TECHNICAL NOTE

Comparison of pressure and volume preset nasal ventilator systems in stable chronic respiratory failure

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Comparison of pressure and volume preset nasal ventilator systems in stable chronic respiratory failure. D.J. Meecham Jones, J.A. Wedzicha. ©ERS Journals Ltd.
ABSTRACT: Nasal intermittent positive pressure ventilation (NIPPV) has been widely used in the treatment of chronic respiratory disease. Ventilators may be volume or pressure preset; each type has theoretical advantages, but to date there has been no formal comparison. We wanted to assess the efficacy on blood gas changes that may be achieved and overall acceptability of four nasal ventilators (two pressure preset: Respironics bilevel positive airway pressure (BiPAP®) and the Thomas NIPPY; and two volume preset: BromptonPac and Monnal-D) in patients with stable chronic respiratory failure.

Median age was 59 yrs (range 48–71 yrs), mean (SD) arterial oxygen tension (Pa_{O_2}) 7.16 (0.21) kPa, arterial carbon dioxide tension (Pa_{CO_2}) 7.02 (0.35) kPa, forced expiratory volume in one second (FEV_1) 0.76 (0.24) *l*, and forced vital capacity (FVC) 1.58 (0.49) *l*. All had previously used NIPPV.

There were significant changes in blood gases at 2 h with each ventilator: mean change (95% confidence interval); BiPAP® Pa_{O_2} +1.52 (0.95–2.09) kPa, Pa_{CO_2} -1.04 (1.55–0.54) kPa; NIPPY Pa_{O_2} +1.63 (0.85–2.41) kPa, Pa_{CO_2}, -1.1 (1.86–0.34) kPa; BromptonPac Pa_{O_2} +1.22 (0.75–1.67) kPa, Pa_{CO_2} -1.14 (1.52–0.76) kPa; Monnal-D Pa_{O_2} +1.14 (0.42–1.84) kPa, Pa_{CO_2} -1.19 (2.14–0.23) kPa. Analysis of variance showed no significant differences in the efficacy of volume or pressure preset equipment, and all ventilators proved equally acceptable to the patients studied.

We conclude that all four of the volume or pressure preset ventilators examined are suitable for the delivery of nasal intermittent positive pressure ventilation in patients with stable chronic respiratory failure.
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Nasal intermittent positive pressure ventilation (NIPPV) has become a widely-used technique in the treatment of chronic and acute-on-chronic respiratory failure due to chest wall and neuromuscular disease, and is now used increasingly in selected patients with chronic airflow obstruction [1–8]. In recent years, a number of ventilators have been produced specifically for NIPPV, although, as yet, there has been no formal comparison of equipment or ventilator modes.

As with conventional positive pressure ventilators, nasal ventilator systems may be pressure or volume preset [9, 10]. Pressure preset equipment delivers sufficient flow to the patient to raise airway pressure to a predetermined level, and to maintain this pressure for a given time or until flow to the patient falls below a certain critical level. By contrast, volume preset equipment delivers a predetermined tidal volume with each assisted breath regardless of airway pressure, although in practice airway pressure limits may be set to avoid trauma to the airways. Both types of ventilator have been used successfully in patients with chronic respiratory failure, although there are theoretical advantages associated with each type of system.

We have assessed four nasal ventilator systems of contrasting design (two pressure preset and two volume preset) with regard to the blood gas changes that may be achieved and overall acceptability in a group of patients with stable chronic respiratory failure.

Methods

Equipment

Four nasal ventilator systems were studied: the Respironics bilevel positive airway pressure (BiPAP®) and Thomas NIPPY are both pressure preset, whilst the BromptonPac and Monnal-D are both volume preset.

BiPAP®

The BiPAP® spontaneous/timed (S/T) ventilator used in this study (Respironics Inc., Murrysville, PA, USA) is an assist/control nasal ventilator system, which in

normal operating mode (patient-triggered) acts as a flow cycled pressure generator [9]. The ventilator has a flow-dependent trigger (unlike all of the other ventilators studied, which have pressure-dependent triggers) and an inspiratory cycle terminated by a fall in flow to the patient, as ventilator and airway pressures equilibrate. Inspiratory positive airway pressure (IPAP) and expiratory positive airway pressure (EPAP) may be adjusted to deliver the required level of ventilation. In this way, it is possible to deliver positive airway pressure throughout the whole respiratory cycle, with a pressure boost during inspiration. The maximum IPAP that may be achieved is 22 cmH$_2$O; EPAP may be varied in the range 2–22 cmH$_2$O).

