High Frequency Oscillatory Ventilation

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Citation

Abstract
Conventional ventilation can have severe side effects for a patient and can sometimes fail to safely and adequately ventilate a patient. High Frequency Oscillatory Ventilation is now seen as an alternative when conventional ventilation fails. The principles of HFOV and its indications for use are highlighted. There are specific nursing requirements when nursing a patient on an oscillator.

INTRODUCTION
The vast majority of patients who are admitted to an Intensive Care Unit (ICU) will need artificial ventilation (Jones et al 1998). The usual means through which this is achieved will be via positive pressure ventilation. Gas is delivered under positive pressure, allowing alveoli expansion and gas exchange (Adam and Osborne1997).

However, the effects of this non-physiological approach to ventilation are numerous and can be detrimental. Furthermore, in diseased lungs positive pressure ventilation may not always provide adequate CO2 clearance or oxygen delivery and may even result in alveolar/lung damage due to ventilating at high airway pressures (MacIntyre and Branson 2001).

An alternative approach to conventional ventilation has emerged over the last decade and is known as High Frequency Ventilation.

In this paper, High Frequency Oscillatory Ventilation (HFOV) will be discussed. Why it is used, when is should be used and specific nursing aspects of dealing with patients requiring HFOV will be addressed.

PATHOPHYSIOLOGY
In order to understand the benefits of artificial ventilation, it is first important to understand respiratory failure.

Patients need to be intubated and ventilated in order to treat and manage respiratory failure (Oh 1997), of which there are two types

- Type1: hypoxaemia without CO2 retention. These will include asthma, pneumonia, pulmonary oedema and pulmonary embolism.
- Type2: hypoxaemia with CO2 retention. These will include chronic bronchitis, post operative hypoxaemia, chest injuries and chronic lung disease.

Along with patients suffering from respiratory failure, there are certain patients who need ventilatory support for other medical reasons. Post operative ICU admissions for ‘waking, warming and weaning’ are not uncommon (Adam and Osborne 1997) and certain maxillofacial surgical patients require a period of post operative care/management on ICU, during which time the patient is kept sedated and ventilated.

CONVENTIONAL VENTILATION VS HFOV
Once a patient has been identified as needing artificial ventilation, they are intubated and placed on a ventilator and ventilated using positive pressure. Gases are delivered to the patient using pressure to inflate the lungs, expand the alveoli and allow for gas exchange and oxygenation (Weavind and Wenker 2000). Such delivery can be by means of pressure cycled, volume cycled and/or time cycled. However, the point to remember here is that whatever the mode of conventional ventilation used, they will all use positive pressure to deliver gas and achieve their ventilatory goals.

This use of positive pressure ventilation has its side effects (Fort et al 1997). These are briefly described below;

- Decreased cardiac output: Inspiratory pressure are higher than normal and will reduce venous return.
Further, the use of Positive End Expiratory Pressure (PEEP) will further decrease venous return and, thus, cardiac output.

- Decreased urine out put: As the cardiac output fall, the kidneys attempt to retain fluid.
- Risk of ventilator associated pneumonia.
- Risk of tracheal and lung damage if gases are not humidified.
- Lung trauma due to high or increasing airway pressures.

It is the potential risk of barotrauma which HFOV attempts to deal with, and which will now be dealt with in more detail.

Patients who develop Acute Respiratory Distress Syndrome (ARDS) will have reduced lung compliance and increases in their lung resistance (Simma et al 2000). Ventilating patients with either decreased lung compliance and/or increased lung resistance can lead to alveolar and lung damage and exacerbate their respiratory problems (Simma et al 2000, Weavind and Wenker 2000). HFOV is generally considered to be of benefit for patients with diseased lungs for a number of reasons;

1. It uses SMALLER tidal volumes than conventional ventilation. To try to deliver a constant tidal volume to a patient with increasingly ‘stiff’ lungs results in further lung complications. HFOV reduces this risk by delivering small tidal volumes.

2. HFOV keeps the lungs/alveoli open at a constant, less variable, airway pressure. This prevents the lung ‘inflate-deflate’, inflate-deflate’ cycle, which has been shown to damage alveoli and further complicate lung disease (Fort et al 1997).

3. Along with the above lung protection strategy, it is believed that HFOV may enhance gas mixing and improve ventilation/perfusion (V/Q) matching (Fort et al 1997).

