**HIGH FREQUENCY OSCILLATORY VENTILATION IN NEONATES**

<table>
<thead>
<tr>
<th>Full Title of Guideline:</th>
<th>High Frequency Oscillatory Ventilation in neonates</th>
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| Summary of evidence base this guideline has been created from: | See below and evidence table within guideline |

**Summary of evidence base this guideline has been created from:**  
1. NICE Guidance, Royal College Guideline, SIGN (please state which source).  
2a. meta analysis of randomised controlled trials  
2b. at least one randomised controlled trial  
3a. at least one well-designed controlled study without randomisation  
3b. at least one other type of well-designed quasi-experimental study  
4. well–designed non-experimental descriptive studies (ie comparative / correlation and case studies)  
5. expert committee reports or opinions and / or clinical experiences of respected authorities  
6. recommended best practise based on the clinical experience of the guideline developer

**This guideline has been registered with the trust. However, clinical guidelines are guidelines only. The interpretation and application of clinical guidelines will remain the responsibility of the individual clinician. If in doubt contact a senior colleague or expert. Caution is advised when using guidelines after the review date or outside of the Trust.**

**KEY POINTS:**

1. High frequency oscillatory ventilation (HFOV) can be used as a rescue strategy in carefully selected group of neonates where conventional ventilation is proving to be unsuccessful.  
2. Once stabilised, addition of volume guarantee (typically at 1-3ml/kg) may help with better ventilation control and avoid fluctuations in pCO2 levels. (See section 7.4). Default frequency of 10Hz should not be changed without discussion with consultant  
3. It is unusual to need MAP more than 14cm of H2O. Consider the impact on pathophysiology, systemic venous return, pulmonary complications like air-leaks.
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<td>$\Delta P_{hf}$</td>
<td>Amplitude</td>
</tr>
<tr>
<td>BP</td>
<td>Blood pressure</td>
</tr>
<tr>
<td>DCO2</td>
<td>Gas transport coefficient</td>
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<tr>
<td>ECG</td>
<td>Electrocardiogram</td>
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<tr>
<td>ETT</td>
<td>Endotracheal tube</td>
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<tr>
<td>fhf</td>
<td>Frequency</td>
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<tr>
<td>FiO2</td>
<td>Fraction of inhaled O2</td>
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<tr>
<td>HFOV</td>
<td>High Frequency Oscillatory Ventilation</td>
</tr>
<tr>
<td>I:E</td>
<td>Inspiratory to Expiratory ratio</td>
</tr>
<tr>
<td>MAP</td>
<td>Mean Airway Pressure</td>
</tr>
<tr>
<td>MV</td>
<td>Minute Ventilation</td>
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<tr>
<td>OI</td>
<td>Oxygenation Index</td>
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<tr>
<td>PaCO2</td>
<td>Partial pressure of arterial CO2</td>
</tr>
<tr>
<td>PaO2</td>
<td>Partial pressure of arterial O2</td>
</tr>
<tr>
<td>PCO2</td>
<td>Partial pressure of CO2</td>
</tr>
<tr>
<td>PVR</td>
<td>Pulmonary vascular resistance</td>
</tr>
<tr>
<td>RDS</td>
<td>Respiratory Distress Syndrome</td>
</tr>
<tr>
<td>Te</td>
<td>Expiratory time</td>
</tr>
<tr>
<td>Ti</td>
<td>Inspiratory time</td>
</tr>
<tr>
<td>VG</td>
<td>Volume guarantee</td>
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<tr>
<td>VThf</td>
<td>Tidal volume during high frequency ventilation</td>
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**ALGORITHM 1: INITIATION OF HFO VENTILATION**

**Assess**
- Has conventional ventilation been optimized?
- Discuss with the consultant the aims, potential benefits and risks of HFOV
- Review Chest x-rays and clinical parameters to assess nature of lung disease
- Assess circulating volume, Blood pressure and Lactate
- Ensure adequate monitoring: *consider arterial access*
- Identify appropriate lung strategy: The ‘default’ for rescue should be an **open lung or optimal lung volume strategy**. A **Low volume strategy** may be appropriate for certain clinical situations like PIE or air leaks. (*Discuss with consultant*)

