Clinical Practice Guidelines

High Frequency Oscillatory Ventilation (HFOV)

Intensive Care, Prince of Wales Hospital

Background

The injured lung (ALI / ARDS) is susceptible to iatrogenic injury as a result of mechanical ventilation (ventilator induced lung injury, VILI).

Lung over-inflation as a result of excess pressure (barotrauma) or volume (volutrauma); repetitive alveolar collapse and recruitment (atelectotrauma); and stimulation of the inflammatory response resulting from lung injury giving rise to further cytokine-mediated lung and distant organ injury (biotrauma) are all thought to contribute to VILI.

Lung protective ventilator strategies are based upon the following principles:

- Use low tidal volume to limit lung stretch.
  - ARDsNet study used 6 mL/kg predicted body weight.
- Attain and maintain lung recruitment to prevent atelectotrauma, which may occur even if using low tidal volumes. Use lung recruitment manoeuvres and PEEP.
- Limit plateau pressure to < 32 cmH2O.

Adjunctive strategies:

- Permissive hypercapnoea (consequence of low tidal volume and rate used in order to limit frequency and degree of lung stretch).
- Prone ventilation to recruit lung and improve distribution of ventilation (may also improve removal of secretions).
- Nitric oxide to improve oxygenation and ? reduce vascular stress.
- Positioning - lateral rotation therapy

HFOV produces very small tidal volumes (less than anatomical dead space) and achieves CO_2 clearance without the large cyclical pressure changes required in conventional ventilation. HFOV is able to maintain relatively high mean airway pressure (mPaw) (and thus increase lung volume and oxygenation) without the risk of cyclical lung overdistension. HFOV has been shown to provide adequate ventilation and oxygenation in ARDS patients and shows promise as a means of applying lung-protective ventilation in patients where conventional ventilation is failing (1,2)

Principle of operation

The SensorMedics 3100B HFOV produces a pressurised patient circuit (best characterised by the mean airway pressure) by passage of a continuous flow of gas (bias flow) and a control valve. The gas in the patient circuit is oscillated by means of an electrically driven diaphragm. The frequency of oscillation can be varied between 3 and 15 cycles per second (Hertz, Hz). The amplitude of forwards and backwards displacement of the diaphragm from the resting position can be varied. The amount of diaphragm displacement, the speed of displacement, and characteristics of the circuit, airway and respiratory system compliance determine the pressure swing around the mean airway pressure (the delta pressure, ΔP). Even though the ΔP is high, pressure transmission beyond the endotracheal tube (ETT) is greatly attenuated. Pressure attenuation is determined by ETT diameter, oscillator frequency, airway resistance and respiratory system compliance. The degree of chest "wiggle" seems to be related to the degree of pressure transmission ie. more pressure transmission = more "wiggle". The tidal volumes produced are less than dead space volume and are determined by ΔP, frequency, airways resistance (mainly from the ETT), and respiratory system compliance. FiO2 and mPaw determine oxygenation (3).

Mechanisms of CO_2 transport (4)

CO_2 transport in HFOV is complex and depends upon the following mechanisms:

- Convection - bulk movement of gas in proximal gas exchange units.
- Convection and diffusion resulting from:
  - Turbulence, asymmetric gas velocity profiles resulting in radial mixing of fresh inspired and expired gas.
  - Time constant inequalities and phase differences between lung units (differences in regional resistance and compliance) resulting in convective transport.
  - Oscillations resulting from cardiac contraction contribute to gas mixing.
  - Diffusion (Brownian motion) in distal gas exchange units.

Effect of frequency and tidal volume on ventilation (4)

Tidal volume has a greater effect on ventilation than frequency. However tidal volume is dependent upon the pressure amplitude transmitted to the lung, with increased ΔP resulting in greater pressure transmission and thus tidal volume. Pressure amplitude transmitted to the lung is reduced with increasing frequency. To maximise lung protection emphasis is place upon achieving as high as possible frequency in combination with the lowest ΔP.

