REVIEW

Proportional assist ventilation versus conventional synchronized intermittent mandatory ventilation in chronic obstructive pulmonary disease

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KEYWORDS
Proportional assist ventilation; Synchronized intermittent mandatory ventilation; Chronic obstructive pulmonary disease

Abstract Background: Proportional assist ventilation (PAV) is a physiological ventilation mode with better patient ventilator synchrony. However its role in intubated patients with chronic obstructive pulmonary disease (COPD) is still not well defined.

Objective: To evaluate the efficacy of PAV mode in intubated patients with COPD exacerbation in comparison with conventional synchronized intermittent mandatory ventilation (SIMV) mode.

Patients & methods: Fifty COPD patients presented with hypercapnic respiratory failure who are intubated and ventilated were recruited to the study. After 12 h of assist-control ventilation, 25 patients shifted to SIMV mode (group 1) while the other 25 patients shifted to PAV mode (group 2). Vital signs, gasometric and mechanical parameters, duration of ventilation and intensive care unit (ICU) stay were measured.

Results: The successful outcome was achieved in 76.0% in group 1 versus 72.0% in group 2. Significant improvement in vital signs, gasometric and mechanical parameters was observed in all patients. Comparison between the two groups after 24 h of ventilation showed significantly higher values in the PAV group for respiratory rate, heart rate, and systolic blood pressure ($P < 0.001$). Significantly lower pH ($P < 0.01$), higher partial arterial carbon dioxide pressure (PaCO$_2$) ($P < 0.001$), significantly lower tidal volume, peak inspiratory pressure, auto-positive end expiratory pressure (auto-PEEP), missing efforts, inspiratory time over total time (Ti/Ttot), shorter duration of ventilation and ICU stay were observed in the PAV group ($P < 0.01$ for each).

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Conclusion: PAV can maintain improvement of clinical, gasometric and ventilator parameters in intubated COPD patients with the advantages of shorter duration of ventilation and hospitalization compared with SIMV.

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Introduction

Synchronized intermittent mandatory ventilation (SIMV) is a ventilation mode in which the ventilator breaths are synchronized with patient inspiratory effort [1]. SIMV, with and without pressure support has not been shown to have any advantages over continuous mandatory ventilation (CMV) as regards mortality [2] or weaning success [3]. Moreover, it has been shown to result in longer weaning times when compared to t-piece trials or gradual reductions in pressure support [4]. Some studies have shown an increase in patient work of breathing when switched from CMV to SIMV [5,6], and others [7] have demonstrated that SIMV mode has potential detrimental effects on respiratory drive and respiratory muscles.

Proportional assist ventilation (PAV) is a new mode of assisted ventilation which, reduces the inspiratory effort needed to overcome respiratory system elastance (Ers) and resistance (Rrs), by applying pressure in proportion to volume (volume assist, VA) and flow (flow assist, FA) [8]. Thus, it should be possible to reduce the elastic and resistive work of breathing performed by the patient [9]. Through, unloading the respiratory muscles PAV mode returns the relationship between the inspiratory effort and ventilatory output (i.e. volume and flow) back toward normal [10]. This would be beneficial in certain circumstances where respiratory impedance is increased (restrictive or obstructive lung disease) as well as conditions where the ability of the respiratory muscles to generate pressure is impaired (neuromuscular disease).

In comparison with other forms of assisted ventilation, PAV is considered the unique mode that can regulate the amount of ventilatory support provided in proportion to the identified abnormalities in respiratory function without affecting the breathing pattern [11]. Therefore, it is more physiological and improves patient ventilator synchrony. However its role in intubated patients with acute exacerbation of chronic obstructive pulmonary disease (COPD) is assessed in few studies and not well identified.

Patients and methods

Fifty patients with acute exacerbation of COPD with hypercapnic respiratory failure and respiratory acidosis were included in the study after failure of a trial of non-invasive ventilation. Written consent was taken from the patients’ relatives. They underwent endotracheal intubation (ETI) and received invasive mechanical ventilation via Puritan Bennett, 840 ventilator (Tyco, Gosport, UK) in a tertiary hospital in the period from November 2011 to January 2013.

