Comparison of Five Bilevel Pressure Ventilators in Patients With Chronic Ventilatory Failure: A Physiologic Study

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Comparison of Five Bilevel Pressure Ventilators in Patients With Chronic Ventilatory Failure*

A Physiologic Study

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Objective: **To compare patient-ventilator interaction and comfort in patients with chronic ventilatory failure (CVF) who are undergoing noninvasive positive-pressure ventilation with five different commercial bilevel pressure home ventilators. Also, we wanted to evaluate the short-term effects of the five ventilators on physiologic variables, namely, breathing patterns and inspiratory muscles.**
Design: **Randomized, controlled physiologic study.**
Setting: **Pulmonary division of a rehabilitation institution.**
Patients: **Twenty-eight patients with CVF due to COPD (17 patients) and restrictive chest wall diseases (11 patients).**
Measurements: **Sensation of comfort, breathing patterns and minute ventilation ($\dot{V}_E$), respiratory muscles and mechanics, and patient-ventilator interaction during both unassisted and assisted ventilation with the five ventilators applied randomly.**
Results: **The five ventilators showed different flow and pressure waveforms. The level of comfort was somehow different among the studied ventilators. When compared to unassisted ventilation, all ventilators induced a significant increase in $\dot{V}_E$ ($p < 0.01$) without any significant difference among ventilators. Use of the five ventilators resulted in significant differences in peak airway opening pressure (Pao,peak) but not in mean airway opening pressure computed over a period of 1 min (PTPao,min), and in a duty cycle. Ineffective efforts (IEs) were similar among the studied ventilators. In comparison with unassisted ventilation, all ventilators induced significant reductions in inspiratory muscle effort ($p < 0.001$). No significant relationship was found between level of comfort and PTPao,min, Pao,peak, or the number of IEs.**
Conclusions: **In stable, awake patients with CVF, all of the studied ventilators were well-tolerated, although with a great intersubject variability in comfort, and performed well in terms of improvement in $\dot{V}_E$ and inspiratory muscle unloading, thus fulfilling the aims of mechanical ventilation. This effect was obtained with similar levels of PTPao,min, despite the fact that Pao,peak was different among some ventilators. The number of IEs was similar among the studied ventilators.**

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Key words: breathing pattern; COPD; hypercapnia; noninvasive mechanical ventilation; respiratory failure; respiratory muscles; restrictive chest wall disease

Abbreviations: ANOVA = analysis of variance; CV = coefficient of variation; CVF = chronic ventilatory failure; EPAP = expiratory positive airway pressure; *f* = respiratory frequency; H = Harmony ventilator; He = Helia ventilator; IE = ineffective effort; IE-flow = ineffective efforts calculated as a lack of ventilator triggering in the presence of an inspiratory deflection of the flow signal; IE-Pes = ineffective efforts that were unable to trigger a ventilator cycle despite a negative swing in esophageal pressure; IPAP = inspiratory positive airway pressure; NPPV = noninvasive positive-pressure ventilation; O = Onyx ventilator; Pao = airway opening pressure; Pao,peak = peak airway opening pressure; PEEPi,dyn = dynamic intrinsic positive end-expiratory pressure; Pes = esophageal pressure; PTP = pressure-time product; PTPao,min = mean airway opening pressure; PTPes,min = changes in the pressure-time product that were calculated over a period of 1 min; PV = PV 102 ventilator; RCWD = restrictive chest wall disease; Re = Respicare CV ventilator; SB = spontaneous breathing; T_I = inspiratory time; T_{TOT} = total cycle duration; VAS = visual analog scale; $\dot{V}_E$ = minute ventilation; V_T = tidal volume

Long-term noninvasive positive-pressure ventilation (NPPV) is widely used in the management of chronic ventilatory failure (CVF) resulting from restrictive chest wall disease (RCWD) and from COPD,[1] although, in the latter case, strong evidence of significant clinical benefit is still lacking.[2,3] Pressure support ventilation is the most common mode of providing ventilatory assistance in the chronic

setting, with and without some level of positive end-expiratory pressure.[4,5]

For editorial comment see page 1881

Criner et al[6] found that only 50% of patients with COPD continued to use NPPV during prolonged follow-up. In clinical practice, long-term NPPV is delivered by means of the so-called *domiciliary bilevel pressure ventilators* and is set to achieve a decrease in $Paco_2$ and optimal patient compliance, which is crucial for adherence to treatment.[1,6] Setting pressure support ventilation on the basis of patient comfort was effective in improving arterial blood gas levels and in unloading inspiratory muscles.[4]

Home NPPV is often prescribed after in-hospital practice sessions that are performed with the commercial ventilators available at the moment (often a single one), which may not necessarily be the one that is used by the patient at home, without the possibility of choosing among ventilators that have been tailored to the patient. Although the large majority of the so-called *home care* ventilators perform as well as traditional and more expensive ventilators used in the ICU,[7,8] it has been demonstrated that, at least in bench studies, each individual ventilator performs differently from others.[7–11] To the best of our knowledge, only one study[12] has compared patients' compliance to commonly prescribed commercial ventilators, but no specific comparison of the physiologic effects of updated ventilators in stable patients with chronic hypercapnia has been reported yet. Indeed, a consensus conference[13] has recommended studies of the determinants of patient tolerance and compliance. Therefore, we undertook a study to compare patient-ventilator interaction and patient comfort with five different commercial, bilevel pressure, in-home ventilators, all of which were set on the basis of the maximal tolerated inspiratory positive airway pressure (IPAP). In a subset of patients, we also evaluated the short-term effects of the five ventilators on physiologic variables, namely, breathing pattern and inspiratory muscles.

