lung inflation.
5. Blood pressure and systemic blood flow should be optimised; any volume replacement contemplated should be completed and inotropes commenced if necessary.
6. Correction of any metabolic acidosis.
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. For some larger babies requiring high HFOV settings, it may be necessary to change the humidifier water chamber on the Fisher & Paykel MR850 humidifier to the smaller domed chamber to minimize deadspace- this chamber has a manual water fill feature, so it is possible to minimize the dead space volume more efficiently by increasing the water level in the chamber. If this is done, you would need to complete a breathing circuit check prior to commencing HFOV. Due to the increased flow of gas the VN500 utilises during HFOV, the chamber water level should be checked at least hourly as the water level can reduce quickly, thus increasing the dead space volume again.

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.
1.4. Switching the Draeger VN500 to HFOV: Initial settings.

- From conventional ventilation press the ‘ventilation settings’ button on the top right of the screen (red arrow on photo below) to get the ‘ventilation settings’ screen.

- Press the ‘PC-HFO’ tab (green arrow) to get the HFO ventilation settings screen.
On the HFO ventilation settings screen,
  o We would usually leave the I:Ehf at 1:2 and leave amplitude on the
default setting of 20 and adjust as below after you’ve switched to
PC-HFO.
  o Adjust MAPhf to 2cms H2O above the MAP on conventional
ventilation.
  o Select the frequency (fhf) if you want to vary from the default of 10
Hz.

1.5. 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.
Ventilation: Changes in paCO2 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 the default amplitude then increase the amplitude in increments of 10
until the chest wall is seen to visibly vibrate 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. In general, our default setting will be 10Hz though small infants with RDS may be managed at up to 15 Hz. In babies with stiff lungs, lower frequencies may be necessary. **NOTE:** If adjustment of frequency is needed, decreasing the frequency increases CO2 removal (opposite to CV). Always discuss this option with the consultant.

**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 CV and tolerate a higher FiO2.

• **For rescue HFOV:** Starting MAP should be 2 cm H2O above that used on CV.
  • MAP should be increased in 1 cm H2O increments until the FiO2 is less than 30%. The response may not be immediate so patience is needed in waiting for the oxygenation. At lower MAPs (10-15 cms H2O), it would be fine to increase every 10-15 mins, above 15 cmsH2O allow longer for a response. Generally it is unusual to need MAP >20 cm H2O. (Moving from point A to point B in figure 2).

• **Lung inflation (to avoid getting to point C)** should be assessed by regular chest 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 should be considered if the diaphragm is at 10+ ribs, intercostal bulging of lungs present or sub-cardiac air is visible as a crescent under the apex.
  • Under-inflation should be considered if there is a high diaphragm. When managing RDS there will also be clearing of the lung fields as atelectasis resolves.
  • Once the baby is stable in a FiO2 <30%, the MAP should be cautiously reduced in 1 cm H2O steps as allowed by the oxygenation. (to get to point D) FiO2 rising above 30% 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.
• 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:
• Decrease FiO2 to <30%
• Decrease MAP in 1 cm H2O steps as allowed by the blood gases
• At a MAP of 8 cm H2O either extubate to CPAP, or
• Change to PC-AC + VG. This may be a valuable step if there are particular problems with secretions requiring vigorous physiotherapy and suction.

1.6. Troubleshooting during HFOV

Low PaO2: Consider:
• ET tube patency
• Leak around the ET tube.
• 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?
• Ronsider chest x-ray

High PaCO2: 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 i.e. point A in figure 2
• Over-inflated lungs, amplitude being delivered on non-compliant part of the pressure volume curve i.e. point C in figure 2
• If all the above seem OK try reducing oscillator frequency; lung impedance and airway resistance fall, leading to increased VT.

Persisting acidosis/hypotension: Consider:
• Over-distension: Reduce MAP; does oxygenation improve?
• Consider chest x-ray
Key Points

<table>
<thead>
<tr>
<th>Key Point</th>
<th>Level of Evidence</th>
</tr>
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<tbody>
<tr>
<td>There is no proven benefit on mortality for elective HFOV compared with conventional ventilation in preterm babies.</td>
<td>I</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 in preterm infants.</td>
<td>I</td>
</tr>
<tr>
<td>Low volume strategies for HFOV are not recommended</td>
<td>II</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>III</td>
</tr>
<tr>
<td>There is no RCT evidence to support the use of rescue HFOV in preterm or term infants.</td>
<td>I</td>
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</tbody>
</table>

PERFORMANCE MEASURES

Incident reporting system

DEFINITIONS

HFOV = High Frequency Oscillatory Ventilation
CLD = Chronic Lung Disease
CV = Conventional Ventilation
CPAP = Continuous Positive Airway Pressure
MAP = Mean Airway Pressure
ETT = Endotracheal Tube
FiO2 = Fractional Inspired Oxygen Concentration

REFERENCES AND LINKS

6. Zivanovic S; Peacock J; Alcazar-Paris M; Lo JW; Lunt A; Marlow N; Calvert S; Greenough A; United Kingdom Oscillation Study Group. Late outcomes of a randomized

7. Bhuta T, Henderson-Smart DJ. Rescue high frequency oscillatory ventilation versus
conventional ventilation for pulmonary dysfunction in preterm infants. Cochrane Database
of Systematic Reviews 1998, Issue 2. Art. No.: CD000438. DOI:
10.1002/14651858.CD000438.

8. De Paoli AG, Clark RH, Bhuta T, Henderson-Smart DJ. High frequency oscillatory
ventilation versus conventional ventilation for infants with severe pulmonary dysfunction
born at or near term. Cochrane Database of Systematic Reviews 2009, Issue 3. Art. No.: 
CD002974. DOI: 10.1002/14651858.CD002974.pub2.

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