For any given setting of ΔP, frequency, or mPaw the pressure transmitted to the lung is dependent upon the mechanical properties of the endotracheal tube, airways, lung and chest wall.

Mechanical factors influencing pressure transmission (4, 5)

- As impedance increases higher ΔP is required to maintain flow / volume delivery to gas exchange units.
- Impedance is dependent upon elastance, resistance and inertance of the ventilator, ETT and respiratory system. *Inertance describes rate of change in gas flow and respiratory system volume for a given pressure change. Although relatively unimportant in convention ventilation inertance become significant at the high frequencies used in HFOV.*

Factors affecting impedance

The lung behaves as an overdamped system - with increased frequency there is increased attenuation of pressure amplitude.

The natural frequency of adult ARDS lung has been estimated to be 8.6 Hz and a corner frequency (the frequency at which the response falls off) of about 3.2 Hz. These values correspond to the frequencies used in clinical practice (ie > 3 Hz). These values will be changed by relative changes in inertance and resistance ie. increasing resistance shifts the corner frequency to lower values.

- There will be increased pressure transmission to the alveoli with decreased compliance.
- Increasing airway resistance will reduce the pressure transmission to the alveoli but increase the pressure amplitude in the trachea.

Tracheal tube

The ETT contributes > 50% of total impedance and about 90% of inertance.

Patient Selection / Starting Criteria (6, 7)

A trial of HFOV will be considered if a patient fulfils the criteria for ARDS;

- Diffuse bilateral infiltrates
- No clinical evidence of left ventricular failure
- PaO_2 to FiO_2 ratio < 200 mmHg

Plus

- Intubated and on conventional mechanical ventilation for 48 hours and;
  FiO_2 is > 0.6 and unable to maintain PaO_2 > 65mmHg (PEEP at least 15 cmH_2O)

If bronchoscopy or CT scan is required it should be done before initiation of HFOV.

Goals of therapy
Ventilation: To maintain arterial pH in the range 7.20 to 7.35. In order to limit the need for increased ventilation consider administration of $NaHCO_3$ to accelerate metabolic compensation for respiratory acidosis if pH < 7.2 *(pH will be < 7.2 if the $PaCO_2$ > 70 mmHg and the SBE is in the normal range).* Administer 100 mmol (100 mL of 8.4% $NaHCO_3$) over 2 to 4 hours and reassess. *The increase in strong ion difference (SID = $Na^+ + K^+ - Cl^-$) (by the addition of Na^+ without Cl^- (ie. $NaHCO_3$)) required for complete compensation can be estimated from the relationship for chronic respiratory acidosis ie. $\Delta SBE = 0.4 \times \Delta PaCO_2$. (8)* *Therefore the required increase in SID is estimated by 0.4 X increase in $PaCO_2$ (actual $PaCO_2$ – normal $PaCO_2$) = 0.4 X ($PaCO_2$ – 40) mEq/L* *Na^+ required = (Body weight X 0.6 (distribution volume for Na^+) X required increase in SID) mmol/L*
Oxygenation: PaO_2 55 – 80 mmHg or SpO_2 88 – 95% (defer to PaO2 target if only one is out of range)