NIPPY

The NIPPY (Thomas Respiratory Systems, London, UK) is an assist/control nasal ventilator, which functions as a time cycled pressure generator. There are inspiratory and expiratory time settings, by means of which the duration of the respiratory cycle and respiratory rate may be controlled, and a variable trigger threshold. Airway pressure (measured at the expiratory valve adjacent to the mask) may be monitored by means of a pressure gauge. Flow to the patient, and hence airway pressure, is controlled by a valve which is servo-controlled on pressure linked to a variable flow generator.

BromptonPac

The BromptonPac (PneuPAC UK, Luton, UK) is a volume preset assist/control nasal ventilator system. It functions as a time cycled flow generator, pressure limited, with a sensitive trigger. Inspiratory and expiratory time settings may be adjusted as required. Inspiratory flow may be adjusted over the range 0.7–1.3 $l \cdot s^{-1}$ to generate the desired tidal volume, and the airway pressure monitored by means of a pressure gauge on the control panel.

Monnal-D

The Monnal-D ventilator (TAEMA, Paris, France) is volume preset and is also used in the assist/control mode, in which case it functions as a time cycled flow generator. The necessary minute volume, trigger sensitivity, ratio of inspiratory/expiratory time and underlying back-up rate may be preset. The maximum minute volume that can be achieved is 20 $l \cdot min^{-1}$. Airway pressure may be monitored within predetermined safety limits by means of a pressure gauge calibrated in millibar (cmH$_2$O).

Patients and methods

Eight patients (median age 59 yrs, range 48–71 yrs) with stable chronic respiratory failure were recruited from the out-patient clinic. All were judged to have been in a stable clinical state for at least one month prior to commencing the study. Five patients had chronic airflow obstruction, one had bronchiectasis and a previous lobectomy, and two had thoracoplasties, although spirometry showed an obstructive defect in each case. The mean (SD) forced expiratory volume in one second (FEV$_1$) of the group was 0.76 (0.24) l and forced vital capacity (FVC) 1.58 (0.49) l. Resting arterial blood gases showed hypoxia and hypercapnia, with a mean (SD) arterial oxygen tension (Pao$_2$) of 7.16 (0.21) kPa and arterial carbon dioxide tension (Paco$_2$) of 7.02 (0.35) kPa. Further details are given in table 1. Five of the subjects were established on domiciliary nocturnal ventilation (three with the BromptonPac nasal ventilator, one each with the BiPAP® and Monnal-D), and all of the others were familiar with the technique, either through previous domiciliary use, or through in-hospital treatment during acute exacerbations of chronic respiratory failure.

On Day 1 of the study, the patient underwent a trial period using each ventilator. Settings were adjusted on the BromptonPac and Monnal-D ventilators to deliver the maximum calculated minute volume that the patient could comfortably tolerate. The BiPAP® and NIPPY were

Table 1. – Patient characteristics

Pt no.	Age yrs	Sex	Diagnosis	FEV$_1$ l	FVC l	Pao$_2$ kPa	Paco$_2$ kPa	Usual ventilator
1	52	M	COPD	0.70	1.60	7.07	6.81	BromptonPac
2	60	M	COPD	0.71	1.56	7.66	7.59	BromptonPac
3	48	F	Bronchiectasis + L. lobectomy	0.66	1.30	7.44	7.33	–
4	54	M	COPD	0.55	1.44	6.88	6.27	Brompton Pac
5	57	M	COPD	1.00	2.40	6.49	7.24	–
6	67	F	Bilateral thoracoplasty	0.80	1.30	7.54	6.24	Monnal-D
7	68	F	R. thoracoplasty	0.44	0.88	7.07	8.38	BiPAP®
8	71	M	COPD	1.20	2.20	7.19	6.32	–
Mean (SD)				0.76 (0.24)	1.60 (0.49)	7.16 (0.21)	7.02 (0.35)	

COPD: chronic obstructive pulmonary disease; FEV$_1$: forced expiratory volume in one second; FVC: forced vital -
Pao$_2$: arterial oxygen tension; Paco$_2$: arterial carbon dioxide tension; BiPAP®: bilevel positive airway pre·

