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Physiologic evaluation of non-invasive pressure support ventilation in trauma patients with acute respiratory failure

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Abstract *Objective*: To investigate the effectiveness of noninvasive (face mask) versus invasive (endotracheal tube) equal pressure values on blood gases and respiratory pattern and to evaluate the feasibility of using mask ventilation after the short term physiologic study.
Design: Open, prospective, physiologic study and uncontrolled clinical study.
Setting: Intensive care unit of a trauma center.
Patients: 22 intubated trauma patients were studied.
Interventions: Patients were intubated and ventilated in a pressure support mode (IPSV) of 13.5 ± 1.5 cmH_2O and a post end-expiratory pressure (PEEP) of 5.8 ± 2.57 cmH_2O. After a T-piece trial to assess patient's ability to breath spontaneously, patients were switched over to noninvasive pressure support (NIPSV). The pressure levels were set as during IPSV. Blood gases and respiratory parameters were measured during IPSV, during the T-piece trial, and after 1 h of NIPSV. After the physiologic study, all patients were asked if they wished to continue on NIPSV. The patient's subjective compliance with IPSV and NIPSV was measured by means of an arbitrary score. A successful outcome was defined as no need for reintubation.
Measurements and results: IPSV and NIPSV showed no statistical differences for blood gas and respiratory parameters by using the same values of PSV (13 ± 5 vs 12.8 ± 1.7 cmH_2O, NS) and PEEP (5.8 ± 2.5 and 5.2 ± 2.2 cmH_2O NS). The median length of time on NIPSV was 47 h (range 6 to 144). All patients wished to continue on NIPSV, but 9 patients (40.9 %) were reintubated after 54 ± 54 h. Six of them died after 36 ± 13 days while still on mechanical ventilation. There was no statistically significant difference in compliance score between IPSV and NIPSV.
Conclusions: NIPSV is comparable to IPSV in terms of blood gases and respiratory pattern. The clinical uncontrolled study indicates that NIPSV could be used in selected trauma patients.

Key words Mask ventilation · Traumatic acute respiratory failure · Non-invasive pressure support ventilation · Invasive pressure support ventilation

Introduction

Noninvasive mask ventilation has an established role in the intensive and subintensive environment in providing ventilatory support in patients with chronic and acute respiratory failure [1, 2]. The significant potential advantage of mask ventilation is to avoid endotracheal intubation and its complications [3, 4]. Endotracheal intubation often allows the upper part of the trachea (above the cuff of the tube) to become a continuous reservoir

Table 1 Clinical characteristics of patients, etiology and outcome (*Tr* trauma, *RTI* upper respiratory tract infection, *RPF* respiratory pump failure, *NI* not reintubated, *I* intubated, *T* tracheostomy, *S* survived, *D* died, *NIPSV* noninvasive pressure support ventilation)

Patient No.	Age (years)	Weight (kg)	Sex	Diagnosis	Outcome	Survival	NIPSV (h)
1	24	80	M	Chest, abdominal Tr/RPF	NI	S	36
2	20	70	M	Abdominal Tr/RTI	NI	S	48
3	50	60	F	Chest Tr/RTI	NI	S	48
4	20	75	M	Multiple bone fractures Tr/RTI	NI	S	72
5	17	65	F	Multiple bone fractures Tr/RTI	NI	S	36
6	53	80	M	Chest Tr	NI	S	24
7	24	80	M	Chest, abdominal Tr	NI	S	48
8	53	95	M	Chest, abdominal, spinal Tr/RTI	I	D	6
9	65	60	M	Chest Tr	I	D	48
10	30	60	F	Chest, abdominal, multiple bone fractures Tr/RTI	NI	S	24
11	40	80	M	Chest, abdominal, multiple bone fractures Tr/RTI	I	S	8
12	27	62	F	Chest, multiple bone fractures Tr/RTI	NI	S	36
13	50	70	M	Chest, abdominal, multiple bone fractures Tr/RTI	NI	S	36
14	70	40	F	Multiple bone fractures Tr/RTI	I	D	140
15	64	68	M	Chest Tr/RPF	NI	S	56
16	40	70	M	Abdominal, multiple bone fractures Tr	I	D	12
17	66	81	M	Abdominal, multiple bone fractures Tr	I	D	48
18	54	65	M	Chest, abdominal Tr/RTI	I	D	14
19	41	73	M	Chest, spinal Tr/RPF-RTI	T	S	70
20	68	80	M	Chest, multiple bone fractures Tr/RPF	NI	S	72
21	40	60	M	Flail chest Tr/RPF	I	S	144
22	61	80	F	Chest, multiple bone fractures Tr/RPF	NI	S	46

for bacteria, which are easily spread into the lower airways [5]. It also alters mucociliary activity and glottis function, hindering the physiologic clearance of secretions. Moreover, keeping a translaryngeal tube in situ may underestimate the patient's potential for extubation [5].

