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A concise review on different modes of ventilation in Acute Respiratory Distress Syndrome

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ABSTRACT

Acute respiratory distress syndrome is a fatal lung condition defined by direct alveolar epithelial injury or indirect capillary endothelial injury resulting in increased permeability and plasma leakage, non-compliant lungs, refractory hypoxemia and shunt, pulmonary hypertension and right ventricular failure. Lung-protective ventilation is a time-proven strategy for its management. Numerous modes of ventilation have been tried in the last few years such as airway pressure release ventilation, biphasic positive airway pressure, high frequency oscillatory ventilation, proportional assist ventilation, adaptive support ventilation, and neurally adjusted ventilatory assist. Each of these modes has its own merits and demerits which they have been reviewed in this article.

Key words: ARDS–modes–ventilation–refractory hypoxemia

1 BACKGROUND

Acute Respiratory Distress Syndrome (ARDS) is a life-threatening condition requiring intensive care unit (ICU) admission. Among the various strategies used in the management of ARDS, the only time-proven intervention in reducing mortality is lung protective ventilation.[1] The recent years have seen great advancements in managing ARDS with newer modes of ventilation. But with the data available currently, it is difficult to conclude that anyone of the mode is better than others. We have reviewed some of the currently available evidence on diffrent modes.

2 COMMONLY USED MODES

a) Assist Volume Control and Pressure Control Ventilation

Volume-Control Continuous Mandatory Ventilation (VC-CMV) functions by administering set tidal volumes, with the volume and flow remaining constant. The pressure varies based on the changes in respiratory mechanics due to the disease process. Control over volume is achieved in two ways- 1) piston or bellows displacement, 2) flow modulation, since volume and flow are inverses of time.

Pressure-Control Continuous Mandatory Ventilation (PC-CMV) operates by administering the set pressure which will be constant, but the volume and the flow will vary with the patient's dynamic lung pathology. Tidal volume depends on variables such as- 1) inspiratory pressure, 2) patient's respiratory efforts, 3) elasticityand resistance of lung tissue. Decelerating flow pattern reduces the peak pressures, causes a more homogeneous distribution of gases, and improves gas exchange. The major downside is that the volume delivered cannot be guaranteed, especially when lung mechanics are changing.

Chacko B et.al conducted a meta-analysis of 1089 patients intending to study the correlation between Pressure Control Ventilation (PCV) and reduction of in-hospital mortality and morbidity.[2,3] They concluded that the risk ratio with PCV compared with Volume Control Ventilation (VCV) was 0.83 and 0.84 for in-hospital and ICU mortality respectively. Another study showed no mortality benefit at 28 days. The effect of PCV and VCV on barotrauma was not conclusive. The current evidence from various trials is inconclusive of whether PCV or VCV is advantageous for ARDS patients.[4]

b) Pressure Regulated Volume Control (PRVC) is a pressure-limited, volume-targeted, time-cycled, patient or ventilator triggered dual control mode. The peak inspiratory pressure (P_{IP}) delivered varies with each breath to achieve the set tidal volume depending on the dynamic changes in compliance and airway resistance. The decelerating flow pattern is explained by a wide pressure difference between the ventilator and the lung which results in maximal flow at the initiation of inspiration. With the subsequent breaths, the pressure difference minimizes due to an increase in intrathoracic pressure resulting in a decreased inspiratory flow. In contrast, the inspiratory flow being constant in volume control ventilation the resulting intrathoracic pressure keeps on increasing. Hence, the same volume is delivered at a lower peak inspiratory pressure in PRVC mode.[5] Riverso et al conducted a study in nine randomized patients with moderate-severe ARDS comparing the effect of PRVC with VCV mode. Ventilation initiated with VCV followed by PRVC mode for a stabilizing period of 60 minutes each and the following parameters were unchanged: tidal volume, Respiratory rate, fraction of inspired oxygen (FiO2), Positive end-expiratory pressure (PEEP), and Inspiratory: Expiratory (I:E) ratio. The parameters they studied were: P_{IP}, Compliance-static, the partial pressure of oxygen (PaO_2) and carbon dioxide, alveolar arterial gradient, and cardiovascular status. PRVC mode of ventilation showed a significant decrease in P_{IP} with improvement in PaO_2 and oxygen saturation of arterial blood in this study.

Henrik Guidager et al[6] randomized 44 patients with acute respiratory failure. Patients were stabilized for the duration of eight hours, after which a cross over trial of PRVC and VCV was conducted for two hours each without altering the ventilator parameters. Parameters assessed were: ventilator days, failure of allocated ventilation mode, and survival. The study showed a significant decrease in P_{IP} during PRVC when compared to VCV. He hypothesized that PRVC improves the dynamics of respiration and outcomes compared to VCV in acute respiratory failure.

