Section 2: Respiratory problems and management
high-frequency oscillatory ventilation (HFOV)
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HIGH-FREQUENCY OSCILLATORY VENTILATION (HFOV)

NURSING A NEONATE ON HFOV

High frequency oscillation ventilation uses tidal volumes that may be less than or equal to the anatomical dead space volume. It produces adequate gaseous exchange at lower peak airway pressures, theoretically reducing the risk of barotrauma.

Breaths are delivered by a vibrating diaphragm that provides for both a positive inspiration and active exhalation.

MODE OF ACTION

- This utilises a piston –diaphragm to produce oscillatory gas flows within the airway.
- A vibrator diaphragm moves a small volume of gas toward and away from the patient.
- A continuous gas flow eliminates C02 build up and delivers 02. It allows continuous gas flow to escape while maintaining vibration of gas in the airway.
- Bias flow is delivered to the proximal airway in order to provide a supply of oxygen and a means of CO2 removal.
- Lung volume is maintained above FRC by the use of a constant distending pressure determined by end-expiratory or mean airway pressure.
- Frequencies range from 3-20 Hz.
- Some oscillators have adjustable I:E ratios (Sensormedics); others are fixed (Draeger/Humming V).
- Proximal airway pressure, not alveolar pressure, is monitored by the ventilator.

INDICATIONS

1. Severe lung disease that is unresponsive to conventional ventilation - “rescue therapy”.
2. Pulmonary air leaks, pulmonary interstitial emphysema, pneumothorax, bronchopleural fistulas, and pneumopericardium.
3. Hypoplastic lung, diaphragmatic hernia.
4. Persistent Pulmonary Hypertension (PPHN) of the newborn, meconium aspiration.

ADVANTAGES OF HFOV

HFOV effectively separates oxygenation from ventilation in that changes made to alter oxygenation have little effect on CO2 removal, and vice versa, therefore one has control of induced respiratory alkalosis, without oxygenation deteriorating, as in conventional ventilation.

During HFV, lung volume is held constant and the cycle of inflation and deflation is greatly reduced, therefore HFOV:

- Avoids high lung volumes and prevents overinflation of the more compliant lung units.
- Avoids low lung volumes and prevents collapse of the less compliant lung units.
- Prevents the propagation of lung injury by supporting adequate gas exchange with small tidal volumes (0.8-2 ml/kg).

- Improves ventilation/perfusion, decreases dead space volume, and maintains gas exchange with less lung injury.
- Improves lung volume recruitment, therefore less barotrauma.
- HFOV may also improve cardiac status.

DISADVANTAGES OF HFOV

HFOV may impair cardiac function (increased PEEP in CMV, and increased MAP in HFOV) due to limited cardiac reserve in the very sick neonate (ECMO candidate) and inhibition of pulmonary blood flow.

Impede venous return as the relatively constant pleural pressure and minimal lung volume changes result in nearly constant (and sometimes higher) intrathoracic pressure.

Result in further gas-trapping and air-leak.

PARENT EDUCATION

Explain the purpose and function of the oscillator to the parents, stressing that the neonate may not exhibit spontaneous respirations. Promote parental involvement in care as much as possible.

CLINICAL MANAGEMENT OF HFOV

The goal is to maintain optimal lung inflation and the lowest level of FiO2 necessary to maintain adequate oxygen saturation.
To switch to HFOV from CMV one must consider 3 aspects of the patient's physiology:

- Current Mean Airway Pressure (MAP) -CMV settings are used as a reference point.
- Inflation of Lung fields
- Disease Pathology - will determine the strategy used with HFOV

COMMENCING HFOV FROM CONVENTIONAL VENTILATION

1. Read mean airway pressure.
2. Switch to HFOV.
3. Set PIP value (Humming V only) to 2-5 cmH_2O below conventional PIP value (this becomes the Sigh pressure).
4. Set MAP as ordered (usually 2-3 cmH_2Oabove conventional MAP).
5. Set oscillatory frequency as ordered according to patient age and disease pathology (usually between 10-15 Hz).
6. Commence amplitude at 100% and prepare to connect baby to HFO tubing.
7. Connect HFO tubing to ETT and commence HFO
8. Adjust amplitude up until the baby's chest wall is visibly vibrating.
9. Assess lung inflation with a chest X-ray 30 to 60 minutes after commencing HFO. Optimal lung inflation correlates with obtaining an 8 to 9 posterior rib level expansion.

