RECENT ADVANCES IN NEONATAL MECHANICAL VENTILATION?

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ABSTRACT

Conventional time cycled, pressure-limited ventilation has been used in neonatal intensive care units for many years. Meta-analysis of randomised trials demonstrated that conventional ventilation at rates of at least 60 breaths per minute rather than at slower rates significantly reduced the risk of airleak. Patient triggered ventilation more successfully than conventional ventilation promotes synchronous ventilation; nevertheless, randomised trials demonstrated the only advantage of patient triggered ventilation was that it was associated with a shorter duration of ventilation. More sophisticated triggered modes, pressure support, volume guarantee and proportional assist ventilation, have been developed. Results from physiological studies suggest these modes may be advantageous, but they have not been tested in large randomised controlled trials with long-term outcomes. Many anecdotal studies report avoidance of intubation and mechanical ventilation by use of continuous positive airways pressure reduces bronchopulmonary dysplasia, but the randomized trials which have been undertaken have been too small to appropriately address that outcome. Prophylactic high frequency oscillatory ventilation has been examined in many trials, but overall no benefit or disadvantage has been demonstrated. In conclusion, studies to date have not identified a clear advantage of any of the newer ventilation modes.

Key words: prematurity; ventilation; chronic lung disease

Introduction

The survival of prematurely born infants, even those born at very early gestations, has improved over the last three decades, but unfortunately this has been associated with a high respiratory morbidity, particularly due to bronchopulmonary dysplasia (BPD). The aetiology of BPD is multifactorial, but it is important to avoid baro- or volutrauma and in infants with established BPD the risk of further lung damage should be minimised. Many new techniques of ventilator support have been introduced with the aim of reducing volu/barotrauma to the lung. The aim of this review is, by critical examination of the literature, to describe the strengths and limitations of the ventilatory techniques currently available and hence enable the reader to make evidence based decisions regarding which ventilatory modes should be used in infants at risk of BPD or with established disease.

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Conventional mechanical ventilation (CMV)

CMV is delivered as pressure or volume limited ventilation. Time cycled, pressure limited ventilation is usually delivered with a square airway pressure waveform. The rise time of the peak pressure can be varied, but there are no randomised comparisons of different rise times and, if the same peak (PIP) and end expiratory (PEEP) pressures are used, a slow rise time would be associated with a lower mean airway pressure (MAP), compromising oxygenation. During CMV, positive pressure inflations are delivered at rates up to 120 breaths/minute (bpm) regardless of the infant's respiratory frequency. As premature infants with respiratory distress syndrome (RDS) breathe at fast rates,[1] use of ventilator rates below 60bpm is frequently associated with asynchrony and the infants may actively expire against positive pressure inflations resulting in airleaks.[2] Increasing the ventilator rate to 60 breaths/min or above (high frequency positive pressure ventilation) and shortening the inspiratory time has been shown to entrain the infant's respiratory efforts with inspiration and inflation coinciding (synchrony) with a consequent improvement in blood gas tensions.[3] Active expiration against positive pressure inflation was reduced by increasing ventilator rate, which may explain the lower incidence of pneumothoraces in infants supported by high frequency positive pressure ventilation in randomised trials.[4] The trials, however, were undertaken in infants not routinely treated with antenatal steroids and postnatal surfactant nor receiving sedation, thus their results may not be generalisable to the present population of ventilated infants. In infants with developing BPD, elevation of ventilator rate above 60 breaths/min was not shown to improve blood gases.[5] During volume cycled ventilation (VCV), a constant volume is delivered. In two randomised trials, VCV was shown to be superior to pressure limited ventilation; VCV was associated in one[6] with less hypotension and serious intracerebral haemorrhage and in the other[7] a shorter duration of respiratory support. Both studies, however, were of small sample size and long-term outcomes were not assessed.