Volume assist- control mode (AC) was adjusted to all patients. After 12 h on AC, those patients were classified into two groups: group 1 (G1) 25 patients shifted to SIMV volume control mode and group 2 (G2) 25 patients shifted to PAV mode. Both groups were matched as regards age, sex, body mass index (BMI) and premorbid FEV1.

The following settings were adjusted in SIMV: tidal volume (VT) 8 mL/kg; respiratory rate (RR) 8–10 breath/min; peak inspiratory flow 60 L/min; adjust flow waveform to square form; inspired oxygen fraction (FiO2) is adjusted to obtain oxygen saturation by pulse oximetry (SpO2) > 90%; positive end expiratory pressure (PEEP) 5 cmH2O. Pressure support (PS) is adjusted to equal plateau pressure minus PEEP value to avoid fluctuation in positive pressure when shifted from mandatory to spontaneous breaths.

The following settings were adjusted in PAV mode: Volume assist (VA), flow assist (FA), and % of set that was adjusted at 80% of set VA and FA and decreased to 50% after 24 h. VA and FA corresponded elastance and resistance respectively. Elastance and resistance calculated automatically; FiO2 was adjusted to obtain SpO2 > 90%; PEEP is set to 5 cmH2O. In both groups, the following parameters were monitored and recorded after 2, 6, and 24 h ventilation: Heart rate (HR), systolic blood pressure (BP), RR, VT, minute ventilation (VE), peak airway pressure, missing efforts, auto-PEEP, and arterial blood gases (ABGs). Auto-PEEP was measured by using the expiratory pause button of the ventilator during SIMV. On the other hand, in the PAV group we shifted to volume control...
Table 1  Baseline demographic, clinical, and gasometric parameters of the studied patients.

<table>
<thead>
<tr>
<th>Baseline parameters</th>
<th>G1 (25) Mean ± SD</th>
<th>G2 (25) Mean ± SD</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>60.6 ± 5.9</td>
<td>61.0 ± 5.2</td>
<td>NS</td>
</tr>
<tr>
<td>RR (breath/min)</td>
<td>35.2 ± 3.1</td>
<td>36.4 ± 3.2</td>
<td>NS</td>
</tr>
<tr>
<td>HR (beat/min)</td>
<td>115.6 ± 5.8</td>
<td>115.1 ± 4.7</td>
<td>NS</td>
</tr>
<tr>
<td>Systolic BP (mmHg)</td>
<td>143.0 ± 9.9</td>
<td>143.6 ± 9.4</td>
<td>NS</td>
</tr>
<tr>
<td>pH</td>
<td>7.18 ± 0.04</td>
<td>7.19 ± 0.03</td>
<td>NS</td>
</tr>
<tr>
<td>PaCO2 (mmHg)</td>
<td>102.6 ± 7.8</td>
<td>99.2 ± 8.1</td>
<td>NS</td>
</tr>
<tr>
<td>PaO2 (mmHg)</td>
<td>49.2 ± 7.1</td>
<td>48.7 ± 6.3</td>
<td>NS</td>
</tr>
<tr>
<td>SaO2</td>
<td>85.0 ± 5.1</td>
<td>83.6 ± 4.7</td>
<td>NS</td>
</tr>
</tbody>
</table>

Definition of abbreviations: G1 = group 1; G2 = group 2; RR = respiratory rate; HR = heart rate; BP = blood pressure; PaCO2 = partial pressure for carbon dioxide; PaO2 = partial pressure for oxygen; SaO2 = oxygen saturation; NS = non significant.

Figure 1  (a) The outcome of all patients with success rate of 74%. (b) The outcome of both groups. A comparable success rate without significant difference between the two groups.

Figure 2  Follow up of respiratory rate (a), heart rate (b) and systolic blood pressure (c) in studied patients. AC: assist-control, G1: group 1, G2: group 2, 2 h ventilat: 2 h ventilation, 24 h ventilat: 24 h ventilation, BP: blood pressure. *Statistically significant difference between the two groups (P < 0.05).
during measurement of auto-PEEP by using the expiratory pause button of the ventilator. Missing efforts were estimated as RR patient – RR ventilator. Inspiratory time over total time (Ti/Ttot) was also measured.

