SHORT PAPER

Comparison of proportional assist ventilation and pressure support ventilation in chronic respiratory failure due to neuromuscular and chest wall deformity

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Thorax 2002;**57**:979–981

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Revised version received 20 May 2002
Accepted for publication 19 June 2002

Background: The physiological and symptomatic effects of proportional assist ventilation (PAV) and pressure support ventilation (PSV) were compared in stable awake patients with neuromuscular and chest wall deformity (NMCWD).

Methods: Oxygen saturation (Sa_{O_2}), transcutaneous carbon dioxide (Tc_{CO_2}), minute ventilation (V_E), tidal volume (V_T), respiratory rate (RR), and diaphragm electromyography (EMGdi) were measured in 15 patients during both modes. Subjective effort of breathing and synchrony with the ventilator were assessed using visual analogue scales.

Results: Three of 15 patients failed to trigger the ventilator in either mode and were excluded. In the 12 remaining patients there were similar improvements in Sa_{O_2}, Tc_{CO_2}, V_E, V_T, and RR during both modes. The mean (SD) percentage fall in EMGdi was greater during PSV (–80.5 (10.7)%) than during PAV (–41.3 (35.2)%; p= 0.01). Effort of breathing (p=0.004) and synchrony with the ventilator (p=0.004) were enhanced more with PSV than with PAV.

Conclusion: Both PSV and PAV produced similar improvements in physiological parameters. However, greater diaphragm unloading was observed with PSV than with PAV, associated with greater symptomatic benefit. These findings suggest that tolerance to PAV may be compromised in patients with NMCWD.

Proportional assist ventilation (PAV) is an alternative mode of partial ventilatory support that amplifies the patient's instantaneous flow and volume to reduce both the elastic and resistive loads.[1] PAV differs from conventional non-invasive ventilation (NIV), which delivers a preset volume or pressure, and is reported to improve neuroventilatory coupling and to enhance patient-ventilator synchrony.[1] Although previous short term studies with PAV have reported physiological and symptomatic improvements in patients with chronic respiratory failure (CRF) due to chronic obstructive pulmonary disease (COPD) and cystic fibrosis,[2–4] no studies have compared PAV with pressure support ventilation (PSV) in patients with CRF due to neuromuscular and chest wall deformities (NMCWD), a group of patients commonly treated with nocturnal NIV.[5] In this short term randomised trial we compared the physiological and symptomatic effects of PAV and PSV in patients with NMCWD.

METHODS

The protocol was approved by the local research ethics committee. Patients with CRF secondary to NMCWD established on domiciliary PSV were included in the study. All patients gave informed consent.

Flow was measured with a pneumotachograph (Hans Rudolph Inc, USA) and integrated to provide minute ventilation (V_E), tidal volume (V_T), respiratory rate (RR), inspiratory time (Ti), total duty cycle (Ttot), and Ti/Ttot. Bipolar electrodes (Kendall, USA) on the ventral surface of the sixth and seventh intercostal spaces[6] measured the diaphragm electromyogram (EMGdi) which was integrated and rectified (Digitimer, UK) and expressed as a percentage of baseline during ventilation. Measurements of transcutaneous carbon dioxide (Tc_{CO_2}) and oxygen saturation (Sa_{O_2}) were measured from forearm (Radiometer, Denmark) and finger probes (Nellcor, USA), respectively. All signals were analysed using Labview software (National Instruments, USA).

Nasal NIV was delivered by a Vision ventilator (Respironics, USA) set at a continuous positive airway pressure (CPAP) of 4 cm H_2O. PSV was set at the same level as the patient's home ventilator. The levels of volume assist (VA) and flow assist (FA) during PAV were set using the runaway method according to previous studies.[2–4] Although previously used in patients with COPD and restrictive lung disease,[2] the runaway method was mainly developed in patients with obstructive lung disease.[1 3 4] However, the runaway method is the only practical method available for setting the levels of VA and FA since measuring the elastic and resistive loads is generally too invasive and complex for routine clinical practice. The Vision ventilator defaults to controlled PSV if the patient fails to trigger; the back up rate was set to that of the patient's home ventilator.