Materials and Methods

The investigative protocol was approved by the institutional ethics committee (S. Maugeri Foundation, Gussago, Italy) and was conducted according to the declaration of Helsinki. Informed consent was obtained from all the patients before their enrollment into the study.

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Patients

The study was conducted in the Pulmonary Division of the Scientific Institute of Gussago, S. Maugeri Foundation, from March 1 to December 31, 2000. Thirty-one patients (COPD, 19 patients; RCWDs, 12 patients) with CVF were recruited for this study. A diagnosis of COPD was made according to the American Thoracic Society Guidelines.[3,14] The diagnosis of CVF was based on clinical records showing values for $Paco_2$ that were persistently > 45 mm Hg during spontaneous breathing (SB) with room air in the months, if not the years, preceding the study. All patients were in stable clinical condition, as assessed by an arterial pH of > 7.35, and had not experienced an exacerbation of their condition in the preceding 4 weeks. Patients with chronic organ failure, cancer, or the inability to cooperate also were excluded from the study. All the patients were receiving drug treatment according to the prescriptions of their general practitioners. In particular, COPD patients were receiving regular treatment with inhaled bronchodilators, avoiding therapy with either systemic or inhaled steroids, apart from during exacerbations. At the time of the study, 28 of the 31 patients were receiving long-term oxygen therapy. Seven COPD patients and five RCWD patients had been receiving long-term home NPPV by nasal mask for 8 to 29 months, with bilevel pressure ventilators, with a mean use of NPPV of about 7 h per night. Three of 31 patients were admitted to the hospital for indications of domiciliary NPPV, and 1 of those 3 patients was discharged to receive home NPPV. Therefore, at the end of the study 13 patients went home to receive home NPPV. The other 16 patients underwent respiratory rehabilitation programs. The characteristics of the patients are shown in Table 1.

Measurements

Routine static and dynamic lung volumes were measured with a constant-volume body plethysmograph (CAD-NET system 1085; Medical Graphic Corp; St. Paul, MN) with the patients in the seated position and performed according to standard procedures.[15] The predicted values of Quanjer[16] were used. Arterial blood was sampled at the radial artery with patients in a semi-recumbent position and breathing room air. Pao_2, $Paco_2$, and pH were measured by means of an automated analyzer (model 840; Ciba Corning; Medfield, MA).

Comfort: The sensation of comfort was measured at baseline and during sessions of NPPV by means of a visual analog scale (VAS), consisting of a 20-cm horizontal line, with 0% indicating the most comfortable and 100% representing the worst sensation.[17]

Respiratory Muscles: In 10 patients (COPD, 5 patients; RCWD, 5 patients), lung mechanics and respiratory muscles were evaluated during unassisted and assisted ventilation. For the experimental procedures of this study, flow was measured by means of a heated pneumotachograph (model No. 1; Fleisch; Lausanne, Switzerland) that was connected to a flow transducer (model 47304A; Hewlett-Packard; Cupertino, CA) and was inserted between the nasal mask and the nonrebreathing valve of the ventilator circuit.[18] Volume was obtained by the numerical integration of the flow signal. The airway opening pressure (Pao) was measured with a differential pressure transducer (model 143PCO3D; Honeywell; Freeport, IL) connected to one port of the nasal mask. Changes in pleural pressure were estimated from changes in esophageal pressure (Pes) by means of a transducer (Motorola X2010 $\pm$ 100 cm H_2O; Colligo, Elekton; Agliano Terme, Italy) by means of the balloon-catheter technique, with an esophageal balloon catheter, as previously described.[5]

Data Analysis: All signals were digitized by an analog-to-digital converter with 12-bit resolution that was connected to a personal computer (Pentium 100; Intel; Santa Clara, CA) at a sampling

Table 1—*Individual Data for Demographic, Anthropometric, and Functional Characteristics of Patients in the Study

