**High Frequency Oscillatory Ventilation (temporary guideline)**

BAPM guidelines state that there is insufficient evidence to prove that HFOV is better than conventional ventilation, for either rescue or primary use in the preterm infant. More recently a randomised trial of early use of HFOV in preterm infants (UKOS 2002) showed no advantage over conventional ventilation.

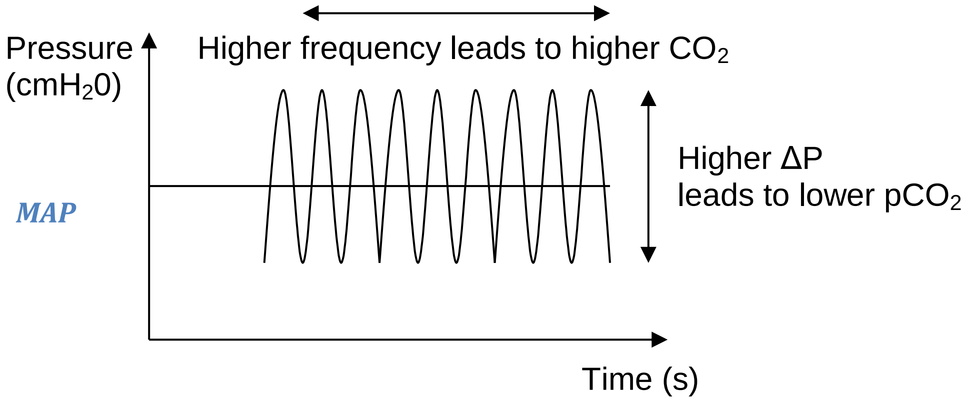
HFOV uses a constant mean airway distending pressure with a high frequency oscillating pressure superimposed upon it. The theoretical advantage of this mode of ventilation is that inspiratory shearing forces are reduced thus reducing barotrauma and perhaps subsequent chronic lung disease (Cochrane review 2002).

Principles of HFOV

HFOV has been described as ' CPAP with wobble'

The CPAP is sustained inflation and recruitment of lung volume by the application of a distending mean airway pressure (MAP) to achieve oxygenation.

The 'wobble' is an oscillating pressure waveform on the MAP at an adjustable frequency (Hz) and an adjustable amplitude (ΔP). In HFOV the rate of excretion of $CO_2$ is controlled by making changes to the ?P and frequency.




**Indications for HFOV**

Treatment of preterm infants with Surfactant Deficient Disease
 Primary therapy (discuss with consultant first)
 Rescue therapy: Failure of conventional ventilation
Meconium aspiration
Persistent pulmonary hypertension of the newborn
Cystic lung disease/pneumothorax
CDH / Hypoplastic lungs
Hydrops
Pneumonia

**<u>Sensormedics 3100A Set Up:</u>**

Circuit Calibration and Ventilator Test sequence:

This procedure should be carried out each time a new circuit is connected. The aim is to calibrate the circuit to the machine and test the capability of the oscillator thus identifying problems **before** attaching the patient to the ventilator.

1. Connect air and oxygen sources and mains power.

2. Ensure stopper in ET connector.

3. Switch on using mains on/off power switch.

4. Depress and hold Reset button to pressurise system.

5. Set the following parameters:
   Bias Flow: 20 lpm
   Pressure Limit and Pressure Adjust controls to maximum
   Frequency: 15 Hz
   % inspiratory time: 33%

6. Mean Pressure Display should read 39-43 cm$H_2O$. If needed adjust patient circuit calibration screw on right side of ventilator.

7. Set MAP to 19-21 cm$H_2O$ using the mean pressure adjust control. Check the bias flow is still exactly 20 lpm.

8. Press start button.

9. Unlock the Power control, set ?P to 6 (in window), relock

10. Centre piston

11. The following readings should now be displayed:
    ?P = 56-75 cm$H_2O$
    MAP = 17-23 cm$H_2O$
    If these readings are not achieved, repeat steps 1-10 then call for technician support. If readings achieved reduce ?P to reduce the noise for the next steps.