Other modes of ventilation:-

a) Inverse Ratio Ventilation (IRV): Any standard control ventilation mode will use I:E ratios of 1:2, or as high as 1:3 or 1:4 in certain cases, which closely mimics normal physiologic breathing. In contrast IRV uses higher inspiratory time with ratios of 2:1, 3:1, 4:1, and it may sometimes be as high as 10:1.[7] IRV can be administered in different ways such as: 1) volume-cycled ventilation with an end-inspiratory pause, or with a slow or decelerating inspiratory flow rate; or 2) PCV with a long inspiratory time. IRV increases duration on higher pressure portion of the cycle which leads to an increase in mean airway pressure (MAP) while minimizing risk for pulmonary injury due to aggressive oxygenation or high PEEP or inspiratory pressure. Disadvantages include hemodynamic imbalance due to auto-PEEP; increased use of sedatives. However, IRV failed to improve mortality, ventilator days, and number of ICU days.[8]

b) High Frequency Oscillatory Ventilation (HFOV) utilises the concept of delivering very low tidal volume at high frequencies in contrast to conventional gas exchange mechanisms. In conventional Pressure Controlled Intermittent Mandatory Ventilation (PC-IMV), lesser volume generated by spontaneous patient efforts are overlaid on larger volume mandatory breaths whereas, in HFOV mandatory breaths (oscillations) with smaller tidal volume are superimposed on spontaneous breaths. HFOV delivers minimal tidal volume of 1-3ml/kg lesser than anatomical dead space at a very high rate of 122-900/min which facilitates gas exchange at the alveoli. Using high frequency jet ventilation, high pulses of gases are injected into the airway by a jet. HFOV is denoted "CPAP with a wiggle" because it vibrates the bias flow conveyed at the end of the endotracheal tube. Advantages of HFOV include: 1) it reduces cyclical overdistention due to minimal alveolar tidal pressure changes and 2) derecuitment prevented by maintaining higher MAP of 25-34 cmH_2O.[1] HFOV was found beneficial in severe ARDS in one randomized controlled trial suggesting improved outcome. Preliminary data suggest that HFOV should be able to prevent ventilator-induced lung injury. However, large randomized controlled trials on the use of HFOV have not shown beneficial outcomes. On the contrary, they suggest a deleterious effect if HFOV is used as an early lung-protective strategy in ARDS.

In the case of refractory hypoxemia, HFOV can still, be used as a rescue measure. But one has to exercise caution that right ventricular dysfunction and increased intrathoracic pressure lead to hemodynamic compromise when applying HFOV.[9]

c) Airway Pressure Release Ventilation (APRV) and **Biphasic Positive Airway Pressure (BiPAP):** APRV is a pressure-limited, time-cycled ventilator mode that maintains constant pressure during unassisted breaths. APRV and BiPAP are similar modes of ventilation, differentiated by the time spent in lower pressure, i.e, (T_{low}) < 1.5s in APRV whereas in BiPAP two pressure level, the time spent in higher pressure (T_{high}) and T_{low} are set using an active exhalation valve. At either pressure level, the patient is free to breathe spontaneously.[1] APRV/BiPAP are useful modes of ventilation in acute lung injury or ARDS. This is because 1) it increases the MAP by gradually recruiting alveoli without an increment in applied PEEP, during long deflation phase 2) In comparison to other controlled modes, superadded spontaneous efforts increase both cardiac filling and recruitment during inflation 3) improves gas exchange at a lesser rise in maximal airway pressures compared to control ventilation.[10]

A study randomized 138 patients with ARDS to conventional LTV with a low PEEP strategy vs. APRV within the first 48 hours. The primary outcome of the study was ventilator-free days. The range was median 19 days (IQR 8–22 days) in the APRV group versus 2 days (IQR 0 – 15 days) in the LTV group. Parameters like respiratory compliance, improving gas exchange, and less ICU stay constituted secondary outcomes. All these were also better in APRV than LTV groups.[11] The LTV group also showed a higher incidence of tracheostomy (29.9%). This value was more than double what was reported in the Lung Safe study (13%) whereas the APRV group showed a lower incidence (12.7%) which was comparable to the latter. The requirement for sedation was higher in LTV than the APRV group. The T_{high} increased the transpulmonary pressures during spontaneous breaths which worsened the heterogeneous lung injury. This study introduced a new strategy for minimizing transpulmonary pressure swings. It entails the titration of the level of sedation to achieve and maintain the desired respiratory effort.[10,11]