The following parameters are measured in the PAV group only: Elastance (EPAV), resistance (RPAV), % set, and work of breathing (WOB).

Medical management

Nebulized salbutamol and ipratropium bromide were administered through a piece connected to ventilator circuit near the mouth. Intravenous hydrocortisone 100 mg/12 h, was administered to all patients until discharge from ICU. Theophylline was administered intravenously 6 mg/kg over 20–30 min, followed by a continuous infusion of 0.6 mg/kg/h. Antibiotics was administered as combination therapy with Cefepime 1 gm or Ceftazidime 1 gm/12 h plus levofloxacin 500 mg/24 h or amikacin 500 mg/12 h as all our patients had bacterial infection exacerbation. Nutrition management was the same in both groups.

Statistical analysis

Statistical analysis was performed using Statistical package for the Social Sciences (SPSS-version 16). All values were described as mean ± standard deviation. A chi-square statistics test was used for categorical data. An unpaired Student’s t test was used to compare numerical data between the two groups. A Paired Student’s t test was used to compare the different stages of the same variable. A P value less than 0.05 was considered statistically significant.

Results

Table 1 shows baseline parameters in all patients. There was no significant difference between the two groups regarding

<table>
<thead>
<tr>
<th>Parameter</th>
<th>G1 (25) Mean ± SD</th>
<th>G2 (25) Mean ± SD</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal volume (Vt) (ml)</td>
<td>430 ± 20</td>
<td>390 ± 59</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Peak airway pressure (cmH2O)</td>
<td>33 ± 4.8</td>
<td>23 ± 3.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Auto PEEP (cmH2O)</td>
<td>4.9 ± 0.9</td>
<td>1.5 ± 0.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Missing efforts (breath/min)</td>
<td>3.0 ± 0.8</td>
<td>0.6 ± 0.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ti/Ttot (%)</td>
<td>0.39 ± 0.08</td>
<td>0.29 ± 0.07</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Definition of abbreviations: G1 = group 1; G2 = group 2; Vt = tidal volume; PEEP = positive end expiratory pressure; Ti/Ttot = inspiratory time/total time.
age, clinical, gasometric, and laboratory data. Male sex was predominant in both groups (88% in G1 and 92% in G2).

Fig. 1 shows the outcome of the studied patients. There was no significant difference between the two groups regarding success or failure.

Fig. 2 shows follow up of RR, HR and systolic BP in the studied patients. A significant \((P < 0.001)\) reduction in these vital signs in all patients on AC which persisted up to 24 h of ventilation in both groups for RR and HR was detected. There was a significantly higher RR, HR and systolic BP in the PAV group after 2 h and persisted up to 24 h of ventilation \((P < 0.001)\).

Gasometric parameters are demonstrated in Fig. 3. A significant improvement of pH, \(\text{PaCO}_2\) and \(\text{PaO}_2\) was observed in all patients on AC \((P < 0.01)\), with significantly lower pH and significantly higher \(\text{PaCO}_2\) in the PAV group \((P < 0.01)\) for each.

Table 2 demonstrates the mechanical parameters in both groups after 2 h ventilation. There was a significant \((P < 0.001)\) lower peak airway pressure, lower auto PEEP, decrease of number of missing efforts, and lower duty cycle \((\text{Ti}/\text{Tot})\) in the PAV group. Also VT revealed significant \((P < 0.01)\) lower values and more variable in the PAV group (390 ± 59 versus 430 ± 20 in SIMV). The same changes were maintained after 24 h ventilation (Table 3). The settings and displayed parameters of PAV are demonstrated in Table 4 after 2 h and 24 h ventilation. In spite of a decrease of % set from 80% to 50% there was no significant increase of WOB.

Table 5 shows that duration of ventilation and ICU stay was significantly \((P < 0.01)\) shorter in the PAV group.