Attaching the patient:

The following set up instructions are designed to be used following the Circuit Calibration and Ventilator Test sequence, that is immediately prior to patient connection. The aim is to ensure settings are within clinical and safety guidelines.

1. Plug in humidifier and oscillator to electricity and gas supply. Fill humidifier and switch on.

2. Check the following parameters are set correctly:
   Bias Flow 20 1pm
   Frequency 10Hz
   % inspiratory time 33%
   Select $FiO_2$

3. Decide starting MAP. This will depend whether treatment is rescue or elective.

Rescue: MAP on Conventional Mechanical Ventilation + 1-2cm $H_2O$

Elective: 10cm $H_2O$ for infants <1000g, 10-12cm $H_2O$ for infants >1000g

4. Set desired value for MAP using the Pressure Adjust control
   Set Max Pressure alarm to MAP + 2cm $H_2O$
   Set Min Pressure alarm to MAP – 2cm $H_2O$

5. Adjust the Pressure Limit control so that it just allows the desired MAP to be delivered. The MAP cannot now be raised inadvertently above this level by the Pressure Adjust control or by circuit occlusion. The Pressure Limit control will need turning up in tandem with the Pressure Adjust control to achieve a higher MAP. Likewise as the MAP is reduced during weaning the Pressure Limit control should be turned down to maintain limits.

6. Unlock the Power control, set ?P to 20 and relock.

7. Adjust the ventilator tubing so that the humidity drains back into the oscillator.

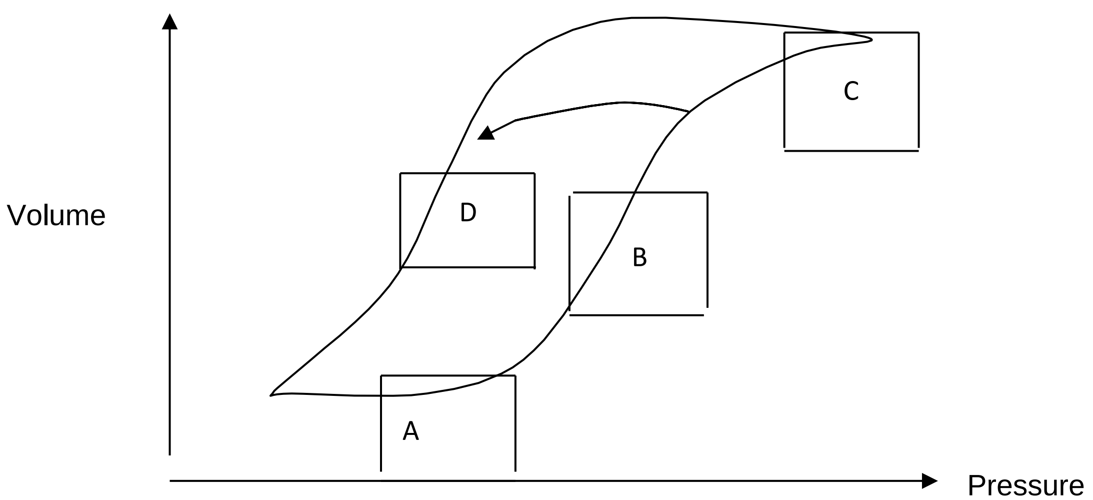
8. Centre piston and readjust MAP with Mean Pressure Adjust control if required

9. Connect infant

10. Adjust ?P until the chest vibrates and readjust MAP and centre piston as required.

Optimising lung function with MAP:

Oxygenation of the blood depends on gaining adequate lung volume, matching of ventilation and pulmonary blood flow and $FiO_2$.
Lung volume is regulated by MAP. As MAP is increased lung volume rises, pulmonary blood flow increases, shunt decreases, and $FiO_2$ can be reduced. It is useful to see HFOV as if you are taking the baby's lungs around a pressure volume hysteresis loop.
The art of HFOV is to achieve and maintain optimal lung inflation (aiming for most of the alveoli on the expiratory limb of the pressure volume loop). Gradual increments in MAP causing alveolar recruitment and thus optimal oxygenation can be achieved without over-distension of the lungs.