Trauma patients are often intubated in an emergency situation. Tracheal intubation can be tried again once the patient is in an intensive care environment. So far, no study has compared the efficacy of noninvasive pressure support ventilation (NIPSV) on gas exchange and respiratory pattern against conventional endotracheal pressure support ventilation (IPSV) in trauma patients.

We set up a short-term physiologic study to compare blood gases, tidal volume, and respiratory rate at equal pressure values delivered invasively (tracheal tube) and noninvasively (face mask). Moreover, an uncontrolled study was performed in order to survey the follow-up among patients in the intensive care unit who continued on mask ventilation after the physiologic study.

Patients and methods

Patients

Twenty-two patients with traumatic acute respiratory failure (ARF) without pre-existing chronic lung disease were included in the study. Sixteen patients were male. The median age was 45.5 (range 17 to 70 years). The Simplified Acute Physiology Score (SAPS) was worked out for all patients before NIPSV was initiated [6]. Primary diagnostic categories and clinical information are listed in Table 1.

Pneumonia was defined by the presence of new or progressive pulmonary infiltrates on the chest X-ray, a temperature over 38.5 °C, leukocytosis (white blood count > 12000/ml), and purulent endotracheal aspirate. Upper respiratory tract infections were defined by the presence of all the the above features except for the radiographic findings. Respiratory pump failure was determined by clinical signs of muscular fatigue [7].

Patients were intubated and ventilated in pressure support mode (IPSV) for 4 ± 2 days and none experienced unsuccessful weaning attempts. Patients were extubated based on the following criteria: (a) pressure support ventilation < 15 cmH_2O, respiratory rate < 25 breaths/min, arterial oxygen tension/fractional inspired oxygen ratio (PaO_2/FIO_2) > 200, arterial carbon dioxide tension ($PaCO_2$) < 50 mmHg; (b) minimal airway secretions; (c) ability to breathe spontaneously for at least 15 min during a T-piece trial with arterial oxygen saturation (SaO_2) > 90.

Patients who had hemodynamic instability as defined by a mean arterial pressure < 65 mmHg or severe arrhythmia, or were unconscious or had a history of seizures, were excluded from the study. Each patient was evaluated by his or her attending physician with regard to undergoing reintubation within 30 m after extubation.

After the study period, patients were asked if they would like to go back to IPSV. The patient's subjective compliance with IPSV and NIPSV by means of an arbitrary score (1 = bad; 2 = sufficient; 3 = good) was recorded after 24 h on NIPSV. Sedation was never used. The details of the treatment, including risks, were explained to each patient, usually in the presence of members of his or her family. The study was approved by the hospital's Ethics Committee.

Table 2 Respiratory parameters in 22 patients

	IPSV	T-piece trial (A)	NIPSV 1 h (B)	
PaO_2/FIO_2	230.2 ± 83.4	133.4 ± 40.1	270 ± 106.3	A vs B $p < 0.01$
$PaCO_2$ (mmHg)	38.8 ± 6.1	37.2 ± 8.5	37.6 ± 5	NS
PSV (cmH_2O)	13.5 ± 1.5	–	12.8 ± 1.7	NS
Peep (cmH_2O)	5.8 ± 2.6	–	5.2 ± 2.2	NS
f/min^{-1}	18.6 ± 3.2	33.4 ± 4.5	15.9 ± 2.2	A vs B $p < 0.01$
V_{Te} (ml)	774 ± 128.7	414 ± 131.7	838.6 ± 157.5	A vs B $p < 0.01$

(*IPSV* invasive pressure support ventilation, *NIPSV* noninvasive pressure support ventilation, *PSV* pressure support ventilation, f/min^{-1} respiratory rate, V_{Te} expiratory tidal volume)

Interventions

After extubation, patients underwent NIPSV at the same pressure level used during IPSV. All patients were ventilated during IPSV or NIPSV by a Servo 900 C Ventilator (Siemens-Elema, Sweden) connected to a standard humidifier. Each patient received NIPSV with one of the following masks: an inflatable pneumatic cushion face mask (Gibeck, Upplands Vasby, Sweden) or the flail face mask (Gibeck, Upplands Vasby, Sweden). The masks were tightly fitted using velcro headstraps. They were modified to insert a nasogastric tube, which was positioned in all the patients. Skin breakdown was prevented by a patch of wound-care dressing on the bridge of the nose.