Subject No./Age,† yr/Sex	Disease	Weight, kg	Po_2, mm Hg	Pco_2, mm Hg	FEV_1, % predicted	VC, % predicted	Home MV ‡
1/69/M	COPD	43	57	52	41	94	No
2/67/M	COPD	81	60	79	22	44	No
3/60/F	COPD	98	46.3	51.6	32	72	No
4/61/M	Mixed	83	56.9	53.6	50	59	BiPAP-S
5/59/F	COPD	55	42	65	22	37	Moritz II
6/79/F	Mixed	70	63	76	32	45	No
7/53/F	COPD	61	59	52.9	23	67	No
8/67/M	COPD	69	61	51	17	50	No
9/64/M	COPD	85	54	55.3	22	44	Moritz II
10/68/M	COPD	103	55.7	62.3	27	52	No
11/75/M	COPD	85	42	54	27	68	BiPAP
12/70/M	COPD	57	45	56	18	52	Drager
13/72/M	COPD	51	49.6	54.8	19	41	BiPAP
14/72/M	COPD	78	65	51.6	27	NA	No
15/59/M	COPD	69	61.2	55.2	32	67	No
16/75/M	COPD	80	52.8	54.5	60	78	No
17/61/F	COPD	95	61	61	33	60	BiPAP
18/63/F	KS	43	35	85	34	20	No
19/61/M	Myopathy	71	65	47	43	65	PV 102
20/47/F	After polio	75	55.6	57.4	21	17	No
21/51/M	KS	58	55	57	30	30	No
22/57/F	KS	72	62.6	51.6	27	28	Horizon
23/76/M	KS	51	54.6	59.5	33	41	No
24/51/M	KS	68	65.6	54	29	30	No
25/26/M	Myopathy	50	69.6	64.9	NA	NA	No
26/68/M	After TB	90	61.2	54.9	32	41	BiPAP
27/55/F	Myopathy	54	64.9	59.9	26	30	Breas
28/77/F	Obesity	117	60.1	54.7	70	NA	No
Mean 63		72	56	58	32	49	
SD 11		19	8	9	13	19	

*KS = kiphoscoliosis; NA = not available; M = male; F = female; VC = vital capacity; MV = mechanical ventilation; TB = tuberculosis.
† Mean (SD) age, 63 years (11 years).
‡ Manufacturers: Moritz II, MAP, Martinsreid, Germany; BiPAP-S, Respironics, Inc.; Horizon, Sunrise Medical, Somerset, PA.

frequency of 100 Hz. Subsequent analyses of breathing patterns and pulmonary mechanics were performed using a software package (ANADAT, version 5.2; RHT-Infodat; Montreal, PQ, Canada) interfaced with the respiratory monitoring system used in the present study. Using the *Abreath* mode of the software package, the mean value of each physiologic variable was computed and was used subsequently for statistical analysis. Tidal volume (VT), respiratory frequency (*f*), minute ventilation ($\dot{V}E$), total cycle duration (TTOT), inspiratory time (TI), expiratory time, and duty cycle (*ie*, TI/TTOT ratio) were calculated from the flow signal as average values from 1 min of continuous recording of flow and volume. Dynamic intrinsic positive end-expiratory pressure (PEEPi,dyn) was measured as the negative deflection in Pes from the onset of the inspiratory effort to the start of the inspiratory flow.[19] Changes in the magnitude of the effort of the inspiratory muscles were estimated from changes in Pes swings, as well as from changes in the pressure-time product (PTP), that were calculated over a period of 1 min (PTPes,min).[19,20] The latter measurement was expressed also as pressure developed per liter of ventilation (*ie*, PTPes,min/$\dot{V}E$ ratio).[5]

The peak Pao (Pao,peak) signal was calculated as the average value from 10 consecutive respiratory acts in which the breathing pattern and mechanics were calculated. In addition, in the same 10 consecutive breaths, mean airway pressure was measured as the area subtended by Pao, since the onset of inspiratory effort to the inspiratory flow tracing inversion (from beginning of inspiration to beginning of expiration). This value was multiplied for respiratory rate to calculate the minute area subtended by Pao (PTPao,min).

Ineffective Efforts: Patients' inspiratory efforts that were unable to trigger a ventilator cycle (lack of Pao) despite a negative swing in Pes were defined as *ineffective efforts* (IEs) [IE-Pes].[21] Furthermore, IEs were calculated also as a lack of ventilator triggering in the presence of an inspiratory deflection of the flow signal (IE-flow) in the same tracings (Fig 1). As in the subset of 10 patients, IE-Pes and IE-flow were highly correlated (Fig 2), as demonstrated by a Bland-Altman plot, IE-flow was used as a measurement of IE in all 28 patients using all ventilators. The mean number of IEs per minute, recorded > 5 min, was expressed as percentage of the patient respiratory rate (*ie*, the number of IEs per minute/*f* [in breaths per minute]·100).

Ventilatory Setting

All patients were blind to the ventilators used. Table 2 shows the characteristics of the studied ventilators.

For each ventilator, the level of IPAP was increased slowly by 2-cm H_2O steps, starting from 8 cm H_2O, until the patients indicated that breathing was uncomfortable. Hence, that level of IPAP was decreased by 1 cm H_2O, and the resultant level was applied.