Table 2. – Ventilator settings used during study

Pt No.	BiPAP®		NIPPY			BromptonPac				Monnal-D		
	IPAP cmH₂O	EPAP cmH₂O	Insp. time s	Exp. time s	Airway pressure cmH₂O	TI s	TE s	Flow l·s⁻¹	Airway pressure cmH₂O	I/E ratio	V Del l·min⁻¹	Airway pressure cmH₂O
1	20	4	1.5	2.5	25	1.5	2.5	0.8	28	1/2.5	18	22
2	16	2	1.5	2.5	28	1	3	0.8	25	1/2.5	18	20
3	18	4	1.5	2.5	25	1.5	2.5	0.8	25	1/2.5	18	18
4	22	4	1.5	2.5	25	1.5	3	1.1	30	1/2.5	18	20
5	18	4	1.5	2.5	22	1	3	0.8	25	1/2	18	18
6	22	4	1.2	2.5	28	1.5	2.5	1.2	25	1/2.5	18	22
7	22	4	1.5	2.5	25	1	3	0.7	25	1/2	14	18
8	22	4	1.2	3	28	1	2.5	1.0	25	1/2.5	18	20

BiPAP: bilevel positive airway pressure; IPAP: inspiratory positive airway pressure; EPAP: expiratory positive airway pressure; TI: inspiratory time; TE: expiratory time; I/E ratio: inspiratory/expiratory time ratio; V Del: minute volume.

Table 3. – Mean changes in Pao_2 and $Paco_2$ and 95% confidence intervals (CI) for each ventilator studied

Ventilator	Initial Pao_2 kPa	ΔPao_2 kPa	95% CI	Initial $Paco_2$ kPa	$\Delta Paco_2$ kPa	95% CI
BiPAP®	7.00 (0.22)	+1.52	0.95–2.09	7.03 (0.25)	-1.04	-1.55 to -0.54
NIPPY	7.48 (0.33)	+1.63	0.85–2.41	7.05 (0.28)	-1.10	-1.86 to -0.34
BromptonPac	7.06 (0.24)	+1.22	0.75–1.67	7.05 (0.35)	-1.14	-1.52 to -0.76
Monnal-D	7.13 (0.23)	+1.14	0.42–1.84	6.97 (0.32)	-1.19	-2.14 to -0.23

For abbreviations see legends to tables 1 and 2.
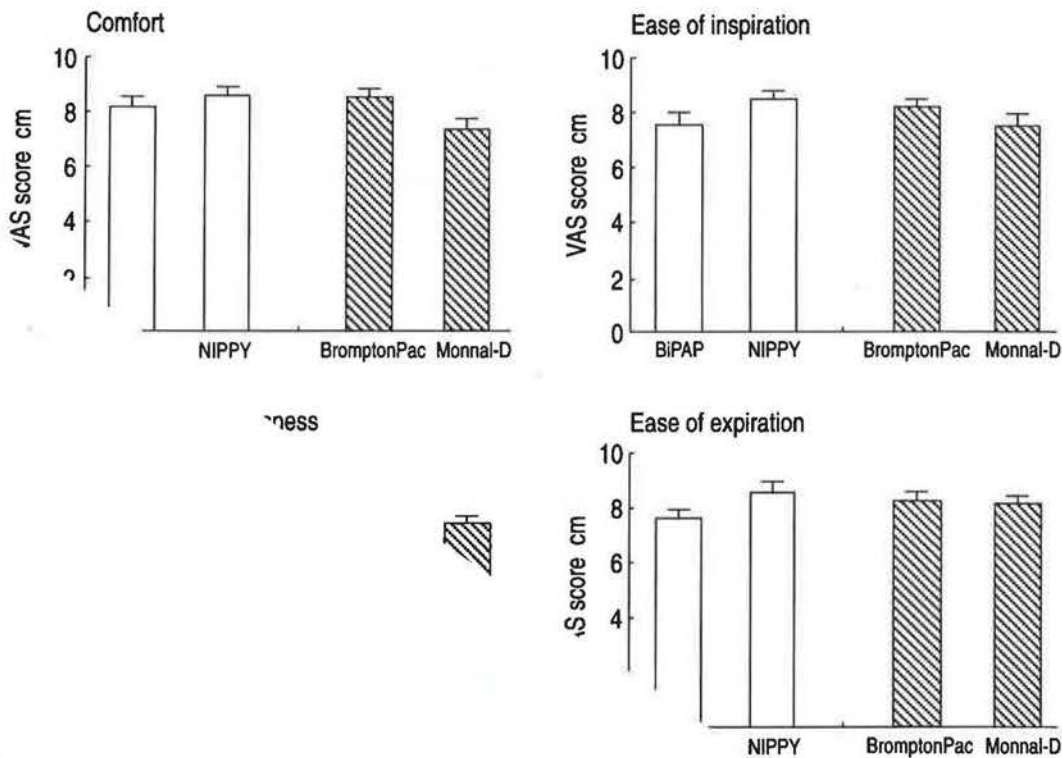
oreset; ▨: volume preset. BiPAP: bilevel

adjusted to generate the highest airway pressure that the patient could tolerate. On subsequent study days, each subject underwent a further 2 h period of ventilation with each system (in randomized order) at the ventilator settings derived on Day 1, although these settings were rechecked prior to each study period. In all, each patient attended on three separate days, with studies carried out in mornings and afternoons. All studies were performed in a standardized manner, in the same room, with the subject in a sitting position throughout. No supplemental oxygen was administered during the course of the study. Arterialized blood gases were obtained from the ear lobe [11] at the start and end of each period of ventilation and 10 cm visual analogue scale scores regarding breathlessness, comfort and ease of inspiration/ expiration were administered on completion of each period [12].