Patient Triggered Ventilation (PTV)

During PTV, the infant's spontaneous inspiratory effort can trigger positive pressure inflations. In Assist/Control (A/C) mode, otherwise named synchronised intermittent positive pressure ventilation (SIPPV), any number of inflations can be triggered provided that the change in pressure, flow, or volume exceeds the critical trigger level. In synchronised intermittent mandatory ventilation (SIMV) only a preset number of inflations can be triggered regardless of the frequency of the infant's spontaneous respiratory efforts.
In physiological studies, PTV compared to CMV was associated with higher rates of synchrony, better blood gas tensions, and less fluctuations in blood pressure and cerebral blood flow velocity. Meta-analysis[4] of the results of randomised trials, however, showed that the only advantage of PTV was that it was associated with a shorter duration of ventilation and then only when used in the recovery, not the acute, stage of RDS. Explanations for the limited success of PTV in the randomised trials may be that CMV was used in a manner successfully promoting synchrony and/or use of sedation may have influenced the results by reducing respiratory efforts. It is also possible that the ventilators and/or the triggering systems used also influenced the results. Delivered volume is compromised at fast rates and short inflation times in some ventilators and in the largest PTV trial[8] the majority of infants were supported by a ventilator incorporating an airway pressure trigger, which has been shown to have a significantly lower sensitivity and longer trigger delay than an airflow trigger.[9] It, however, remains speculation as to whether improvements in ventilator and triggering system performance would ensure greater success for PTV. A/C and SIMV modes have not been compared in randomised studies in infants with acute respiratory distress, but has been during weaning.[10, 11] Two of the trials showed no significant differences between the two trigger modes, but in the third trial A/C was associated with a shorter duration of weaning.[11] The duration of weaning was significantly shorter on A/C than on SIMV when the supported breath rate was reduced below 20 breaths/min as, at such a low level of ventilator support, oxygen consumption and the work of breathing are increased.[12]

Pressure support Ventilation (PSV)

During PSV, the patient triggers a pressure-supported breath at a preset level and inflation is terminated when the inspiratory flow is reduced to a certain level. Inflation is terminated when the flow is reduced to 15% of the maximum inspiratory flow when the Draeger Babylog 8000 (Draeger Medical, Luebeck, Germany) is used in PSV mode and between 5% and 25% of the maximum inspiratory flow if termination sensitivity is used with

the Bird VIP (Bird Products, Palm Springs, California, USA). In physiological studies, PSV appears to be advantageous in that increasing the termination sensitivity to maximum (that is with the Bird VIP 25% of the maximum inspiratory flow) has been shown to almost eliminate asynchrony;[13] there are however, no data to determine whether this would translate into a reduction in airleaks. The reduction in asynchrony is the result of the inflation times being shorter during PSV, thus the infants must make a greater contribution to maintain minute volume and whether this is achievable throughout an infant's ventilatory career remains untested.

Volume Guarantee (VG)

In VG, the PIP is servocontrolled so that the volume preset by the clinician is delivered during SIPPV, SIMV, or PSV. It has been demonstrated that adequate gas exchange can be achieved at lower mean airway pressures during VG,[14] this may be the result of a greater contribution by the infant's spontaneous respiratory efforts to minute ventilation.[15] Another advantage of VG is that there may be lower breath to breath variability,[16] but this is not a universal finding.[14]

Proportional Assist Ventilation (PAV)

During PAV, the applied pressure is servocontrolled based on input from the patient throughout each spontaneous breath and the frequency, timing, and amplitude of lung inflation are controlled by the patient.[17,18] The ventilator pressure waveform can be tailored to compensate for changes in lung compliance and airway resistance, reducing the elastic and resistive work of breathing. This is called unloading and the degree of unloading can be modified to reduce the patient's work of breathing to normal. If, however, too much unloading is used then runaway ventilator pressures can result. There are very few data on PAV in neonates, but use of PAV has been associated with similar gas exchange at lower mean airway pressures[19] and less thoracoabdominal asynchrony.[20]

Continuous Positive Airway Pressure (CPAP)

During CPAP, a continuous pressure is applied to distend the alveoli throughout the respiratory cycle to prevent the complete collapse of alveoli during expiration. CPAP may be delivered via a Gregory box, an endotracheal tube, single or dual nasal prongs. Gregory boxes are no longer used and, in a randomised trial, placing an infant on endotracheal CPAP rather than extubating directly from intermittent mandatory ventilation was demonstrated to be disadvantageous.[21] As a consequence, most infants receive CPAP via single or usually dual nasal prongs. CPAP is administered to infants with apnoea or post extubation and more recently as the prime mode of respiratory support in infants with RDS. CPAP has been shown in physiological studies to help infants with obstructive but not central apnoea, but due to a lack of randomised trials, the relevant Cochrane review concluded that this area needs further evaluation.[22] There have, however, been many studies which have demonstrated that use of nasal CPAP in VLBW infants can facilitate successful extubation. Anecdotally, use of nasal CPAP very early in infants' respiratory careers has been associated with a reduction in the need for intubation and ventilation and a lower rate of BPD. There are, however, only a few small randomised trials and as a consequence it was concluded in the Cochrane review that there is insufficient evidence to assess the risk and benefit of prophylactic nasal CPAP.[23]