After setting the IPAP, a level of expiratory positive airway

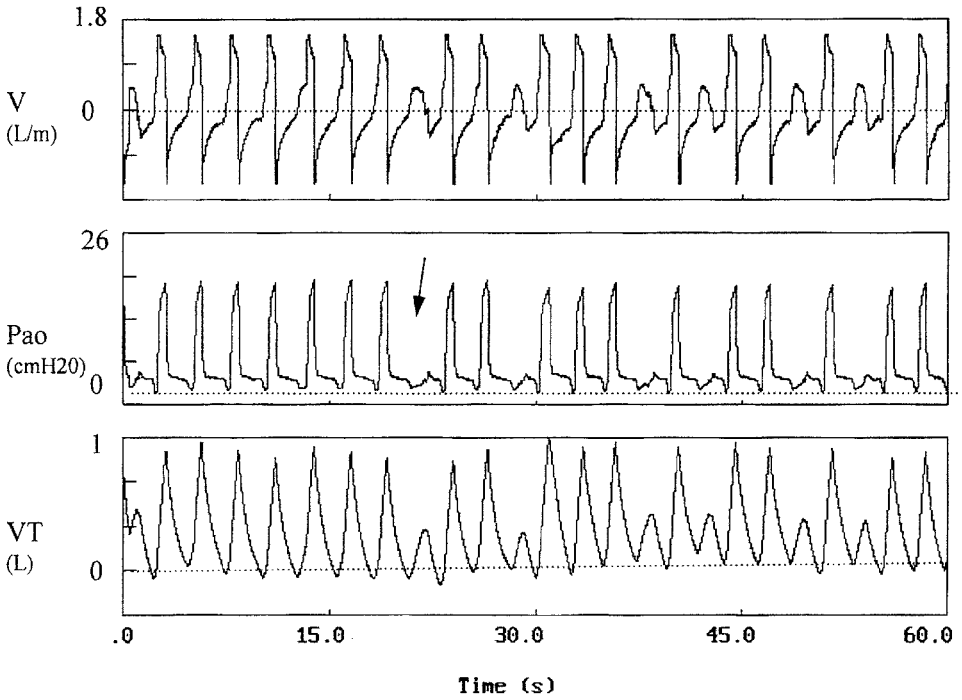

FIGURE 1. Polygraphic recording during assisted ventilation in a representative patient. An IE is demonstrated by the presence of airflow in the absence of corresponding Pao (*ie*, the lack of triggering of the ventilator) as shown by the arrow. V = flow.

pressure (EPAP) was added. In RCWD patients, the minimum default level of EPAP for each ventilator (see Table 2) was added. In COPD patients, EPAP was set at the patient's comfort level up to an arbitrary maximum level of 5 cm H_2O. All COPD patients tolerated up to 5 cm H_2O, but two patients tolerated only 3 cm H_2O EPAP.

The ventilator inspiratory trigger sensitivity was set at the lowest default value for each ventilator. The expiratory trigger sensitivity, when available (see Table 2), was set at 30% of peak flow (*ie*, the inspiratory flow was switched to expiratory flow when at least 70% of the inspiratory flow was delivered). Due to different characteristics of pulmonary mechanics, the slope rise of the inspiratory flow was the fastest available in COPD patients and was the slowest in RCWD patients. The minimum back-up

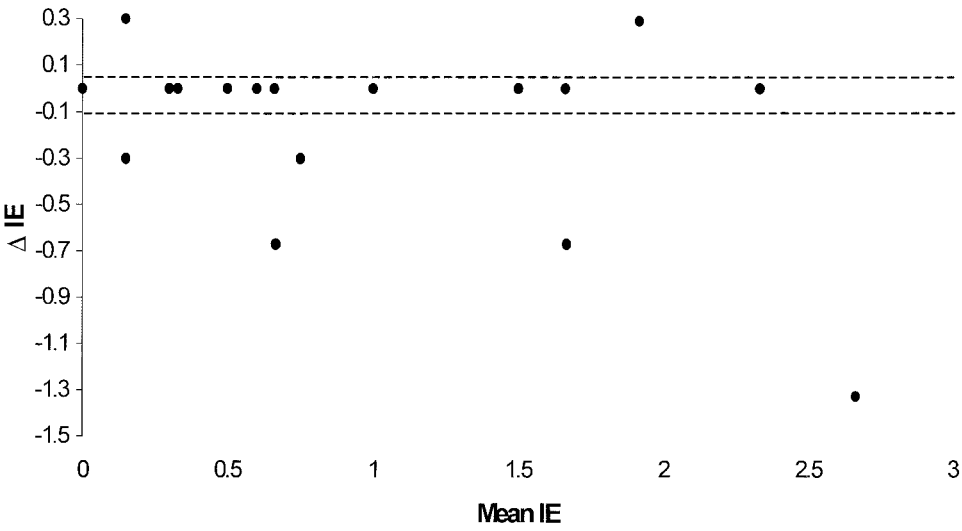

FIGURE 2. A Bland-Altman plot of the change in IE (ΔIE). The change in IE was calculated as the difference between that measured on the flow tracing and that measured on the IEs tracing (see the "Materials and Methods" section). The mean IE values were calculated as the mean of the two measurements obtained on the two tracings. Five pairs of measurements were made for each patient.