**Set MAP**
- **Optimal lung volume strategy**: Start with a MAP 2cm above the MAP used on conventional ventilation
- **Low volume lung strategy**: Start at the same MAP value as on conventional ventilation

**Set Other settings**
- Set **Frequency** to 10Hz
- Amplitude ($\Delta P$): start at twice the set MAP (or 20-25cm) of H2O. Adjust in increments of 3-5 until the chest wall is seen to gently bounce
- Set **I:E Ratio** to 1:2
- Minute ventilation (MV) alarm settings may need changing

**Optimise**
- Stay with the patient and slowly increase MAP in 1-2cm of H2O increments while closely monitoring O2 saturations, blood pressure and arterial PaO2. These should slowly improve. Reduce MAP if they deteriorate. It is extremely rare to need MAP above 20cm of H2O.
- Once the observations and FiO2 have stabilized to an acceptable level (typically <40%), consider lowering MAP by 1-2cm while continuing to observe the patient
- Continue close monitoring including blood gas
- Consider addition of volume guarantee based on VThf, DCO2 and PaCO2. Usually a VThf of 1-2ml/kg is usually sufficient.
- Arrange for a chest x-ray in 1-2 hours (sooner if clinically indicated) to assess lung volumes; aim for 8-9 posterior ribs in the ‘open or optimal lung volume strategy’
ALGORITHM 2: HFO VENTILATION: MAKING CHANGES

High PaCO₂

- Review patient and assess ‘wobble’
- Is the ET tube at the right place?
- Consider in-line ET suction
- Consider increasing VThf or ΔP
- Consider adding volume guarantee if not already in use
- Reassess in 20-30min and repeat blood gas

Low PaCO₂

- Review patient and assess ‘wobble’
- Consider reducing VThf or ΔP
- Consider addition of volume guarantee if not already being used
- Review overall ventilation strategy based on PaO₂ and clinical status

Low PaO₂

- Increase FiO₂
- Consider increasing MAP by 1-2cm
- Consider chest x-ray to review lung expansion, if over-expanded reducing MAP may improve PaO₂
- Consider additional non-ventilation strategies like surfactant, optimizing perfusion as clinically appropriate
ALGORITHM 3: HFO VENTILATION: TROUBLESHOOTING AND ALARMS

Sudden deterioration, loss of wobble/bounce

- Check Ventilator connections, ET tube, consider suction
- Is there pneumothorax?
- Consider BOLDPEEP - Bad lung disease, Obstructed ETT, Long ETT, Dislodged ETT, Pneumothorax, Patient interaction and Equipment Problem (Refer to Guideline B1 for details)

Set ΔP or VThf not achieved or MV low

- Consider ET tube obstruction and need for suction
- Consider chest x-ray
- If on high MAP (>14cm), consider changing IE ratio to 1:1
- Some babies may need to reduce frequency (Discuss with consultant)

MV high

- Are the alarm limits appropriate?
- Review patient, assess chest wobble and VThf
- Consider blood gas and if appropriate weaning ΔP and volume targeted HFOV

Lack of improvement

- Stay at bedside, review clinical and ventilator parameters
- Consider increasing MAP by 1-2 cm
- Consider BOLDPEEP (see above)
- Consider muscle relaxation; treat hypotension if present
- Some babies do not improve with HFOV and may benefit from switching back to conventional ventilation

Hypotension

- Consider over-distension: Can MAP be weaned?
- Is baby hypovolaemic?
- Consider cause and need of inotropes
4. INTRODUCTION

HFOV is a method of mechanical ventilation that relies on alternative mechanisms of gas exchange such as bulk convection, asymmetric velocity profiles, pendelluft, cardiogenic mixing, Taylor dispersion and turbulence, molecular diffusion and collateral ventilation(1).

HFOV delivers continuous distending pressure to maintain lung expansion and superimposes small tidal volumes, which are equal to or smaller than anatomic dead space, at an extremely rapid rate (300 to 1500 breaths per minute)(2). Different HFOV ventilators are currently available and deliver similar ventilation although their power and effectiveness may vary within different patient groups.