Thus, patients who are at risk of further lung damage due to increases in airway pressure secondary to increases in resistance and decreases in compliance, may benefit from HFOV. When conventional ventilation fails to safely and adequately provide respiratory support, HFOV can be considered an alternative.

HIGH FREQUENCY OSCILLATORY VENTILATION

Essentially, HFOV provides small tidal volumes (not really a tidal volume, but an Amplitude, usually referred to as Delta P: P) usually equal to, or less than, the dead space; 150 millilitres, at a very fast rate (Hertz-Hz) of between 4-5 breaths per second. The delivery of tidal volumes of dead space or less at very high frequencies enables the maintenance of a minute volume. Lungs are kept open to a constant airway pressure via a mean pressure adjust system. Further, HFOV allows for the decoupling of oxygenation from ventilation: it allows the clinician to separately adjust either oxygenation or ventilation.

This is a very simplified way of describing HFOV, and needs more detail if the principles are to be understood.

The core of a HFOV system will be a piston assembly. Cairo and Pilbeam (2000) describe the working of such a piston assembly very well;

“Such a system will incorporate an electronic control circuit, or square-wave driver, which powers a linear drive motor. This motor consists of an electrical coil within a magnet, similar to a permanent magnet speaker. When a positive polarity is applied to the square-wave driver, the coil is driven forward. The coil is attached to a rubber bellows, or diaphragm, to create a piston. When the coil moves forward, the piston moves toward the patient airway, creating the inspiratory phase. When the polarity becomes negative, the electrical coil and the attached piston are driven away from the patient, creating an active expiration.”

The amount of polarity voltage applied to the electrical coil determines the distance that the piston is driven toward/away from the patient’s airway. Therefore increasing the polarity voltage increases the piston movement, or amplitude. The easiest way to conceptualise this polarity voltage, or amplitude, is to view it as the means by which tidal volumes are delivered, the greater the piston displacement (amplitude) the more volume delivered to the patient. It is the piston displacement which causes the oscillations. The extent to which the amplitude increases depends on the resistance the piston encounters to forward movement (Cairo and Pilbeam 2000). For example, when the oscillator is used with a patient with low compliance or high resistance, the piston meets greater pressure during the inspiratory phase.

Since tidal volumes are so low, gas transport mechanisms
other than conventional bulk flow must be invoked to explain gas and CO2 flow. This will be explained later.

Along with the above mentioned amplitude which provides ventilatory volumes, a Mean Pressure Adjust control knob allows for adjustments in mean airway pressure (Paw). This control varies the resistance placed on a mushroom shaped control valve on the patient circuit at the terminus of the expiratory limb. This allows the clinician to manipulate the Paw. Adjusting the Paw enables lung recruitment, keeps lungs and alveoli open at a consent pressure, thus avoiding lung expansion/collapse, lung expansion/collapse which is detrimental to the lungs. Research has also shown that increasing the Paw during HFOV does not effect cardiac out put, unlike conventional ventilation, and increases oxygenation (Fort et al 1997).

The mean pressure adjust control is Bias Flow dependent. Bias flow is the rate at which the flow of gas, through the oscillator, is delivered to the patient.

The speed at which the oscillator runs is set by manipulating the frequency. The frequency control sets the breaths per minute in Hertz (Hz). One Hz is equal to one breath per second, i.e., 60 breaths per minute. A frequency of 5 Hz gives a frequency of 5 breaths per second, or 300 breaths per minute. An important point to remember is that as frequency is increased, the excursion of the piston is limited by the time allocated for each breath cycle. Thus, changes in frequency will effect Paw and the amplitude.

In conjunction with amplitude, mean airway adjust, bias flow, and frequency control, an oscillator will usually also allow for the inspiratory time to be adjusted. The inspiratory time will be displayed as % Inspiratory Time. Further, as with conventional ventilators, alarm limits can also be set.

**USES FOR HIGH FREQUENCY OSCILLATORY VENTILATION**

The use of HFOV in neonates and paediatric patients is well researched and established (Goldsmith and Karotkin 1998). However, its use with adults has only relatively recently been realised. Research is now being conducted into its use with adult patients.

The conceptual advantages of using HFOV are: smaller tidal volumes, a constant, less variable, airway pressure and the fact that nonbulk-flow mechanisms may improve V/Q matching. HFOV is used to avoid conventionally ventilating atelectasis prone lungs in ARDS (Clark et al 1994). Over distention of the lungs and ongoing atelectasis contribute to progressive lung injury which arises not directly from the disease process itself, but from the impact of the ventilator patterns used to support gas exchange during the course of the illness by conventional ventilation (Isabey et al 1984). Atelectasis can be halted, and even reversed, during HFOV, while avoiding the over distention so commonly seen with conventional ventilation (Froese 1997, Tseng et al 1998, MacIntyre and Branson 2001).

