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Influence of Respiratory Behavior on Ventilation, Respiratory Work and Intrinsic PEEP during Noninvasive Nasal Pressure Support Ventilation in Normal Subjects

Dominique Vanpee[a] Charbel El Khawand[b] Laurent Rousseau[b]
Jacques Jamart[c] Luc Delaunois[b]

[a]Emergency Unit, [b]Pneumology Unit, and [c]Biostatistical Unit, Université Catholique de Louvain,
Mont-Godinne Hospital, Yvoir, Belgium

For editorial comment see p. 294.

Key Words
Pressure support ventilation · Noninvasive ventilation

Abstract

Background: In clinical practice, patients have different inspiratory behaviors during noninvasive pressure support ventilation (PSV): some breathe quietly, others actively help PSV by an additional effort, and others even resist the inspiratory pressure of PSV. ***Objective:*** What is the influence of patient collaboration (inspiratory behavior) on the efficiency of PSV? ***Methods:*** We ventilated 10 normal subjects with nasal PSV (inspiratory/expiratory: 10/0 and 15/5 cm H_2O) and measured their flow and volume with a pneumotachograph and their esophageal and gastric pressures during three different respiratory voluntary behaviors: relaxed inspiration, active inspiratory work and resisted inspiration. ***Results:*** When compared with relaxed inspiration with 10/0 cm H_2O PSV: (1) an active inspiratory effort increased tidal volume (from 789 ± 356 to 1,046 ± 586 ml; $p = 0.006$), minute ventilation (from 10.40 ± 4.45 to 15.77 ± 7.69 liters/min; $p < 0.001$), transdiaphragmatic work per cycle (from 0.55 ± 0.33 to 1.72 ± 1.40 J/cycle; $p = 0.002$) and inspiratory work per cycle (from 0.14 ± 0.20 to 1.26 ± 1.01 J/cycle; $p = 0.003$); intrinsic positive end-expiratory pressure ($PEEP_i$) increased from 1.23 ± 1.02 to 3.17 ± 2.30 cm H_2O; $p = 0.002$); (2) a resisted inspiration decreased tidal volume (to 457 ± 230 ml; $p = 0.007$), minute ventilation (to 6.93 ± 3.04 liters/min; $p = 0.028$) along with a decrease in transdiaphragmatic work but no change in $PEEP_i$. Data obtained during a bilevel PSV of 15/5 cm H_2O were similar to those obtained with the 10/0 cm H_2O settings. ***Conclusions:*** Active inspiratory effort increases ventilation during PSV at the expense of an increased breathing work and $PEEP_i$. Resisted inspiration inversely decreases inspiratory work and ventilation with no air trapping. These differences between inspiratory behaviors could affect the expected beneficial effects of PSV in acutely ill patients.

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Dr. Dominique Vanpee
Department of Emergency Medicine
Catholic University of Louvain, Mont-Godinne Hospital
B–5530 Yvoir (Belgium)
Tel. +32 81423111, Fax +32 81423115, E-Mail Dominique.Vanpee@rean.ucl.ac.be

Introduction

Noninvasive ventilation (NIV) may bring considerable benefits in the treatment of acute respiratory failure, especially in patients with chronic obstructive pulmonary disease [1–3]. Randomized controlled trials have demonstrated the ability of NIV to decrease the need for endotracheal intubation, hospital stay and mortality. This technique seems to be increasingly used in emergency situations [4–8]. The implications of these studies are that NIV should be part of the first-line treatment for certain patients with acute exacerbation of chronic obstructive pulmonary disease.