Blood pressure, electrocardiography, pulse oximetry were all monitored throughout the study period (1281, Siemens-Elema, Sweden). All of the respiratory parameters were measured by a CP-100 pulmonary monitor (Bicore, Irving, Calif., USA). Expiratory tidal volume V_t and respiratory rate were averaged during 1 min of stable respiratory cycle. A flow transducer was placed at the external port of the tube during both IPSV and the T-piece trial. It was placed at the external port of the mask during NIPSV. Blood gases, respiratory rate, and V_t were measured prior to the application of the mask (IPSV), during the T-piece trial, and after 1 h on NIPSV. Blood was sampled from an arterial cannula used for the monitoring of arterial blood gases.

The criteria for discontinuing NIPSV and for reintubating the patients were any of the following: respiratory rhythm disturbances or respiratory rate > 35 breaths/min; $SaO_2 < 90$; $PaCO_2 > 45$ mmHg or pH < 7.3, sputum retention, defined by the inability to clear tracheal secretions even after manual suctioning through the nose; need for sedation.

Post-1 h study period: NIPSV readjustment and measurements

The titration of PSV/post end-expiratory pressure (PEEP) was adjusted to include all of the following criteria: $SaO_2 > 90$ with additional oxygen; respiratory rate < 30 breaths/min; $PaCO_2 <$ 45 mmHg and pH > 7.3.

We used a nasal mask (Respironics, Murraysville, Penna., USA) as an alternative to a face mask after the assessment of the patient's subjective compliance in order to improve the patient's tolerance. Oxygen saturation was monitored continuously as mentioned above. Patients were considered weaned from ventilation when all of the following criteria were satisfied for at least 12 h without ventilatory support: $SaO_2 > 90$ with or without additional oxygen; respiratory rate < 25 breaths/min; $PaCO_2 < 45$ mmHg and pH > 7.3; absence of paradoxical abdominal motion.

Patients received supplemental oxygen with a Venturi mask when they were off NIPSV. A successful outcome was defined as no need for reintubation. The possible complications of NIPSV were considered.

Statistical analysis

A two tailed Student's *t*-test and single-factor repeated measures ANOVA were used to determine differences between groups (Anova-Statview II, Abacus Concepts, Berkeley, Calif., USA, 1987). A multivariate GAM logit was estimated, using a stepwise procedure to evaluate the influence of clinical and instrumental variables on the probability of observing a positive outcome [8]. The data are reported as means ± standard deviation. A p value less than 0.05 was considered to be significant.

Results

No statistically significant differences were found between invasive versus noninvasive ventilation by using an equal pressure value of PSV (13 ± 5 vs 12.8 ± 1.7 cmH_2O, NS) and PEEP (5.8 ± 2.5 and 5.2 ± 2.2 cmH_2O, NS) for blood gas and respiratory parameters. The PaO_2/FIO_2 ratio significantly increased from 133 ± 40.1 to 270 ± 106.3 ($p < 0.01$) when patients switched from spontaneous breathing (T-piece trial) to NIPSV. At the same time, expiratory V_t significantly increased from 414 ± 131.7 to 838.6 ± 157.5 ml ($p < 0.01$), with a concomitant reduction in respiratory rate from 33.4 ± 4.5 to 15.9 ± 2.2 breaths/min ($p < 0.01$). Mean $PaCO_2$ was unchanged. The data are presented in Table 2.

All patients wished to continue on NIPSV. All patients underwent NIPSV for 6 h; 19 patients maintained NIPSV for more than 12 h, but only 13 patients (59.1 %) were weaned to spontaneous breathing without being reintubated. The average ventilation compliance score was 2 ± 0.4 for IPSV and 2.7 ± 0.4 for NIPSV for the 18 patients who stayed for at least 24 h on face mask ventilation. The median period of NIPSV was 47 h (range 6 to 144).

The 9 patients (40.9 %) who failed to respond to long-term NIPSV were intubated after a mean time of 54 ± 54 h. Two patients were intubated for mask intolerance. Four patients failed NIPSV due to their inability to clear their secretions, even after continuous attempts at nasal suctioning. Of these 4 patients, 2 had abdominal trauma with multiple bone fractures, which hindered postural changes and favored sputum retention.

