# Proportional assist ventilation   methodology and therapeutics on COPD patients compared with pressure support ventilation

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**Objective**    To investigate the impact of proportional assist ventilation   PAV   on tolerance and breathlessness in ventilated chronic obstructive pulmonary disease   COPD    and to describe the patient-ventilator interaction   hemodynamic state   breathing pattern and work of breath during PAV and pressure support ventilation   PSV  .

**Methods**    Ten intubated COPD patients on weaning from mechanical ventilation were studied. Elastance and resistance were measured by both the inspiratory-hold technique during a brief period of volume control ventilation and runaway technique during PAV. Each assistance level of PAV   80%   60% and 40%   and PSV was selected randomly. Patients' response   hemodynamics   blood gas and lung mechanics were monitored.

**Results**    Tidal volume and respiratory rate didn't change in a consistent manner as the level of assist was decreased   $P > 0.05$  . With the level of assist increasing   peak inspiratory pressure was increasing significantly   $P < 0.05$    while patients' work of breath had the tendency to decrease   $P < 0.05$  . A significant difference in the Borg Category Scale was observed between PAV and PSV   0.50 1.50   vs 0.75 2.00    $P < 0.05$   at the same degree of respiratory muscle unloading. $PaCO_2$ was significantly higher on PAV   54 23   mm Hg   than on PSV   48 23   mm Hg    $P < 0.05$  . Peak inspiratory pressure on PAV was significantly lower than on PSV   16 ± 4 cm $H_2O$ vs 21 ± 3 cm $H_2O$   respectively   $P < 0.05$  . Hemodynamics and oxygenation remained unchanged.

**Conclusions**    PAV is a feasible method for supporting ventilator-dependent patients and was well tolerated. It can improve the breathing pattern and reduce inspiratory effort. At the same degree of respiratory muscle unloading   PAV can be implemented at much lower peak inspiratory pressure than PSV. It can also apply proportional pressure support according to the patients' ventilatory demand.

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$W$ith the development of microprocessor technology   it is now possible to determine flow and pressure characteristics and particular attention was given to improving synchronization with the spontaneously breathing patient in developing new modes of ventilation. Proportional assist ventilation   PAV   is a form of ventilatory support in which airway pressure increases in proportion to patient effort. In recent years   more studies have been published on the subject of PAV. If PAV was to be routinely used on patients it is useful to gain a broad range of clinical experience and develop simple therapy recommendations. The objective of this study was to investigate the impact of PAV on breathlessness in ventilated patients with chronic obstructive pulmonary disease   COPD    and to describe patient-ventilator interaction   hemodynamic state   breathing patterns and work of breath during PAV and pressure support ventilation   PSV  .

## METHODS

### Patients

Ten COPD patients   7 men and 3 women   induced respiratory failure requiring intubation and ventilatory

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support from June 1998 to February 1999 in the RICU of the Beijing Institute of Respiratory Medicine were evaluated. The mean age was $70.1 \pm 0.4$ years. Hemodynamics were monitored and different levels of assistance were compared among eight patients. All patients had been conscious and hemodynamically stable for at least 12 hours before the study. An informed consent was obtained from the patient or from next of kin.

## Apparatus

Respironics BiPAP Vision ventilator with PAV and PSV was used. Ventilatory support was established by the ventilator cycling between an inspiratory pressure level and a baseline expiratory positive airway pressure level in proportion to the patient-generated volume and/or flow. The parameters of PAV included  volume assistance  VA  cm $H_2O$/L    flow assistance   FA   cm $H_2O$ $L^{-1}$ $s^{-1}$    and % assist.

## Protocol

The elastance and resistance values in Table 1 were those determined before PAV with the inspiratory-hold technique[1] during a brief period of assist/control ventilation. The patient's spontaneous breathing was suppressed with sedation  Midazolam  1 mg – 3 mg  and muscle-relaxation   Vecuronium    0.05  mg/kg – 0.08  mg/kg    during measurement. No severe side effects were observed.