Table 2—*Characteristics of the Studied Ventilators*

Ventilator	Inspiratory Trigger	Adjustable Expiratory Trigger	Minimum EPAP	Minimum Backup *f*	Digital Display of *f* and VT	Expiratory Valve †	Adjustable Slope of Pressure Rise
H	Flow	No	4	4	No	Plateau valve	Yes
O	Pressure	Yes	0	4	Yes	Mallinckrodt Dar	Yes
PV	Flow	Yes	4	6	No	Plateau valve	Yes
He	Pressure*	Yes	0	0	Yes	Mallinckrodt Dar	Yes
Re	Flow	Yes	2	6	Yes	E-Vent Dräger	Yes

*The trigger used was a pressure trigger because a flow trigger is available only with the inspiratory-expiratory circuit.
†Manufacturers: plateau valve, Respironics, Inc, Murrysville, PA; Mallinckrodt Dar, Mallinckrodt Inc, Minneapolis, MN; E-Vent, Dräger, Fairfax, VA.

respiratory rate (*ie*, 4 to 6 breaths/min) available on the single ventilator was added (see Table 2).

Experimental Procedure

The whole procedure was performed under continuous monitoring of arterial oxygen saturation by pulse oximetry (Oxicap Monitor; Ohmeda; Louisville, CO). Patients were evaluated in the morning (COPD patients were evaluated at least 2 h after the inhalation of their bronchodilating medications) and were free to choose the most comfortable position. All patients adopted a semi-recumbent position.

The procedure to evaluate respiratory muscles and mechanics has been extensively detailed elsewhere.[4,5,19] Briefly, in 10 patients, after the application of topical anesthesia (xylocaine spray, 10%; Astra Pharmaceuticals SpA; Milan, Italy), the balloon-tipped catheter was inserted through the nose into the middle third of the esophagus and thereafter was inflated to 0.5 mL. Then, the nasal mask was applied and connected to the pneumotachograph. The occlusion test[22] was finally performed to check the proper functioning of the esophageal balloon. A pneumatic shutter was inserted into the line proximal to the pneumotachograph only to perform this maneuver, and then it was removed. The results of the occlusion test were satisfactory in every instance.

Initially, no patients were connected to the ventilator, and they breathed room air through the nose mask (Profile; Respironics Inc; Murrysville, PA) for about 20 min. All the patients were instructed to breathe through the nose mask and to keep the mouth closed during the experimental procedure to prevent leaks. Subsequently, NPPV was applied using, in random order, five domiciliary commercial ventilators (Table 2) for 20 min each, the trials being separated by periods of SB through the mask that lasted the length of time it took to change the ventilator, which usually was about 10 min. All the devices were equipped with a standard single-tube circuit with the nonrebreathing valve that was recommended by each manufacturer (see Table 2). The same nasal mask was used for all the devices in study. In 16 patients, oxygen supply was added through an external hole in the mask to obtain a target arterial oxygen saturation of $> 92\%$ and $< 96\%$.

Statistical Analysis

Results are shown as the mean ± SD and also as the median for VAS values. The variability of the parameters was evaluated as the coefficient of variation (CV) [*ie*, SD/mean %]. Differences among the five ventilators in breathing pattern, IE, and comfort were evaluated by analysis of variance (ANOVA) for repeated measures. Differences between paired groups of data were evaluated with *post hoc* paired *t* test with Bonferroni adjustment and were applied as requested by ANOVA interaction. A p value < 0.05 was considered to be significant. A χ^2 test was used to evaluate nonparametric data. The Bland-Altman test[23,24] was used to compare the measurements of IEs obtained on the Pes and flow tracings and to evaluate the repeatability of the IE measurements (Fig 2). The Pearson test was used to evaluate correlations between levels of comfort and IE, PTPao,min, and Pao,peak, respectively.

Results

Patients

Thirty-one patients were enrolled in the study. All but three patients (COPD, two patients; RCWD, one patient) completed the study and tolerated the experimental procedure well. Two of the patients who dropped out did not tolerate the mask, and the other one withdrew his consent. The individual characteristics of the 28 patients completing the study are shown in Table 1.

Breathing Pattern and $\dot{V}E$

Figure 3 shows a polygraphic tracing from a representative patient (patient 7) during the application of the studied ventilators. The five ventilators showed different flow and pressure waveforms.

Table 3 shows levels of assistance, breathing pattern, IE, and level of comfort with the studied ventilators. When compared to SB, all ventilators induced a significant increase in $\dot{V}E$ ($p < 0.01$) without any significant difference among them. All studied ventilators exhibited a large interpatient variability in both the Pao,peak (CV range, 14.2 to 25%) and PTPao,min (CV range, 20 to 54%). ANOVA showed that the studied ventilators resulted in significant differences in Pao,peak but not in PTPao,min and duty cycle. *Post hoc* analysis showed lower values of Pao,peak with the PV 102 ventilator (PV) [Breas Medical AB; Molndal, Sweden] than with the Onyx (O) [Pierre Medical; Verrieres Le Buisson, France] and Respicare CV (Re) [Drager; Lubeck, Germany] ventilators ($p < 0.02$). IEs, as assessed on the flow tracing, were similar among all the studied ventilators.