Table 1. Adjusting settings *(from references 6 and 7)*

Ventilation	Oxygenation
Overall; aim for highest frequency and lowest ΔP	**Overall;** aim for mPaw $\leq$ 30 cmH2O, FiO2 $\leq$ 60%
Initial settings; **ΔP** = 60 cmH_2O **Frequency** = 6 Hz If PaCO2 > 60 mmHg on conventional ventilation use; **ΔP** = 70 cmH_2O **Frequency** = 5 Hz	**Initial settings;** **mPaw** = mPaw on conventional ventilation + 5 cmH2O but not exceeding 35 cmH_2O FiO2 = 1.0 **Perform cycle of up to 3 RMs at commencement of HFOV – see note on RM for details.**
Adjustments; **pH in target range** – (a) increase frequency by 1 to 2 Hz to max of 12 Hz **pH is too high** – (correct metabolic alkalosis if indicated) (a) increase frequency by 1 to 2 Hz to max of 12 Hz. (b)decrease ΔP in 5 cmH2O steps to minimum of 20. **pH is too low** – (correct metabolic acidosis if indicated). consider altered disease process:- possibility of pneumothorax, partial ETT obstruction, brochospasm, de-recruitment). (a) increased ΔP in steps of 5 cmH_2O to max of 90 cmH_2O then; (b) add cuff leak (see note below). (c) decrease frequency in 1 Hz steps to min of 3 Hz. Allow 30 minutes between changes – use ABGs to guide.	**Adjustments;** **If oxygenation below target** – increase mPaw by 5 cmH_2O steps (max of 45 cmH_20) – consider recruitment manoeuvre (RM). **If oxygenation is improving;** (a) Reduce FiO_2 in 0.1 steps till FiO_2 < 0.6. (b) Decrease mPaw in 5 cmH2O steps to minimum of 20 cmH2O. Allow 30 mins between steps for worsening oxygenation. Allow 4 hours between steps for improving oxygenation. Use SpO_2 and ABGs to guide. RM (see note on RM) if SpO_2 decreases $\geq$ 5% with; – Suctioning – Bronchoscopy – Circuit disconnection
Failure of HFOV Increased PaCO2 with pH < 7.2 despite maximum ΔP, frequency of 3 Hz, and cuff leak. (ensure ETT patency). *Consider inhaled nitric oxide and/or prone position.* Return to conventional ventilation.	

Setting cuff leak - reduce cuff pressure until mPaw falls by 5 cmH_2O. Increase bias flow to re-establish original mPaw.

Consider size 6 ETT tube placed in hypopharynx if upper airway oedema (swelling, burns) to help gas escape.

Recruitment manoeuvres

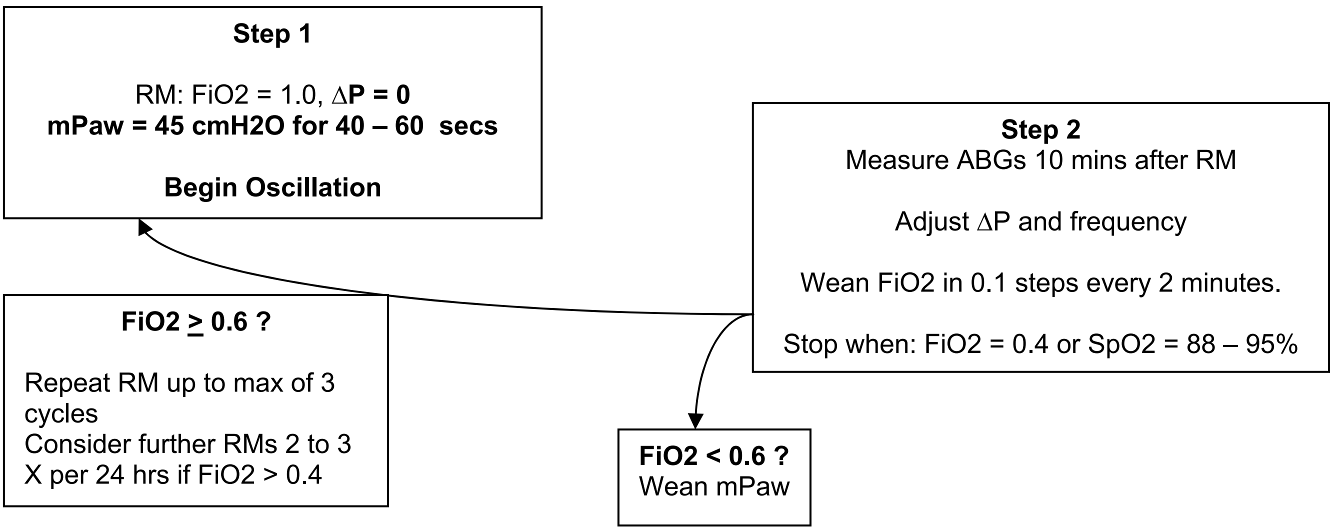
To be conducted only after assessment of adequacy of cardiovascular function and volume status.
ICU Consultant or Registrar must be in attendance during procedure.