A Under-inflation:
High pulmonary vascular resistance (PVR)

- Relatively large changes in pressure produce small changes in volume.
- High oxygen requirement
- Poor chest wall movement

→ Increase MAP

B Optimal inflation:
Low PVR

- Small changes in pressure give larger changes in volume
- Low oxygen requirement
- Good chest wall movement

  → Slowly wean MAP (see D)

**C** **Over-inflation:**

- Systemic circulation compromised (low MABP, narrow heart on CXR)
- Relatively large changes in pressure produce small changes in volume.
- Oxygen requirement initially low but will eventually rise
- Poor chest wall movement

  → Wean MAP rapidly to **B** to prevent lung damage. Over-distension may be difficult to pick-up clinically. CXR still remains the best diagnostic tool.

**D.** **Optimal weaning:**

The goal should be to move from **B** to **D** avoiding **C** as shown by the arrow. Having achieved optimal lung inflation by slowly reducing MAP it should be possible to maintain the same lung inflation and ventilation at a lower MAP. If MAP is lowered too far oxygen requirements will start to rise.

Initial management using HFOV:

Preparation:

Check there is no significant leak around the ET tube, you may need a new one.

- Organise appropriate monitoring (see below)
- Blood pressure and perfusion should be optimised; any volume replacement contemplated should be completed and inotropes commenced if necessary.
- Muscle relaxants are not indicated in preterm infants unless already in use. Term babies may not tolerate HFOV without paralysis.
- Sedation with opiates is indicated in line with UNIT guidelines.

Infant with compliant lungs:

VLBW babies who have minimal lung disease and / or have received early surfactant.

| | |
|---|---|
| Bias flow | 20 lpm |
| Frequency | 10Hz |
| % inspiratory time | 33% |
| FiO2 | 0.3 |
| MAP | 6-8 cmH2O for babies <1000g, 8-10 cmH2O for babies =1000g |
| ΔP | 10 for <1000g, 15 ?1000g |

Adjust MAP to maintain a $PaO_2$ of 7-10 kPa and ?P to maintain a $PaCO_2$ of 5-6 kPa (aiming for pH of 7.30-7.40). See hysteresis loop and below for guidance on gaining optimal lung volume and controlling $PaCO_2$. Although oxygenation and $CO_2$ control are best considered separately, adjusting the ventilator for one parameter will alter other settings and so after making a change always check the other settings.

Infant with Hyaline membrane Disease:

Oxygenation:

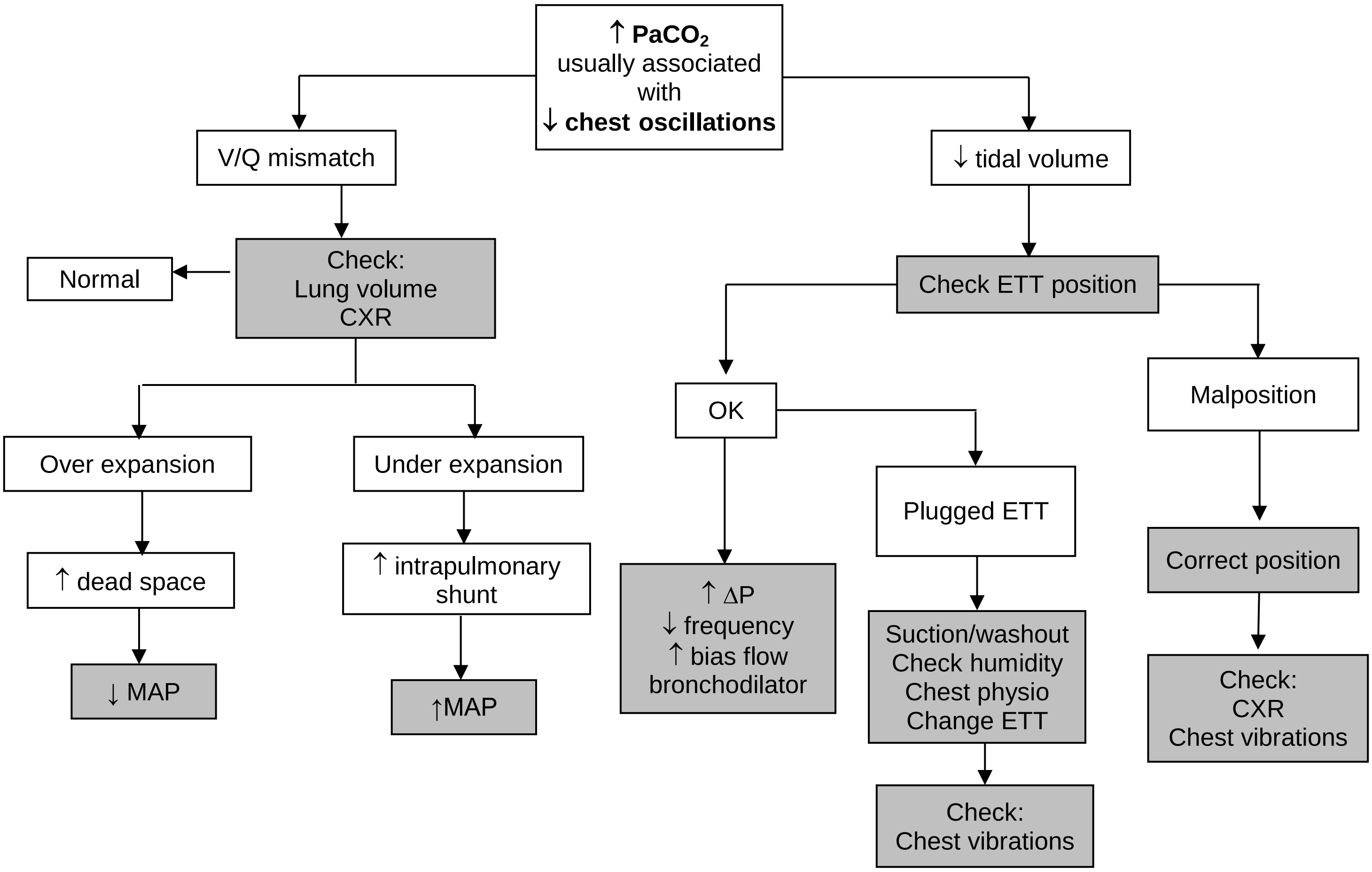
1. Commence with MAP 10-12 cm $H_2O$ or MAP on CMV + 1-2 cm $H_2O$

2. Aim for a ‘high volume’ strategy by increasing the MAP in 1cm $H_2O$ steps every 10-15 minutes reducing $FiO_2$ until:
   a PaO$_2$ ceases to rise or begins to fall (ie $FiO_2$ can no longer be reduced)
   b $PaCO_2$ begins to rise
   c CVP rises
   d Cardiac output (MABP) falls.

   It is very unusual to need a MAP > 20 cm $H_2O$
1. Aim to reduce the $FiO_2$ to 0.3 – 0.4 and check on x-ray that there is a radiolucent radiograph, with 8-9 posterior ribs above the diaphragm. Over-inflation is indicated with 10 or more posterior ribs above the diaphragm on CXR, by bulging of the pleura at the intercostal space and a compressed cardiac silhouette.
2. If you think you are pressing too hard reduce the MAP by 2-3 cm $H_2O$ and watch the oxygen saturation and $TcPO_2$. If they rise you are pressing too hard and if they fall you probably have a little way to go.
3. Once an adequate high lung volume has been achieved it will be possible to drop the MAP a little without loss of volume and rise in $FiO_2$.