Discussion

COPD is a leading cause of global morbidity and mortality. Severe exacerbation; however remains the largest cause of emergency admissions for respiratory disease. SIMV with pressure support was the most frequently used ventilatory mode in management of acute exacerbation of COPD [12].

PAV is hypothesized to have the following advantages; comfort [10], less airway pressure [13], less likelihood of over-ventilation [10], and better triggering and synchrony [14], where PAV targets inspiratory flow as a surrogate of effort and reduces the problem of failure to sense the onset of expiration, in contrast to asynchrony during PSV especially in the presence of air leaks or in patients with severe airflow obstruction [15]. Thus, PAV was proposed as a powerful mean of improving the patient-ventilator interaction by bringing one of the two oscillatory pumps (the ventilator) under control of the other (the patient’s central control of breathing). It is a mode of ventilation designed on physiological bases, where the technical solutions offered by the ventilators did not come first [16].

The initial clinical trial to detect the effectiveness of PAV in a ventilator dependent patient was done in 1992 by Younes et al. [10], who concluded that PAV is a feasible method of supporting ventilator dependent patients that is well tolerated and can be implemented at much lower peak airway pressures, and the spontaneously adopted breathing pattern during PAV does not appear to compromise gas exchange. Furthermore, Navalesi et al. [8] studied the effects of PAV in eight intubated

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Ventilatory parameter after 24 h on SIMV and PAV.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>G1 (25) Mean ± SD</td>
</tr>
<tr>
<td>Tidal volume ((V_T)) (ml)</td>
<td>439 ± 18</td>
</tr>
<tr>
<td>Peak airway pressure (cmH(_2)O)</td>
<td>31 ± 4.9</td>
</tr>
<tr>
<td>Auto PEEP (cmH(_2)O)</td>
<td>3.8 ± 1.1</td>
</tr>
<tr>
<td>Missing efforts (breath/min)</td>
<td>2.1 ± 0.7</td>
</tr>
<tr>
<td>(\text{Ti}/\text{Tot}) (%)</td>
<td>0.38 ± 0.07</td>
</tr>
</tbody>
</table>

*Definition of abbreviations: G1 = group 1; G2 = group 2; \(V_T\) = tidal volume; PEEP = positive end expiratory pressure; \(\text{Ti}/\text{Tot}\) = inspiratory time/total time.*

<table>
<thead>
<tr>
<th>Table 4</th>
<th>PAV parameter after 2 and 24 h ventilation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>PAV group after 2 h Mean ± SD</td>
</tr>
<tr>
<td>Elastance (cmH(_2)O/L)</td>
<td>25.1 ± 3.6</td>
</tr>
<tr>
<td>Resistance (cmH(_2)O/L/s)</td>
<td>14.4 ± 2.5</td>
</tr>
<tr>
<td>% set</td>
<td>80%</td>
</tr>
<tr>
<td>Work of breathing (J/L)</td>
<td>0.3 ± 0.05</td>
</tr>
</tbody>
</table>

SIMV: synchronized intermittent mandatory ventilation, PAV: proportional assist ventilation.

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Duration of ventilation, and length of stay in both successful groups.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>SIMV group (19) Mean ± SD</td>
</tr>
<tr>
<td>Duration of ventilation (days) mean ± SD</td>
<td>3.8 ± 0.3</td>
</tr>
<tr>
<td>ICU stay (days) mean ± SD</td>
<td>5.8 ± 0.8</td>
</tr>
</tbody>
</table>

SIMV: synchronized intermittent mandatory ventilation, PAV: proportional assist ventilation, ICU: intensive care unit.
patients with acute respiratory failure. The results demonstrated that PAV can improve the breathing pattern while reducing inspiratory effort. Further, a series of studies compared PSV and PAV, most of them were conducted for intubated patients [14,17–25] during weaning and revealed superiority of PAV over PSV in improving patient ventilator synchrony, decrease work of breathing, and less peak airway pressure. On the other hand, in a recent study, tolerance, duration of ventilation and clinical outcomes during weaning were similar in PSV and PAV [26].