- Cycle of up to 3 RMs at commencement of HFOV
- RM if SpO_2 decreases $\geq$ 5% with;
  - Suctioning
  - Bronchoscopy
  - Circuit disconnection

Procedure.

Set high airway pressure alarm to 50 cmH2O Inflate cuff to occlude leak Set HFOV to standby Increase mPaw to 40 – 45 cmH_2O for 40 – 60 secs *(watch BP and decrease mPaw immediately if MAP $\leq$ 60 mmHg or fall more than 20 mmHg)*
Return mPaw to previous setting Reset cuff leak Restart piston

Recruitment manoeuvres algorithm at commencement of HFOV ***(from reference 10)***



Assessment

- Note mPaw on conventional ventilation.
- Obtain ABG prior to and 15 mins post commencement of HFOV.
- ABGs half hourly for the first 2 hours of HFOV and then 4th hourly / prn.
- Assess for hyperinflation – anterior 6th rib visible above the diaphragm.

Observations

- Set mPaw alarm at mPaw +/- 5 cmH_2O.

Hourly ;
- mPaw,
- amplitude,
- Inspired %,
- Frequency,
- Bias flow,
- SpO_2,
- power setting
- humidifier water level

Changes in observations

- Increase in ΔP for same power setting may indicate;
  - Increased ETT resistance (eg, kink, partial blockage, misplacement).
  - Bronchospasm

- Spontaneous breathing will cause mPaw and ΔP fluctuations
- Changes in lung compliance will cause changes in ΔP

Table 2. Affects of clinical situations on ΔP and tidal volume (6)

Condition	Vt	$\Delta P_{carinal}$	$\Delta P_{proximal}$	Treatment
Alveolar overdistention	▼	▲	▼	**Decrease mPaw incrementally**
Tension pneumothorax	▼	▲	▼	**Decrease mPaw. ? chest tube**
Mucous plugging	▼	▲	▼	**Bag, saline lavage and suction. ? bronchoscopy**
Bronchoconstriction	▼	▲	▼	**Bronchodilators / steroids**
Acute pulmonary oedema	▼	▼	▲	**Increase mPaw**
Partial ETT obstruction	▼	▼	▲	**Bag, saline lavage and suction. ? bronchoscopy**
ETT occlusion	▼	▼	▲	**Bag, saline lavage and suction. Reintubation**
Alveolar recruitment	▲	▼	▲	**Monitor for overdistension**

$\Delta P_{proximal}$ is measured in the oscillator circuit and displayed on the ventilator.
Table from; Higgins J, Estetter B, Holland D, Smith B, Derdak S. High-frequency oscillatory ventilation in adults: respiratory therapy issues. Crit Care Med 2005;33(Suppl 3):S196-S203.

Analgesia / sedation / Neuromuscular blocking agents

- Titrate analgesia and sedation to ensure tolerance (ie. < 5 cmH_2O swing in mPaw) of HFOV.
- Use bolus doses of neuromuscular blocker agent (NMBA) in preference to continuous infusion.
- If continuous NMBA infusion required then adjust to lowest dose required to achieve tolerance of HFOV.

Infection Control (8)

The HFOV does not have exhaled gas filtering – therefore; routinely use expiratory gas scavenging.

Use Personal Protective Equipment (PPE) routinely - plus;
- **If patient has known requirement for respiratory isolation or infectious state is unknown nurse in single room.**
- **Staff to wear PPE and use N95 masks.**

Returning to Conventional ventilation (6,7)

Consider trial of CV when FiO2 $\leq$ 0.4 and mPaw $\leq$ 24 cmH_2O

- Set up conventional ventilator / turn on.
- Set HFOV to standby.
- Clamp ETT and disconnect HFOV circuit.
- Attach conventional ventilator circuit using the following settings;
  - Assist / control
  - FiO2 0.1 > than HFOV setting
  - PEEP 15 cmH_2O (? 5 cmH2O less than final mPaw)
  - PCV pressure 17 cmH_2O(to achieve tidal volume of approx 6 mL/Kg)
  - Rate 15 breath per min
  - Ti 1.8 secs

ABGs in 15 mins – reassess settings.

