Paediatric Intensive Care Unit

High Frequency Oscillation Ventilation (HFOV)

Staff relevant to:	Medical and Nursing staff caring for children in the PICU
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Contents

1. Introduction:

HFOV is a form of mechanical ventilation (MV) that uses a constant distending pressure, usually called mPaw, coupled with sinusoidal oscillations at supra-physiologic respiratory frequencies. The principal advantage of HFOV over conventional ventilation is its ability to maintain adequate ventilation and oxygenation at lower peak alveolar pressures.

2. Background and management information

2.1 Terminology

Amplitude & mPaw:

The constant distending pressure (mean airway pressure) allows for alveolar recruitment while avoiding repetitive opening and closing of alveoli (atelectrauma), and has been shown to improve oxygenation. HFOV may also decrease the occurrence of volutrauma and barotrauma.

Frequency:
Respiratory frequencies used in clinical practice range from 5 to 15 Hz (1 Hz = 60 breaths per minute i.e., 300 to 900 bpm) with a small delivered tidal volume (VT), lower than the anatomical dead space, generally around 1 - 3 ml/kg.

HFOV differs from conventional MV in that both inspiration and expiration are active.

Oxygenation and ventilation are fairly **independent** during HFOV with oxygenation being controlled by FiO2 and mPaw while ventilation is controlled by VT (amplitude) and frequency (f).

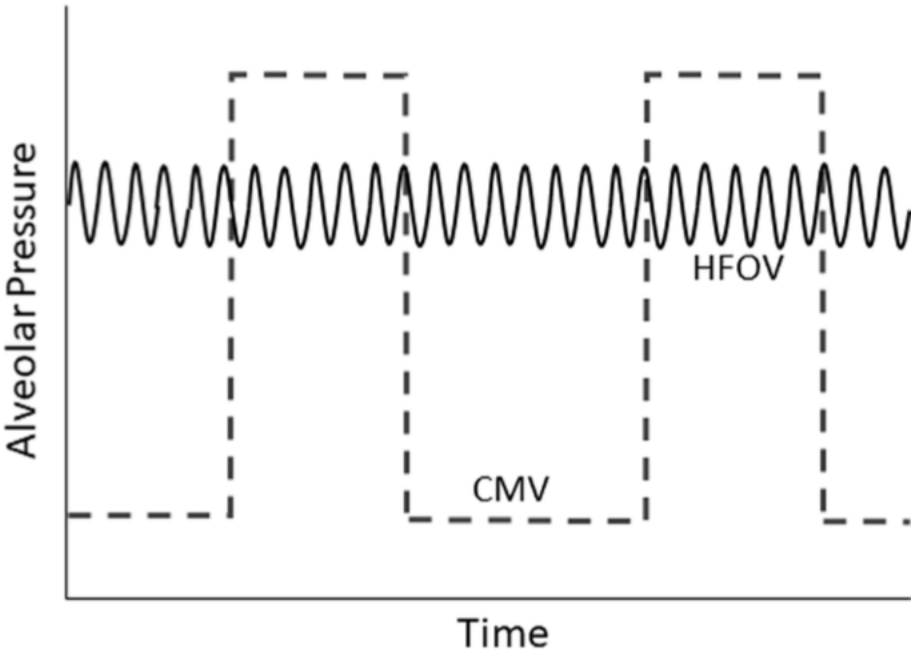


FIGURE 2 | Schematic representation of alveolar pressure over time during conventional mechanical ventilation (CMV) and high-frequency oscillatory ventilation (HFOV).

Various mechanisms contribute to gas exchange during HFOV; these include gas flow turbulence in large airways, bulk convection, turbulent flow with radial mixing, pendelluft, asymmetric inspiratory and expiratory velocity profiles, Taylor dispersion, collateral ventilation, and cardiogenic mixing. (Slutsky and Drazen, 2002; Pillow, 2005)

2.2 Indications

- Failure of conventional ventilation (CV) or to prevent barotrauma when CV settings are high.
- Recommended when PIP >30cm H2O, FiO2 >0.6, MAP >15cm H2O.
- Consider when OI index >15.
- Consider early intervention with HFOV prior to aggressive use of conventional ventilation.
- Consider use in air leak syndromes.