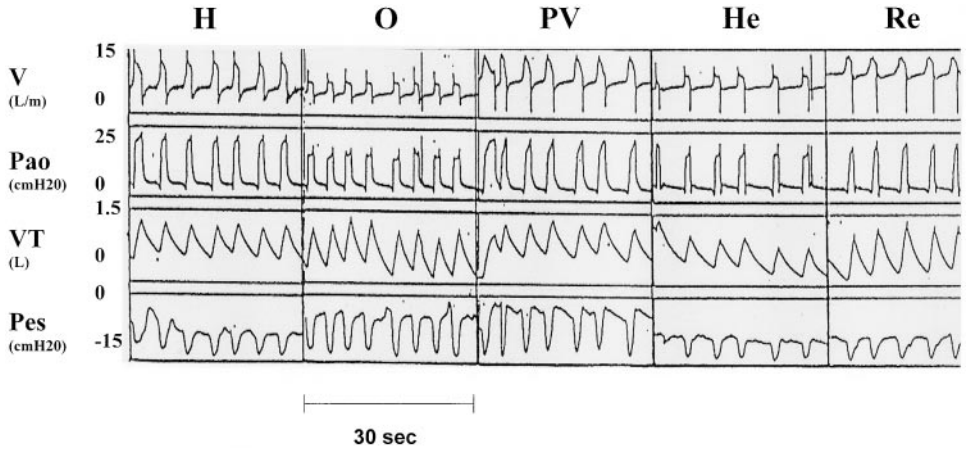

FIGURE 3. Polygraphic recording during different periods of assisted ventilation with the studied ventilators in a representative patient. See Figure 1 for abbreviations not used in the text.

Table 3 shows the mean values of comfort reported by patients using the studied ventilators according to the diagnosis. ANOVA showed that levels of comfort were different among the studied ventilators. *Post hoc* analysis showed that the Harmony (H) [Respironics Inc; Murrysville, PA] ventilator induced significantly greater comfort than the Helia (He) [Sairne SA; Savigny Le Temple, France] ventilator. Figure 4 shows the distribution of comfort scores (by VAS) with the studied ventilators.

Inspiratory Muscles and Mechanics

Table 4 shows the effect of the studied ventilators on inspiratory muscle effort and IE in the 10 patients undergoing evaluation of inspiratory muscles. In

Table 3—*Level of Assistance, Ventilatory Pattern, IEs, and Comfort During SB and Assisted Ventilation With Studied Ventilators**

Variable	Baseline	Ventilator				
		H	O	PV	He	Re
Pao, peak, cm H_2O						
All		15 ± 3	16 ± 4	14 ± 2†‡	15 ± 3	17 ± 3
COPD		16 ± 2	17 ± 4	15 ± 2	16 ± 2	18 ± 3
RCWD		14 ± 3	14 ± 3	13 ± 2	14 ± 3	15 ± 3
PTPao, min, cm H_2O/s/min						
All		249 ± 51	297 ± 162	256 ± 81	265 ± 97	219 ± 68
COPD		252 ± 40	341 ± 193	272 ± 86	302 ± 83	247 ± 64
RCWD		244 ± 66	234 ± 69	233 ± 72	211 ± 93	179 ± 53
$\dot{V}_E$, L/min	9.3 ± 3.1	13.7 ± 4.6§	15.2 ± 6.8§	12.8 ± 4.7§	16.3 ± 11.2§	15.2 ± 5.9§
V_T, mL	456 ± 198	742 ± 317§	744 ± 283§	699 ± 282§	796 ± 354§	775 ± 309§
f, breaths/min	22 ± 6	20 ± 5	21 ± 6	19 ± 6	21 ± 7	21 ± 7
T_I, s	0.9 ± 0.2	1 ± 0.3	1 ± 0.3	1.2 ± 0.4	1 ± 0.3	1 ± 0.3
T_I/T_{TOT}	0.35 ± 0.07	0.33 ± 0.07	0.34 ± 0.09	0.37 ± 0.09	0.45 ± 0.5	0.45 ± 0.67
IE, n/min/f·100		0.45 ± 1.16	1.82 ± 3.21	0.52 ± 1.19	4.14 ± 7.41	3.30 ± 6.25
Comfort (VAS), %						
All	25 ± 23	18 ± 16	31 ± 18	26 ± 24	37 ± 25‖	29 ± 20
RCWD	20 ± 17	15 ± 14	27 ± 18	23 ± 23	37 ± 28¶	25 ± 22
COPD	32 ± 31	23 ± 18	38 ± 17	31 ± 26	35 ± 19	36 ± 16

*Values given as mean ± SD.
†$p < 0.02$ vs O.
‡$p < 0.001$ vs Re.
§$p < 0.01$ vs baseline.
‖$p < 0.001$ vs H.
¶$p < 0.02$ vs H.