**Table 1.** Compare two ways to set parameters of PAV

| Patient No. | Inspiration-hold technique | | Runaway technique | | Ventilator settings |
| --- | --- | --- | --- | --- | --- |
| | VA | FA | VA | FA | VA/FA |
| | cm $H_2O$/L | cm $H_2O$ $L^{-1}$ $s^{-1}$ | cm $H_2O$/L | cm $H_2O$ $L^{-1}$ $s^{-1}$ | cm $H_2O$/L   cm $H_2O$ $L^{-1}$ $s^{-1}$ |
| 1 | 33 | 12 | 33 | 16 | 30/12 |
| 2 | 23 | 20 | 35 | 25 | 23/20 |
| 3 | 24 | 15 | 26 | 18 | 24/16 |
| 4 | 26 | 13 | 28 | 16 | 26/13 |
| 5 | 30 | 10 | 35 | 15 | 30/10 |
| 6 | 18 | 10 | 22 | 14 | 18/12 |
| 7 | 18 | 15 | 24 | 19 | 18/15 |
| 8 | 18 | 12 | 25 | 13 | 18/12 |
| 9 | 26 | 12 | 27 | 14 | 26/12 |
| 10 | 18 | 12 | 24 | 14 | 24/14 |

Patients were switched from the Drager-Evita Ⅱ ventilator to BiPAP Vision. The inspired $O_2$ fraction and extrinsic positive end-expiratory pressure  PEEPe  levels were matched to the level set on the conventional ventilator. PAV adjustment entailed setting levels for VA and FA by a " runaway technique".[2 3] Default settings of 5 and 3 for VA and FA and pressure limit of 20 cm $H_2O$ were used initially. VA was progressively increased till the pattern of " runaway " appeared. VA at this point was equal to the patient's Ers. In any case  at the " runaway " point the patient was receiving enough VA to cancel the entire elastic work. FA was also increased in small steps. A few breaths later the patient was asked to describe whether the change made him positive or negative.

PAV or PSV was selected randomly. For PAV  the level of assistance was set 80%  60% and 40% each. For PSV support  pressure was set to make tidal volume  VT  to 5 ml/kg – 10 ml/kg. Each level was maintained for 1 hour. The observation items were as follows   1  Subjective assessment by the patient. The patient was asked to point to the number that best described how hard it was to breathe on a 10-point Borg scale.[4]    2  Scale for accessory muscle use[3]  were used to assess all patients.  3  Swan-Ganz tube was deposited to monitor values of hemodynamics.   4  Arterial and pulmonary arterial blood samples were obtained.   5  Inspiratory effort was measured using an esophageal catheter.[5]    VarFlex  flow  transducer of Bicore CP-100 pulmonary monitor was connected to an artificial airway.

## Statistical analysis

Variables of different assist levels of PAV were processed with one way ANOVA test. Correlated analysis was done between VT and peak inspiratory pressure  PIP . The data of PAV and PSV was processed with a matched pair $t$ test to reach the value $P$.

## RESULTS

VA and FA were set by an inspiratory-hold technique and runaway technique respectively. The values of two groups correlate significantly  $r = 0.928$   $P < 0.01$  .

Different levels of assistance did not affect the values of hemodynamics and blood gas  Tables 3 and 4  significantly. Oxygenation was at a good level. Neither VT   $P > 0.05$  nor respiratory rate  $P > 0.05$  changed in a consistent way as the level of assistance was decreased. PIP was increased significantly  $P < 0.05$  and the patients' work of breath   WOBp   was decreased   $P < 0.05$ . VT correlated significantly with PIP on 80%  60% and 40%   $r = 0.854$   $r = 0.919$ and $r = 0.728$   respectively  $P < 0.05$ .

