Understanding Neonatal Ventilation:

An Overview of Strategies to guide decision making

in the neonatal intensive care unit

Abstract

Neonatal ventilation is an integral component of care delivered in the neonatal unit. The aim of any ventilation strategy is to support the neonate's respiratory system during compromise while limiting any long-term damage to the lungs. Understanding the principles behind neonatal ventilation is essential so that health professionals caring for sick neonates and families have the necessary knowledge to understand best practice. Given the range of existing ventilation modes and parameters available, these require explanation and clarification in the context of current evidence particularly for the novice nurse or for the more experienced nurse who requires an update of knowledge. Enhancement of understanding for health professionals caring for neonates receiving ventilation aids decision making in this area. Many factors can influence clinical decision making on both an individual level and within the wider perspective of neonatal care.

Introduction:

Providing respiratory support in the sick and/or preterm neonate is a significant component of the care delivered in the neonatal unit. Many of the neonates admitted to neonatal care require some degree of mechanical ventilation. A core aim of neonatal ventilation is to achieve adequate gaseous exchange without any resultant lung injury or chronic lung disease (1), a potential and significant long-term effect of prolonged mechanical ventilation in the neonatal period. Understanding the complexities of care given to any neonate requiring mechanical ventilation is essential to deliver safe and effective care. The range of associated terms, modes and parameters in ventilation practice can pose a challenge and often requires clarification to fully achieve understanding for both the novice nurse and for those more experienced who require an update of knowledge. Moreover, some experienced nurses who work in units staffed with Respiratory Therapists designated for neonatal intensive care only, may be less knowledgeable about or less involved in ventilation strategies and management and could also benefit from an overview of this topic. The decision to use a specific type of strategy depends on a complex interplay of factors such as: the nature and progression of the underlying condition, the state of the lungs, age and gestation. The first aim of this paper is to provide the reader with an understanding of the range of strategies used to fully support the neonate's respiratory system in the intensive care unit. Secondly, the paper will outline the factors that can guide and assist decision-making for learners in this area of practice. This topic will be considered with the underlying goal of protecting the lung and preventing adverse outcomes in our vulnerable neonates. The reader is directed to many sources for further reading in this area that provide an overview of ventilation modes and strategies in neonatal practice (1-13).

Neonatal positive pressure ventilation: overview

Ventilation strategies can be viewed across a continuum of dependency starting with the neonate that requires oxygen only, through to the fully ventilated neonate requiring intensive care. This paper will focus on the latter area; that of positive pressure ventilation for the intensive care neonate specifically.

Positive pressure ventilation (sometimes referred to as mechanical, mandatory, artificial or intermittent positive pressure ventilation / IPPV) is a term that applies to the whole spectrum of ventilation modes that deliver pressure according to parameters set on a ventilator. It is used for full respiratory support in neonates who have undergone endotracheal intubation (Figure 1) that are unable to self ventilate adequately and where non-invasive methods such as continuous positive airway pressure (CPAP) are not sufficient to maintain adequate respiratory function. Full ventilation includes firstly 'conventional' modes which aim to mimic the normal respiratory cycle and are based on traditional pressure limited, time cycled ventilators (11). More recently 'non-conventional' and newer modes of mechanical ventilation have been introduced, namely, pressure support, volume targeting and high frequency oscillation, with benefits documented (2). Adjunct therapies such as inhaled Nitric Oxide (NO) and Extracorporeal membrane oxygenation (ECMO) that are used as 'rescue' therapies for specific cases are beyond the scope of this paper.

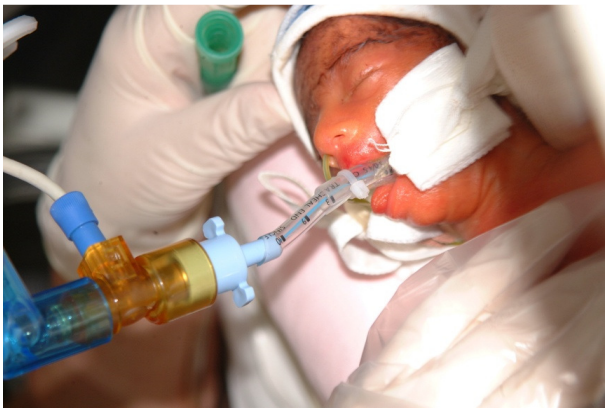


Figure 1: An intubated neonate receiving full ventilator support

Ventilator modes

The actual terminology of available modes used *may* differ between makes and models of different ventilators which will be explained where applicable. The reader should refer to Appendix 1 for explanations of ventilator terminology, relevant formulas and values referred to throughout this paper. In addition, the modes and the relevant changes made between them with rationale according to the individual pathophysiology and assessment can be seen in Case Studies 1, 2 and 3.

Continuous mandatory ventilation (*CMV*). This term refers to mandatory ventilation where there is a continuous flow of gases and the neonate can attempt to take spontaneous breaths between ventilator breaths (9, 10, 12). However, the ventilator will deliver a breath regardless of the neonate's efforts therefore leading to the potential for asynchronous ventilation between the neonate and ventilator. This mode is used for neonates who require maximum support in the presence of little or no spontaneous effort or where breathing should be minimal to avoid 'asynchrony' between the neonate attempting to breathe and the ventilator delivering a mechanical breath.

Synchronized intermittent mandatory ventilation (SIMV). SIMV delivers a pre-determined number of breaths per minute but the breaths are delivered 'in-tune' with the neonate's efforts by detecting their spontaneous breathing efforts and synchronizing the delivery of the ventilator breaths to match the neonate's own breaths (2, 3, 4, 6, 7, 13). In SIMV the neonate can take additional spontaneous breaths between the ventilator-assisted breaths. SIMV can be used to wean the ventilator support and move towards extubation reducing the pre-set rate and pressure over time. If a neonate has a high respiratory rate, it is challenging for them to fit all their own breaths along with those set as backup into one minute, particularly difficult unless the inspiratory time (Ti) is minimal (less than 0.4 seconds; see later section). This mode is a widely used choice in neonatal practice (5).

Patient trigger ventilation (PTV) or 'assist control' (A/C). For this mode, each time the neonate starts to breathe, this triggers the ventilator to deliver a breath or assist the neonate's breath at a set pressure and Ti. Therefore the rate delivered and recorded is determined by the neonate. If the neonate becomes apnoeic and does not trigger a breath, the ventilator will deliver the set back-up rate, again with the pre-determined pressure and Ti. This mode can also be used to wean from ventilation support by reducing pressure only, since rate is controlled by the neonate. A meta-analysis (14) comprising 14 studies concluded that triggered ventilation leads to a shorter duration of ventilation overall as well as a reduction in air leaks compared to mandatory conventional ventilation. Another recent randomized, crossover trial of 26 stable preterm neonates with a mean gestational age of 27 weeks, found that a reduced back up rate (30bpm compared to 50) resulted in greater triggering of breaths and no discernible difference in cardiovascular stability (15). Supporting a neonate's own respiratory efforts

should therefore be encouraged by the use of triggered ventilation with an optimum back up rate while allowing them to take control of their own breathing in time.

Target tidal volume (TTV) or Volume guarantee (VG) TTV or VG can be added to either SIMV, PTV OR A/C. A desired tidal volume (Vt) is set by the operator and delivered by the ventilator using the lowest possible pressure necessary to reach the set volume. A further explanation of Vt follows later on in the paper and within Appendix 1. TTV or VG ensures that the neonate receives an optimal Vt but at minimal pressures to avoid the risk of barotrauma (8) and volutrauma to the lungs. It should be remembered that the *measured* peak inspiratory pressure (PIP) is likely to vary with each breath particularly as the lung compliance changes; in other words how easy or not it is to expand the lung. For example, as the lung compliance worsens, the desired Vt will be more difficult to deliver at lower pressures and so the maximum set PIP will be reached and measured. Therefore, it is very important to set an appropriate *maximum* pressure limit should it become difficult to deliver the set Vt in deteriorating lung conditions. Conversely, as lung compliance improves, it is easier for the desired volume to be delivered at lower pressures and therefore the measured PIP will be lower, not reaching the maximum limit. By this, one can observe that when the PIP needed to generate the desired Vt decreases, this signals improving lung conditions and readiness for weaning. The ability of VG to show changes in lung compliance is seen one of the main benefits of this ventilation mode (16, 17). Generally, evidence supporting VG suggests that further benefits stem from the ability to deliver a guaranteed and *consistent* Vt at the lowest pressure which potentially reduces trauma to the lungs (18), a feature not achievable by traditional pressure limited time cycled ventilation (16).

Brown and DiBlasi, based on their extensive review of the evidence (19) propose that the use of small tidal volumes in the range of 4-6mls / kg is one of the key strategies for protecting the neonatal lung during mechanical ventilation. Cheema et al state 4 mls/kg should be aimed for (20). However, a higher Vt than this may be required with conditions such as pneumonia, broncho-pulmonary dysplasia (BPD) or other lung pathology that results in increased resistance to air flow and the need for a greater volume to be delivered (21). The reader should refer to three systematic reviews in this mode of ventilation for a full summary of the research in this area and the potential benefits of volume guarantee ventilation (22, 23, 24). A comprehensive guide is also available on the practical application of this mode (8).

Pressure support ventilation (PSV); With PSV, the neonates breathing efforts are supported with ventilator breaths set to a pre-determined pressure. This is similar to PTV but the neonate now determines both the rate *and* Ti. The flow termination sensitivity is set so that the Ti will terminate at a pre-determined percentage of the peak flow. Full PS is a mode in it's own right and may be useful for neonates who are weaning from their support allowing them more control in line with their own breathing dynamics (25). The main principles of PSV are summarized within the recent literature as a new and emerging mode (3-6, 10, 25, 26, 27, 28).