- Consider if using Nitric oxide as HFOV uses continues gas flow and therefore gives more even delivery of the nitric oxide.

2.3 Precautions/Considerations

- Cardiac output may be impaired due to elevated intrathoracic pressures and reduced preload. Inotropic support or volume may be required.
- Relative contraindication in right ventricular failure.
- Caution in patients with air trapping conditions, i.e asthma, as may lead to pneumothorax
- Caution in increased intracranial pressure (ICP) as raised mean airway pressure (MAP) can impede jugular venous flow.
- Ensure patency of ETT, perform suction prior to HFOV as obstruction can effect waveform delivery.
- Ensure adequate titration of sedation, analgesia, and neuromuscular blockade while the patient is still on conventional ventilation. Paralysis is usually only required for the transition on to HFOV.

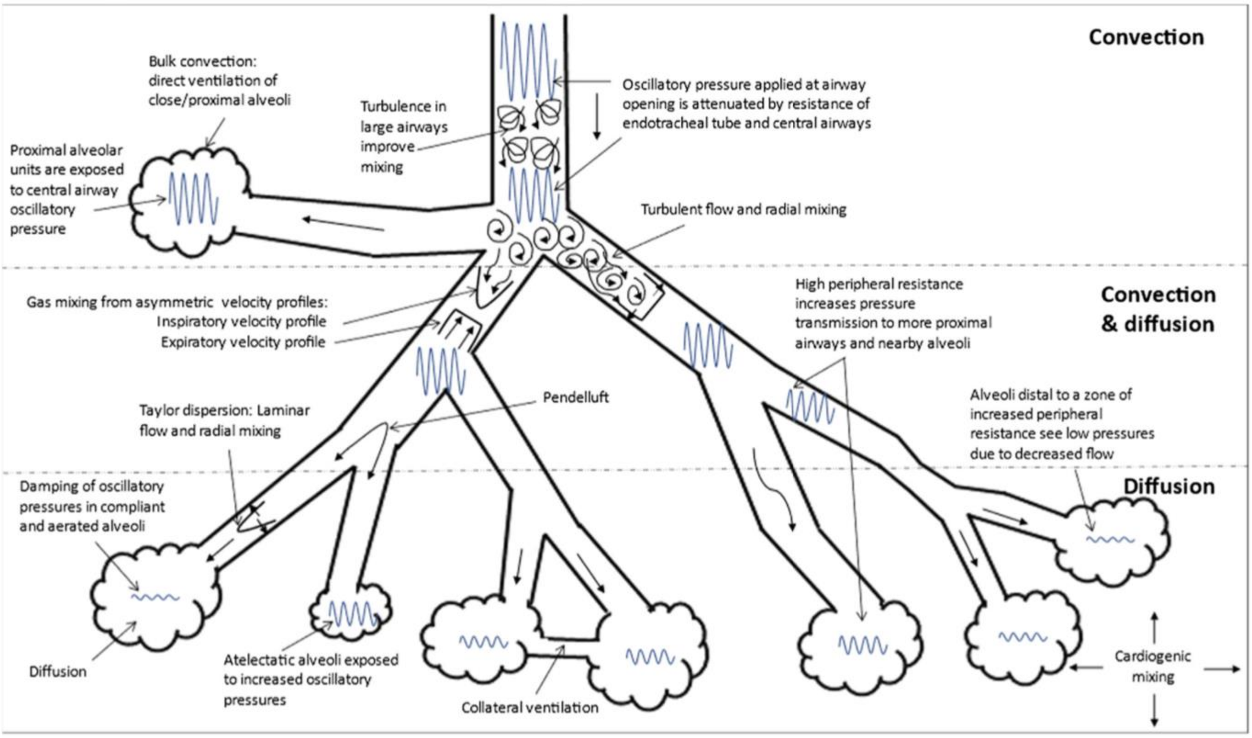


FIGURE 3 | Gas Transport Mechanisms During High Frequency Oscillatory Ventilation (HFOV). Adapted from references: (Slutsky and Drazen, 2002; Pillow, 2005). The gas exchange mechanisms that function in each region (convection, convection and diffusion and diffusion alone) are shown. The various mechanisms that contribute to gas transport during HFOV are: 1) turbulence in large airways producing improved mixing; 2) bulk convection (direct ventilation of close alveoli); 3) turbulent flow with lateral convective mixing; 4) pendelluft (asynchronous flow among alveoli due to asymmetries in airflow impedance); 5) asymmetric inspiratory and expiratory velocity profiles (gas mixing due to velocity profiles that are axially asymmetric resulting in streaming of fresh gas toward alveoli along the inner wall of the airway and the streaming of alveolar gas away from the alveoli along the outer wall); 6) Taylor dispersion (laminar flow with lateral transport by diffusion); 7) collateral ventilation through non-airway connections between neighboring alveoli; and 8) cardiogenic mixing (rhythmic, pulsatile