Pressure support ventilation (PSV) has been widely used for NIV [3, 5, 7, 9]. This mode of ventilation, if well used, should normally result in an increase in tidal volume, a reduction in spontaneous respiratory frequency and a decrease in breathing work. A number of failures of the technique have been reported, and efforts are needed to understand them. The motivation and the training of the medical and nonmedical staff can also play an important role in the success rate of the technique. Collaboration of patients during PSV could also be obtained. In an initial work, we showed that during noninvasive PSV with a nasal mask in spontaneously breathing subjects, the inspiratory behavior was different in normal individuals and patients with stable COPD. Normal subjects often presented an increased ratio of minute ventilation as well as an increased inspiratory work, as if normal subjects made an active inspiratory effort during PSV. On the other hand, COPD subjects presented an increased minute ventilation but decreased respiratory work, as if the behavior of patients with COPD was passive during NIV [10].

Similarly, in clinical practice, patients behave differently during NIV. So, in this study, we tried to find out whether different voluntary inspiratory behaviors (relaxed, active, resisted) would influence ventilation, inspiratory work and intrinsic positive end-expiratory pressure ($PEEP_i$) during spontaneous breathing with noninvasive nasal PSV in normal subjects. We postulated that different inspiratory behaviors during PSV could modify the expected improvement in acutely ill COPD patients, and started our study in normal subjects for safety reasons (in order to avoid worsening of ventilation in patients).

Materials and Methods

We studied 10 normal volunteers selected among medical and laboratory personnel (age: 34 ± 7 years, weight: 78 ± 14 kg, height 1.80 ± 0.09 m, all with a normal respiratory function). This study protocol was approved by the Institutional Ethics Committee. The subjects gave their informed consent to participate in the study.

Measurements (fig. 1)

Breathing Parameters. Airflow was measured with a Fleisch pneumotachograph connected to a differential pressure transducer (Validyne DP 45 ± 5). Volume was obtained from numerical integration of the flow signal. Minute ventilation, tidal volume and respiratory frequency were calculated as average values from 1-min continuous recordings of flow and volume.

Mechanical Parameters. Changes in pleural (P_{pl}) and abdominal (P_{ab}) pressures were measured from esophageal (P_{es}) and gastric (P_{ga}) pressures, respectively. Both P_{es} and P_{ga} were measured using a catheter-mounted (110 cm length, 2.1 mm external diameter), with two manometric transducer sensors (Gaeltec®) and connected to a Medatech amplifier (Brussels, Belgium). This system has recently been shown to be reliable for acute changes in respiratory pressures and studies of respiratory muscle strength [11]. Transdiaphragmatic pressure (P_{di}) was obtained by subtracting P_{es} from P_{ga}. Data from these measurements were acquired and processed with a commercial respiratory software (Anadat 5.2, D. Bates, Montréal, 1995) which calculates the respiratory work by the method of Campbell [12]. Inspiratory work (W_{es}) was computed from the negative deflection of P_{es}, and the volume and transdiaphragmatic work (W_{di}) were calculated from difference in P_{di} and the volume. Dynamic intrinsic PEEP ($PEEP_{i,\,dyn}$) was measured as the amount of negative deflection in P_{pl} preceding the start of the inspiratory flow [13, 14]

Experimental Procedure

After local anesthesia (xylocaine spray 10%), the catheter was inserted through the nose into the stomach. Physiologic measurements during spontaneous breathing were performed when the subject appeared to be relaxed. Then a customized nose mask was applied for PSV. Spontaneously breathing subjects were submitted to PSV of 10 cm H_2O and to bilevel PSV with an inspiratory pressure of 15 and expiratory pressure of 5 cm H_2O with a Bipap (Respironics).

The measurements were performed and standardized under three conditions: (1) relaxed inspiration (the subject is instructed to breathe as usually and in a relaxed fashion but with PSV); (2) active inspiratory effort (the subject is instructed to actively help the respirator by a simultaneous inspiratory effort, and (3) resisted inspiration (the subject is instructed to passively resist the insufflation of the PSV machine).

Between every measure, the patient breathed normally during 5 min without the ventilator.