Additional points

- Ensure humidifier chamber does not empty.
- In-line suction.
- Ensure HFOV circuit does not kink.

References

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2. Derdak S, Mehta S, Stewart TE, Smith T, Rogers M, Buchman TG, et al. High-frequency ventilation for acute respiratory distress syndrome in adults. Am J Respir Crit Care Med 2002;166:801-808.

3. Operators manual, 3100B High Frequency Oscillatory Ventilator. 767164 Rev.K, SensorMedics Corporation 2001.

4. Pillow JJ. High-frequency oscillatory ventillatory ventilation: mechanisms of gas exchange and lung mechanics. Crit Care Med 2005;33(Suppl 3):S135-S141.

5. Van de Kieft M, Dorsey D, Morison D, Bravo L, Venticinque S, Derdak S. High-frequency oscillatory ventilation: Lessons learned from mechanical test lung models. Crit Care Med 2005;33(Suppl 3):S142-S147.

6. Higgins J, Estetter B, Holland D, Smith B, Derdak S. High-frequency oscillatory ventilation in adults: respiratory therapy issues. Crit Care Med 2005;33(Suppl 3):S196-S203.

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Intensive Care, Prince of Wales Hospital
HFOV – Bedside Guide

Goals of therapy
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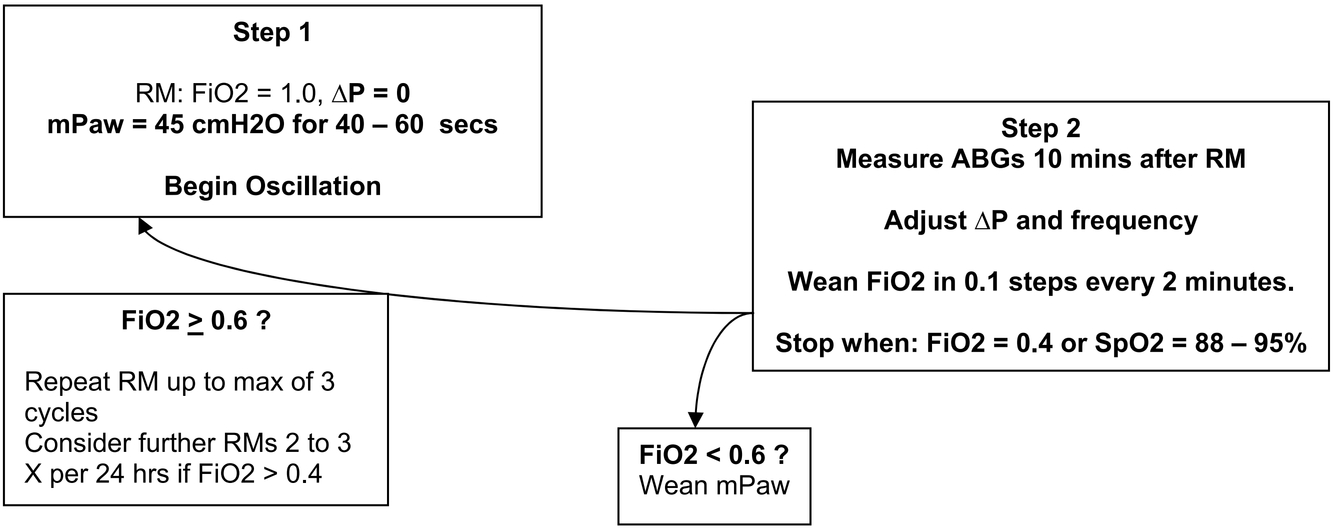