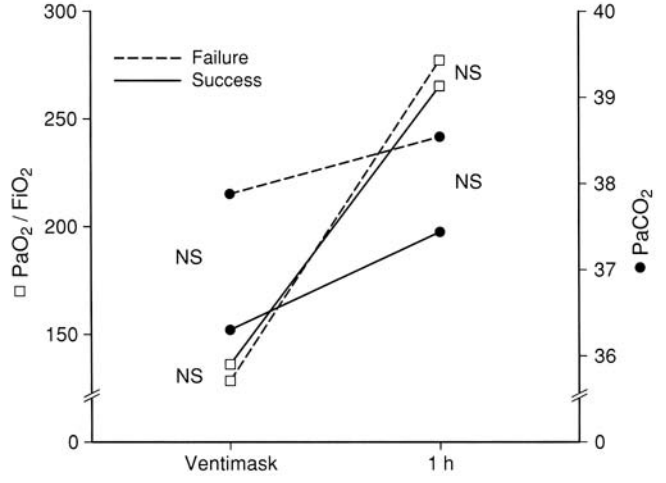

Fig. 1 Mean values for PaO_2/FIO_2 and $PaCO_2$ during the short-term study period in the successfully and unsuccessfully treated patients with NIPSV

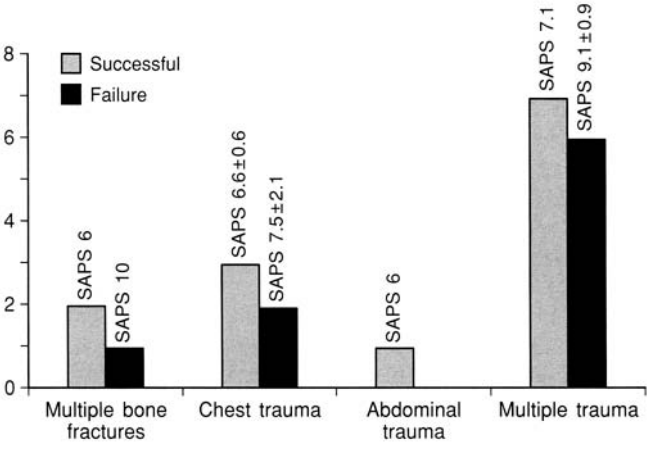

Fig. 2 Outcome as a function of pathology. (*S* successful, *F* failure, *SAPS* Simplified Acute Physiology Score)

Two had multiple rib fractures, making coughing inefficient.

One patient underwent intubation for a respiratory rate greater than 35 breaths/min due to a pulmonary abscess in a flail chest. Two patients were no longer noninvasively ventilated: 1 cardiovascular impairment due to severe arrhythmia and 1 because of a septic syndrome. In both, SaO_2 was less than 90 during NIPSV. This led to prompt reintubation.

No differences were found between successful and unsuccessful patients with regard to the mean values of PaO_2/FIO_2 and $PaCO_2$, during the first hour, as shown in Fig. 1. NIPSV success versus failure, as a function of pathology, is shown in Fig. 2.

PEEP and PSV levels were inversely related to a positive outcome after weight and age were adjusted for, as

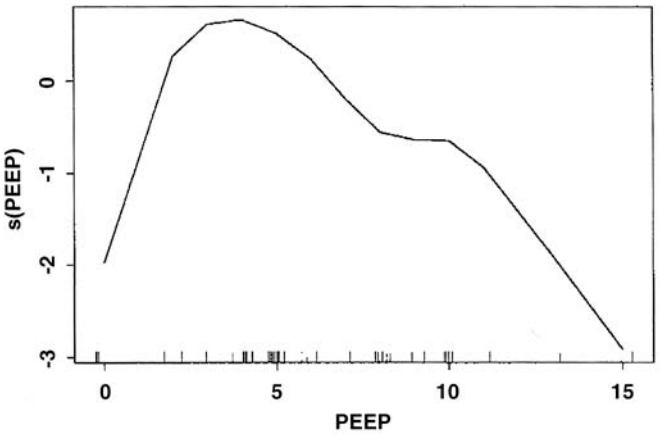

Fig. 3 Relationship between the probability of a positive outcome s(PEEP) and the PEEP levels. The probability of success decreases with the increased level of PEEP. The model is a Generalized Additive Model fitted using splines plotted on the linear predictor scale

shown in Fig. 3. Six of 9 patients (66%) who failed NIPSV died after 36 ± 13 days after being reintubated while still on mechanical ventilation.

Only 1 patient had gastric distension even though the nasogastric tube was suctioning. Skin breakdown was present in most of the patients ventilated for longer than 48 h. No complications were reported during reintubation maneuvers.