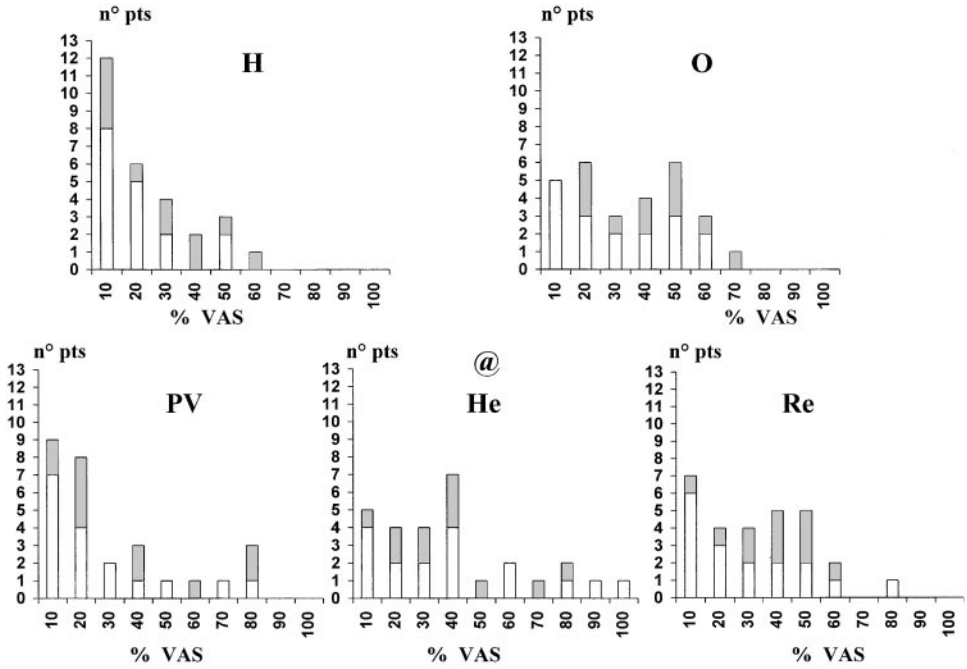

FIGURE 4. Distribution of patients according to reported comfort level (by VAS) with the studied ventilators. Shaded portion of the bars = RCWD patients; nonshaded portion of the bars = COPD patients.

comparison with unassisted ventilation, all ventilators induced significant ($p < 0.001$) reductions in inspiratory muscle effort, which was expressed as the PTPes,min/$\dot{V}E$ ratio, spending 26 to 39% of their PTPes per breath to trigger the ventilators without any statistically significant difference among ventilators.

All ventilators were able to reduce the baseline level of PEEPi,dyn by 18 to 46%. Table 4 shows also the mean values for IE assessed on both the flow and Pes tracings in these 10 patients with different ventilators. There was no difference in the number of IEs among the ventilators studied.

There was no significant difference in the evaluated parameters according to the previous use of NPPV. No significant relationship was found between comfort and PTP,min, Pao,peak, or number of IEs.

DISCUSSION

This study shows that in stable, awake patients with CVF, all of the studied ventilators were tolerated quite well, although with a great intersubject variability in comfort. All ventilators performed well

Table 4—*Inspiratory Effort and PEEPi,dyn During Unassisted and Assisted Ventilation With the Studied Ventilators in 10 Patients**

Variables	Baseline	Ventilators				
		H	O	PV	He	Re
Pes, cm H_2O	10 ± 5	7.9 ± 6	6.0 ± 4	7.1 ± 4.6	6.5 ± 3.4	8.5 ± 5.7
PEEPi,dyn, cm H_2O	2.19 ± 2.7	1.5 ± 1.8	1.8 ± 2.1	1.17 ± 1.2	1.4 ± 1.8	1.7 ± 2.59
PTPes per breath, cm H_2O	11 ± 2	7.55 ± 1.5	4.95 ± 1.9†	8.21 ± 2	6.72 ± 1.6	8.19 ± 2.1
PTPes per minute, cm H_2O	240 ± 128	151 ± 127	104 ± 92†	156 ± 111	141 ± 133	172 ± 146
PTPes/$\dot{V}E$, cm H_2O/s/L	38 ± 33	11.4 ± 9‡	7.7 ± 6.5‡	12 ± 7‡	10 ± 8‡	12 ± 7‡
PTPes/trigger, cm H_2O		2.2 ± 3.1	1.6 ± 1.55	2.5 ± 3.4	2.9 ± 5.4	2.9 ± 3.9
IE-flow, No./min/f*100		2.01 ± 3.08	2.47 ± 3.82	1.75 ± 1.69	3.37 ± 3.94	5.25 ± 3.39
IE-Pes, No./min/f*100		2.29 ± 3	2.47 ± 3.82	2.24 ± 2.96	3.72 ± 5.96	5.39 ± 3.38

*Values given as mean ± SD.
†$p < 0.01$ vs SB.
‡$p < 0.001$ vs SB.

in terms of improvement in $\dot{V}E$ and inspiratory muscle unloading, thus fulfilling the aims of mechanical ventilation.[25] IEs were similar among the studied ventilators. Among the ventilators, there was no significant difference in PTPao,min levels, whereas some ventilators differed in Pao,peak levels.

There are few studies comparing home mechanical ventilators, and most of them have been performed on lung models.[7–12] Only one study[12] compared "old-fashioned" ventilators with preset volume and pressure levels *in vivo*. Furthermore, no study compared the inspiratory muscle unloading and IE induced by different ventilators. To the best of our knowledge, this is the first study to compare *in vivo* physiologic effects and subjective comfort to the NPPV of the most used ventilators in clinical practice, at least in Europe.