The difference between active and resisted inspirations was checked on pleural pressure: the measurements were begun in a relaxed behavior, and the inspiratory deflection of P_{es} was recorded; the subjects were then asked to actively assist the pressure support or to passively resist: the active behavior was confirmed by an increased deflection of P_{es} and the resisted inspiration by a less negative deflection or a progressively more positive P_{pl} during expiration. Patients were instructed to keep their mouth closed. PSV was delivered via a portable ventilator (Bipap S/T-D20, Respironics) during spontaneous breathing. The maximal flow of this ventilator is to 280 liters/min. The maximal inspiratory flow of our subjects varied from 45 to 120 liters/min, so factor limiting of the respirator did not influence the results. We did not try to impose the respiratory rate on the subjects because it is one of the constituents of spontaneous breathing.

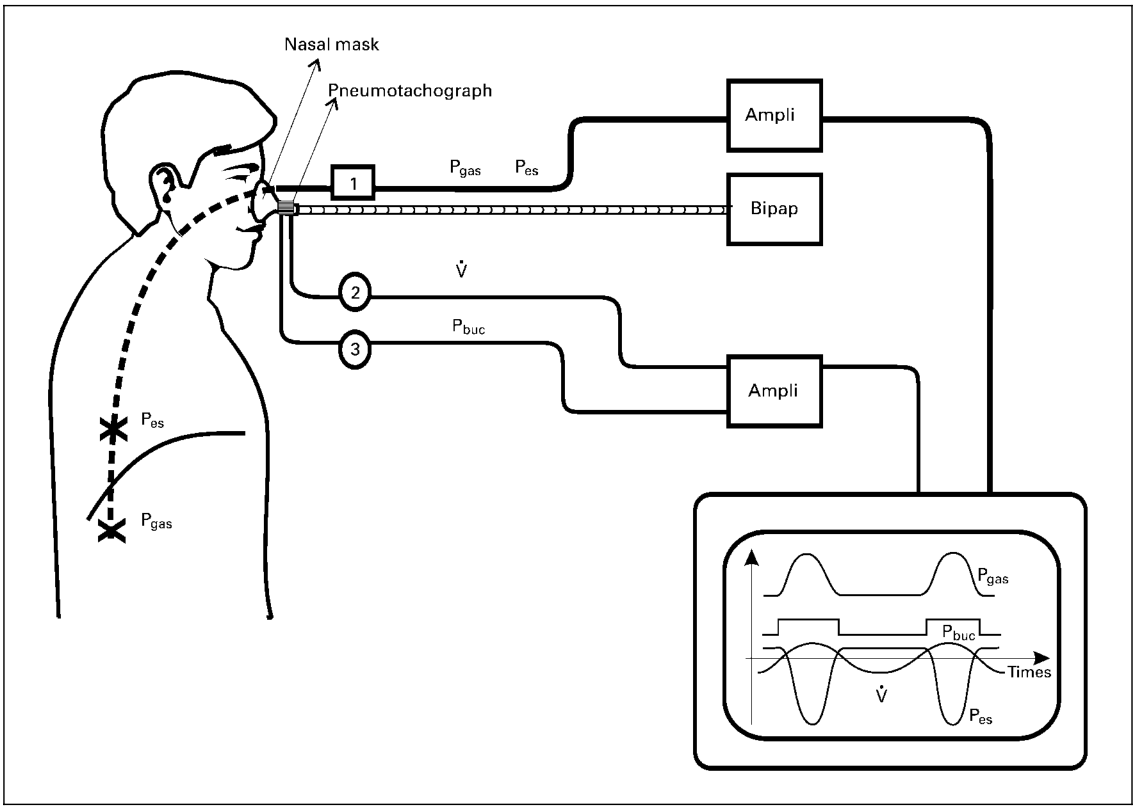

Fig. 1. Schematic diagram of equipment setup. 1–3 = P/T transducer; P_{buc} = buccal pressure. Other abbreviations, see text.