HFO ventilators work by pushing gas into the lung during inspiration and actively drawing the gas during expiration (active expiration) which means that gas trapping is unlikely(3). Commonly used frequencies vary from 8-15Hz(4) and tidal volumes are 1-3ml/kg(2). The aim of high frequency oscillatory ventilation (HFOV) is to achieve optimal oxygenation and ventilation at appropriate lung volumes with a lower risk of lung injury.

The variables used to achieve these are:

- **Mean airway pressure (MAP)**
- **Tidal Volume (VThf) & Gas Transport Coefficient (DCO₂)**
- **Frequency (set by default to 10Hz)**
- **I:E Ratio (set by default to 1:2)**

Continuously applied pressure (MAP) helps with the recruitment of atelectatic areas by increasing the surface area available for gas exchange through increased ventilated lung volume and optimizing ventilation perfusion matching by the effects of optimal lung inflation on pulmonary vascular resistance (PVR), resulting in improved oxygenation.

An ‘escalating recruitment manoeuvre’, i.e. stepwise increase in MAP is the most effective method of volume recruitment and optimal oxygenation on initiation(5,6). However, over-distension of the lungs will compress alveolar vessels thereby increasing PVR (Figure 1) and may also compromise venous return and lead to reductions in cardiac output(7–9). The aim is to achieve maximum alveolar recruitment without causing over distension of the lungs (usually at 8-9 posterior ribs on the chest x-ray).
Figure 1. Increased pulmonary vascular resistance at extremes of lung volumes\(^{(9)}\)

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)(10).

Figure 2: Pressure-volume hysteresis loop during HFOV
**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 wobble.

**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 wobble.

**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 wobble is easy to miss. Chest X-ray and a drop in blood pressure may help recognising over-inflation.

**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 (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.

During HFOV, CO$_2$ elimination correlates to DCO$_2$, which is determined by the equation (4):

$$DCO_2 = (V_{Thf})^2 \times fhf$$

Therefore, CO$_2$ elimination is more dependent on tidal volume than it is during conventional ventilation. DCO$_2$ trends are very useful when linked to blood gas CO$_2$ trends and minute ventilation. Also, with increasing ventilator frequency, lung impedance and airway resistance increase, the tidal volume delivered to the alveoli decreases (4).

Although the amplitude ($\Delta P_{hf}$) of each breath appears large compared to conventional ventilation pressures, the attenuation of oscillation through the endotracheal tube means that the transmitted amplitude at the level of the alveolus is very small.

### 5. PATIENT GROUPS AND INDICATIONS

HFOV has not been proven to be beneficial as an elective ventilation strategy for preterm infants with respiratory dysfunction and may be associated with an increase in intraventricular haemorrhage (11,12), however rescue treatment is shown to be beneficial in selected patients (see below). HFOV is used as a ‘Rescue Therapy’ i.e. used when conventional therapy has failed or is close to failing in the following conditions:

**Severe Symmetrical Lung Disease**
• RDS unresponsive to, or deteriorating despite surfactant therapy (13–18)
• Meconium aspiration syndrome (16,19) (Refer to guideline B16)
• Persistent pulmonary hypertension of Newborn (PPHN) (19–21)
• Pneumonia (20)
• Atelectasis (14)
• Respiratory failure unresponsive to conventional ventilation (12)

Pulmonary Hypoplasia
• Congenital diaphragmatic hernia (20,22) (Refer to guideline B4)
• Pulmonary hypoplasia (19,21)

Air Leak
• Pulmonary interstitial emphysema (12,20,23)
• Air Leak

Generally HFOV is much more difficult to use in the presence of non-uniform lung disease, for example congenital lobar pneumonia, unilateral lobar collapse. It may be difficult to produce even lung expansion and runs the risk of air leak. However it may be useful in carefully selected patients with a ‘Low-volume lung strategy’ (See Algorithm 1) but close monitoring of effect and regular review of the need for HFOV is essential. In sick children in these circumstances particular attention should be paid to circulatory adequacy as HFOV may mask under-filling, and appear to fail when simple restoration of the circulatory volume will produce dramatic improvements in gases.