GUIDELINES TO VENTILATOR ADJUSTMENT USING HFOV

- Keep Bias Flow as low as possible to achieve MAP (ie: can be reduced from 20 L/min to ~12 L/min)
- MAP is increased during the initial volume recruitment phase until PaO_2 improves by 20-30mmHg, or until CXR shows normal inflation, or until CVP increases with signs of decreased systemic blood flow. During the initial optimisation phase, changes in MAP may need to occur

every 10 min in order to avoid prolonged periods of atelectasis. During subsequent treatment, 30-60 min should be allowed between changes in MAP to assess effect.

- MAP is not reduced until FiO_2 is at <0.6 (unless signs of over inflation). MAP should then be decreased in steps, until FiO_2 requirements increase. (Volume Optimisation)
- $PaCO_2$ is the best indicator of tidal volume.
- CXR are obtained frequently to assess lung volume, and assess tube position.
- In-line suctioning is preferred, to minimise the amount of lung collapse and the period before lung volume is re-established.

HYPOXIA

Increase MAP up to 25 cmH_2O max (if CVP does not increase). Increase bias flow if necessary to achieve the higher MAPs.
Alternatively, apply intermittent sustained inflation or sigh manoeuvre (10-20 s at PIP 5-10 cmH_2O above MAP)

HYPEROXIA

Reduce $Fi0_2$ down to about 0.6-0.3.
Decrease MAP in steps until FiO_2 starts to increase, return to previous MAP.
Low MAP (ie 6-7 cmH_2O) can be achieved by using low bias flow.

HYPERCAPNIA

Decrease amplitude of oscillation.
Decrease frequency (however this is accompanied by increased barotraumas, and should be reserved for high resistance diseases).
Occasionally, hypercapnia is due to generalised atelectasis, or over distension. Changes in MAP at extremes of lung volume may also affect $PaCO_2$.

HYPOCAPNIA

Decrease amplitude.
Increase frequency.

OVERINFLATION

Reduce MAP.
Discontinue HFO.

HYPOTENSION / INCREASE IN CVP

Volume expansion in hypotension.
Dopamine/Dobutamine.
Reduce MAP.
Discontinue HFO.

MAP/OXYGENATION

- Adjustment of lung volume allows manipulation of oxygenation.
- Lung volume is established with MAP, which has the most profound effect on oxygenation.
- Optimum MAP corresponds to an A-P chest film of 8 to 9 posterior ribs.
- Manipulation of the amplitude (Delta-P), affects oxygenation when lungs are either over- or under-inflated.

AMPLITUDE/VENTILATION

- TV during HFOV is influenced by the length and internal diameter of the tracheal tube, airway resistance, and lung compliance.
- CO_2 elimination during HFOV is closely tied to the delivered volume (V_T) and less to frequency (*f*). It is proportional to $f \times V_T^2$. This differs from conventional ventilation where minute volume ($f \times V_T$) is the determinant of CO_2 removal. Thus despite delivering small tidal volumes, HFOV is very efficient at removing CO_2 and maintaining acid-base balance.

Three ventilator parameters that affect the tidal volume in HFOV:

Amplitude (Delta-P).
Frequency (Hz).
% I-Time.

AMPLITUDE - Primary manipulations in $PaCO_2$ are achieved by altering the oscillatory pressure amplitude (or power). Increasing the amplitude increases the displacement of the diaphragm, increasing the V_T delivered to the patient, lowering the $PaCO_2$.

FREQUENCY - In contrast to CMV, lowering the frequency increases the tidal volume (when there is a fixed I:E ratio- ie the IT is a fixed percentage of the total cycle time), thereby lowering the $PaCO_2$.

However, as frequency decreases, the percentage of the oscillatory amplitude transmitted to the proximal airways increases. The frequency at which this amplitude increases significantly, is influenced by the mechanical properties of the lung.

The appropriate frequency is dependent on the disease being treated. As a general rule, higher frequencies (12-15 Hz) are used for low compliance (eg HMD), whilst lower frequencies (8-10 Hz) are used in the presence of high resistance (eg early phase meconium aspiration, CLD). Smaller babies with poorly compliant lungs require higher frequencies than more mature infants.
Gas Trapping is not an issue during HFOV due to active expiratory phase, unless mean airway pressure is inappropriately low, when choke points can form in the airways preventing full expiration.

% INSPIRATORY TIME (IT) - In extreme cases (large patients with severely elevated physiologic dead space) % IT can be increased to improve CO_2 elimination, by allowing a longer inspiratory phase thus maximising the delivered tidal volume from 33 % to 50 %.