Data Analysis

All variables were converted with an analog-to-digital converter and entered into a personal computer. The mean value of each physiologic variable from a 1-min recording was used for subsequent analysis. Numerical variables are expressed as mean ± standard deviation and were compared by a two-way analysis of variance for repeated measurements, taking into account the three conditions and the two pressure modalities (10/0 and 10/5) using Datasim statistical software (Desktop press, Lewiston, Me., USA).

Results

All subjects easily performed the three maneuvers.

The mean inspiratory deflection of P_{es} during the 3 inspiratory behaviors with PSV (10/0 and 15/5 cm H_2O) is presented in table 1. During resisted inspiration, there were three levels of pressure: trigger inspiratory pressure, mean inspiratory pressure and the pressure at which the flow stopped.

PSV 10/0 cm H_2O, when compared to relaxed inspiration: an active inspiratory effort increased tidal volume (from 790 ± 356 to 1,046 ± 586 ml; p = 0.006) (fig. 2a) and minute ventilation (from 10.40 ± 4.45 to 15.77 ± 7.69 liters/min; p < 0.001) (fig. 2b) but without a significant change in respiratory frequency (from 13.4 ± 1.5 to 16.0 ± 3.6 min; NS) (fig. 2c). W_{di} per cycle, per liter and per minute increased from 0.55 ± 0.33 to 1.72 ± 1.40

Table 1. Mean inspiratory deflection of P_{es} (mean ± SD cm H_2O)

	PSV 10/0	PSV 15/5
Relaxed inspiration	−6.2±6	−3.2±6.1
Active inspiratory effort	−20.6±10.7	−20.2±9.16
Resisted inspiration	4.5±1.6	4.2±1.5
	−1.4±0.5[1]	−1.8±1.1[1]
	9.4±3.2[2]	8.7±3[2]

1 Triggers inspiratory pressure.
2 Pressure at which the flow stopped.

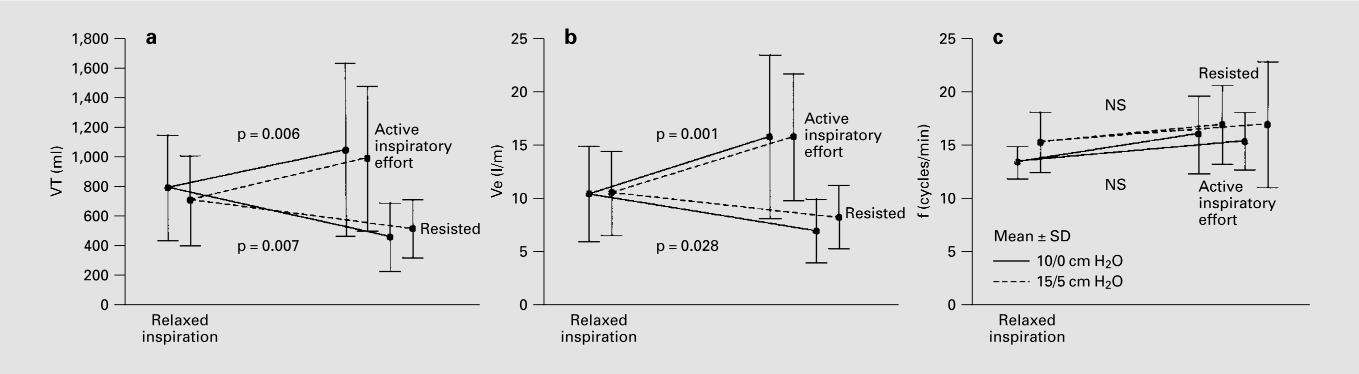

Fig. 2. Influence of respiratory behavior (relaxed inspiration, active inspiratory effort and resisted inspiration) on tidal volume (VT; a), minute ventilation (Ve; b) and respiratory frequency (f; c) during noninvasive PSV (10/0 and 15/5 cm H_2O) in normal subjects.