6. COMMENCING HFOV

Please refer to algorithm 1.

6.1 Decision to commence HFOV
• Review nature of lung disease
• Consider potential benefits of HFOV
• Review CXR and blood gas pattern
• Discuss with Consultant
• Can conventional ventilation be optimised?

6.2 Patient Preparation
• Consider invasive BP monitoring.
• Blood pressure and perfusion should be optimised prior to HFOV; any volume replacement contemplated should be completed and inotropes commenced if necessary.
• Muscle relaxants are not indicated unless previously in use or clinically indicated.
• Sedation with opiates as clinically indicated.

6.3 Switching from Conventional ventilation to HFOV
Refer to Algorithm 1

6.4 Suggested Start-up Settings:
6.4a Rescue Therapy with Optimal Lung Volume Strategy

- **MAP**: Start 2cm above the MAP on conventional ventilation
- **Amplitude**: start at 20-25 or twice the MAP and then slowly increase in increments of 3-5 until the chest wall is seen to gently bounce (‘wobble’).
- **Frequency**: 10Hz
- **I:E** ratio of 1:2
- Stay with the patient and slowly increase MAP in 1-2cm of H₂O increments every 5-10min (*escalating recruitment manoeuvre*), observing oxygenation (saturations and arterial PaO₂ (if available) and blood pressure. These should improve as the lungs are better recruited²¹. It is extremely rare to need MAP above 20cm of H₂O.
- Once the FiO₂ has stabilised to an acceptable level e.g.<40%, consider lowering the MAP by 1 cm of H₂O continuing to observe the patient
- Watch blood pressure and perfusion carefully
- Arrange for a chest X-ray when gases are stable to assess lung volume (see below) - usually after 1-2 hours, aiming for 8-9 posterior ribs as a measure of expansion.
- Once stability is gained, consider the addition of Volume Guarantee (VG). The tidal volumes typically vary between 1-3ml/kg but the close observation of ventilator measured parameters (VThf, DCO₂), clinical examination and blood gases would guide the setting for VG.

6.4b Rescue Therapy with Low Lung Volume Strategy (e.g. Air Leak)

- **MAP**: Start at the MAP on conventional ventilation
- **Amplitude**: start at 20-25 or twice the MAP and then slowly increase in increments of 3-5 until the chest wall is seen to gently bounce (‘wobble’).
- **Frequency**: 10Hz
- **I:E** ratio of 1:2
- Stay with the patient and slowly increase MAP in 1-2cm of H₂O increments (*escalating recruitment manoeuvre*), observing oxygenation (saturations and arterial PaO₂ (if available) and blood pressure. These should improve as the lungs are better recruited²¹. It is extremely rare to need MAP above 20cm of H₂O.
- Once the FiO₂ has stabilised consider lowering the MAP by 1 cm of H₂O continuing to observe the patient, before weaning the FiO₂
- Watch blood pressure and perfusion carefully
- Arrange for a chest X-ray when gases are stable to assess lung volume (see below) - usually after 1-2 hours, aiming for 6-8 posterior ribs as a measure of expansion.
- Once stability is gained, consider the addition of Volume Guarantee (VG). The tidal volumes typically vary between 1-2ml/kg but the close observation of ventilator measured parameters (VThf, DCO₂), clinical examination and blood gases would guide the setting for VG.

7. ADJUSTING SETTINGS DURING HFOV
7.1 OXYGENATION
- Oxygenation is controlled by adjusting the MAP and FiO₂.
- MAP may be increased or decreased in 1 cm H₂O increments.
- Generally it is rare to use MAP levels >20 cm H₂O
- Increasing the MAP will initially improve lung inflation (recruitment) but if the lungs become over distended oxygenation will worsen and paradoxically MAP will need to be reduced (see fig 1). Over inflation can be assessed clinically or by X-ray. Bedside indicators like drop in blood pressure and poor perfusion may be seen beyond the peak of J curve (figure 1).