Discussion

In interpreting our data, it is important to consider that we studied a selected group of patients with acute respiratory failure without pre-existing chronic lung disease. Our population was completely different from those in other studies that used NIPSV in mechanically ventilated patients with chronic obstructive pulmonary disease (COPD) after a period of muscle rest [9]. Therefore, our conclusions may not be applicable to COPD patients or more generally to patients with high respiratory resistance. Moreover, it can also be argued that the T-piece trial was too short or that the pressure support level was too high to extubate our patients [10, 11]. The T-piece trial was not performed as the rationale to extubate our patients. It was used only to determine the patient's capability of breathing without ventilatory support for at least 15 min. Thus, our rationale was to assess if the patients could safely undergo NIPSV.

However, originally our idea was to compare invasive versus noninvasive equal pressure values even with the limitation of not measuring real tracheal pressure levels. The results of this study demonstrate that NIPSV can achieve two major results: it both increases V_t tidal volume and decreases respiratory rate, so that

minute volume remains constant, allowing ventilation comparable to that administered during IPSV. This is an unexpected finding, since the presence of the endotracheal tube provides added resistance to airflow depending on tube size, length, and inspiratory flow rate. Hence, an increased inspiratory V_t at a comparable level of pressure support would be expected. It must be realized that normal reflex abduction of the vocal cords is often lost after a period of translaryngeal intubation [12]. This was unlikely to occur in our patients because the average intubation time was too short. Therefore, the presence of "fluttering" or "saw tooth" patterns or upper airway damage with tissue edema cannot be ruled out [13]. All of these could result in a disproportionate increase in upper airway resistance that reduced the advantage of a larger cross sectional area at the glottis level [14].

An important limitation of the study is that it has not been compared in a controlled randomized trial after the physiologic evaluation. In spite of the fact that we adjusted our analysis for possible confounders, no reliable predictor of response can be worked out from our clinical data. However, we noted that PEEP and PSV levels show an inverse relationship with the probability of a positive outcome after adjusting for weight and age. This is in contrast with other studies in which nonresponders received a lower amount of PSV compared to responders [15]. These contradictory results can be explained by differences in the study population. In our study, PEEP and PSV levels of patients who failed NIPSV were adequate in restoring blood gases at V_t and minute volume (V_E) similarly to successful patients. This suggests equivalent severity in underlying disease at the time of the NIPSV trial.

The success rate (67 to 92%) of the other NIPSV studies on nontraumatic ARF is not very different from our results [5, 16–18, 20]. However, we performed the first NIPSV study only on trauma patients. Therefore, we used stricter criteria for intubation of our patients than in other studies [2].

Sputum retention was the main cause of reintubation, even though one of the criteria for entering the physiologic study was minimal airway secretion. This is not a common finding in most series of patients [5, 17, 19, 20]. Two patients failed the treatment due to face mask intolerance. All attempts to increase mask tightness were ineffective as was switching to a nose mask, because the mouth was used mainly for respiration. Although a mask is apparently more comfortable than an endotracheal tube, the average compliance score was not significant. Skin breakdown was present in most of the patients ventilated over 48 h, as reported in other studies [16, 18, 19, 21, 22]. Gastric distension occurred in one patient, which might have been due to an increase in the set pressure above to 30 cmH_2O [5, 17, 23].

Six of 9 patients who failed NIPSV died 36 ± 13 days after being reintubated while still on mechanical ventilation. Although the SAPS predicted mortality was lower, this might be explained by the patient's age or underlying disease: three patients were over 65 years. One patient died of myocardial infarction 15 days after being reintubated. The other five patients who died had severe pneumonia. They died of multiple organ failure after having sepsis. Three of them already had an upper respiratory tract infection at the time of extubation and their clinical conditions worsened because of their underlying disease. One patient underwent further abdominal surgery after 5 days. Another patient had a progressive and unremitting increase in bilirubin values. The remaining patient had severe renal failure and required dialysis.

The remaining 2 patients did not have respiratory tract infections when switched to reintubation: 1 patient had a severe ileal paralysis and pneumonia was diagnosed 15 days after reintubation. The other patient had an abdominal abscess. Pneumonia was diagnosed 14 days later and he developed septic shock.

Current data suggest that reintubation could increase the rate of complications. However, the stay in the intensive care unit before NIPSV, and time spent on NIPSV, did not differ between patients who died and those who were successfully extubated. Moreover, recently, reintubation in trauma patients in intensive care has been shown not to be necessarily associated with poor outcome [24]. The mortality in ventilated patients who developed pneumonia is not far from ours. It ranges from 48 to 65%, if due to "high risk" pathogens [4, 25].

In conclusion, NIPSV has been demonstrated to be as effective as IPSV during the short-term physiologic evaluation. The clinical uncontrolled study indicated that NIPSV could be used in selected trauma patients, thus limiting the probability of a subsequent reintubation to 40%. This value could be taken as a lower limiting value for the probability of reintubation in future randomized, controlled clinical studies.

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