The effects of PAV and PSV on hemodynamics and lung mechanics are shown in Tables 4 and 5. At the same degree of respiratory muscle unloading  a significant difference in the Borg Category Scale was observed between PAV and PSV   0.50 1.50  vs 0.75 2.00   $P = 0.038$ . No significant difference of hemodynamics was found when the patients' circulatory function was steady. $PaCO_2$ was significantly higher on PAV than on PSV  $P = 0.013$ . PIP on PAV was significantly lower than on PSV  $P = 0.016$ .

**Table 2.** The effect of different level of assist on patients' appraise and lung mechanics $\bar{x} \pm s$

| Levels | n | Borg category scale△ | Use of accessory muscles△ | VT  L | RR  min⁻¹ | VE  L/min | PIP  cm H₂O | WOBv△  J/L | WOBp△  J/L | Ti/Ttot |
|---|---|---|---|---|---|---|---|---|---|---|
| 80% | 8 | 0.25  2.50 | 1.00  2.75 | 0.39 ± 0.13 | 25 ± 8 | 10 ± 4 | 16 ± 4 | 1.06  0.51 | 0.54  0.45 | 0.36 ± 0.060 |
| 60% | 8 | 0.75  2.00 * | 0.50  2.00 | 0.37 ± 0.13 | 26 ± 8 | 9 ± 3 | 14 ± 3 | 0.87  0.31 * | 0.84  1.01 * | 0.35 ± 0.052 |
| 40% | 8 | 2.00  2.75 * | 2.00  1.00 | 0.34 ± 0.09 | 27 ± 6 | 9 ± 2 | 11 ± 2 * | 0.67  0.16 * | 1.15  1.03 * | 0.36 ± 0.058 |

\*   compared with 80%   $P < 0.05$   △ M  75% – 25% percentiles   RR  respiratory rate   WOBv  work of breath by ventilator   WOBp  work of breath by patient.

**Table 3.** The effect of different level of assit on hemodynamics and blood gas $\bar{x} \pm s$

| Levels | n | HR min⁻¹ | SBPm mm Hg | PAPm mm Hg | CI△ L min⁻¹ m⁻² | PVRI mm Hg min L⁻¹ | PaO₂ mm Hg | PaCO₂△ mm Hg | DO₂I L min⁻¹ m⁻² | VO₂I L min⁻¹ m⁻² |
|---|---|---|---|---|---|---|---|---|---|---|
| 80% | 8 | 103 ± 9 | 88 ± 6 | 28 ± 8 | 4.45  1.24 | 3.61 ± 1.20 | 81 ± 18 | 54  18 | 0.76 ± 0.23 | 0.15 ± 0.02 |
| 60% | 8 | 100 ± 12 | 89 ± 8 | 28 ± 8 | 4.03  0.93 | 3.76 ± 1.11 | 75 ± 17 | 56  26 | 0.71 ± 0.20 | 0.15 ± 0.04 |
| 40% | 8 | 103 ± 11 | 94 ± 13 | 28 ± 8 | 4.19  1.48 | 3.76 ± 1.35 | 76 ± 15 | 58  26 | 0.69 ± 0.21 | 0.16 ± 0.05 |

△ M  75% – 25% percentiles   HR  heart rate   SBPm  systemic mean blood pressure   PAPm  pulmonary arterial mean pressure   CI  cardiac output index   PVRI pulmonary vascular resistance index   DO₂I  oxygen delivery index   VO₂I  oxygen consumption index.

**Table 4.** The effect of PAV and PSV on patient appraisal and lung mechanics $\bar{x} \pm s$

| Groups | n | Borg Category Scale△ | Use of accessory muscles△ | VT  L | RR  min⁻¹ | VE  L/min | PIP  cm H₂O | WOBv  J/L | WOBp  J/L | Ti/Ttot |
|---|---|---|---|---|---|---|---|---|---|---|
| PSV | 10 | 0.75  2.00 | 0  1.25 | 0.45 ± 0.14 | 22 ± 8 | 9.2 ± 1.7 | 21 ± 3 | 1.60 ± 0.33 | 0.80 ± 0.39 | 0.35 ± 0.08 |
| PAV | 10 | 0.50  1.50 * | 0.50  2.25 | 0.38 ± 0.12 | 24 ± 8 | 8.9 ± 2.3 | 16 ± 4 * | 1.19 ± 0.27 * | 0.76 ± 0.29 | 0.37 ± 0.06 |
| P values | | < 0.05 | > 0.05 | > 0.05 | > 0.05 | > 0.05 | < 0.05 | < 0.05 | > 0.05 | > 0.05 |