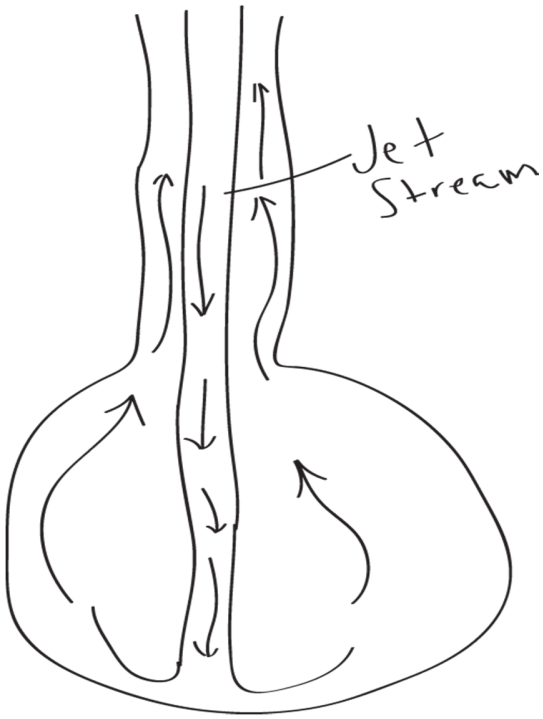
As well as a mode used alone, PSV can also be used in conjunction with other modes by turning this on as an additional feature (13). For example, SIMV with PV added will ensure that every spontaneous breath is supported by the ventilator at a set percentage pressure relative to peak pressure set for the mandatory breaths on SIMV.

So, whereas with PS mode alone or PTV (A/C) with PS, all breaths are supported; in SIMV with PS, the neonates' breaths only are supported. However, this imparts greater support for a neonate who perhaps will not be able to manage on SIMV alone and who requires additional support for their own breathing efforts. Adding in PSV *with* SIMV can be useful as a more gradual step-down once the back-up rate on SIMV starts to be reduced during weaning. Here, the neonate's own breaths continue to be supported at a certain pressure until such time that they do not require this additional PS. It should be remembered that the measured Vt will vary with each pressure supported breath.

High frequency ventilation; this is a mode of ventilation that uses breath rates or 'frequencies' much greater than normal physiological breath rates with a tidal volume near anatomic dead space. One example is high frequency jet ventilation (HFJV) that introduces small pulses of gas under pressure into the airway at a very fast rate or frequency (4-11 Hertz; see below) for a brief duration (approximately 0.02 seconds) using very small Vt of ≤ 1 ml/Kg thus creating lower distal airway and alveolar pressures than that produced by a mechanical ventilator. Exhalation during HFJV is passive. It was thought this may reduce the severity of lung injury associated with mechanical ventilation (29, 30). The jet actively pulses gas into the neonates' lungs which travels down the center of the tracheal tube. CO2 then spirals up and around that jet of gas, and out of the expiratory circuit passively (See Figure 2). This mode was originally used for short-term ventilation during airway surgery because of its capability to ventilate in the presence of air leaks. The short Ti and small Vt are thought to minimize flow through leaks within the lung fields (31), for example in a condition such as Pulmonary interstitial Emphysema (PIE). In addition, in Meconium aspiration Syndrome (MAS) where gas

trapping may occur, passive exhalation of the jet helps CO2 TO be removed without causing further trapping, and preventing over expansion of the lungs. Literature also indicates its use for other short term conditions such as Pulmonary hypertension of the Newborn (PPHN) and during transport (32, 33, 34). However, the practicalities of administration and the necessity for two machines have meant that other forms of high frequency ventilation may be more suitable; hence it is not as widely used.

Figure 2 – Pattern of gas flow in HFJV



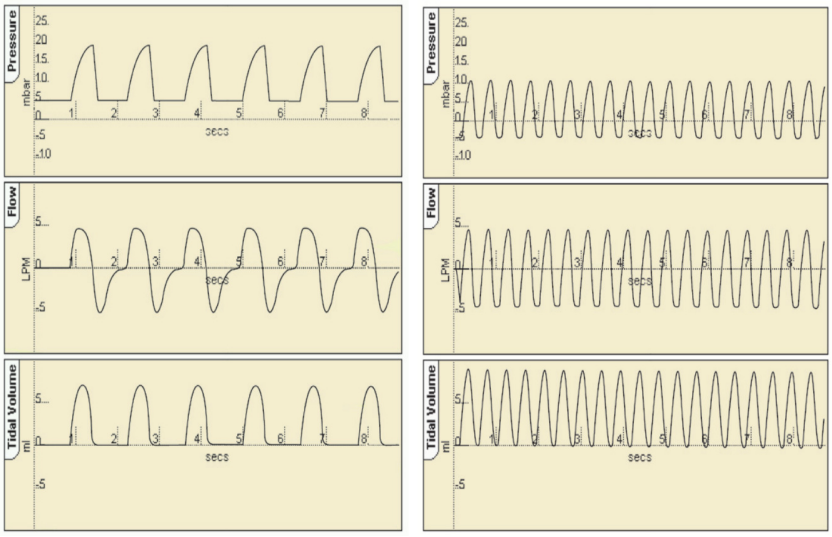
SOURCE: http://en.wikipedia.org/wiki/File:Drawing_of_air_movement_in_alveoli_during_jet_ventilation,_HFV-P.png

More commonly used is high frequency oscillatory ventilation (HFOV) where the pressure 'oscillates' around a constant distending pressure which in effect is the same as positive end-expiratory pressure (PEEP)and equivalent to Mean Airway Pressure (MAP).

A further explanation of MAP will follow later and is detailed in Appendix 1. Thus gas is pushed into the lung during inspiration, and then pulled out during expiration. HFOV generates very low tidal volumes that are generally less than the dead space of the lung. Figure 3 depicts the waveforms for conventional verses high frequency ventilation (3 a and b); the typical pressure graph for HFOV is therefore very different to what we see in conventional modes. Oscillation causes the chest to ''wiggle'' or vibrate. The increasing use and growing trends of HFOV from the neonatal experience has been documented (35). In neonatal practice, this is a mode used either as a 'rescue' therapy when conventional modes have been ineffective or in some neonatal units, as a first-line ventilation strategy. However; as for HFJV, evidence has not found a link between HFOV and improved outcomes (36, 37, 38).

Figure 3 : Waveforms for (a) conventional ventilation and (b) High Frequency Oscillatory Ventilation (HFOV) Image source:

http://www.sle.co.uk/_assets/documents/brochures/SLE5000.pdf



Proportional Assist Ventilation (PAV) – This mode gives assistance that is proportional to the neonate's effort whereby the applied pressure increases in proportion to the Vt and

flow generated by the neonate with the frequency, timing and rate of lung inflation being controlled by the neonate themselves (39, 40). However, this new mode is not frequently utilized at present compared to other modes discussed thus far. It is stated that in order for it to work effectively, there should be no leak and a mature respiratory system should be in place; clearly this is not the case in preterm neonates (4).

Neurally adjusted ventilatory assist (NAVA); NAVA is another new mode of ventilation designed to reduce the asynchrony that can exist between the ventilator and the neonate. Gas delivery from the ventilator is triggered, controlled and cycled by a diaphragmatic electromyelogram (EMG) signal. The ventilator is aware of the change in EMG by the insertion of a specially designed nasogastric tube (NGT) with EMG electrodes that cross the diaphragm. A number of preliminary studies in neonates have demonstrated that patient ventilator synchrony is improved with the application of NAVA (41, 42, 43) and this may be a strategy for future work and application.

Understanding settings in ventilation

In addition to understanding what each mode is and how it works, it is important for the neonatal nurse to also understand the settings on the ventilator (Appendix 1). Nurses record settings hourly on an ongoing basis and so having the knowledge behind what they mean is paramount.

Firstly, the desired number of breaths per minute (bpm) is set which are time cycled and pressure limited. They can either be set by a bpm dial or in some ventilators, the rate is set by adjusting inspiratory (Ti) and expiratory times (Te) separately (see below).

A *back-up* respiratory rate is set for some modes (e.g. PTV, A/C and PS). As seen in Appendix 1 and Figure 4, rate along with the Vt affects 'minute volume' (Vmin) and so affects CO2 clearance. Increasing Vmin improves CO2 elimination and decreasing it will lower this elimination.

The Ti is usually set at no higher than 0.36 – 0.4 seconds in the preterm neonate particularly, recommended due to short physiological time constants in neonates (44). Ti may be slightly higher than this in older neonates or when the rate used is slow, but usually no higher than 0.5 seconds. Increasing Ti will raise the MAP so improving oxygenation and vice versa as this is one component of it's formula in Appendix 1. Ti and Te can be independently set on some ventilators to adjust and set the rate. I.e.; the Ti is confirmed and then Te adjusted until the desired rate is obtained. How to set rate using this method can be seen in Appendix 2. Te should always be longer than Ti.

Both the peak inspiratory pressure (PIP; at the end of inspiration) and the positive end expiratory pressure (PEEP; at the end of expiration) are set according to the needs of the neonate and condition. These are depicted in the pressure graph in Figure 3a (top image). Increasing PIP and PEEP will raise the MAP and improve oxygenation since, as for Ti, they are an integral components of the MAP formula. Conversely, reducing PIP and PEEP will lower MAP when oxygenation is adequate. Making changes to PIP and PEEEP will also affect the Vt for each breath and so also influence CO2 elimination – this will be covered again later in the paper. The side effects of high or low settings for PIP and PEEP should be kept in mind during setting these parameters. A high PIP particularly above 25 cm water can damage the delicate lung alveoli by barotrauma in association with

shearing forces of mechanical ventilation. Raising the PIP also increases Vt and therefore a risk of volutrauma is also present. Too low a PIP of course may not be effective in achieving adequate chest expansion leading to hypoventilation. A high PEEP can lead to an inadequate expiratory phase with poor emptying of gas and limiting C02 elimination as the end pressure for each breath is not sufficient to remove this from the respiratory dead space. Conversely, setting the PEEP too low may lead to the lungs collapsing down and a poor functional residual capacity (FRC). Therefore, optimum settings should be undertaken with sound rationale and evaluation tailored to the individual neonate.