Xirouchaki et al. [27] compared the two modes of assisted ventilation, PSV versus PAV in critically ill patients after 36 h on controlled ventilation, targeting possible differences in outcomes: failure of assisted ventilation necessitating switch to controlled modes, rates of successful weaning, mortality and patient–ventilator dysynchrony. They concluded that PAV may be used as a useful mode of support in critically ill patients. Compared to PSV, PAV increases the probability of remaining on spontaneous breathing while considerably reduces the incidence of patient-ventilator asynchronies.

Our study is the first study that compares SIMV with PAV in critically ill COPD patients who intubated and ventilated with AC for 12 h. Thus we study the early effects of PAV in this acute care setting. One recent study [27] evaluated the clinical factors associated with the success of PAV in the acute phase of critical illness. Mechanically ventilated patients > 12 h were switched from AC ventilation to PAV as soon as they regained spontaneous breathing activity. PAV was set to deliver the highest assistance. They compared patients in whom PAV succeeded versus those in whom it failed. They concluded that, PAV proved feasible as first-line ventilatory support in 63% of the patients, mostly in individuals without extreme derangements in work of breathing. Tachypnea and hypercapnia were the clinical factors associated with failure, though statistical significance was not reached. The outcome of the PAV group in our study was 72% success that is comparable to this update study and to the study of Aguirre-Bermeo et al. [26] who revealed that 30% in the PAV group required a return to volume AC ventilation due to clinical deterioration. As regards breathing pattern, the results of our study demonstrated significantly higher respiratory rate and significantly lower tidal volume with high variability identified by high standard deviation in the PAV group. This is illustrated by the fact that, this mode is a physiological spontaneous mode and is consistent with Luo et al. [29] who revealed higher respiratory rate during PAV. Incompatible with this, another study [18] revealed that the mean values of respiratory rate and tidal volume did not differ by a large amount between PAV and PSV. However, the higher variability of VT during PAV indicates an increased ability of the patients to control in spontaneous breathing activity if lung distension exceeds a certain threshold that is well below total lung capacity. Contrary to other assisted modes, PAV does not interfere with the operation of these reflexes, since with this mode, inhibition of inspiratory muscle activity results in an automatic termination of pressure delivery [32]. End inspiratory pressure in the PAV group in our results was below 26 cmH2O thus agree with this rationale. Also, Ye et al. [21] investigated the impact of PAV on tolerance and breathlessness in ventilated COPD and found that peak inspiratory pressure on PAV was significantly lower than on PSV.

Duty cycle (Ti/Ttot) is significantly lower during PAV indicating better neuroventilatory coupling. This could illustrate decreased patient ventilator asynchrony in previous trials [24,25,28,33].

In this trial PAV reduced WOB to 0.3 ± 0.05 J/L at 80% set (PAV 80) and non significantly increased it at 50% set (PAV 50%) to 0.4 ± 0.07 J/L. In a recent clinical trial [34] WOB is reduced to 0.2 ± 0.07 J/L at PAV80 and to 0.6 J/L ± 0.06 at PAV30. They concluded that the increase in the PAV levels decreases work of breathing, without significantly changing the breathing pattern. Levels lower than 30% of PAV are associated to excessive work of breathing. On the other hand, Wrigge et al. [18], studied thirteen COPD patients being weaned from mechanical ventilation. PSV was adjusted to match the same mean inspiratory pressure as during PAV 80%. A reduction in assist during PAV 50% resulted in an increase in WOB which reflected an increase in patient effort. Other studies confirmed that PAV significantly reduce WOB in acute exacerbation of COPD with hypercapnic respiratory failure [19,21,29,31].

PAV significantly reduced duration of mechanical ventilation and hospitalization compared with SIMV in this study. In a previous study comparing non invasive PAV and PSV, we demonstrated no significant difference in duration of ventilation and hospitalization between the two groups as the modes were spontaneous in all patients [35].
Conclusion

PAV is a more physiological and comfortable mode that can maintain improvement of respiratory distress and gas exchange in intubated COPD patients with the advantages of lower airway pressure, less auto PEEP, better patient-ventilator synchrony, and shorter hospitalization compared with SIMV.

Conflict of Interest

There is no conflict of interest.

References