   $CO_2$ control:

1. To ensure adequate $CO_2$ excretion the ?P must be sufficient to ensure that the chest vibrates on palpation.
2. Adjust the ?P to obtain a $PaCO_2$ of 5 – 6 kPa.
3. As for conventional ventilation the rate of excretion of $CO_2$ ($VCO_2$) is proportional to the frequency. You would expect an increase in frequency to reduce the $PaCO_{2.}$ However it causes a reduction in ?P paradoxically increasing the $PaCO_{2.}$ It is usually unnecessary to change the frequency from 10 Hz. Nevertheless if the $PaCO_2$ is too low and ?P is minimal you can raise the $PaCO_2$ by increasing the frequency from 10Hz to 15Hz.
4. If with good chest vibrations and lung volume the $PaCO_2$ is still too high, reducing the frequency may increase the $VCO_2$ and reduce the $PaCO_2$




Administration of Surfactant:

1. Surfactant can be administered in the usual way by bolus.
2. Disconnection may result in loss of lung volume, decreased chest vibration and an initial rise in $FiO_2$.
3. Therefore increase ?P till chest vibrates at the same MAP. Wait 10 minutes or until the $PaO_2$ rises and the $FiO_2$ can be reduced.
4. Decrease MAP in steps as the surfactant works and the $FiO_2$ rises.
5. Gradually increase the MAP as the surfactant effect wears off.
6. Often only one dose is required.

Weaning:

It is valuable to get the lung onto the descending limb of the pressure volume curve. When this is done the MAP can be reduced in steps of 0.5 - 1cm $H_2O$ provided the $FiO_2$ remains between 0.3 and 0.4. There is then little change in lung volume or fall in $PaO_2$.

WHEN REDUCING THE MEAN AIRWAY PRESSURE MAKE SURE YOU REDUCE THE Max Pressure Airway ALARM. IF YOU DON'T, WHEN MAP GETS TO 20% OF Max Pressure Alarm THE RED BALLOON DUMPS AND YOU CANNOT START THE MACHINE UNTIL YOU HAVE LOWERED THE Max Pressure Alarm.

The ?P can be reduced as necessary to maintain a normal $PaCO_2$.

If you wean too fast the lungs collapse and the $FiO_2$ goes up and you end up on the bottom end of the ascending limb of the pressure volume loop. You may have to raise the MAP to quite high levels to get back onto the descending limb.

If you wean too slowly, as the lung compliance increases, over distension and compression of the circulation may result.

Extubation:

When MAP $\leq$ 6-8cm $H_2O$, $FiO_2$ <0.3 and ?P low with good chest wall movement and breath sounds on spontaneous breathing. Extubate onto flow driver or into headbox or nasal cannula oxygen. CMV may be a valuable step if there are particular problems with secretions requiring vigorous physiotherapy and suction.

Assessing failure of HFOV:

Do not be too quick to assume a trial of HFOV has failed. Before changing to conventional ventilation request an urgent CXR to assess the state of inflation and assess the circulation carefully. A short period of careful bagging may be of value in assessing the lung compliance and help decide the CMV settings after a failed trial of HFOV.

Infant with PIE/Pneumothorax:

Adopt a ‘low volume’ strategy.
Reduce MAP to 1-2 cm $H_2O$ <CMV MAP or reduce in 1 cm $H_2O$ steps.
Tolerate a higher $FiO_2$
Reduce ?P to a minimum to maintain a $PaCO_2$ of 6-8 kPa and pH > 7.25.
It may be useful to try a low frequency (eg 8Hz)
For unilateral disease try rotating the bevel of the ETT to the normal side, and lying on the affected side.

Infant with meconium aspiration syndrome:

MAP equal to that on CMV.
Frequency 10Hz
% inspiratory time 33
$FiO_2$ maximum before putting up MAP
Then increase MAP by 1cm $H_2O$ at intervals of 30-60 minutes.

Adjust ?P to maintain a $paCO_2$ of 4.5-5.5 kPa.