7.2 VENTILATION
- Lungs must be optimally inflated.
- Changes in PaCO₂ may be affected by changing
  - Amplitude of oscillation (ΔPhf)
  - VThf (in VG mode)
  - Frequency
- Ventilation (CO₂ clearance) may be increased by increasing the set VThf in VG mode or by increasing amplitude (ΔPhf) of oscillation.
- Chest wall bounce should be assessed clinically and the amplitude adjusted accordingly.
- Frequency is usually set at 10Hz. Small infants with RDS may require higher frequency up to15 Hz and some term infants may require lower frequency. The oscillator is less powerful at higher frequencies e.g.12-15Hz.

NOTE: If adjustment of frequency is needed, DECREASING the frequency (to 8-9) INCREASES CO₂ clearance (opposite to effect in CMV). Always discuss with the consultant.

7.3 I:E Ratio
The normal starting ratio is 1:2 i.e. 33% inspiration to 67% expiration. At 10Hz it is equivalent to a Ti of 0.03 sec. However, occasionally a ratio of 1:1 may be used to increase the power of the oscillator, but this may lead to air trapping and eventually poorer CO₂ clearance and impedance of venous return.

7.4 Volume Guarantee
Once stability is achieved and the lungs are recruited, then the VG function may offer optimal control over CO₂ clearance. Start with a VThf value generated by the baby to gain stability or 2ml/kg initially. The amplitude will then vary to deliver this volume. Watching the DCO₂ will help identify the optimum VThf. During HFOV, the ratio between Ti and Te remains constant regardless of VThf. As the VThf increases, the time available to deliver VThf comes down. This explains the reduction in VThf and CO₂ elimination with an increase in
frequency, opposite to the trend in conventional ventilation\((24)\). However, addition of volume guarantee attempts to maintain a constant VThf and therefore, increase in frequency—similar to conventional ventilation, leads to higher minute ventilation and better CO2 clearance.

8. RADIOLoGY

Radiological assessment of lung inflation is a very important part of clinical management during HFOV; it may be necessary to perform Chest X-rays 6-12 hourly if difficulties are encountered. Normal inflation should allow the hemi-diaphragm to be at the 7-8th rib.

OVERINFLATION is occurring if\((25)\) (on chest x-ray):

- Flattening of diaphragm below the 9th rib
- Intercostal pleural bulging of lungs is present
- Sub-cardiac air is visible as a crescent under the apex

However, the assessment of inflation should be considered in the context of clinical condition and other ventilatory and bedside parameters. For example, in babies with pulmonary hypoplasia or congenital diaphragmatic hernia, hyperinflation should not solely rely on diaphragms position but also the appearance of the hypoplastic lungs.

UNDERINFLATION is indicated by a high diaphragm. Lung volume is difficult to assess in the presence of pulmonary hypoplasia, diaphragmatic hernia or abdominal distension, e.g. post gastroschisis repair. When managing patients with air leak or congenital diaphragmatic hernia; consider maintaining normal PaO\(_2\) levels with the minimum possible MAP and accept higher FiO\(_2\) levels.

9. MONITORING, SUCTION AND SURFACTANT

All babies on HFOV need close monitoring. Intensive care nursing observation chart should be contemporaneously completed with particular emphasis on:

- O\(_2\) Saturations (Consider pre-ductal and post ductal for PPHN)
- ECG and heart rate
- Ventilator measurements like VThf, DCO\(_2\), Amplitude, MAP and frequency
- Blood pressure (Consider arterial access for invasive BP and PaO\(_2\) monitoring)
- Blood gases and oxygenation index (OI)

\[ \text{OI} = \frac{\text{FiO}_2 \times \text{MAP}}{\text{PaO}_2 \times 7.5} \]

- Chest bounce is a subjective measurement but may assist in overall assessment

9.1 Disconnection and Suction
• Maintenance of lung volume is critical and thus even temporary disconnections must be discouraged.
• Ensure ventilator circuit is kept free from water condensation as this can impair oscillation. Position the tubing to ensure that the water does not drain down the tubing to the baby.