The protocol was a single blind, randomised, crossover trial. Stage 1 was a 10 minute run in of spontaneous breathing (SB); stage 2 consisted of 40 minutes of either PAV or PSV followed by 30 minutes rest; stages 3 and 4 consisted of another 10 minute run in of SB followed by 40 minutes of either PAV or PSV. Subjective comfort was evaluated following PAV and PSV using a visual analogue score (VAS).[7] The patients rated effort of breathing and synchrony with the ventilator (0=least, 10=most).

Statistical analysis

All data are expressed as mean (SD) values. Differences between and within PAV and PSV were evaluated using analysis of variance (ANOVA) (Fisher's test). Differences between paired groups of data were evaluated using a paired *t* test. p values of <0.05 were considered statistically significant.

RESULTS

Fifteen patients of mean (SD) age 46.3 (15.3) years and vital capacity 1.0 (0.3) l were studied. Nine had chest wall deformity and the remaining six patients had a neuromuscular cause

Table 1 Comparison of differences in respiratory parameters from baseline with the two modes of ventilation

	Baseline	PAV	Baseline	PSV	PAV – PSV (95% CI)
Sa_{O_2} (%)	94.5 (3.3)	96.1 (2.2)	94.1 (5.5)	96.3 (2.2)	–0.17 (–1.46 to 1.12)
Tc_{CO_2} (kPa)	6.0 (0.8)	5.1 (0.9)†	5.9 (0.7)	4.9 (0.9)*	0.16 (–0.28 to 0.60)
V_E (l/min)	8.0 (1.3)	14.3 (4.1)†	8.1 (1.6)	15.5 (6.0)*	–1.23 (–4.64 to 2.18)
RR (breaths/min)	19.5 (5.6)	17.0 (4.2)	19.4 (5.9)	16.9 (3.8)	0.08 (–1.44 to 1.60)
V_T (l)	0.44 (0.14)	0.91 (0.39)†	0.47 (0.20)	0.98 (0.58)*	–0.09 (–0.31 to 0.13)
V_T/Ti (l/s)	0.39 (0.10)	0.78 (0.31)†	0.40 (0.10)	0.88 (0.38)*	–0.11 (–0.31 to 0.08)
Ti/Ttot	0.37 (0.04)	0.45 (0.11)†	0.38 (0.04)	0.33 (0.04)*	0.12‡ (0.05 to 0.18)

Results are mean (SD).
PAV=proportional assist ventilation; PSV=bilevel pressure support ventilation; PAV – PSV = mean difference between PAV and PSV; Sa_{O_2}=oxygen saturation; 95% CI = upper and lower 95% confidence intervals; Tc_{CO_2}=transcutaneous carbon dioxide; V_E=minute ventilation; RR=respiratory rate; V_T=tidal volume; V_T/Ti=mean inspiratory flow rate; Ti/Tot=inspiratory time as a ratio of the duty cycle (n=12).
*Difference from baseline with PSV, p<0.05. †Difference from baseline with PAV, p<0.05. ‡Difference between PAV and PSV.

for their chronic ventilatory failure. Mean arterial oxygen and carbon dioxide tensions (Pa_{O_2} and Pa_{CO_2}) for the 15 patients were 9.7 (1.5) kPa and 6.0 (0.7) kPa, respectively. Three of the 15 patients failed to trigger in either mode and only 12 patients were used for comparative analysis; eight of these had complete EMGdi data. Mean FA, VA and pressure support were 2.5 (0.8) cm H_2O/l/s, 22.3 (6.2) cm H_2O/l and 21.1 (6.3) cm H_2O, respectively.

There were similar improvements in Sa_{O_2}, V_E, V_T, V_T/Ti, Tc_{CO_2}, and RR in both modes (table 1). The percentage fall in EMGdi was greater with PSV than with PAV (–80.5 (10.7)% *v* –41.3 (35.2)%; p=0.01). This was associated with greater comfort during PSV with less effort of breathing (1.6 (1.2) cm *v* 3.7 (2.3) cm; p=0.004) and enhanced synchrony with the ventilator (7.5 (1.8) cm *v* 4.5 (2.8) cm; p=0.004).