Oxygen is set from a dial which blends air and oxygen keeping this to the minimum possible due to the potential damaging effects of oxygen toxicity. Flow (in liters/minute) is set in some ventilators (to 8-10 l/min) while in others this is automatically delivered without needing to be set. A flow graph is depicted in Figure 3a (middle image). In addition, the trigger threshold should be set on the *maximum* sensitivity in neonates (i.e. the minimum effort for the neonate). In flow triggering, they will only have to generate a change in flow of approximately 0.2- 0.4 mls / kg for the ventilator to recognize spontaneous effort. Any higher than this, the neonate's effort may not be strong enough to actually trigger.

In addition, if PS is added to an existing mode, this is turned to 'on' and a percentage (%) is set; i.e. any spontaneous breaths by the neonate will be supported by flow cycled, pressure limited breaths to the set % of the set PIP. Flow termination sensitivity is also set – i.e. when the pressure supported breath flow is terminated. For the use of TTV or VG; this is turned to 'on' and a Vt is set at approximately 4-6 mls / kg (19) or higher if the neonate's

condition necessitates this, as stated earlier. Refer to Case Studies 1 and 2 to see how PSV and VG are 'turned' on with other existing modes.

Alarm Limits should also be set; for example, high and low pressure, Vt alarm and high and low minute volume (Vmin) alarm thresholds are set. An apnea alarm is also set on some ventilators, often functional if the bpm is less than 20.

Oscillation settings;

For HFOV, the frequency of oscillations is expressed in Hertz. There are 60 breaths in 1 Hertz (Hz). This mode will deliver very small tidal volumes at very high rates, for example 600bpm. The MAP is set within this mode and manipulated to control oxygenation and this is usually set above the MAP that was given for conventional modes (for example; 2 cm water higher). Pressure amplitude (or Delta P) is the 'power' setting and determines the strength of the oscillations (and so the extent of 'chest wiggle' in the neonate). Increasing the Delta P will increase chest wiggle and increase the height of the pressure trace as displayed in Figure 3b. This controls the volume entering the lungs and so controls CO2 elimination. Oxygen, high and low alarm pressure, Vt alarm threshold and minute volume high and low alarm thresholds are also set.

Humidification is also an essential element of normal respiratory function. *Any mode,* beit non-invasive or full ventilation should deliver warm, humidified gases by a humidifier within the inspiratory limb of the ventilator circuit. A humidifier should ensure an airway temperature of as close to 37 degrees Celsius as possible.

Understanding measurements in ventilation

All *measured* readings of the dynamics of the neonate's lungs are taken by the flow sensor situated on the connection between the ventilation tubing and the endotracheal tube. This sensor is designed to measure certain parameters which are then displayed in various forms. The ventilator screen panel displays the measured and calculated parameters. It is important to calibrate the flow sensor prior to use (flow calibration) and to prevent damage or disruption of the measuring capability due to excessive condensation from the tubing. In the absence of a flow sensor, dynamic measurements are not possible but the ventilator will still be able to deliver the desired settings. However the breaths will not be synchronized with the neonate's respiratory efforts.

The following measurements can be recorded by the neonatal nurse at the bedside. Mean Airway pressure is the total pressure within the lungs throughout the respiratory cycle as determined by PIP, PEEP, Ti and Te. MAP has a direct influence on oxygenation – for example, if you need to increase oxygenation, the MAP must be increased by manipulation (increasing) of one or more of the PIP, PEEP, Ti. If oxygenation is adequate or high, then the values can be *decreased* to reduce MAP. So although MAP is a *measured* value in conventional modes, it *can* be manipulated by changing the parameters that make up its formula as seen in Appendix 1.

As stated, the relationship between the Ti and Te is expressed as the I:E ratio. E.G. – If the Ti is 0.5 seconds and the rate is 60, the Te will also be 0.5 seconds. The I:E ratio will therefore be 1:1. With a lower Ti of 0.4, a rate of 60 will mean a Te of 0.6 with an I:E ratio of

1:1.2 (Appendix 2). The ventilator will measure the total number of breaths detected and delivered by the ventilator (mechanical and patient triggered). The number of patient triggered breaths is usually displayed separately and is an indication of neonatal respiratory effort.

Volume is also measured and gives us valuable information about the dynamics of ventilation. The tidal volume (Vt) is the volume of gas delivered to the lungs in one breath and is measured as the expired V in milliliters (mls). Minute volume Vmin (l) is the accumulated expiratory tidal volume over a one-minute period. Vt multiplied by the rate gives the minute volume (Vmin); this has a direct influence on CO2 clearance in that by increasing either the rate or Vt (or both) will increase removal of CO2. However, this will not work if the CO2 is high due to over distension and/or impeded pulmonary venous return. Such actions could in these cases hamper C02 removal. Generally, the opposite works to slow CO2 removal – i.e. decreasing rate and Vt or both. Therefore being mindful of the neonate's underlying pathophysiology is essential (45).

The difference between the inspiratory and expiratory flow expressed as a percentage leak and can indicate the need for endotracheal tube change. Further lung dynamics are also monitored by measuring the resistance; the total change in the applied pressure to the lung divided by the maximum flow into the lung (resistance to flow); and Compliance; the ratio of the change in lung volume to change in the applied pressures. Oscillation measurements comprise the total rate or frequency (bpm), Vt, Vmin, leak, MAP and oxygen. Graphical representations of the dynamics of the neonate's breathing

pattern can be seen on the ventilator display screen. As stated, Figure 3 (a and b) shows pressure graphs for both conventional and high frequency ventilation.

A summary of all modes discussed including what is both set and measured can be seen in Appendix 3; Summary of settings and measurements for ventilation modes.

Decision making in neonatal ventilation

Selecting or switching modes of ventilation

The decision to move a neonate from one strategy to another is influenced by the severity and progression of the neonate's underlying condition, lung pathology and the response to ventilation changes and attempts at weaning. Gestation, birth weight and age should also be considered. This emphasizes the importance of matching ventilation strategies to the underlying pathophysiology (45) and individualized factors applicable to each neonate. The type or level of a specific unit in which a neonate is delivered or admitted also needs to be considered as this will determine the level of support and strategies available. If a unit is only able to deliver special care, transfer may be necessary to a higher level unit and the type of ventilation may then be determined by unit practices and trends of use of various modes. A UK wide survey of ventilation strategies within 54 tertiary level neonatal units was undertaken (46) and found that the use and availability of modes to be variable. 98% response to a structured questionnaire found that pressure controlled ventilation was most frequently used as the primary form of ventilator support (69.8%) compared to volume targeted (24.5%) and HFOV (5.7%). Similarly, an international survey of 50 tertiary units in Australia, New Zealand, Sweden,

Denmark, Finland and Norway evaluating the use of volume targeted ventilation again found that use was variable (47) ranging from 40-60% of units. The most common reason cited for it's use was the reduction in BPD. Overall, it is clear that no single ventilation mode or strategy has shown to have a truly significant benefit in terms of mortality or chronic lung disease (CLD) (19, 48). Moreover, while there is a wealth of research on ventilation strategies, each individual neonatal unit will be unique in their application of research data, preferences, patient specific population and unit outcomes.
However for any neonatal unit, accurate patient assessment is of vital importance for the decision making process. This is a key element in coming to a diagnosis but also to gain a full picture of how compromised the respiratory system is as well as the other related systems, on which to act and transfer appropriately if necessary.

Decision Making Tools for neonatal ventilation practice

Various tools exist in neonatal ventilation practice to guide and inform decision making in practice. However, they should never replace a holistic approach to care of the neonate and family. Careful consideration of each neonate should always remain paramount. Nonetheless, nurses can be assisted in their practice by tools that can facilitate understanding of interventions their neonates undergo. Tools may provide clarification and guidance at a novice level which may serve to facilitate safer practice. Appendix 4 gives an example of a tool in the form of a blood gas algorithm including normal and abnormal values. Whatever tool is employed however, assessment is central when deciding what modes and parameters are suitable for any specific neonate. While it is difficult to set standard regimes for ventilator management of all neonates, some general principles can be useful. Some of these principles have already been discussed

in line with the specific ventilator settings previously. To re-iterate, for example, oxygenation can be addressed by manipulating the MAP. CO2 clearance can be manipulated by controlling the minute ventilation by either changing the tidal volume with each breath or the rate or both. Changes to pressures will also affect the tidal volume – i.e. the two variables of pressure and volume are closely related. Since the Vt in and out is the volume of gas moving between the PEEP and PIP, then making changes to either of these will alter the Vt. (e.g. – increasing PIP alone will increase Vt and vice versa. Decreasing PEEP alone will increase Vt).

Making changes to ventilation parameters

Overall, changing ventilation parameters is based on assessment in the first instance of both blood gas analysis and clinical picture. Then, the initial question to ask is ''what am I trying to achieve?'': is it the need to change oxygenation, CO2 or both? Other questions may be: What is the target oxygen saturation? What does the neonate look like – for example, chest movement, and synchrony? Do ventilation requirements need increasing or decreasing or remain static? Balance is Important or in other words, in line with protecting the lungs, there is a need to balance the ventilator settings. For example, if a neonate is in 100% oxygen but with low pressures settings, it may be preferable to reduce the FiO2 but increase the pressures. Similarly, if the neonate is on high pressure settings but a low rate, it may be better to give a faster rate and lower pressures.