d) Proportional Assist Ventilation (PAV): In PAV, pressure support is proportional to the patient's effort. The proportion of support provided depends on compliance, resistance, and patient-generated flow and volume which is measured by the ventilator in real-time. Based on these, the ventilator will deliver a proportional amount of inspiratory pressures. It offers spontaneous breaths where the timing and size of breaths are controlled by the patients. Safe limits of volume and pressure delivered is entered by the operator. The patient effort is supported in proportion with the work of breathing set by the clinician. The delivered pressure, flow, and volume is proportional to the patient's effort. In theory, PAV must reduce the work of breathing (WOB); prevent asynchrony; spontaneous adaption to dynamic patient effort and lung mechanics; reduce operator-ventilator interaction; decrease the use of sedatives in ARDS.[1]

e) Adaptive Support Ventilation (ASV) It is a closed-loop controlled mode of ventilation, which reduces the patient's WOB. The controlled breaths delivered initially calculate resistance, compliance, and expiratory time constant. The parameters which can be set by the clinician include calculated minute ventilation and body weight for the estimation of anatomic dead space. It then separates the frequency-tidal volume pattern thereby minimizing ventilator work (pressure × volume) and force applied to the lung. Reduction in *ventilator*-induced lung injury (VILI) occurs as lesser ventilator work may translate into lesser stretching forces on the lungs. Occasionally, the tidal volume delivered by ASV could be higher than 6 mL/kg. This type of interactive breaths during mechanical ventilation can enhance comfort and reduce the need for sedation.[1]

Agarwal et al[12] randomized 48 patients with ARDS to ASV or VCV. The primary outcomes were ventilation days, de novo organ dysfunction, and the number of days in hospital. Other parameters considered were daily arterial blood gas (ABG) count, daily sedative requirement, neuromuscular blocker use, visual analog scale to assess the comfort on the mode of ventilation used and mortality.[3] Most parameters like ventilation days, delta sequential organ failure assessment scores, ICU and hospital stay, comfort on mode of ventilation, daily ABG count, and sedation dose were similar in the two groups. VCV had higher mortality of 36% compared to ASV (34.7%). Thus there was no significant difference in the outcomes of patients with ARDS ventilated with either VCV or ASV.[12]

Neurally Adjusted Ventilatory Assist (NAVA)) Electrical signal from the diaphragm is used to trigger and cycle ventilatory assistance. Electromyography (EMG) sensor is placed at the level of the diaphragm in the esophagus. Phrenic nerves of inspiratory muscles get excited and simultaneously trigger ventilator breath, whereas contraction of inspiratory muscles ceases the breath cycle. Improvement in the trigger and ventilator asynchrony with NAVA is proven in smaller studies but there is a lack of data suggesting improved outcomes such as ventilator-free days and need for sedation.[1,13]

A small study randomly ventilated twelve ARDS patients with PCV-AC, NAVA, and PSV. Parameters assessed were transpulmonary pressure, tidal volume, diaphragm electrical activity, and patient-ventilator interaction. The coefficient of variation of tidal volume was used to assess respiratory variability. During inspiration, transpulmonary pressure was slightly lower with NAVA, tidal volumes were similar, but respiratory variability was higher with NAVA. Patient-ventilator interaction was better with NAVA. In conclusion, in mild-to-moderate ARDS patients, NAVA eased the ventilator operability, provided better lung-protective ventilation for tidal volume and lung-distending pressure, and offered superior patient-ventilator interaction with minimal respiratory variations.

Another study assessed four patients of severe ARDS undergoing extracorporeal membrane oxygenation (ECMO). After assisted ventilation, the following strategies were tested randomly for 30 minutes each where, PEEP (8cmH2O), Fio2 (0.55), Tidal Volume (2.8 ml/Kg), ECMO (2.9L/min of VV-ECMO for 23 days) settings were unchanged.[5] They compared NAVA with pressure support (PS) with an expiratory trigger at 30% of the flow peak value (PS30) and PS with an expiratory trigger at 1% (PS1). It showed 1) Tidal Volumes were comparable among PS30, PS1, and NAVA. 2) During NAVA, P/F improved non-significantly, occlusion pressor (P0.1), and respiratory rate were reduced and Asynchrony Index significantly decreased in comparison of PS30 and PS1. The study concluded that NAVA may increase oxygenation and decrease patient's efforts by reducing the asynchrony between patient and ventilator in such patients undergoing ECMO.[14]

3 CONCLUSIONS

Even though the different modes of ventilation have their own merits and demerits, which prevent us from touting one mode as superior over the other, they offer an exciting avenue for further research. The different modes have to be used judiciously and tailored to the need of individual patients.

Conflict of interest: None [1–14]

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