Thus, HFOV is used to minimize ventilator-related lung injuries in ARDS. The protective strategy of a constant airway pressure, with smaller tidal pressure swings, preventing over distention, are reasons why HFOV is used.

In addition to this better alveoli recruitment strategy, the rapid flow pattern may enhance gas mixing and improve V/Q matching. However, since tidal volumes are smaller than usual, gas transport mechanisms other than conventional bulk flow transport must be discussed to explain oxygen and CO2 flow. There are a number of mechanisms to explain gas transport under these non-physiologic conditions. The following have been suggested by Weavind and Wenker (2000):

- Bulk flow can still provide conventional gas delivery to proximal alveoli with low regional dead space volumes.
- Coaxial flow. Gas in the centre flows inward, while gas on the periphery flows outward. This can develop because of the asymmetric low profile of high velocity gases.
- Taylor dispersion can produce a mixing of fresh and residual gas along the front of a flow of gas through a tube.
- Pendelluft can mix gases between lung regions having different impedances.
- Augmented molecular diffusion can occur at the alveolar level secondary to the added kinetic energy from the oscillations.

The importance of each of these is debated. It has been suggested by MacIntyre (1998) that perhaps all of the above may be operative simultaneously during HFOV.

The combination of these non-physiological, non bulk flow gas mechanisms and a constant airway pressure, are the advantages of HFOV over conventional ventilation.
Improvements in V/Q matching and the preventing of over distention have led HFOV to be viewed as an alternative to conventional positive pressure ventilation. In a study by Fort et al (1997) HFOV was evaluated in terms of safety and effectiveness in patients with ARDS and with whom conventional ventilation had failed. This prospective study (n=17) included patients who had failed conventional ventilation, had very high peak inspiratory pressure (peak pressure of 54.3 +/- 12.7cm H2O), a PaO2/FiO2 ratio of 68.6 +/- 21.6 and positive end expiratory pressure of 18.2 +/- 6.9cm H2O. HFOV was instituted after varying periods of conventional ventilation (5.12 +/- 4.3 days). A lung volume recruitment strategy was employed, consisting of incremental increases in mean airway pressures to achieve a PaO2 of > or to 8.0 kPa.

During the study 13 patients demonstrated improved gas exchange and an overall improvement in PaO2/FiO2 ratio. Cardiac output was not compromised in any of the patients, despite increases in mean airway pressure. The authors of the study maintain that HFOV is both safe and effective in adult patients with severe ARDS failing conventional ventilation. They do, however, acknowledge the need for continual research into HFOV in adult patients who fail conventional ventilation.

COMPLICATION OF HIGH FREQUENCY OSCILLATORY VENTILATION

A number of complications of HFOV have been identified in the literature.

Although approved for use and despite the research into the effects of HFOV, oscillatory ventilators are still, largely, experimental devises (Goldsmith and Karotkin 1998). There are a number of devises available and this raises the issue of staff training. Generalisation for one oscillator may not be applicable to another (Goldsmith and Karotkin 1998).

The possibility of lung over distention due to trapping of gas has also been investigated (Boros et al 1985). Such distending pressure is commonly called inadvertent PEEP. Since this can not be measured directly, the exact extent to which this is a problem is controversial. As is the problem of lung under distention. In normal circumstances, small tidal volumes delivered at a constant mean airway pressure may actually exacerbate, and indeed result in, progressive atelectasis, one of the problems HFOV is thought to overcome!! Again, this is controversial (Goldsmith and Karotkin 1998).

A number of studies have linked high frequency ventilation to tracheal inflammation and a condition called Necrotizing Tracheobronchitis (NTB) (Boros et al 1985, Wilson et al 1987, Goldsmith and Karotkin 1998). These conditions highlighted the vital need of adequately humidifying respiratory gases.

SUMMARY

To summarise the above, HFOV:

- Enables stable lung inflation
- Allows recruitment of alveolar space
- Reduces the risk of volutrauma
- Reduces risk of high peak airway pressure
- Reduces the risk of airway stretching
- Improves V/Q matching

NURSING A PATIENT RECEIVING HIGH FREQUENCY OSCILLATORY VENTILATION

When nursing a patient on an oscillator, there are a number of specific nursing aspects that should be highlighted.