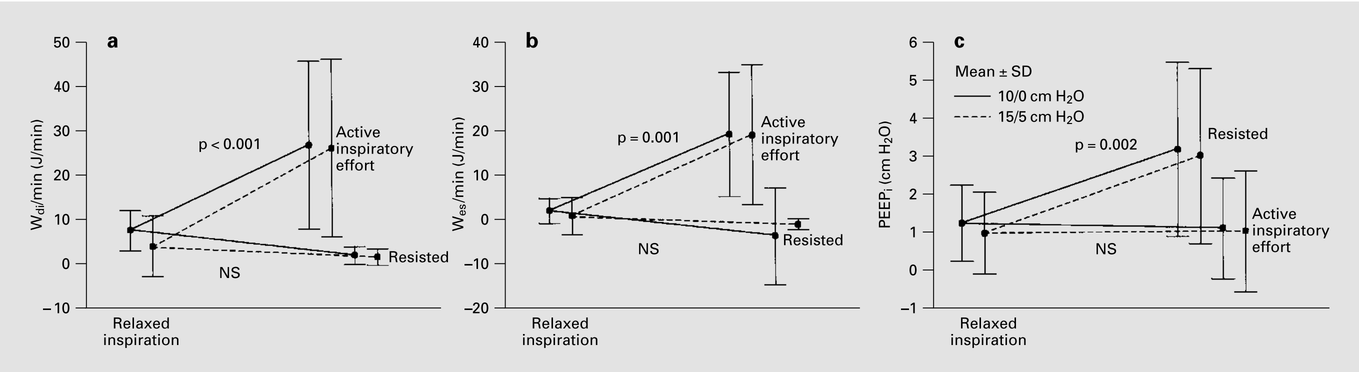

Fig. 3. Influence of respiratory behavior (relaxed inspiration, active inspiratory effort and resisted inspiration) on the W_{di}/min (a), W_{es} (b) and $PEEP_i$ (c) during noninvasive PSP (10/0 and 15/5 cm H_2O) in normal subjects.

J/cycle, respectively; p = 0.002, from 0.71 ± 0.47 to 1.69 ± 0.84 J/l; p < 0.001, from 7.45 ± 4.61 to 26.49 ± 18.93 J/min; p < 0.001 (fig. 3a). Inspiratory work per cycle increased (from 0.14 ± 0.20 to 1.26 ± 1.01 J/cycle; p = 0.003), as inspiratory work per liter (from 0.19 ± 0.33 to 1.22 ± 0.86 J/l; p< 0.001) and inspiratory work per minute (from 1.99 ± 2.80 to 19.06 ± 14.05 J/min; p = 0.001) (fig. 3b). $PEEP_i$ increased from 1.23 ± 1.02 to 3.17 ± 2.30 cm H_2O; p = 0.002 (fig. 3c).

Resisted inspiration decreased tidal volume to 457 ± 233 ml (p = 0.007) (fig. 2a), minute ventilation to 6.93 ± 3.04 liters/min (p = 0.028) (fig. 2b) along with a decrease in W_{di} per cycle to 0.09 ± 0.10 J/cycle, per liter to 0.20 ± 0.21 J/l (p = 0.044) and per minute to 1.58 ± 1.99 J/min (fig. 3a). Inspiratory work per cycle (–0.31 ± 0.85 J/cycle, p = NS), per liter (–0.39 ± 0.90 J/l) and per minute (to –3.94 ± 10.88 J/min) (fig. 3b) and $PEEP_i$ (1.08 ± 1.32 cm H_2O) (fig. 3c) were not significantly different from values during relaxed inspiration.

Results of bilevel PSV (15/5 cm H_2O) are similar to those of 10/0 cm H_2O PSV (fig. 2, 3).

Discussion

PSV is an assisted mode of ventilation that supplies a constant level of positive airway pressure during spontaneous inspiratory efforts. PSV allows the patient to maintain control of inspiratory and expiratory time and then interacts with a set pressure to determine flow and tidal volume [15]. The aims of PSV include the correction of hypoventilation and the relief of the inspiratory muscles.