The additional inspiratory time results in a greater V_T being delivered to the patient by either allowing for more piston displacement or by allowing the piston to remain in the forward position longer (at the same amplitude), resulting in more volume transfer across the endotracheal tube.

WEANING FROM HFOV

- Maintenance of lung volume during weaning is the key to success.
- It is important to consider disease pathology when setting/adjusting HFOV parameters.
- Reduce $Fi0_2$ in increments down to 0.3 - 0.4. If MAP is maintained too long during weaning then over-distension will result which will impair oxygenation therefore a CXR may be needed to determine level of distension.
- Once $Fi0_2$ is reduced to appropriate levels then MAP should be reduced in 1-2 cmH_20 increments every 2-4 hours (monitored by ABG and TCM). If MAP is weaned too rapidly then atelectasis can occur and blood gases will deteriorate. If this occurs, the MAP should be increased 2 cmH_2O above the weaning value and decreased more slowly.

- Once MAP is 8-9 cmH_2O, amplitude can then be decreased, until the infant is either extubated to CPAP or conventional ventilation is (re-)introduced. If further decrease in MAP is desired, this can be achieved by decreasing Bias Flow.

DIFFUSE ALVEOLAR DISEASE

(ie Hyaline Membrane Disease/Respiratory Distress Syndrome, Pneumonia, Pulmonary

haemorrhage, and Acute hypoxic respiratory failure).

The goal is to recruit gas exchange surface area by opening alveoli and increasing lung volume, without compromising cardiac function and avoiding barotrauma.

In the Preterm Infant:

- MAP is started 2-3 cmH_2O above that on CMV, but must be sufficient enough to inflate the lungs (ie with complete white-out and stiff lungs, may require a much higher MAP).
- Aggressive weaning of MAP as lung volume and compliance improve.
- Frequency ranges from 12-15 Hz (<1000 gm: Generally start at 12 Hz when the $PaCO_2$ is low, and 15 Hz for infants < 750 gm).
- The amplitude is set to achieve least chest wall movement and the desired $PaCO_2$, which will usually be at a delta P of 20-25 cmH_2O.
- Fractional IT is left 0.33 sec.
- If adequate PaCO2 is not achieved with the max amplitude, the frequency is decreased to increase the tidal volume (and visa versa for over ventilation).
- May apply sustained inflations to improve lung volume (IMV breaths on the draeger), providing pulsatile periods of increased pressure during oscillation to re-expand atelectatic alveoli and to bring the lung onto the deflation limb of the pressure volume curve.

Term and near term:

- MAP commences 2-4 cmH_2O greater than that on IMV.
- Frequency of 10-12 Hz.
- Amplitude is as above, although usually higher for term infants (rough rule of thumb amplitude = 3 x MAP).

PULMONARY INTERSTITIAL EMPHYSEMA (PIE)

With air-leak syndromes, the goal of optimising alveolar surface area is reduced to allow for resolution of the air leak syndrome, resulting in adequate by not optimal oxygenation and ventilation.

- Allow elevated $PaCO_2$ levels but with pH > 7.25.
- MAP should be set equal to, or slightly less than that on CMV.
- Frequency at 10-15 Hz.
- Amplitude set to achieve minimal chest wall movement.
- The use of low oscillatory pressure amplitudes (c/w PIP or CMV) often leads to resolution of the air-leak without requiring great reductions in MAP.
- In those with severe air-leak/PIE, continuation of HFO for 24-48 hours after the resolution of the leak is sometimes recommended (to allow complete resorption of interstitial air).
- In cystic air-trapping, use a MAP ≈ than that on CMV and accept low arterial PaO_2 and high $PaCO_2$ and gradually increase in small increments.
- Weaning MAP is given priority over FiO_2 in those with large cysts.

- In those whose PIE fails to improve, wean back to IMV after FiO_2 is reduced to 50 % and PIP< 30 cmH_2O (sometimes associated with mobilisation of pulmonary oedema and clearance of airway secretions).

GROSS AIR LEAK

"The Low Pressure Approach"

Initial MAP is dependent on the volume of the non-air leak lung, which needs to be normalised to attain adequate gas exchange. If atelectasis occurs in the good lung, a minimal leak may have to be accepted while re-opening the lung.

In the Preterm infant:

MAP is set 1 cmH_2O above that on CMV.
Frequency 10-15 Hz depending on the patient's size.
Amplitude as before.