\*   compared with PSV   △ M  75% – 25% percentiles .

**Table 5.** The effect of PAV and PSV on hemodynamics and blood gas $\bar{x} \pm s$

| Groups | n | HR min⁻¹ | SBPM mm Hg | PAPM mm Hg | CI△ L min⁻¹ m⁻² | PVRI mm Hg min L⁻¹ | PaO₂ mm Hg | PaCO₂△ mm Hg | DO₂I L min⁻¹ m⁻² | VO₂I L min⁻¹ m⁻² |
|---|---|---|---|---|---|---|---|---|---|---|
| PSV | 8 | 105 ± 14 | 84 ± 7 | 28 ± 9 | 4.18  1.57 | 3.6 ± 1.1 | 79 ± 16 | 48  23 | 0.72 ± 0.27 | 0.16 ± 0.03 |
| PAV | 8 | 103 ± 15 | 87 ± 6 | 28 ± 8 | 4.45  1.24 | 3.6 ± 1.2 | 78 ± 18 | 54  23 * | 0.76 ± 0.23 | 0.15 ± 0.02 |
| P values* | | > 0.05 | > 0.05 | > 0.05 | > 0.05 | > 0.05 | > 0.05 | < 0.05 | > 0.05 | > 0.05 |

\*   compared with PSV   △ M  75% – 25% percentiles .

## DISCUSSION

With PAV there was no target flow  volume or pressure and the responsibility of guiding the ventilatory pattern was shifted completely from the physician to the patient with the purpose of improving the patient-ventilator interaction. PAV was described by Prof. Younes[2]  who investigated the practical application of this type of breathing support.[6]   At any instant during the breath  the pressure applied to the respiratory system  Ptot  was dissipated against the elastic and resistive elements of the respiratory system. During supported ventilation except that Ptot was not only patient-generated pressure  Pmus  but also the artificial pressure applied across the respiratory system by the ventilator  Pven  . During supported ventilation the instantaneous relation between the opposing forces was

$$Ptot = Pmus + Pven = V \times Ers + \dot{V} \times Rrs$$

where V was volume above FRC and $\dot{V}$ was flow rate. Because the pressure applied by the ventilator was proportional to volume and flow during VA and FA respectively  it follows that

$$Pmus = V \times  Ers - VA  + \dot{V} \times  Rrs - FA$$

From this equation it can be seen that the degree of assistance depended on the levels of VA and FA chosen relative to the mechanical properties of the respiratory system. It is also illustrated that the relationship between inspiratory effort and its ventilatory consequences can be improved. By relating the positive pressure applied to volume and flow  and as a consequence  inspiratory effort  the development of patient-ventilator asynchrony and related complications should also be reduced.

In this study  the inspiratory-hold technique and runaway technique were adopted in determining VA and FA. The values of each group correlated significantly. Ideally  Ers and Rrs should be known and VA and FA should be set to be the same fraction of Ers and Rrs  respectively. Limitation of conditions and state of illness were often met. It was a certain difficulty for clinical use. Our results indicate that the runaway technique is simple and feasible. In theory