This reduction in muscle effort could be deduced from modifications of the breathing pattern, increase in tidal volume and reduction in respiratory frequency. However, the variables of the breathing pattern commonly used at the bedside appear to be inaccurate and misleading interferences of the inspiratory work [16]. Using only the breathing pattern as the primary criterion to detect patients with a good evolution could result in an inappropriate overload of respiratory muscles. The inspiratory work should then be measured simultaneously with the breathing pattern [16], but this is sometimes difficult in the clinical setting.

PSV can either totally or partially relieve ventilatory muscles during spontaneous breathing [17]. Total relief occurs when the only effort made by the patient is to trigger the respiration. PSV should then be able to reduce the work of breathing and improve the ventilatory parameters in a well-relaxed and cooperating subject. This beneficial effect of PSV in acute respiratory failure is associated with an increased tidal volume, a decreased respiratory rate, an improved gas exchange, and a significant reduction in diaphragmatic activity [18]. These changes usually occur within the first hour of treatment [1, 3, 19]. But in clinical practice, some patients with early improvement of their initial blood gases have to be intubated later. Conversely, the absence of an immediate drop in $PaCO_2$ does not necessarily indicate a failure of PSV. The evolution during PSV in patients with the same respiratory failure can then be dissimilar. This difference could be due to the patients.

Implementation of PSV requires a cooperative patient [20], a comfortably fitting interface and properly adjusted ventilation settings. Unfortunately, the respiratory behavior can vary hugely from one patient to another: some breathe quietly with PSV, others actively help PSV by an additional inspiratory effort, and others even resist the inspiratory pressure of PSV. The aim of our study has been to analyze the effects of these three respiratory behaviors on ventilation and inspiratory work during PSV.

The main findings of this study were:

(1) When comparing with relaxed inspiration, an active inspiratory effort not only increases ventilation, but also the inspiratory work and the air trapping, as shown by the change in $PEEP_i$.

(2) When comparing with a relaxed inspiration, resisted inspiration decreases both ventilation and W_{di}, with no increase in air trapping. These results are no different when applying PSV or bilevel PSV at least at the pressures we used.

In this study, during active deep inspiration, $PEEP_i$ increased by 1.9 cm H_2O and the respiratory frequency by only 3 cycles/min. In an earlier work on normal subjects, $PEEP_i$ increased by 1.5 cm H_2O along with an increase in respiratory frequency from 16 to 30 cycles/min (= 0.1 cm H_2O/cycle) [21]. So, this slight increase in respiratory frequency could only partially explain the increase in $PEEP_i$.

Our results should be useful to adapt the initial treatment with PSV. The harmful consequences of the active inspiratory effort could be more deleterious in COPD patients and could affect the expected beneficial effects of PSV in acutely ill patients. Indeed, an improvement of the blood gases (by increasing the ventilation) should then be obtained at the expense of increased inspiratory work that could later induce muscle fatigue and a still more critical respiratory failure.

Conversely, a resisted inspiration will decrease ventilation (as expected) and thus worsen the gas exchange. The inspiratory work then seems to decrease, but this is a false impression: indeed we should remember the uselessly increased work of the expiratory muscles during inspiration. Resisted inspiration is deleterious in such cases.

For safety reasons, this study only included normal subjects. Future studies should evaluate the influence of respiratory behavior on ventilation and respiratory work during noninvasive PSV in COPD.

Conclusion

The patient's cooperation strongly influences both his ventilation and his inspiratory work: an active inspiratory effort increases the ventilation during PSV, but unfortunately it also increases the inspiratory work and air trapping. Such inspiratory behavior is not efficient because the goal of PSV is to increase the ventilation, but by decreasing the respiratory work. Conversely, resisted inspiration is also deleterious because it decreases the ventilation and despite the fact that the inspiratory work seems to decrease, there is a useless increase in the work of the expiratory muscles. Relaxed spontaneous breathing during PSV should then be encouraged.

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