The sight of someone being ‘oscillated’ can be disturbing for the family and friends of the patient (ManIntyre and Branson 2001). It is therefore essential to ensure adequate information is provided by the nurse to the patient’s family and friends.

After a patient has been attached to an oscillator, the Paw will be increased. Observation of the patient for equal and continuous chest vibrations should be performed. This is known as the ‘chest wiggle factor’. Chest wiggle is more accurate than using terms such as ‘belly wobble’, as not all patients have wobbly bellies!

Chest wiggle must be evaluated upon initiation and followed closely thereafter. If chest wiggle diminishes it may be that the ET tube has moved or is obstructed. Chest wiggle on one side only may indicate that the patient has developed a pneumothorax. Chest wiggle assessments should be thereafter performed following any patient re-positioning.

It is nigh on impossible to auscultate the chest in the normal way whilst a patient is on an oscillator. Because the movement of gases through the lungs is different during HFOV, nurses must rely on other clinical signs. Listening to the piston via the chest has been suggested. The clinician can
listen to the intensity or sound that the piston makes throughout the chest. However, what sounds the clinician is supposed to hear is debated and unclear. It is generally deemed, therefore, unnecessary to perform chest auscultation during HFOV.

A closed system suction unit should be used. It is not necessary to disconnect the patient to suction as this will potentially de-recruit lung volumes. Unless otherwise indicated, suctioning for the first 24 hours is not necessary. When using a closed system suction system, it is important to draw back the suction catheter all the way from the ET tube on completion. Ideally, the patient would be thoroughly suctioned before HFOV is commenced (Senormedics 1998). The point at which the ET tube is cut and secured at the lips should initially be noted. This measurement will act as a reference point in case there is confusion over whether the ET tube has moved.

ET tube position should be checked regularly. When the suction system is changed, two nurses will be needed to ensure safety. Once the patient is oscillated, the nurse must try not to disconnect the patient from the oscillator, or de-recruitment may occur. This is a controversial point. There is very little research/evidence into de-recruitment following disconnection from an oscillator. Further research is needed in order to establish the problem of disconnection associated de-recruitment.

The nurse must monitor blood gases, specifically PO2 and PCO2 and monitor cardiovascular status continuously (Kidd 1988). The nurse must also set alarm limits to within safe and acceptable boundaries.

The recognising of possible complications will involve the nurse being able to recognise ET tube obstruction (amplitude will increase, SpO2 will decrease and CO2 will increase). Recognise pneumothorax (decrease in SpO2, dissimilarity in the height of the left and right chest walls and a fall in blood pressure). To be able to recognise possible lung over-distension (Fall in blood pressure, increase in central venous pressure and decrease in SpO2). Should the nurse suspect any of these complications, then informing the appropriately trained medical staff is of, obvious, importance.

When positioning a patient, it is recommended that at least two nurses assist with ET tube protection to ensure that patient- ET tube disconnection does not occur (Senormedics 1998).

Finally, it is very important to humidify gases before they are delivered to the patient. A standard Fisher and Paykel system, for example, adequately humidifies gas and helps to prevent Necrotizing Tracheobronchitis (Goldsmith and Karotkin 1998).

**SUMMARY OF NURSING CARE AND DUTIES**

- Perform thorough suction before connecting to the oscillator.
- Assess patient upon commencement of HFOV. Monitor vital signs.
- Check for changes in pitch/rhythm of delivered breaths. Check chest wiggle and changes in chest wiggle.
- Use closed system suction catheter. Check position of ET tube. Never change closed system catheters on your own.
- Always humidify gases.
- If oscillator stops during suctioning; silence alarm, pull back catheter and restart oscillator.
- Observe for signs of pneumothorax, ET tube blockage and/or lung over-distension.
- Obtain blood gases and chest x-ray within first hour of commencement.
- Avoid disconnection.
- Ensure appropriate relative information regarding the oscillator.

**CONCLUSION**

In conclusion, then, HFOV improves V/Q matching, enables decoupled oxygenation and ventilation improvements, at a constant airway pressure. This means that pressure swings are reduced and high peak airway pressure are avoided. Atelectasis is minimalised.

Although HFOV is not without its complications, research seems to suggest that it is an alternative for the patient with ARDS who has failed conventional ventilation.

Specific nursing aspects need to be observed when nursing an oscillated patient.

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References
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