nature of the heart conferring a mixing of gases). The extent to which the oscillatory waveform is attenuated is also shown in this figure. Atelectatic alveoli will experience higher oscillatory pressure and lesser damping compared to normally aerated alveoli. Increase in peripheral resistance, other the other hand increase pressure transmission to more proximal airways and nearby alveoli such that alveoli distal to this zone of increased peripheral resistance experience lower pressures due to decreased flow.

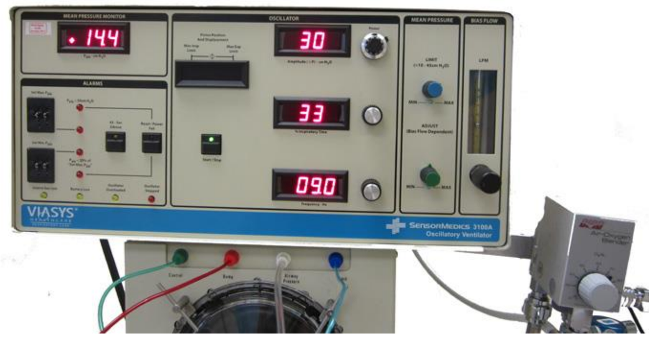
2.4 Ventilation Strategies in HFOV

Homogeneous Lung Disease without Significant Air Leak: e.g. pneumonia and respiratory distress syndrome.
For these diagnoses, follow the general strategies as below.

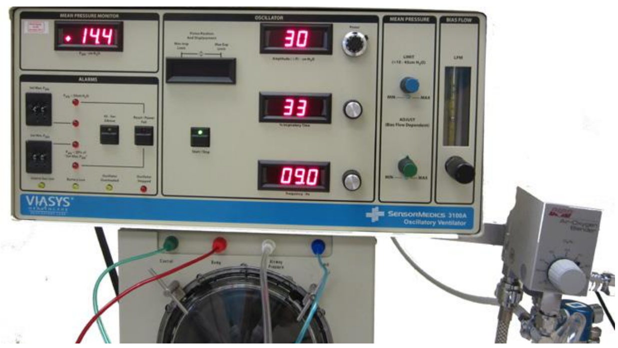
Non-Homogeneous Lung Disease: Air Leak Syndromes and Airway Disease e.g. meconium aspiration syndrome, pulmonary interstitial emphysema (PIE), and severe recurrent pneumothoraces.
For these diagnoses, also follow the general strategies, but with the following important changes in emphasis and pressure levels:
• a. When FIO2 is above 0.6, place equal emphasis on weaning mean airway pressure lower,
• b. Initiate therapy at a frequency of 10 Hz and adjust according to CO2 clearance. (Higher frequencies are deemed to be more “lung protective” compare to lower frequencies)

2.5 Which to use:

Sensormedics 3100A recommended up to 35Kg, MAP up to 50cm H2O



Sensormedics 3100B over 35Kg only, MAP up to 60cm H20.



CO2 clearance - Dependent on Amplitude, Hertz and Inspiratory Time.

High CO2

Increase Amplitude in increments of 2-4, until chest oscillations are optimal (visible wobble).
If increased by more than 10 and no improvement
Decrease hertz in increments of 0.5. (increasing the tidal volume allows longer for gas exchange)
N.B: Note that higher frequency = more lung protective. **Minimum 5.** Adjustments to frequency have a larger effect on delivered VT than changes to amplitude.