A full summary of the principles behind changing ventilation can be seen in Figure 4. The clinical application of how changes are made in practice can be seen in Case Studies 1, 2 and 3.

Figure 4: Changing ventilation – A general guide (References 10, 12, 49 & 50)		
Manipulating oxygenation MAP controls oxygenation. *So oxygenation can be influenced by changing any of the variables that alter MAP (PIP, PEEP, Ti and Te)*		
CONVENTIONAL VENTILATION		
DESIRED OUTCOME	**AIM & POSSIBLE ACTIONS**	**EVALUATION**
To increase oxygenation (increase MAP)	Increase Fi02 in increments of 5-10% Increase MAP by increasing PIP or PEEP in increments of 1-2 cm H20 Increase Ti but no higher than 0.4 seconds for preterm neonates Consider adding PSV, if on SIMV Consider starting HFOV if Map and Fi02 significantly increase	Observe oxygen requirement, pulse oximetry or transcutaneous oxygenation and pa02 on blood gas analysis. Look for improvements in lung compliance; e.g. chest expansion Observe pulmonary dynamics / graphs – e.g. volume / pressure loop and pressure graph
To decrease oxygenation when condition improves and/or during weaning (decrease MAP)	Aim to get Fi02 to an acceptable level Reduce MAP by reducing PIP or PEEP(again, in small steps of 1-2 cm H20 at a time) Ti can also be reduced slightly aiming for range 0.36- 0.4 seconds for the preterm neonate Stop PSV if this has been added to another mode Change mode to a 'trigger' mode that synchronizes spontaneous breaths and / or responds to a trigger threshold and neonate's own breathing.	As above
Manipulating CO2 elimination *Minute volume (Vmin) controls C02 elimination. CO2 levels will be influenced by any changing measure which affects Vmin i.e. manipulating the rate, Vt or both will alter the Vmin*		
To clear more C02 CO2 elimination will be improved by any measure which increases respiratory Vmin (i.e. increasing the rate, Vt or both will increase the Vmin)	Increase rate (in increments of 5-10bpm) to increase minute volume and remove more C02. OR increase PIP (in steps of 1-2 cm H20) with caution which will increase Vt for each breath and increase Vmin. Decrease PEEP; However, this may cause a reduction in oxygenation which needs to be observed. In addition, if CO2 is increased due to atelectasis, decreasing the PEEP may worsen the situation and increase C02; again this needs to considered If on VG (TTV), increase set or desired Vt	Observe measured Vt and Vmin on the ventilator Check CO2 on blood gas analysis and or Tc monitoring

To clear less C02 when weaning – CO2 elimination will be reduced by any measure which decreases respiratory Vmin (i.e. decreasing the rate, Vt or both will decrease the Vmin)	Reduce rate in increments of 5-10 bpm. And / or reduce PIP (in steps of 1-2 cm H20) Consider reducing PEEP as the PIP is reduced Reduce set / desired Vt if VG (TTV) is being used	As above
HIGH FREQUENCY OSCILLATORY VENTILATION		
DESIRED OUTCOME	**AIM & POSSIBLE ACTIONS**	**EVALUATION**
To increase oxygenation	Increase Fi02 in increments of 5-10%. Increase MAP in increments of 1-2 cm H20	As for conventional ventilation. Ensure chest x-ray is done after being put onto HFOV
To decrease oxygenation when weaning	Aim to get Fi02 to an acceptable level Reduce MAP in increments of 1-2 cm H20	As for conventional ventilation
To clear more C02	Increase amplitude (Delta P) in increments of 2-5cm H20 according to blood gas (CO2) and chest wiggle OR decrease frequency (Hz) allowing greater efficiency of oscillations to reach the peak and trough of the pressure wave	As for conventional ventilation Observe for adequate chest wiggle / bounce
To clear less C02 when weaning –	Reduce amplitude in increments of 1-2 cm H20 according to blood gas (CO2) and chest wiggle	As above

NB: Suggested actions and changes should be based on assessment of the individual neonate

One important change in ventilation practice is the weaning of support. In essence, weaning a neonate from a ventilator should be a central objective at the point of intubation and should be commenced as soon as possible in line with a protective lung strategy. However, it is reported that approximately 30% of intubated neonates may fail attempted extubation (51) and so, bearing in mind the clinical implications of this, appropriate decision making for weaning must be employed. Strategies for weaning

include any change to any parameter that facilitates the neonate taking control of their own ventilation. Weaning can be done on any mode mentioned thus far, with the exception of CMV which should be changed to a synchronized or trigger mode as soon as possible. Oxygen should certainly be weaned down within any mode of ventilation to the minimum requirement needed for adequate oxygenation of the neonate. The Ti should be bought down to the minimum, to be as close as possible to the neonates own physiological time. SIMV has been found to be the most common mode in practice and therefore it follows that this mode is most commonly used for weaning (5). In this mode, rate, pressure or both are reduced in increments depending on individual assessment of blood gas analysis and clinical picture. If PS is turned on, the % pressure support is gradually reduced until this is eventually switched to off, so that the neonate's breathes are no longer supported. Some clinicians prefer to wean from PTV / A/C mode as this has been found to be associated with a shorter duration of weaning (14). In this mode, pressure alone is reduced. If PSV is used, similarly the level of pressure support is reduced gradually. In A/C or PSV, since the neonate controls the ventilator rate, reducing the ventilator rate has no effect on delivered rate unless respiratory effort is poor or the back-up rate is greater than the spontaneous breathing rate.

Weaning from VG ventilation automatically weans the PIP as lung function improves (3-5). The only parameters that should be altered during weaning are the FiO2 and the set Vt. When the set Vt is below the neonate's spontaneously generated Vt, the PIP will be reduced. This may mean that the neonate will then be breathing on CPAP via the ETT, potentially increasing the work of breathing and the risk of subsequent extubation failure due to fatigue (8). If this is observed for more than short periods, extubation should be

considered [7, 52, 53]. Extubation is considered if the MAP is consistently <8 to 10 cm H2O with set Vt T 3.5 to 4.5 ml kg with satisfactory blood gases (8). Readiness for extubation can also be ascertained by assessing the neonate's spontaneous breathing (54).

To serve as a guide, protocol led care has been recommended (11, 55). Overall however, there does not seem to be any one strategy that is recommended for weaning (55, 56, 57). In relation to any weaning strategy, *k*ey questions should be considered as seen in Figure 5. Always important to emphasize here, that whatever strategy is chosen, each change must have rationale. Moreover, the individualized evaluation of any change made is vital in order to know if this has been effective in the best interest of the neonate.

Figure 5; Considerations when weaning ventilation

NB: As before, suggested actions should be based on assessment of the individual neonate and evaluation of any change made is a key part of the weaning process

AIM: To wean any neonate from positive pressure ventilation as soon as possible in line with protective lung strategies, to avoid potential damage from long-term or unnecessary ventilation

If a mandatory mode (CMV) is in use, is the neonate making spontaneous efforts to breath relative to the ventilator supported breaths so that a synchronized / trigger mode can be employed; e.g. SIMV, PTV, TTV, PS? Determine this by observing breath rate noting the ventilator breathes verses neonates own breaths. In addition, one can observe the number of measured 'triggered' (baby controlled) breathes on the ventilator

If no, the neonate may not be ready to wean

If yes

CONSIDER;

- Have the blood gas values normalized? See Figure 5 for possible changes to ventilation during weaning in line with oxygenation or CO2 elimination or both. Wean whichever parameter is appropriate
- Has the oxygen requirement improved, preferably below a Fi02 of 0.6 (60%) – reference? Wean down oxygen as tolerated
- Has the compliance of the lungs improved, determined by observing chest expansion, and expanded lung fields on chest x-ray, ….
- If on VG, is the PIP needed to reach the target volumes decreasing?
- Have any opiates or sedatives that could affect respiratory drive been stopped?
- Has the neonate been started on respiratory stimulants (for example Caffeine) to increase their respiratory drive, according to their gestation & individual unit policy

If no to any of these questions, the neonate may not be ready to wean

If yes

Continue to waen either pressure, rate or other parameters in stages appropriate to the mode of ventilation

Evlauate the effect of each change

Prior to extubation, are the ventilator settings low enough to be close to the neonate's physiological parameters (PIP 16-18 cm water/ PEEP 4-5 cm water: MAP < 10 and minimal oxygen requirement, preferably able to ventilate in air)?

Extubate when appropariete based on the above requirements

Following extubation, continue to assess and evaluate regularly

Ventilation focused Case Studies

Case Study 1: CMV, SIMV, SIMV plus PSV and PSV

Baby John was a preterm neonate born at 27 weeks gestation (birth weight 1kg) by spontaneous vaginal delivery. The neonate's mother received a course of antenatal steroids on admission to hospital; the aim was to enhance surfactant maturation and reduce the severity of respiratory distress syndrome. The neonate was rigorous and active at birth, spontaneously breathing and required no resuscitation except for some stimulation and prevention of heat loss. He was placed onto binasal CPAP with a pressure of 5 cm H20 and 35% oxygen to maintain an oxygen saturation (Sa02) target of 89-93%. An initial arterial blood gas (ABG) showed; pH 7.3, pa02 64mmHg (8.5kPa), CO2 45mmHg (6kPa), Base -2 and bicarbonate 22 mEq/L; all within satisfactory limits (See Appendix 4).