Statistical methods

Changes in blood gases were compared using parametrical statistical tests, and differences between individual ventilators were assessed by a repeated measures analysis of variance.

Results

All of the patients completed the study, and the individual ventilator settings used for each patient are shown in table 2.

The mean initial Pao_2 and $Paco_2$ ($\pm$SEM) at the start and the mean changes (with 95% confidence intervals) achieved with each ventilator are shown in table 3. In each case, there was a statistically significant rise in Pao_2 and fall in $Paco_2$. A repeated measures analysis of variance performed on these mean values showed no significant differences between any of the ventilator systems, or between the pressure and volume preset equipment.

The mean visual analogue scale scores representing overall comfort and breathlessness at the end of each study period, and the ease of inspiration and expiration, are depicted in figure 1. All of the equipment proved to be acceptable, and a repeated measures analysis of variance performed on the mean values showed no significant differences between any of the ventilators studied.

Discussion

The aims of ventilatory support in chronic and acute-on-chronic respiratory failure are to increase alveolar ventilation, with a consequent improvement in arterial blood gas tensions, and to offset some of the workload of the respiratory muscles. Although nasal ventilation has been shown to achieve both of these goals [13, 14], there is still considerable debate as to the most efficient and effective means of delivery.

In this study, we have investigated the blood gas changes that can be achieved by four contrasting nasal ventilator systems, as a means of evaluating the degree of ventilation and improvement in gas exchange that can be achieved in patients in stable chronic respiratory failure. We have also attempted to identify any differences in patient acceptability between the various systems. All of the ventilators studied produced significant improvements in blood gas tensions, although no single ventilator proved superior to the others in the magnitude of the changes achieved. There were no differences between the pressure and volume preset systems studied. In addition, all of the ventilators were well-tolerated, again with no significant differences observed in acceptability between the pressure and volume preset equipment.

Although NIPPV is usually used overnight, this study was performed in conscious, awake patients during the daytime. Most patients are established on nasal ventilation during the day, and settings are adjusted according to acceptability and clinical effect at that time, as in this study. Thus, our results are of direct clinical relevance to the establishment of patients on NIPPV. Furthermore, nasal ventilation is now used by day in normal clinical practice, particularly during the treatment of acute exacerbations of chronic respiratory failure, and also in weaning from conventional assisted ventilation [15–17]. The performance of the ventilators may be different at night, but to evaluate this fully would require at least five sleep studies per subject, which would prove to be both technically difficult and unacceptable to most patients.

In assessing pressure and volume preset ventilators, one must take into account the potential advantages of each type of system. In order to maintain a constant airway pressure, pressure preset equipment automatically adjusts flow rates to deliver additional ventilation to the patient to overcome any leaks within the system, usually from around the nasal mask. In compensating for such leaks, pressure preset equipment has the advantage of overcoming one of the major causes of inefficient ventilation [5]. In addition, we have previously observed that many patients find pressure preset equipment more comfortable, probably because of the characteristics of the flow wave produced. Volume preset equipment may generate a very high airway pressure, but this is often distributed unevenly throughout the inspiratory cycle, with a sharp early rise and subsequent fall. Many patients find this pattern of airflow delivery uncomfortable, with consequent problems of acceptance and compliance with treatment. In this study, however, visual analogue scale scores failed to identify any differences in overall acceptability between the ventilators studied. This may be due to the fact that all of the patients were familiar with the equipment, and four were already established on long-term domiciliary nasal ventilation with volume preset equipment.

Our results in this study suggest that any of these ventilators would be suitable for use in patients with stable chronic respiratory failure. It is, however, possible that the results may be different in patients with acute-on-chronic respiratory failure, in whom the reduction in lung compliance might result in inadequate tidal volumes at the maximum pressure generated by the ventilators. It has been suggested that, under such conditions, volume preset equipment may provide a more reliable means of

delivering the necessary additional tidal volume [8]. We believe that, provided sufficiently high airway pressures can be achieved, pressure preset equipment is as effective as volume preset equipment for the delivery of NIPPV.

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