- Increase I.T to a maximum of 50%. Use with caution as can increase the risk of air trapping.
- Consider deflating ETT cuff to allow end tidal CO2 to be washed out by the bias flow gas. (in order to compensate for the leak the bias flow may need to be increased to maintain MAP)
- Consider pneumothorax, ETT displacement, secretions, hyperinflation or under inflation.

Low CO2

- Ensure I.T at 33%
- Ensure hertz at optimal setting
- Decrease amplitude in increments of 2 to 4

Summary of HFOV Therapeutic Intervention and Rationale

Clinical Indicators	Therapeutic Intervention	Treatment Rationale
FIO2 above .60 High PaCO2 with:		
PaO2 = okay	Increase ΔP	Increase ΔP to achieve optimal PaCO2
PaO2 = low	Increase $\overline{Paw}$, ΔP, FIO2	Adjust $\overline{Paw}$ and FIO2 to improve O2 delivery
PaO2 = high	Increase ΔP, decrease FIO2	Decrease FIO2 to minimize O2 exposure
FIO2 above .60 Normal PaCO2 with:		
PaO2 = okay	No action	No action
PaO2 = low	Increase $\overline{Paw}$, FIO2	Adjust $\overline{Paw}$ and FIO2 to improve O2 delivery
PaO2 = high	Decrease FIO2	Decrease FIO2 to minimize O2 exposure
FIO2 above .60 Low PaCO2 with:		
PaO2 = okay	Decrease ΔP	Decrease ΔP to achieve optimal PaCO2
PaO2 = low	Increase $\overline{Paw}$ /FIO2, decrease ΔP	Adjust $\overline{Paw}$ and FIO2 to improve O2 delivery
PaO2 = high	Decrease FIO2, ΔP	Decrease FIO2 to minimize O2 exposure
FIO2 below .60 High PaCO2 with:		
PaO2 = okay	Increase ΔP	Increase ΔP to achieve optimal PaCO2
PaO2 = low	Increase FIO2, increase ΔP	Increase FIO2 to improve PaO2
PaO2 = high	Increase ΔP, decrease $\overline{Paw}$	Decrease $\overline{Paw}$ to reduce PaO2
FIO2 below .60 Normal PaCO2 with:		
PaO2 = okay	No action	No action
PaO2 = low	Increase FIO2	Increase FIO2 to improve PaO2
PaO2 = high	Decrease $\overline{Paw}$, FIO2	Decrease $\overline{Paw}$ and FIO2 to reduce PaO2
FIO2 below .60 Low PaCO2 with:		
PaO2 = okay	Decrease ΔP	Decrease ΔP to achieve optimal PaCO2
PaO2 = low	Increase FIO2, decrease ΔP	Increase FIO2 to improve PaO2
PaO2 = high	Decrease $\overline{Paw}$, decrease ΔP	Decrease $\overline{Paw}$

2.6 Oxygenation - Dependent on FiO2 and PAW.

Oxygenation during HFOV is directly correlated with alveolar recruitment (i.e. alveolar surface area available for gas exchange), which is controlled largely by mPaw (Meyers et al., 2019). Optimizing mPaw strikes a balance between avoidance of de-recruitment and overdistension (Meyers et al., 2019).

High pO2

1. Wean FiO2 to 0.4 - 0.6 before weaning MAP unless hyperinflation is evident.
2. In cases of air leak weaning MAP may take priority to weaning FiO2.
3. Wean MAP in increments of 0.5 - 2cm H2O. Babies may tolerate extubation to CPAP from HFOV better than infants or children that usually require conversion to CV.
4. Consider converting to CV when MAP less than 15 and amplitude less than 20.

Low pO2

1. Under inflation and hyperinflation - clinical assessment required & may need CXR
2. MAP adjustment: +/- increments of 1 - 3cms H2O until optimal lung volume is achieved.
3. Increase FiO2 to 1.0
4. Consider pneumothorax, underperfusion

2.7 STARTING HFOV

Ensure calibrations and circuit set up performed as per manufacturer’s instructions.

1.

BIAS FLOW 15 – 20 LPM.
Increasing it will increase MAP.

2.