However, six hours later, the neonate started to show signs of tachypnea, chest recession and nasal flaring with poor saturations and an increasing oxygen requirement. The ABG showed a respiratory acidosis; pH 7.2, pa02 57mmHg (7.6kPa), CO2 67mmHg (8.9kPa), Base -3 and bicarbonate 21 mEq/L. Therefore the CPAP pressure was increased to 7cm H20 with a biphasic level added after the ABG an hour later failed to show any significant improvement. This continued and along with both the clinical assessment and a chest X-ray led to a diagnosis of respiratory distress syndrome.

The decision was made to intubate and ventilate the neonate to provide respiratory support and to enable surfactant to be administered. Following intubation, Baby John made little spontaneous effort and CMV was commenced (PIP 22, PEEP 5, Ti 0.4, rate 60). The ABG improved an hour later; pH 7.31, pa02 60mmHg (8kPa), CO2 5.6 Base -2 and bicarbonate 22 mEq/L. After 8 hours, the CXR appearance, lung expansion and ABG values showed improvement. Baby John was also spontaneously breathing but appeared to be in asynchrony with the ventilator breaths exhibiting signs of discomfort. The mode was therefore switched to SIMV to allow the ventilator breaths to be synchronised to his breaths. He remained stable on this mode through the night enabling the pressures and Ti to be reduced in increments to avoid any undue excessive expansion of the lungs. By the morning the settings were; PIP 20, PEEP 4, Ti 0.35, rate 55. The measured Vt was adequate at 4-6mls / kg; spontaneous breathing was approximately one third of the total breaths with synchrony evident on clinical assessment.

By the afternoon, two doses of Surfactant had been administered and he was stable on SIMV; the rate was turned down to 40 as the C02 on the blood gas was satisfactory and Baby John was making good spontaneous efforts between the ventilator breaths. Later, the pressure settings were reduced to 18/4 to limit the applied pressure to the lungs as much as possible. There was good chest expansion and sound clinical assessment at this time with adequate oxygenation (Sa02 and pa02).

Later that day however, a follow up gas was not acceptable with a developing mixed acidosis evident. Therefore rather than increasing the SIMV rate, the decision was made to turn on PSV with SIMV to support Baby Johns breaths at 100% of the set PIP. In other words, the ventilator was set to deliver 40 breaths at 18/4 with all Baby Johns' own breaths supported at this pressure and Ti. This was effective as the blood gases stabilised.

PSV allowed additional support for this neonate who appeared to be becoming tired on SIMV alone. Rather than increasing the settings, adding this additional mode allowed such support without having to increase pressures again. The oxygen requirement throughout the above period had been between 45-55% and after 8 hours on SIMV with PSV, the oxygen requirement was reduced and stable at 40-45%.

Over the course of the next 2 days, the PSV level was slowly reduced in increments to 50% of the set PIP- i.e. the neonates breaths were supported to 50% of the PIP set in the ventilator. Assessment was satisfactory and when the neonate was 5 days old, he was able to be weaned further from the ventilator settings. Since he was making a good spontaneous effort, the decision was made to wean on full PSV; this meant that Baby John controlled his own rate and Ti and the ventilator supported every triggered breath with pressures of 18/4. This pressure was slowly weaned down to 16/4 with an oxygen requirement of 35-40% until he was ready to be extubated to CPAP at the age of 6 days.

Case Study 2: SIMV with VG and A/C

Baby Faye was born spontaneously at 25 weeks gestation to an unbooked mother who presented in precipitous labour and did not receive any antenatal steroids. The neonate had then spent a difficult period on high ventilation requirements leading to a diagnosis of Chronic lung disease of prematurity with patchy appearance of pulmonary interstitial emphysema throughout both lungs. She was now 4 weeks old weighing 900 grammes and continued to be ventilated on SIMV – PIP 23 PEEP 5, Ti 0.36 and a rate of 50. The capillary blood gas showed a picture of permissive hypercapnia accepting a higher than normal CO2 with a pH maintained higher than 7.25 and preventing over ventilating the premature lung; pH 7.28, pa02 37.5mmHg (5 kPa)(capillary), CO2 66mmHg (8.8 kPa) Base +5 , bicarbonate 32 mEq/L. In addition, this gas shows compensation had occurred.

However, it was not possible to wean any further than this as Baby Faye became unstable after any attempts to change the ventilator settings. The last attempt to wean down the pressures led to a drop on Sa02 and a worsening pH of 7.22, below the acceptable range. It was also noted that the measured Vt was very variable and often much lower than 4mls / kg even when the PIP was increased. Therefore, the decision was made to switch on volume guarantee and a target Vt was set at 4ml/kg (3.6 mls); the aim was to achieve a balance between ensuring delivery of an adequate volume whilst also being mindful of limiting the Vt to prevent any further damage from volutrauma. This also allowed the lung volumes to be optimised but at the lowest possible pressures and reducing the incidence also of barotrauma.

On assessment, measured PIP was in a range of 18-20 cm H20, lower than the previous settings on SIMV. However, the pH and PaCO2, although did improve to some degree, did not revert back to the previous acceptable values; pH hovered around 7.24-7.25. Therefore, to optimise the Vt further, the target Vt was increased to 5mls / kg (4.5 mls). The measured PIP continued to remain acceptable and blood gases then improved with greater clearance of CO2. pH was then stable at 7.25-7.28.

Over time, the above situation continued and Baby Faye was then able to be weaned with a gradual reduction of the ventilator rate in increments of 5cm H20.

After 2 weeks, the mode was changed to A/C (PTV) allowing her to control her own rate since she was now 6 weeks old. Overall, this case study shows how the complexity of the lung condition and the associated chronic changes in the preterm neonate necessitates significant support over a lengthy period of time. However, in order to synchronise and tailor the ventilation to a neonate's own efforts while optimising Vt, using a trigger or synchronised mode along with VG can allow this.

Case Study 3; SIMV, HFOV, A/C (PTV)

A term neonate (birth weight 4kg) was born in poor condition in thick meconium following a prolonged and difficult labour. The neonate, Baby Ahmed, required full resuscitation measures at birth and was intubated and ventilated in delivery suite with a subsequent transfer to the neonatal unit. He was ventilated on CMV mode requiring PIP 26, PEEP 5, Ti 0.4 and a rate of 45. ABG showed a severe mixed acidosis; pH 7.1, pa02 37mmHg (4.9kPa), CO2 70mmHg (9.3kPa) Base -8 and bicarbonate 16 mEq/L. The PIP was therefore increased to raise the MAP aiming to increase oxygenation. However, no change was observed to Baby Ahmed's condition or oxygenation and the measured Vt which did not improve regardless of any change in PIP. All parameters continued to be increased until the settings were; PIP 30, PEEP 6, Ti 0.5 and a rate of 45. The required Fi02 was 0.8 (80%) to maintain Sa02 at a range of 95-100% for a term neonate. The measured MAP was 16 and Vt was 12 mls; i.e. only 3mls / kg). Therefore the decision was made to switch Baby Ahmed to HFOV to enable a higher MAP while avoiding excessive lung expansion from any higher PIP and shearing forces of conventional ventilation at high pressures and Ti. Settings were; MAP 18 cm H20, Amplitude 40, Frequency 10 Hz, Fi02 0.75 (75%); set to maintain a MAP 2 cm H20 higher than the previous conventional ventilation and to observe adequate chest wiggle or bounce.

This continued for an 8 hour period during which time, the clinical picture and the blood gases started to improve. Chest X-ray showed god lung expansion. The amplitude was able to be reduced as chest wiggle as pronounced and CO2 started to decrease. Oxygenation was slower to improve but after a 24 hour period on MAP of 18, the Fi02 could be reduced to 0.6 (60%). The Pa02 then also started to increase in value and continued to do so aver the next 24 hours. During this time, the MAP was slowly reduced by increments of 1-2 cm H20 until this reached 14 cm H20. Oxygen requirement was now 50-60%.

Baby Ahmed has started to attempt to take spontaneous efforts on day 3 of life – therefore the decision was made to switch from HFOV to a conventional but trigger (synchronised) mode of ventilation. A/C (PTV) was given as a weaning mode for Baby Ahmed who from this point started to clinically improve. The pressure was reduced in increments as it was futile to reduce the rate since he was breathing above the backup rate. On day 5 of life, Baby Ahmed was able to be extubated onto a short period of nasal CPAP until lungs has significantly improved and all meconium had cleared. By day 6, he was self ventilating in air.

Current strategies to reduce lung injury

The importance of a protective lung strategy has been highlighted throughout the paper so far. To finish, it is worth re-iterating this issue as an integral component of ventilation practice. Ultimately, we must achieve a *balance* between providing optimum respiratory status and support while avoiding over-ventilation or unnecessary length of time on mechanical ventilation and the associated effects on the neonate. When deciding how to deliver optimum ventilator support to neonates, it is important to be aware of these potential negative effects of ventilation and place emphasis on prevention of these; for example: lung injury from barotrauma (pressure) and / or volume (volutrauma) leading to chronic lung disease, oxygen toxicity, hypotension, lung hyperinflation, air leak and nosocomial respiratory infection. Again bedside assessment and monitoring is the key to ensuring any negative effect is identified as soon as possible – e.g. CXR findings, blood pressure, avoiding high oxygen concentrations and continuous o2 monitoring. Current strategies must also have these dangers as a central consideration. As stated above, chronic lung disease (CLD) or BPD is one of the most common long-term complications in very premature infants (50, 58). There has been a revolution in the therapies that are used, either to manage initial respiratory distress syndrome (RDS) with an aim to prevent CLD or to manage the established condition and several devices and strategies have been developed to provide respiratory support with reduced risk of lung injuries. These protective lung strategies include the use of non-invasive ventilation modes such as CPAP and BiPhasic CPAP and minimizing both oxygen delivery along with pressure and volume from the point of birth and beyond (refs). Brown and DiBlasi (19) summarize the key to protecting the neonatal lung during mechanical ventilation is to optimize lung volume, limit excessive expansion, apply appropriate end pressure, use shorter inspiratory

times, smaller tidal volumes and allow permissive hypercapnia appropriately. All these protective lung strategies are clearly seen within all 3 Case Studies 1,2 and 3 highlighting how, within each of the modes included, the differences in management and decision making between conditions but also the vital considerations around minimizing lung damage as much as possible.