when assisted near by 100% work spontaneous breath will reduce to zero. In practice runaway affected by technical stability was easy to occur due to slightly change of breath. Therefore it suggested that the percentage of assist should be set between 40% and 80% . The lacking of consistent changes in VT and RR as the level of assistance varied from 80% to 40% within the tolerable range. It may be concluded that the patient must determine ventilation and breathing pattern by ventilating demand targeted. For a certain period of time within the tolerable range the ventilating demand did not change  which is consistent with the results of Marantz.[7]   Respiratory function improved and respiratory muscle resumed during weaning. Reducing the level of assist gradually PIP and ventilator's work of breath were decreased. PAV may be a new mode for weaning. Marantz[7]    showed that in some patients   there was a tendency for VT to decrease with decreasing levels of assist. This   however   cannot be readily attributed to the lower assist   with PAV   as in the normal situation   VT varies with respiratory drive and the latter may have been accidentally decreasing during the study. Present research on three different levels of assist VT and PIP correlated significantly demonstrating that the level of assist had some effect on ventilating outcome.

One of the premises on the principal of PAV was pressure-volume curve located in steep segment with the relationship between the change of pulmonary volume and the increasing of pressure being in the linear range. That was alveolus dilatation in geometric proportion. FRC was increased in COPD patients. Air trapping resulted in intrinsic PEEP  PEEPi . During inspiration enough pressure was needed to counteract PEEPi. Especially for PAV   effective ventilating support will not be implemented until PEEPi was counteracted by PEEPe. In this study   PEEPi was measured by expiration-hold in assist control ventilation. PEEPe was set at the level of 50% − 70% PEEPi.

Positive pressure ventilation may impact cardiovascular function. As central venous pressure was increased   cardiac output and blood pressure decreased accordingly.[8]    Both PAV and PSV   positive airway pressure was delivered with each inspiratory effort that succeeded in triggering the ventilator. The fundamental difference between the two methods was in the function that governed airway pressure behavior once the machine was triggered. In the present study   all COPD patients were in circulation steady state. Neither PAV or PSV affected hemodynamics significantly.

With PSV   airway pressure follows a predetermined function of time   usually a nearly square pattern. Differences in the level of effort beyond the trigger point should not influence the level of airway pressure. The airway pressure rises to a

level preset by the operator after the ventilator has been triggered. Airway pressure is therefore independent of patient effort. Complex interactions between the patient and ventilator characteristics determine the end of the ventilator inspiration   which may or may not coincide with the end of the patient's inspiratory effort. That means PSV can only roughly track the course of inspiration   with the result that the patient's breathing efforts are alternately over- and under-compensated. With PAV   there is no target flow volume or pressure and the responsibility of guiding the ventilatory pattern is shifted completely from the physician to the patient for the purpose of improving the patient-ventilator interaction. PAV requires an intact control of breathing. The more a patient pulls   the more Paw rises. What is set is the proportionality between instantaneous Paw and instantaneous patient effort. On PAV   pressure support is provided proportionate to the patient's effort throughout inspiration and the patient's needs are directly and continuously met.[5 12-13]    With PAV   the ability of the patient to modulate the ventilatory pattern is enhanced and the potential for discrepancies between patient and machine rates is   much   reduced.   The   ventilator   essentially becomes an extension of the patient's own muscle.[2]    And synchronization between patient and ventilator is advanced. COPD patients exhibit obstructive ventilation dysfunction. $PaCO_2$ is in relative higher level during the stabilized stage. With PSV   physicians have to set a proper pressure adequate to support ventilation and to keep over- and under-compensation from happening. Both are difficult to achieve. With PAV   patients modulated all aspect of breathing to make sure that $PaCO_2$ is in proper level. PIP during PAV was less than the value observed during PSV at the same WOBp. Barotruma may be avoided.

In short   PAV was feasible and well tolerated. It could be used for patient central respiratory output   normal or high. Any PAV device intended for use by critically ill patients   or any other patient in whom central apnea was a possibility must be equipped with a backup system.

Prospective clinical trials aimed at investigating whether PAV has real long term advantages over existing modes of mechanical ventilation have not been completed. Proper setting of PAV according to an individual patient's lung mechanics is still not easy to implement.

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