Nasal Ventilatory modes

A variety of ventilatory modes have been delivered by nasal prong, but there is only limited evidence to date on the efficacy of these techniques. Unfortunately, two randomised trials comparing nasal IPPV to nasal CPAP to support infants with apnoea of prematurity yielded conflicting results[24,25] and neither reported whether any gastrointestinal complications were experienced, an increased risk of gastrointestinal perforation had been noted in earlier reports. It has been suggested that nasopharyngeal SIMV compared to nCPAP may reduce extubation failure[26-28] Use of nasal HFOV was associated with reduction in carbon dioxide levels in infants with moderate respiratory acidosis on nasal CPAP, but there were no randomised comparators and five of the 21 infants studied had to be intubated a few hours later because of carbon dioxide retention and a high oxygen requirement.[29]

High Frequency Jet Ventilation (HFJV)]

High-frequency jet ventilators deliver short pulses of pressurised gas at rates between 150 and 600 breaths/min directly into upper airway through a narrow bore cannula or jet injector.[30] The high flow jet produces a venturi effect that creates an area of negative pressure entraining gas into the airway. Exhalation is passive. Tidal volumes are difficult to measure during HFJV, but appear to be equal to or slightly greater than the anatomical dead space.[31] It may be helpful in conditions, such as pulmonary interstitial emphysema (PIE) with carbon dioxide retention, as during HFJV, CO2 removal has been shown to be achieved at lower peak and mean airway pressures than with either HFPPV or HFO.[32,33] There are, however, few randomised trials of HFJV and they have yielded conflicting results. One study of 42 infants demonstrated no significant differences between infants randomised to HFJV or conventional ventilation [34], whereas a second study[35] demonstrated more rapid resolution of PIE in infants supported by HFJV and a third study demonstrated HFJV use was associated with a reduction in BPD.[36] A fourth study was halted for safety reasons, as use of HFJV was associated with a significant increase in intracerebral haemorrhage and periventricular leukomalacia[37] The review of HFJV versus CMV in the Cochrane database concluded that because of concerns about appropriate strategy and the lack of long term pulmonary and neurodevelopmental outcome studies, HFJV was not been recommended as a primary treatment modality.[38]

High Frequency oscillation ventilation (HFOV)

High frequency oscillators deliver small tidal volumes, usually at frequencies of 10 to 15 Hz., although reducing the frequency below 10 Hz can improve carbon dioxide elimination as the delivered volume increases when rate is decreased.[39] In contrast to other forms of respiratory support, both inspiration and expiration are active. Certain oscillators have a variable inspiratory to expiratory ratio, but increasing the inspiratory fraction from 30% to 50% has not been shown to increase gas trapping[40] and does elevate the MAP and delivered volume with consequent improvements in gas exchange.[41] HFOV has been used with a low volume strategy, that is minimising pressures with the hope of preventing further trauma to the lungs, and a high volume strategy during which a lung recruitment policy is employed. Although these two strategies have not been compared in a randomised study in infants with long term outcomes, in surfactant deficient animals, high volume HFOV resulted in significantly less lung damage than either conventional ventilation or low volume HFOV.[42] There have been many trials in which the efficacy of prophylactic HFOV (that is started before 12 hours of age) has been examined. Meta-analysis of the results of those trials[43] has not shown any advantage or disadvantage of HFOV over conventional ventilation. There have only been two randomised trials comparing HFOV to conventional ventilation in infants with established respiratory failure. In the trial which included infants born prematurely, use of HFOV was associated with a lower incidence of new airleak, but a higher rate of intracerebral haemorrhage.[44] In infants born at or near term, use of HFOV was not associated with any significant long term benefits.[45]

Conclusion

It is essential that new techniques are introduced into routine clinical practice only after appropriate assessment has shown efficacy and no adverse effects. Results from physiological studies and anecdotal series have demonstrated advantages for all the newer ventilatory techniques but, unfortunately, no long term benefits have been highlighted when systematic reviews of the results of large randomised trials have been carried out. On current evidence, therefore, use of the newer techniques rather than conventional mechanical ventilation cannot be recommended and further studies are required.

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