Conclusion:

Technological advances have resulted in improvements in ventilators and strategies that are more sophisticated to be in- synchrony with the neonate's own efforts aiming to limit the damaging effects by pressure and / or volume trauma. Those caring for such sick and vulnerable neonates owe it to them and their families to have a full understanding of common but often complex practices such as ventilation practice while at the same time work towards minimizing any resultant damage and respiratory morbidity.

Knowledge of the modes and terms used in neonatal ventilation practice is valuable since this practice comprises a significant proportion of care given to sick neonates and their families within the neonatal unit. It has not been possible to discuss the *care of* neonates in relation to ventilation modes nor discuss the detail of underlying neonatal physiology. Rather the aim is for the reader to have a basic underlying foundation of knowledge in ventilation practice so they have the rationale for the care they learn about within the clinical area as well as to gain a basis for further learning. The decision to place a neonate onto a specific type of ventilation strategy, and /or change a mode or parameter depends on a complex interplay of factors. It is vital that effective clinical decisions are based on valid, sound judgments which consider the neonate's clinical assessment cues including sound evaluation on an ongoing basis. Finally, ventilation

practice and decision making must be supported by best evidence based rationale not only so that health professionals can learn and progress but also so that parents are given information about the strategies their neonates receive and the outcomes, a vital component of true family centered neonatal care.

APPENDIX 1: Ventilation Terminology - Useful formulas and definitions (adapted from 49, 59 & 60)		
Parameter	**Definition**	**Formula if applicable & further information**
Parameters that influence adequate ventilation status		
Fraction of inspired oxygen (Fi02)	How much oxygen is delivered – expressed as a fraction of 1. Can also be expressed as a percentage.	Multiply Fi02 by 100 to calculate the percentage oxygen delivered e.g. Fi02 of 1 = 100% oxygen Fi02 of 0.3 = 30% oxygen
Mean Airway pressure (MAP)	The total pressure (in cm H20) within the lungs throughout the respiratory cycle as determined by PIP, PEEP, Ti and Te. Along with Fi02, this influences oxygenation	$MAP = \frac{Rate \times Ti}{60} \times (PIP + PEEP) + PEEP$ Pressure is displayed graphically on the ventilator's pressure graph
Tidal Volume (Vt)	The volume of gas entering the lungs in one breath. Expressed in milliliters (mls)	Recommended Tidal volume (Vt) = 4-6mls / kg (reference: 19) Vt is displayed graphically on the ventilators Vt graph
Minute volume (Vmin)	The volume of gas entering the lungs over one minute expressed as liters/ minute. Minute volume affects CO2 elimination	Vmin = Vt – dead space x rate (49)
Ventilator parameters (Conventional)		
Rate	The number of breathe delivered in a minute – as breaths per minute (bpm)	Set by a dial or touch screen or set independently by adjusting Ti and Te – See Appendix 2. Range delivered can be 20 up to greater than 70
Peak inspiratory pressure (PIP)	The peak pressure reached at the end of inspiration (cm H20)	Aim to keep as low as possible, ideally less than 20 cm water (H20); if greater than 25-30 cm H20, HFOV is considered.
Positive End Expiratory pressure (PEEP)	The end pressure reached at the end of expiration (cm H20)	Normal range is 4-6 cm H20 although some neonates may need up to 7-8 cm H20 depending on the underlying pathophysiology (50)
Inspiratory time (Ti)	The inspiratory time of one respiratory cycle expressed in seconds	This should be kept short particularly when using high rates (44, 50) Range is 0.35-0.4 seconds (6)
Expiratory time (Te)	The expiratory time of one respiratory cycle expressed in seconds	With a constant or pre-determined Ti, the Te will vary depending on the required rate (see above)
I:E ratio	The ratio of inspiration to expiration time	Te should be longer than Ti (50)
Flow	The flow of gas delivered. Expressed as liters per minute (L/min). Ventilators will measure inspiratory and expiratory flow.	Flow is displayed graphically on the ventilators Flow graph

Trigger threshold	The sensitivity of the ventilator and flow sensor to detect the neonate's breaths.	In most ventilators, this is a flow trigger i.e. - The threshold of flow that needs to be registered by the ventilator to detect the neonate's spontaneous breathing.
Leak	Flow that is lost from the respiratory circuit	Measured as the difference between inspiratory and expiratory flow
Parameters in High Frequency Oscillation Ventilation (HFOV)		
MAP	As above – controls oxygenation along with Fi02	Set using the PEEP control on some ventilators that deliver both conventional and HFOV modes. Set according to pressure requirements on conventional mode (1-2 cm higher)
Frequency	Measured in Hertz (Hz) – there are 60 oscillations in 1 Hz	Set at a range of 8-10 Hz
Amplitude	The variation round the MAP. Also known as delta P or power and affects chest 'wiggle'. Controls CO2 elimination	Set according to extent of chest wiggle / bounce and blood gas analysis
Other ventilation Terms		
Oxygenation index (OI)	A calculated value to determine a neonate's oxygen demand and associated level of oxygenation. Used as criteria for NOi and /or ECMO in the very sick newborn.	OI= MAP (cm H20) X Fi02 X 100 Pa02 (mmHg) x 100 (References 59 & 60)
Functional residual capacity (FRC)	The volume of gas present in the lung alveoli at the end of passive expiration.	FRC is reduced in conditions such as respiratory distress syndrome (RDS) where there is poor lung compliance. A low FRC will affect optimum gaseous exchange.
Compliance	The elasticity or distensibility of the respiratory system including the lungs and chest wall.	Compliance = volume / pressure The volume / pressure loop displayed on some ventilators represent this relationship graphically.
Resistance	The capability of the airways and endotracheal tube to oppose airflow. Expressed as the change in pressure per unit change in flow	Resistance = pressure / flow Again, this is displayed graphically on some ventilators.
Pulmonary Dynamics	The real-time graphical representations of the neonate's ventilation parameters	As stated above, graphs can be viewed within the Graph section of the ventilator of pressure, Vt, flow, compliance and resistance. These can also be termed waveforms, loops, mechanics and / trending displays, all of which represent the neonate's ventilation status in real-time

NB: All measurements and graphical displays of parameters are dependent on the presence of a Flow sensor. Absence of a flow sensor will mean the ventilator will still deliver breaths but there will be no 'measured' readings

APPENDIX 2- SETTING THE RATE USING Ti and Te

Setting a rate using inspiration and expiration times

Confirm desired rate

Divide this into 60

From this figure, subtract the inspiratory time (Ti)

This gives you the expiratory time (Te) that you need to set to get your desired rate

Example 1 - You want a rate of 60 and Ti of 0.4 seconds.

60 divided by 60 = 1 second

1 minus 0.4 = 0.6 (set the Te at 0.6 second))

This will give you a rate of 60

Example 2 – You want a rate of 40 and Ti of 0.5

60 divided by 40 = 1.5 seconds

1.5 minus 0.5 = 1 second (set the Te at 1 second)

This will give you a rate of 40

APPENDIX 3; Summary of settings and measurements for ventilation modes

Adapted in part from Habre (6)

MODE	SETTINGS	MEASUREMENTS
CMV	Rate (BPM), PEEP, PIP, Ti, Oxygen, High and low alarm pressure thresholds, Vt alarm threshold Vmin minute volume high and low alarm thresholds	I:E ratio, Texp measured, rate (BPM), Vt, Vmin, leak, resistance, compliance, and PIP / PEEP, MAP. Recorded breath rate is what is set, not what the neonate does.
SIMV	Rate (BPM), Apnoea time (if backup breath rate is less than 20 breaths) per minute or lower, PEEP, PIP, Ti, oxygen, trigger threshold, high and low alarm pressure thresholds, Vt alarm threshold, Vmin high and low alarm thresholds	Ti measured, total rate (BPM), trigger (number of neonate's triggered breaths), Vt, Vmin, leak, resistance, compliance and PIP / PEEP, MAP
PTV / A/C	Back up rate (BPM), Apnoea time (if backup breath rate is less than 20), PEEP, PIP, Ti, oxygen, trigger threshold, high and low alarm pressure thresholds, Vt alarm threshold, Vmin high and low alarm thresholds	Ti measured, total rate (BPM), trigger (number of neonate 'triggered' breaths), Vt, Vmin, leak, resistance, compliance and PIP / PEEP, MAP
PSV	Back up rate (BPM), Apnoea time (if backup breath rate less than 20), PEEP, PIP, maximum Ti, oxygen, flow termination sensitivity, trigger threshold, high and low alarm pressure thresholds, Vt alarm threshold, Vmin high and low alarm thresholds	Ti measured, total rate (BPM), trigger (number of neonate' triggered' breaths), Vt, Vmin, leak, resistance, compliance and PIP / PEEP, MAP, oxygen
SIMV + PS	As for SIMV above but turn PS to 'on' and set % of pressure support plus flow termination sensitivity	Ti measured, total rate (BPM), trigger (number of neonate's triggered breaths), Vt, Vmin, leak, resistance, compliance and PIP / PEEP, MAP, oxygen
VG / TTV	As for these modes above but turn on TTV and set Vt required for each breath.	As for each mode above plus 'measured' PIP (will vary)
HFJV	Set short bursts with short Ti, frequency and flow	See below as for HFOV
HFOV	HFO rate (in hertz), Mean pressure, Pressure amplitude (or Delta P), oxygen, High and low alarm pressure thresholds, Vt alarm threshold and Vmin high and low alarm thresholds	Rate (BPM) total, Vt, Vmin, leak, MAP and oxygen
CMV PLUS HFOV	BPM, Ti, PIP, PEEP, HFO rate, HFO activity (oscillations in inspiratory and expiratory phases or expiratory phase only), Pressure amplitude (Delta P), oxygen, High and low alarm pressure thresholds, Vt alarm threshold, Vmin high and low alarm thresholds	I:E ratio, Texp measured, rate (BPM) and HFO rate, and PIP / PEEP, MAP and oxygen
NAVA	Trigger threshold to pick up electrical diaphragmatic activity. Adapt NAVA level to regulate pressure support (6)	As for above