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Affix label

POW ICU
HFOV Data Collection

HFOV Criteria

1. Fulfilling ARDS criteria; • Diffuse bilateral pulmonary infiltrates • No clinical evidence of left ventricular failure • *P/F ratio < 200mmHg*	2. Intubated and on conventional mechanical ventilation for 48 hours and; FiO_2 is $\geq$ 0.6 and unable to maintain PaO_2 > 65mmHg (PEEP at least 15 cmH_2O)

Hospital No
Age
Gender
APACHE II
SAPS
LIS
Number of days on MV prior top HFOV
Diagnosis

At 0900	Pre HFOV	Start HFOV	1	2	3	4	5	6	7
FiO2									
PaO2									
PaCO2									
Rate									
PEEP									
PCVP									
Ti									
mPaw									
Delta P									
Freq									
Insp %									
Cuff leak Y/N									
P/F ratio									
O2 index									
EVLWI									

Outcome
Duration of HFOV
Total days on MV
Failure of O2
Failure of CO2
Complications
Reason for withdrawal of HFOV
ICU survival
Hospital survival
Cause of death
Other therapy – NO or prone.

Do Not File in Notes

Return to; Bruce Dowd RN, C/- ICU, DB1S

Definitions

Oxygenation Index = mean Paw X FiO_2 X $100/PaO_2$

Lung Injury Score

Parameter	Finding	Score
CXR	no alveolar consolidation	0
	alveolar consolidation confined to 1 quadrant	1
	alveolar consolidation confined to 2 quadrants	2
	alveolar consolidation confined to 3 quadrants	3
	alveolar consolidation confined to 4 quadrants	4
Hypoxemia score	PaO_2/FiO_2 > 300	0
	PaO_2/FiO_2 225 - 299	1
	PaO_2/FiO_2 175 – 224	2
	PaO_2/FiO_2 100 – 174	3
	PaO_2/FiO_2 < 100	4
PEEP score	PEEP $\leq$ 5 cm H_2O	0
(if ventilated)	PEEP 6 - 8 cm H_2O	1
	PEEP 9 – 11 cm H_2O	2
	PEEP 12 - 14 cm H_2O	3
	PEEP $\geq$ 15 cm H_2O	4
Resp system	Compliance $\geq$ 80 mL/cm H_2O	0
compliance score	Compliance 60 – 79 mL/cm H_2O	1
	Compliance 59 – 40 mL/cm H_2O	2
	Compliance 20 – 39 mL/cm H_2O	3
	Compliance $\leq$ 19 mL/cm H_2O	4

Score = (sum of parameter values) / number of parameters used .

Interpretation:

Score 0	no lung injury
Score 0.1– 2.5	mild to moderate lung injury
Score > 2.5	severe lung injury (ARDS)

SOFA Score

Organ Score	0	1	2	3	4	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
Respiration (P/F)	> 400	301 - 400	201 - 300	101 – 200 With resp support	≤ 100 With resp support								
Coaggulation (platelets)	> 150	101 – 150	51 - 100	21 - 50	≤ 20								
Liver (bilirubin)	< 20	20 - 32	33 - 101	102 - 204	> 204								
CV (Hypotension)	None	MAP < 70	Dopamine < 5 Any dobutamin	Dopamine > 5 Adren ≤ 0.1 Norad ≤ 0.1 Any vasopressin Any aramine Any phenylephrine	Dopamine > 15 Adren > 0.1 Norad > 0.1								
Renal Creat or UO	<0.11	0.11 – 0.17	0.171 – 0.299	0.3 – 0.44 uo < 500 ml/day	>5.0 < 200 ml/day								

Intensive Care Unit, Prince of Wales Hospital HFOV Observation Chart					***Use expiratory gas scavenging. Use PPE plus; if known need for respiratory isolation, or infectious state unknown, nurse in single room - staff to wear PPE and N95 masks***					***Attach patient label here***		
Date												
Time	**mPaw**	**FiO2**	**ΔP**	**Freq**	**Bias Flow**	**Upper mPaw alarm**	**Lower MPaw alarm**	**PaO2**	**SpO2**	**PaCO2**	**TcCO2**	**RM**
1100												
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