Term and Near Term Infant (2 categories):

a) Air-leak with adequate inflation

MAP to equal that on CMV.
Frequency of 10 Hz.
Amplitude as above.

b) Air-leak with poor inflation

MAP set 1-2 cmH_2O higher than that on CMV.
Frequency of 8-10 Hz.

NON-HOMOGENOUS LUNG DISEASE

- Most often Meconium Aspiration Syndrome (amniotic fluid aspiration, ARDS, pneumonia)
- Any strategy that is effective in opening damaged areas may result in over-inflation and trauma to more normal areas of the lung.
- Focal gas-trapping may be worsened by HFO and result in airway rupture and pneumothorax.
- Less responsive than in diffuse homogeneous lung disease especially if there is marked gas-trapping).
- Allow MAP to equal that on IMV initially, and then volume recruit.
- Frequency 6-10 Hz is required to overcome some of the airway obstruction and associated high resistance present with this pathology, also allows for greater elimination of CO_2.
- Amplitude as above.
- The most severely affected lung is placed in the dependent position to increase resistance to gas delivery to that lung.
- Avoid sustained inflations
- After the first 24 hours in meconium aspiration syndrome, chemical pneumonitis develops and poor compliance may become more important than increased resistance. In this instance, it is worth considering an increase in frequency after the 1^{st} 24 hours.

PNEUMONIA

- Set MAP initially at 1cmH_2O above that on IMV.
- Frequency at 10-15 Hz (use lower frequencies if a viral pneumonia with significant airway involvement).
- Amplitude as above.

HYDROPS

- MAP initially same as that on CMV and then gradually increased to achieve maximum oxygen saturation (at risk of lung injury).
- If still poor oxygenation at 5-6 cmH_2O greater than CMV, re-check X-Ray for lung volume, and position.
- Frequency at 10-15 Hz.
- Amplitude as above.

PULMONARY HYPOPLASIA/CONGENITAL DIAPHRAGMATIC HERNIA

- MAP initially started at equal or greater than that on IMV, depending on the contra-lateral lung. Start in the 10-12 cmH_2O range and increase in 1 cmH_2O increments to optimise inflation of the unaffected lung.
- Try not to go above MAP 15-16 cmH_2O as you are ventilating one lung.
- Be aware of cardiac function when increasing MAP, as the mediastinum may be shifted from its optimal position compromising cardiac output, as well as existing PPHN.
- Frequency 10 Hz. Amplitude as above.
- See Lung protective strategy.

NURSING A NEONATE ON HFOV

- Ensure bullet port *in situ* on HFO tubing. Due to rigid tubing, more attention to TT position is needed to prevent accidental dislodgment and excess pressure on nasal tissues. Use of the plastic block on the side edge of the warmer enables more stability of the tubing.
- Every time the tubing is disconnected consider brief (max 5 min) increase in mean airway pressure of 1-2 cmH_2O.
- Neonate is nursed on a warmer, with a sheepskin, in the supine position.
- Do not muscle relax unless requested to do so by a consultant. Babies can (and should) have spontaneous gentle breathing on HFOV.
- Continuous TCM is usually required with the site rotated every 3 hours, to continuously observe trends in $Pa0_2$ and $PaC0_2$ without need excessive blood gases.
- Pre and post ductal oxygen saturations may be required if PPHN is present.
- Monitor ABG's closely, especially 20-30 minutes after a ventilation parameter change.

PHYSICAL AND AIRWAY ASSESSMENT

- Visual assessment includes activity, posture, behavioural state, chest wall vibration (indicates tidal volume) and symmetry. Chest wall vibration will be affected by the diameter of the ETT, mucous plugging and ETT displacement. A change in the magnitude of chest wall vibration in the absence of alteration in the oscillatory parameters should be investigated immediately.
- Respiratory rate cannot be measured. Auscultation of heart tones, breath sounds and bowel sounds can be achieved by briefly interrupting the oscillation (CPAP will be maintained). Breath sounds can be assessed during oscillation to note air entry and symmetry of oscillatory intensity. Changes in pitch or rhythm of delivered breaths, may indicate changes in ETT position or need for suctioning.
- Suction should only be performed when absolutely necessary and is not required routinely for HFOV. Frequent, even temporary disconnections are discouraged as this results in immediate loss of alveolar recruitment, hence in-line suctioning should be used when possible. Periods of disconnection should be minimised. It may be necessary to temporarily increase MAP (20 % for 2 minutes) to re-recruit lung volume if indicated by deterioration in arterial oxygen saturations post-suctioning.