DISCUSSION

In awake patients established on NIV for CRF due to NMCWD, we found similar increases in alveolar ventilation with PSV and PAV. However, significantly greater diaphragm unloading and enhanced comfort was observed with PSV than with PAV. We acknowledge the limitations of this short term daytime physiological study and appreciate that the results only apply to the PSV and PAV delivered by the Vision ventilator. However, as NIV is generally initiated during the daytime, these studies ensure that new modes of ventilation are evaluated before being considered for use at night. In a group of patients commonly treated with NIV, we unexpectedly found that three out of 15 did not trigger in either mode, an important finding as adequate ventilatory drive is essential for PAV. NIV is generally applied nocturnally, although the monitoring performed in this study would have been difficult at night. This, combined with the lack of benefit of PAV over PSV during the day, suggests that PAV is unlikely to have any significant benefits over PSV at night. In addition, we expect that the effectiveness of PAV may be further compromised during sleep as a result of changes in elastance and resistance that occur as V_T and functional residual capacity fall, or with the increase in air leaks resulting in underassistance or runaway.

Two important questions are raised by this study: (1) why was PAV less comfortable than PSV and (2) why was the fall in EMGdi greater during PSV? Compared with PSV, a similar increase in ventilation during PAV was associated with less of a reduction in EMGdi indicating better neuroventilatory coupling. Despite this, PAV was rated less comfortable in terms of effort of breathing and synchrony with the ventilator, which opposes the original hypothesis proposed by Younes.[1] An obvious reason is that our patients were familiar with PSV and thus were biased away from PAV. Furthermore, PAV differs from PSV both conceptually and in the pressure sensation delivered during ventilation. An alternative explanation relates unloading of the respiratory muscles to dyspnoea. PAV has been shown to unload the respiratory muscles and reduce dyspnoea,[2 3 8] and in the study by Ranieri *et al*[8] PAV reduced dyspnoea more than PSV. However, the unloading of the respiratory muscles in the study by Ranieri *et al*,[8] which was judged by the fall in pressure-time product, was greater with PAV than with PSV. This suggests that patient comfort is associated with the degree of respiratory muscle unloading, a correlation that was highlighted in a recent study by Fauroux *et al*.[9]

The second question raised by our study and observed in previous studies[4] is why the fall in EMGdi is less with PAV than with PSV. During PAV the airway pressure increases as a proportion of the patient's instantaneous flow and volume, whereas during PSV the airway pressure is preset and delivered as a function of time. After the initial active triggering phase in PSV, inspiration can be virtually passive.[10] However, during PAV, V_T depends on the duration and strength of respiratory muscle activity which is reflected by the difference in EMGdi between the two modes. In addition, if the resistive load is predominant during PAV, as in COPD, the peak pressure occurs at the start of inspiration, whereas if the principal load is elastic, as in our patients, the peak pressure occurs towards the end of inspiration. Since it has been shown that peak pressure delivered at the onset of inspiration results in greater diaphragm unloading,[11] we suggest that PAV may be more appropriate in obstructive than in restrictive lung disease. Furthermore, patients with restrictive lung diseases such as chest wall deformity and neuromuscular disease have differing pulmonary mechanics which could also be expected to alter the response to PAV.

We acknowledge that surface electrode recordings of EMGdi as an indicator of diaphragm unloading have certain methodological limitations, especially in patients. An important limitation that should be highlighted in our study is the effect of changes in lung volume on EMGdi. The Vision ventilator has a mandatory CPAP of 4 cm H_2O to prevent CO_2 rebreathing in both the PAV and PSV modes, which would be expected to increase the end expiratory lung volume. However, Gandevia and McKenzie[12] have shown that EMGdi is actually overestimated when lung volume is increased, whereas we observed a decrease in EMGdi with both PAV and PSV, despite the increase in V_T.

In this short term daytime study in stable patients established on NIV for CRF due to restrictive NMCWD, PAV and PSV were equally effective at increasing alveolar ventilation. However, in this patient group there is reduced diaphragm unloading during PAV which is associated with less patient comfort than PSV.

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Nicholas Hart was funded by the Dorothy Osbourne Legacy, a Scadding-Morriston-Davies Respiratory Medicine Research Fellowship, a grant from the Association Française Contre Les Myopathies and a long-term fellowship award from the European Respiratory Society. Angela Hunt was supported by the Brompton Breathers Trust Fund.

The Vision® ventilator was supplied by Respironics Inc, Murrysville, PA, USA.

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