Watch out for air trapping and pneumothorax

Infant with Hypoplastic Lungs:

Frequency of 10Hz
% inspiratory time 33
MAP 10-12 cm $H_2O$ raise slowly
Use CXR to ensure that lungs are not over filled.
?P 25-45
Wean slowly 0.5cm-1.0cm $H_2O$ increments.

The above recommendations are according to lung disease and are based on manufacturer’s advise and strategies developed at Wilford Hall Medical Center, Texas. See also educational material available on the website www.sesormedics.com.

Monitoring HFOV:

Good monitoring is essential to prevent adverse side-effects possible from rapid and excessive fluctuations in $pCO_2$, $pO_2$ and lung volume that may occur with careless use of HFOV.

| | |
|---|---|
| Arterial blood gases: | Every 15 mins until stable, every hour for the first 4 hours Then 4-6 hourly or within 30 mins of a major setting change. Intra-arterial Neotrend monitoring is very useful with HFOV. Once a stable state is reached and good non-invasive monitoring established frequency of blood gas analysis can be safely reduced. |
| Non-invasive: | $O_2$ and $CO_2$ should be continuously monitored transcutaneously. Once the baby is stable and improving, the non-invasive monitoring can be used to wean ventilation in conjunction with intermittent arterial blood gases. |
| Chest X-rays: | Approximately one hour after starting HFOV to assess lung function. Diaphragm should be at the level of 8 to 9 posterior ribs. Repeat CXR daily for first 3 days or if clinical deterioration |
| Blood pressure: | Intra-arterial access should be obtained for continuous monitoring. If hypotensive treat with volume expansion and or inotropes as appropriate. Consider decreased venous return resulting from over-expansion as a cause of hypotension. In this case a reduction in MAP will help. |
| Echocardiography | For diagnosis and management of PDA and assessment of cardiac function. |

Trouble Shooting:

1. $PaO_2$ falling/$FiO_2$ increasing:
   a Check that lung volume is not too high or too low.
   b If uncertain try reducing the MAP by 2-3cn $H_2O$ and watch the $TcPO_2$ and $O_2$ saturation. If they rise you are pressing too hard and if they fall you probably have a little way to go so increase MAP stepwise.
   c If in doubt take a CXR and adjust the MAP appropriately.
   d ? pneumothorax (may not be as clinically obvious as on IPPV)

1. Cannot get MAP over a certain level:
   Adjust Mean Pressure Limit

2. High $PaCO_2$ (See flow diagram above)

3. $PaCO_2$ falling too low
   a Reduce ?P
   b Increase frequency to 15Hz (but not usual practice)

Alteration of Ventilator Settings

1. INCREASING PIP

- should increase $PaO_2$ and decrease $PaCO_2$ by increasing tidal volume or minute ventilation.
- allows maximal dilatation of patent alveoli.
- increases opening of alveoli with high critical opening pressure.
- probably increases risk of barotrauma.

2. INCREASING PEEP OR CPAP

- should increase $PaO_2$ by holding open alveoli and terminal airways by lowering the ‘closing volume’.
- reduces tidal volume and minute ventilation unless significant atelectasis is overcome.
- significantly increases mean airway pressure.
- may lead to $CO_2$ retention if too high.

- may impede venous return.

3. INCREASING VENTILATOR RATE

- should decrease $PaCO_2$ by increasing minute ventilation.
- may decrease $PaO_2$.
- may cause air trapping if insufficient time for expiration.

4. DECREASING VENTILATOR RATE

- usually increases $PaCO_2$.
- may increase $PaO_2$ if PIP also increased.
- may increase $PaO_2$ if I:E ratio increaed.

5. INCREASING INSPIRATORY TIME

- may increase $PaO_2$ and decrease $PaCO_2$ by increasing mean airway pressure.
- allows expansion of atelectatic alveoli at lower PIP.
- may cause 'inadvertent PEEP' (gas trapping) if used inappropriately.
- may use reduction of pulmonary blood flow.