To set the PAW turn the MAP ADJUST (green) to achieve the desired MAP, turn the LIMIT (blue) until it affects the MAP then turn ¼ turn clockwise. This should be reset every time the MAP is adjusted as it prevents the patient receiving high pressures.

MAP(cm H2O)	Start	Conventional → HFOV
Neonate	10	Conventional MAP +2
Infant	15	Conventional MAP +5
Paediatric	20	Conventional MAP +5

Lung recruitment = start MAP+5 or CV MAP+5 (neonate) or 10 (infant & paed) for 20 minutes then reduce to MAP as above.

3.

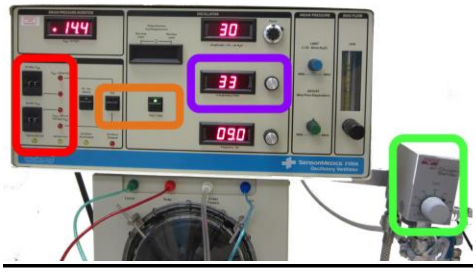
HERTZ/FREQUENCY 1Hz=60bpm.
Recommended Hz

2-5kg	10 to 12	21-20kg	7
5-12kg	9	>30kg	6
12-20kg	8		

4.

AMPLITUDE (DP) often referred to as Power, is dependent on patient size and pulmonary compliance. Oscillations should be visible from chest to mid-thigh. Paediatrics usually 20 - 40. Increasing power will increase tidal volume and improve co2 removal.

5.



Inspiratory time 33% on 3100a and 30% on 3100b

FiO2 set at 100%

Alarm limits set at +/- 5 of MAP

Press and hold the RESET button to pressurise the system before pressing the START/STOP button to commence HFOV

2.8 Monitoring

- Chest X-ray 30 – 60minutes following initiation of HFOV, then daily. Ideal expansion 8-9 posterior ribs visible. NB. Overexpansion or under expansion will result in an increased oxygen requirement.
- ABG should be taken 30 min after initiation and following any change in setting.
- Observation of oxygen saturations, heart rate, blood pressure, capillary refill and urine output should be observed to detect any changes in the patients clinical condition. Chest wiggle should be observed frequently, especially following a change in patient's position to assess for equal or decreased oscillations.

2.9 Suctioning

Suction is indicated for diminished chest wall movement (chest wobble), elevated CO2 and/or worsening oxygenation suggesting airway or ET tube obstruction, or if there are visible/audible secretions in the airway. Avoid in the first 12 hours of HFOV, unless clinically indicated.

2.10 Weaning

Wean to conventional ventilation when all the following conditions have been satisfied:

- Pneumothoraces and/or pulmonary interstitial emphysema (PIE) have resolved, if present. Mean airway pressure has been weaned to the 6–12 cmH2O range.
- ∆P has been weaned to less than 30 cmH2O.
- Arterial blood gases have been stabilized in the following ranges:
- pH = 7.25–7.45
- PaCO2 = 4.66 – 6.66 kPa, (35–50mmHg)
- PaO2 = 6.66 – 10.6 kPa (50–80mmHg)

3. Education and Training

Training and raising awareness are on-going processes. On-going awareness is promoted through the induction and continuous bedside teaching. Training is provided for medical staff during lunchtime teaching and other sessions, and at junior doctors' induction training. Nursing education is supported by the Practice Development teams, and nursing educators.

5. Monitoring Compliance

None identified at present

What will be measured to monitor compliance	How will compliance be monitored	Monitoring Lead	Frequency	Reporting arrangements

5. Supporting References

Wolfe G K, Arnold J H. High frequency oscillation in paediatric respiratory failure. Paediatric and child health 2007; 17(3) 77-80

CareFusion Training Day - manufacturer product information

6. Key Words

High frequency oscilation ventilation, Sensormedics

The Trust recognises the diversity of the local community it serves. Our aim therefore is to provide a safe environment free from discrimination and treat all individuals fairly with dignity and appropriately according to their needs.
As part of its development, this policy and its impact on equality have been reviewed and no detriment was identified.

CONTACT AND REVIEW DETAILS	
Guideline Lead (Name and Title) Adeel Ghias – Higher specialist Doctor	**Executive Lead** **Chief Nurse**
Details of Changes made during review: Updated introduction Added ventilation strategies Added weaning section	