• Babies on HFOV should have inline/verso adapter suctioning
• Repositioning of the baby should be performed by 2 nurses to avoid disconnection of the ventilator.
• Whenever the mean airway pressure falls, e.g. following disconnection and/or suctioning, it may be necessary to increase the mean airway pressure for a short period to re-establish lung volume.

9.2 Surfactant therapy during HFOV

Surfactant may be administered in the routine manner to babies receiving HFOV, including bolus administration followed by a short period of ventilation using the Neopuff ventilator. Surfactant may reduce ventilator requirements rapidly hence may need to adjust the ventilator accordingly.

10. POTENTIAL COMPLICATIONS OF HFOV

• Hypotension due to obstructed venous return(7,8)
• Hyperinflation (focal or generalised)
• Air leak(12)
• Lack of improvement or in fact deterioration (See algorithm 3)
• Necrotising tracheobronchitis(4) (very rare thought to be contributed by local irritation, high MAP and suboptimal humidification)

10.1 Assessing failure on HFOV

HFOV will at least temporarily improve the respiratory status in the majority of neonates. The common iatrogenic reasons for apparent HFOV failure include inadequate MAP, over-distension, inadequate ΔPhf and VThf and ETT issues e.g. ‘small’ ETT, secretions in ETT or tubing.
HFOV is considered failed if after 2 hours the Oxygenation Index (OI) and PCO₂ are rising or oxygen saturations are worsening in spite of good recruitment and ‘wobble’. Severe respiratory disease, coexistent high inotropic requirements, and presence of nonhomogeneous lung disease are also known risk factors for HFOV failure. Some patients deteriorate immediately on transfer to HFOV and need to be stabilised back on a conventional mode of ventilation.

11. **WEANING FROM HFOV**

Weaning should not be done rapidly and lung volume should be maintained during the weaning process. It is not essential for babies to be conventionally
ventilated as part of weaning. Weaning process should be guided by the clinical context but a suggested order of weaning is as follows:

i. FiO\textsubscript{2} to (Typically down to <30-40%)

ii. MAP (decrease in 1 cm H\textsubscript{2}O steps once FiO\textsubscript{2} <30-40% guided by oxygenation parameters)

iii. At a MAP of 8-9 cm H\textsubscript{2}O either:
   • Change to conventional ventilation
   • Extubate (CPAP or ambient O\textsubscript{2} as clinically indicated)

12. **TROUBLE SHOOTING & ALARMS**

See algorithm 3

13. **SUPPORTING PARENTS AND CARERS**

- Explain how HFOV is different to other forms of ventilation in a language that the parents understand, also explain why their child has been commenced on this therapy and why they may need sedation and muscle relaxant.

- The baby will not be able to come out of the incubator for cuddles whilst on HFOV so ensure the parents are encouraged to talk to their baby and show them how to do containment holding to provide comfort.

14. **AUDIT POINTS**

- Monitoring during HFOV including documentation of oxygenation index, and chest radiology results
- Use of HFOV with volume guarantee and impact on pCO\textsubscript{2} and frequency of blood gases
15. REFERENCES:


20. Boynton BR, Mannino FL, Davis RF, Kopotic RJ, Friederichsen G. Combined...


16. **AUDIT POINTS**

1. Conventional ventilation strategies used prior to initiation of HFO Ventilation
2. Review of chest x-rays including documentation of assessment of x-rays and ventilation strategy
3. Volume targeting and control of ventilation; pCO₂ variation, number of blood gases

17. **EVIDENCE TABLE**

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<thead>
<tr>
<th>Statement</th>
<th>References</th>
<th>Level of evidence</th>
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<tbody>
<tr>
<td>No evidence for elective HFOV being better than conventional ventilation for preterm babies</td>
<td>18, 25</td>
<td>2a and 2b</td>
</tr>
<tr>
<td>Over-inflation of lungs during HFOV can cause haemodynamic compromise</td>
<td>7, 8</td>
<td>4</td>
</tr>
<tr>
<td>Individualised lung recruitment manouevre during HFOV does not increase the risk of air leaks</td>
<td>5, 6</td>
<td>4</td>
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