NB – other modes of ventilation are less commonly cited in the literature and so are not included in this paper; for example, volume controlled ventilation, volume limited ventilation, pressure regulated volume control, volume assured pressure support (VCV, VLV, PRVC, VAPS respectively) and high frequency flow interruption (HFFI); Refer to key literature for more information (4, 6)

APPENDIX 4:

Interpretation of Blood gases in the neonatal unit

4 (a) BLOOD GAS VALUES (Adapted from references 61-66)

Values are expressed in both kPa *and* mmHg for PaO2 / PaCO2 and in mEq/L *and* mmols for bicarbonate to account for differences between countries.

In relation to values, different sources may cite slight variations

	pH	C02	02	Bicarbonate	Base	References
CORD (arterial)	7.25 - 7.28	48 mmHg 6.5 kPa	18-22.5 mmHg 2.4 -3 kPa	n/a	-4	35, 36
CORD (venous)	7.28 – 7.35	35-45 mmHg 5-6 kPa	27-38 mmHg 3.8 -5 kPa	n/a	-4	35, 36
NEONATAL (arterial)*	7.35 – 7.45	35-45 mmHg (38) 4.6 –6 kpa	50-90 mmHg 7-12 kpa Term 50-80 mmHg 6.5–10.5kpa Preterm	22-26 mEq/L Term 20-24 mEq/L Preterm(38) Or 22-26 mmols (39)	+2 to -2	37, 38, 39

FOR 'Uncompensated' gas (i.e. pH is abnormal)

Low ph & high C02 =- respiratory acidosis
Low pH and large base deficit /low bicarbonate. = metabolic acidosis
High pH and low CO2 = respiratory alkalosis
High pH and large base excess /high bicarbonate = metabolic alkalosis
= mixed acidosis

FOR 'compensated' gas (i.e. ph is normal but other values are out of range)

PH	CO2	Bicarbonate	Problem
Low normal	High	High	Compensated Respiratory acidosis
High normal	Low	Low	Compensated Respiratory alkalosis
Low normal	Low	Low	Compensated Metabolic acidosis
High normal	High	High	Compensated Metabolic alkalosis

Permissive Hypercapnia

To avoid over ventilating the lungs, keep pH > 7.25
Watch base deficit and keep between -4 to +4 (50)

*NB Capillary venous neonatal sampling can also be considered for all values (pH, CO2, base and bicarbonate) except oxygenation status.

APPENDIX 4B BLOOD GAS ALGORITHM

(References 65 & 66)

1 - ASSESS pH

(Is the pH normal? If not, is it acidotic or alkalotic? – see values)

↓

2 ASSESS RESPIRATORY COMPONENT

Is CO 2 within normal range? See Appendix 4a

↓

3 – ASSESS METABOLIC COMPONENT

Is the bicarbonate within normal range and is there a large base deficit (a minus figure) or base excess (a plus figure). See Appendix 4a

↓

4 – ASSESS IF COMPENSATION HAS OCCURRED

(I.e. the PH has normalized but the other values are out of normal range)

↓

5 – ASSESS OXYGENATION (Pa02)

A low paO2 can contribute to a metabolic acidosis by anaerobic respiration by cells and lactic acidosis accumulation

Plus

CONSIDER LACTATE levels

↓

6 – INTERPRET AND MAKE PLAN OF ACTION

↓

7 - EVALUATE / RE-ASSESS

When to evaluate / re-check a blood gas depends on how abnormal the values are (50). If very abnormal OR a significant change has been made (e.g. Surfactant, HFOV has been commenced for example), the blood gas may need re-checking within 30 minutes. If the neonate is stable, then it will need re-checking less frequently. Decide on an individual basis following discussion with the clinical team.

References

1. Bellettato B, Carlo W, Rosenkrantz T, Carter BS and Windle ML. Assisted Ventilation of the Newborn. 2011 http://emedicine.medscape.com/article/979268-overview (accessed 12th February 2013)

2. Baert AL, Knauth M and Sartor K. *Radiological Imaging of the Neonatal Chest 2nd edition* 2008; Springer Berlin Heidelberg New York

3. HummlerHA and Schulze AA New and alternative modes of mechanical ventilation in neonates *Seminars in Fetal & Neonatal Medicine* 2009; 14: (1), 42-48.

4. Broster SC and Ahluwalia JS. Overview of assisted ventilation of the newborn *Paediatrics and Child Health* 2009; 19: 12, 537–543.

5. van Kaam AHA, Rimensberger PCA, Borensztajn DA and De Jaegere APA. Ventilation Practices in the Neonatal Intensive Care Unit: A Cross-Sectional Study *The Journal of Pediatrics* 2010; 157, 5 767-771.e3

6. Habre WA. Neonatal ventilation *Best Practice & Research Clinical Anaesthesiology* 2010; 24: 3, 353-364.

7. Schulzke SM, Pillow J, Ewald B, Patole SK. Flow-cycled versus time-cycled synchronized ventilation for neonates. Cochrane Database of Systematic Reviews 2010, Issue 7. Art. No.: CD008246. DOI: 10.1002/14651858.CD008246.pub2

8. Klingenberg et al (2011) Klingenberg C, Wheeler KI, Davis PG and Morley CJ. A practical guide to neonatal volume guarantee ventilation *Journal of Perinatology* 2011; 31, 575-585.

9. Mahmoud RA and Schmalisch G. Modern mechanical ventilation strategies in newborns: A review Technology and Health Care 2011; 19: 5, 307-318

10. Goldsmith JP and Karotkin E (2011) Assisted ventilation of the neonate (5th edition) Elsevier Sanders ST. Louis

11. Sant'Anna GM and Keszler M. Developing a neonatal unit ventilation protocol for the preterm baby *Early Human Development*; 2012; 88:12, 925-929

12. Donn SM and Sinha SK (2012) Manual of Neonatal Respiratory care 3rd Edition Springer NY, Dordrecht Heidelberg London

13. Claure N and Bancalari, E. New modes of mechanical ventilation in the preterm newborn: evidence of benefit *Arch Dis Child Fetal Neonatal Ed* 2007; 92: F508-512

14. Greenough A, Dimitriou G, Prendergast M, Milner AD. Synchronized mechanical ventilation for respiratory support in newborn infants. Cochrane Database of Systematic Reviews 2008, Issue 1. Art. No.: CD000456. DOI: 10.1002/14651858.CD000456.pub3.

15. Wheeler K, Morley CJ, Hooper SB and Davis PG. Lower back-up rates improve ventilator triggering during assist-control ventilation: a randomized crossover trial. *Journal of Perinatology* 2012; 32, 111-116

16. Grover, A and Field, D. Volume targeted ventilation in the neonate: time to change? *Arch Dis Child Fetal Neonatal Ed* 2006; 93: F7-F9

17. McCallion N, Lau R, Morley CJ and Dargaville PA Neonatal Volume Guarantee ventilation: effects of spontaneous breathing triggered and untriggered inflations Arch Dis Child fetal and neonatal Ed 2008; 93, F36-39.et al (2008)

18. Singh, J., Sinha, S. Volume-controlled ventilation in the newborn. *Infant* 2006; 2: (6), 229,30,32,33.

19. Brown MK and DiBlasi RM. Mechanical Ventilation of the Premature Neonate. *Respiratory care* 2011; 56: (9), 1298-1313

20. Cheema IU, Sinha AK, Kempley ST, Ahluwalia JS. Impact of volume guarantee ventilation on arterial carbon dioxide tension in newborn infants: a randomized controlled trial. *Early Hum Dev*. 2007; 83: (3), 183-9

21. Patel DS, Sharma A, Prendergast M, Rafferty GF, Greenough A. Work of breathing and different levels of volume-targeted ventilation. *Pediatrics* 2009 (a) ;123: (4), e679-84.

22. McCallion N, Davis PG, Morley CJ. Volume-targeted versus pressure-limited ventilation in the neonate. *Cochrane Database Syst Rev*. 2005;(3):CD003666.

23. Wheeler K, Klingenberg C, McCallion N, Morley CJ, Davis PG. (2010) Volume-targeted versus pressure-limited ventilation in the neonate. Cochrane Database of Systematic Reviews 2010, Issue 11. Art. No.: CD003666. DOI: 10.1002/14651858.CD003666.pub3.

24. Wheeler K, Klingenberg C, Morley CJ and Davies PG Volume-Targeted versus Pressure-Limited Ventilation for Preterm Infants: A Systematic Review and Meta-Analysis. *Neonatology* 2011; 100:219–227 DOI: 10.1159/000326080

25. Reyes ZC, Claure N, Tauscher MK, et al. Randomized, controlled trial comparing synchronized intermittent mandatory ventilation and synchronized intermittent mandatory ventilation plus pressure support in preterm infants. *Pediatrics* 2006; 118: (4), 1409-17.