In a bench study, Bunburaphong et al[7] tested nine home bilevel pressure ventilators and compared their performances with a critical care ventilator (model 7200ae; Nellcor Puritan-Bennett; Hazelwood, MO). The majority of their studied ventilators responded to high ventilatory demands and outperformed the critical care ventilator. Smith and Shneerson,[9] using a patient simulator, observed that two pressometric and two volumetric ventilators produced distinct pressure waves and that they responded differently to leaks. The only other study comparing different *in vivo* ventilators is that by Meecham Jones and colleagues,[12] who, in a study of eight stable restrictive and obstructive patients with CVF, compared two pressometric and two volumetric ventilators that were set at the patient's comfort level. The investigators did not find any differences in the capacity to assure V_T and in patients' comfort levels.

In our study, we used a nasal mask as the patient-ventilator interface, and 2 of 31 patients did not complete the study due to intolerance of the nasal mask. Navalesi et al[26] showed that the nasal mask is the best tolerated when compared to nasal plugs or full face mask in stable patients with CVF. During the short-term application of NPPV, Meecham Jones and colleagues[27] showed a high rate of disruption of treatment due to mask discomfort (53%). A range for lack of compliance to NPPV of 20 to 25%, mainly due to nasal mask discomfort, also was described.[28]

In our study, ventilators were set at the patients' comfort level. In stable COPD patients with chronic hypercapnia, NPPV was effective in improving arterial blood gas levels and in unloading inspiratory muscles, independent of whether the ventilator was set on the basis of the patient's comfort level or was tailored to the patient's respiratory muscle effort and pulmonary mechanics.[5] In our study, despite the fact that the ventilators were set at the patients' comfort level, the sensation reported during the trial was different with each ventilator studied, indicating that each patient experienced different sensations with each individual ventilator. This may be relevant in light of the fact that NPPV needs the patient's cooperation, which cannot be obtained under conditions of discomfort. No significant relationship was found between the level of comfort and either physiologic measurements or the level of Pao or IEs. Therefore, we cannot ascribe the different reported sensations to any measurable characteristic of the ventilator. Although we did not measure some characteristics, like resistances or dead space, having used the same patient-ventilator interface (*eg*, tubing or mask [see the "Materials and Methods" section]), we are confident that we can exclude other factors related to the interface as influencing the different sensations. As no significant relationship was found between comfort and pulmonary mechanics, we can argue that there is no objective method with which to determine which ventilator will be tolerated by an individual patient. The results of this study indicate the need for trials with different ventilators before prescribing NPPV in order to assess the best compliance for the individual patient.

All the studied ventilators were able to improve $\dot{V}E$ and to unload the respiratory muscles, thus fulfilling the aims of mechanical ventilation.[25] All five ventilators improved $\dot{V}E$ by about 50% and unloaded the inspiratory muscles by about 40%. This is the first study to compare the inspiratory effort elicited by five different devices in patients with CVF from different causes. No differences were found among the five ventilators in the trigger inspiratory effort. Lofaso et al[8] compared an ICU ventilator with an home pressure-support ventilator during the weaning of seven patients who had undergone tracheostomy or had been intubated due to different pathologies. The systems were tested in random order, and each patient received the same level of pressure support with the two systems. The author did not find any differences in V_T, f, $PaCO_2$, or arterial pH between the two devices. By contrast, the PTP of the inspiratory muscles was significantly higher (roughly, by 30%) with the home device than with the ICU device.

In ventilator-dependent patients, it has been shown[21,29] that the phenomenon of missing efforts or IEs consists of swings in Pes that make the patient unable to trigger the ventilator. This study also confirms the presence of IEs in stable patients who are receiving NPPV,[5] and it is the first to show that IEs were similar during breathing with different ventilators. An additional result of this study was that the IEs calculated on the Pes tracing were highly correlated with the IEs calculated on the flow trac-

ing. If confirmed by specific comparison studies, this might be relevant for obtaining information on IEs by means of a noninvasive tool.

Having obtained similar physiologic results, ventilators were associated with similar levels of PT-Pao,min. This may be relevant in view of data[30] showing that NPPV can significantly reduce cardiac output in COPD patients.

Limitations of the Study

Our study was performed in awake patients, while home NPPV is usually prescribed for use at night during sleep. Therefore, the appropriate ventilator should theoretically be tested during a formal sleep study. Nevertheless, we reasoned that the lack of information on the physiologic effects of NPPV in those patients would warrant a daytime investigation, in particular when one takes into account the techniques needed to measure the patient's respiratory muscle function, for example, the esophageal balloon.

Comfort of ventilation was assessed only at baseline and during the NPPV session. To correct for the bias induced by anxiety, it would be more appropriate to perform VAS measurement also at the end of the study

Twenty-eight patients is a small number for a clinical follow-up study, as the study was powered to find differences in comfort among the five ventilators. Therefore, before generalization, these short-term results must be confirmed in the long-term clinical setting.

In conclusion, this study suggests that, in order to make an informed decision when prescribing a ventilator for NPPV therapy to the individual patient, it is necessary to understand how the individual ventilator actually performs in the individual patient and how it is accepted by the patient. For that reason, the choice of the ventilator for home NPPV therapy should be made after a comparison of different ventilators and should be tailored to the individual patient.

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