26. Sarkar S, Donn SM. In support of pressure support. *Clin Perinatol*. 2007;34: (1),117-28, vii.

27. Gupta S, Sinha SK and Donn SM. The Effect of two levels of pressure support ventilation on tidal volume delivery and minute ventilation in preterm infants. *Arch Dis Child Fetal Neonatal Ed* 2009; 94: F80-83

28. Patel. DS, Rafferty. GF, Lee.S, Hannam.S and Greenough. A. Work of breathing during SIMV with and without pressure support *Arch Dis Child* 2009; 94: 434-436 doi:10.1136/adc.2008.152926

29. Bhuta T, Henderson-Smart DJ. Elective high frequency jet ventilation versus conventional ventilation for respiratory distress syndrome in preterm infants. Cochrane Database of Systematic Reviews 1998, Issue 2. Art. No.: CD000328. DOI: 10.1002/14651858.CD000328

30. Joshi VH, Bhuta T. Rescue high frequency jet ventilation versus conventional ventilation for severe pulmonary dysfunction in preterm infants. Cochrane Database of Systematic Reviews 2006, Issue 1. Art. No.: CD000437. DOI: 10.1002/14651858.CD000437.pub2.

31. Jones A (2011) High Frequency Jet Ventilation http://rc-edconsultant.com/ http://search.yahoo.com/r/_ylt=A0oG7huWECJRWBMArlFXNyoA;_ylu=X3oDMTE1a2FkOHJyBHNlYwNzcgRwb3MDMgRjb2xvA2FjMgR2dGlkA1NNRTA4MF8xNjc-/SIG=13d1l837r/EXP=1361215766/**http%3a//www.respiratorycare-online.com/lecture_series/jet_ventilation_mp3/HFJV_handout.pdf (accessed 18th February 2013)

32. Coates EW, Klinepeter ME, O'Shea TM. Neonatal pulmonary hypertension treated with inhaled nitric oxide and high-frequency ventilation. J Perinatol. 2008 Oct;28(10):675-9. Epub 2008 Jun 26.

33. Mainali ES, Greene C, Rozycki HJ, Gutcher GR. Safety and efficacy of high-frequency jet ventilation in neonatal transport. J Perinatol. 2007 Oct;27(10):609-13. Epub 2007 Aug 16.

34. Friedlich P, Subramanian N, Sebald M, Noori S, Seri I. Use of high-frequency jet ventilation in neonates with hypoxemia refractory to high frequency oscillatory ventilation. J Matern Fetal Neonatal Med. 2003 Jun;13(6):398-402

35. Froese AB and Kinsella JP. High-frequency oscillatory ventilation: Lessons from the neonatal/pediatric experience *Critical Care Medicine* 2005; 33: (3) (suppl), S115-S121

36. Cools F, Henderson-Smart DJ, Offringa M, Askie LM. Elective high frequency oscillatory ventilation versus conventional ventilation for acute pulmonary dysfunction in preterm infants. Cochrane Database of Systematic Reviews 2009, Issue 3. Art. No.: CD000104. DOI: 10.1002/14651858.CD000104.pub3.

37. Marlow N, Greenough A, Peacock JL, et al. Randomised trial of high frequency oscillatory ventilation or conventional ventilation in babies of gestational age 28 weeks or less: respiratory and neurological outcomes at 2 years. *Arch Dis Child Fetal Neonatal Ed*. 2006; 91: (5), F320-6

38. Henderson-Smart DJ, De Paoli AG, Clark RH, Bhuta T. High frequency oscillatory ventilation versus conventional ventilation for infants with severe pulmonary dysfunction born at or near term. Cochrane Database of Systematic Reviews 2009, Issue 3. Art. No.: CD002974. DOI: 10.1002/14651858.CD002974.pub2.

39. Schulze A, Rieger- Fackeldey E, Gerhardt T, Claure N, Everett R and Bancalari E. Randomized Crossover Compariosn of Proportional Assist Ventilation and Patient-Triggered Ventilation in Extrmeley Low Birthweight Infants with Evolving Chronic Lung Disease *Neonatology* 2007; 92: 1-7.

40. Schulze (2012) Proportional Assist Ventilation in Donn SM and Sinha SK. *Manual of Neonatal Respiratory care 3rd Edition* 2012 Springer NY, Dordrecht Heidelberg London

41. Spahija J, de Marchie M, Albert M, Bellemare P, Delisle S, Beck J, Sinderby C. Patient-ventilator interaction during pressure support ventilation and neurally adjusted ventilatory assist. Crit Care Med. 2010 Feb;38(2):518-26.

42. Breatnach C, Conlon NP, Stack M, Healy M, O'Hare BP. A prospective crossover comparison of neurally adjusted ventilatory assist and pressure-support ventilation in a pediatric and neonatal intensive care unit population. Pediatr Crit Care Med. 2010 Jan;11(1):7-11.

43. Ålander M, Peltoniemi O, Pokka T and Kontiokari T. Comparison of pressure-, flow-, and NAVA-Triggering in pediatric and neonatal ventilatory care *Pediatric Pulmonology* 2012; 47: 1, 76–83.

44. Kamlin COF, Davis PG. Long versus short inspiratory times in neonates receiving mechanical ventilation. Cochrane Database of Systematic Reviews 2003, Issue 4. Art. No.: CD004503. DOI: 10.1002/14651858.CD004503.pub2

45. Greenough A, Donn SM. Matching ventilatory support strategies to respiratory pathophysiology. *Clinics in Perinatol*ogy 2007; 34: (1), 35-53, v-vi.

46. Mallya P, Gupta S, Harikumar C and Sinha S. Neonatal Ventilation: Evidence Based or Technological Conundrum. *Pediatric Research*. 2011; 70, 529; doi:10.1038/pr.2011.754

47. Klingenberg C, Wheeler KI, Owen LS, Kaaresen PI and Davis PG. An international survey of volume-targeted neonatal ventilation. *Arch Dis Child Fetal Neonatal Ed.* 2011; 96: F146–F148. doi:F146 10.1136/adc.2009.181081

48. Tidy. C. *BPD* Document ID: 1890 Document Version: 24Document Reference: bgp1888 Last Updated: 8 Nov 2010 http://www.patient.co.uk/doctor/Bronchopulmonary-Dysplasia.htm (accessed 18th Feb 2013)

49. Invasive Neonatal Ventilation Dr Badr Chaban 28/01/09 http://pdfcast.org/download/neonatal-ventilation.pdf (accessed 12th February 2013)

50. Auckland District Health Board (2011) Newborn Services Clinical Guideline Basic Principles and Guidelines for Conventional Ventilation http://www.adhb.govt.nz/newborn/TeachingResources/Ventilation/VentilationBasics.htm

51. Gizzi. C, Moretti C and Agostino R Weaning from mechanical ventilation. *Journal of Maternal-Fetal and Neonatal Medicine*. 2011; 24; (S1), 61-63

52. Wheeler KI, Wong C, Morley CJ, Davis PG. Volume guarantee ventilation: how low should we go? J Paediatr Child Health 2011; 47(Suppl. 1): 60–116. Abstract

53. Lista G, Castoldi F, Fontana P, Reali R, Reggiani A, Bianchi S *et al*. Lung inflammation in preterm infants with respiratory distress syndrome: effects of ventilation with different tidal volumes. *Pediatr Pulmonol* 2006; 41: 357–363.

54. Kamlin CO, Davis PG, Morley CJ. Predicting successful extubation of very low birthweight infants. Arch Dis Child Fetal Neonatal Ed 2006; 91: F180–F183.

55. Sant'Anna GM, Keszler M. Weaning infants from mechanical ventilation. Clin Perinatol. 2012 Sep;39(3):543-62. doi: 10.1016/j.clp.2012.06.003.

56. Bancalari E, Claure N.Weaning preterm infants from mechanical ventilation. Neonatology. 2008;94(3):197-202. doi: 10.1159/000143722. Epub 2008 Oct 2.

57. Sinha and Donn 2000 *Arch Dis Child Fetal Neonatal Ed* 2000;83:F64–F70 Weaning from assisted ventilation: art or science?Sunil K Sinha, Steven M Donn

58. Mulder EEM, Lopriore. E, Rijken. M Walther. FJ and te Pas. AB. Changes in Respiratory Support of Preterm Infants in the Last Decade: Are We Improving? *Neonatology* 2012; 101:247-253 (DOI: 10.1159/000334591

59. Chang DW Respiratory Care Calculations (3rd edition)2011; Delmar publ: Albany

60. Mathur NB and Seth A. Oxygen Therapy; Chapter 6 in Gupte. S (ed.) *Recent advances in Pediatrics: Special edition Volume 12- Neonatal Emergencies*. 2003; Jaypee Bro publ; Daryaganj

61. Farmand M and Nash P. Blood Gas Analysis and the Fundamentals of Acid-Base Balance. *Neonatal Network*. 2009; 28, 2, 125-128

62. Pomerance J. Perinatal / Neonatal Case Book Umbilical Cord Blood Gas casebook *Journal of Perinatology*. 2002; 22, 504-505

63. Armstrong L and Stenson BJ. Use of umbilical cord blood gas analysis in the assessment of the newborn. *Arch Dis Child Fetal Neonatal Ed*. 2007 November; 92(6): F430 -F434

64. Hartley. P. Neonatal Blood Gas interpretation. 2007 http://www.ceufast.com/courses/viewcourse.asp?id=68#Normal_Values (accessed 18th Feb 2013)

65. Brown B and Eilemann B. Understanding Blood Gas Interpretation. *Newborn and Infant Nursing Reviews*. 2006; Vol 6: (2), pp 57-62

66. Lynch F Arterial Blood Gas Analysis: Implications for Nursing. *Paediatric Nursing*. 2009; 21: (1), 41-44.