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Reduction of patient-ventilator asynchrony by reducing tidal volume during pressure-support ventilation

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Abstract *Objective:* To identify ventilatory setting adjustments that improve patient-ventilator synchrony during pressure-support ventilation in ventilator-dependent patients by reducing ineffective triggering events without decreasing tolerance. *Design and setting:* Prospective physiological study in a 13-bed medical intensive care unit in a university hospital. *Patients and participants:* Twelve intubated patients with more than 10% of ineffective breaths while receiving pressure-support ventilation. *Interventions:* Flow, airway-pressure, esophageal-pressure, and gastric-pressure signals were used to measure patient inspiratory effort. To decrease ineffective triggering the following ventilator setting adjustments were randomly adjusted: pressure support reduction, insufflation time reduction, and change in end-expiratory pressure. *Measurements and results:* Reducing pressure support from 20.0 cm H_2O (IQR 19.5–20) to 13.0 (12.0–14.0) reduced tidal volume [10.2 ml/kg predicted body weight (7.2–11.5) to 5.9 (4.9–6.7)] and minimized ineffective triggering events [45% of respiratory efforts (36–52) to 0% (0–7)], completely abolishing ineffective triggering in two-thirds of patients. The ventilator respiratory rate increased due to unmasked wasted efforts, with no changes in patient respiratory rate [26.5 breaths/min (23.1–31.9) vs. 29.4 (24.6–34.5)], patient effort, or arterial PCO_2. Shortening the insufflation time reduced ineffective triggering events and patient effort, while applying positive end-expiratory pressure had no influence on asynchrony. *Conclusions:* Markedly reducing pressure support or inspiratory duration to reach a tidal volume of about 6 ml/kg predicted body weight eliminated ineffective triggering in two-thirds of patients with weaning difficulties and a high percentage of ineffective efforts without inducing excessive work of breathing or modifying patient respiratory rate.

Keywords Patient-ventilator asynchrony · Patient-ventilator interaction · Assisted mechanical ventilation · Pressure-support ventilation · Work of breathing

Introduction

Assisted or patient-triggered mechanical ventilation may avoid diaphragmatic dysfunction by allowing the patient to generate spontaneous inspiratory efforts [1, 2]. Assisted ventilation seeks to synchronize the ventilator insufflation to the patient's effort in order to optimize comfort and to minimize the work of breathing. Patient-ventilator asynchrony, defined as a mismatch between the patient's neural inspiratory time and the ventilator's insufflation time, is common in clinical practice [3–5]. Nearly one-fourth of intubated patients exhibit major asynchronies during assisted mechanical ventilation [6]. The most common pattern of asynchrony is ineffective triggering, in which

the patient's inspiratory effort fails to trigger a ventilator breath, because dynamic hyperinflation is present at the time of attempted triggering. Ineffective triggering is more common in patients with chronic obstructive pulmonary disease (COPD) or high levels of assistance associated with large tidal volumes, long insufflation times, and decreased respiratory drive [6, 7]. During pressure-support ventilation (PSV), although insufficient ventilatory support may result in respiratory distress [8], excessive support may induce patient-ventilator asynchrony, most notably due to ineffective triggering [6, 7, 9, 10].

High asynchrony rates are associated with prolonged mechanical ventilation [6, 10]. Asynchrony may be a marker of respiratory status severity but may also be related to inappropriate adjustment of ventilator settings prolonging the duration of mechanical ventilation. Several ventilator settings have been suggested to improve synchrony by reducing dynamic hyperinflation, such as application of external positive end-expiratory pressure (PEEP) [9] and reduction of the insufflation time [11] or ventilatory support level [7, 9, 10]. These approaches have not been systematically compared, and their respective effects on work of breathing and tidal volume have not been determined.

To extend our previous work [6] this study was designed to evaluate whether optimizing the ventilator settings would reduce ineffective triggering during PSV without unduly increasing the work of breathing in patients with weaning difficulties displaying ineffective efforts. The preliminary results of this study were presented at the 2006 meeting of the European Society for Intensive Care Medicine [12].

Materials and methods

Patients

The study was approved by an independent review board (CCPPRB Henri Mondor). Patients and/or their family were informed and gave their written consent before being included in the study. Patients who were experiencing weaning difficulties, defined as failure of at least one spontaneous breathing trial or failed extubation, were evaluated for patient-ventilator asynchrony as visualized on the ventilator screen (Fig. 1). Patients with frequent ineffective triggering events (more than 10% of the respiratory efforts) during PSV were eligible for this physiological study. Exclusion criteria were hypoxemia defined as a need for FIO_2 of at least 0.60, hemodynamic instability requiring, central neurological disorders, and agitation.

The study included 12 intubated patients, whose characteristics are presented in Table 1. Most of the patients had underlying respiratory disorders, and one-half had COPD. At inclusion the patients were ventilated using settings previously adjusted by the attending physician; median pressure support was 20.0 cm H_2O (interquartile range, IQR, 19.5–20.0). External PEEP was 5 cm H_2O in all patients. The cycling-off criterion was 25% of the peak inspiratory flow, and ventilator inspiration was flow-triggered and set at the most sensitive value without autocycling. Eight patients failed extubation; among these two failed two extubation attempts and three required tracheostomy because of weaning difficulties. Six of the eight patients who failed extubation were explored after at least one extubation failure. At the time of the study

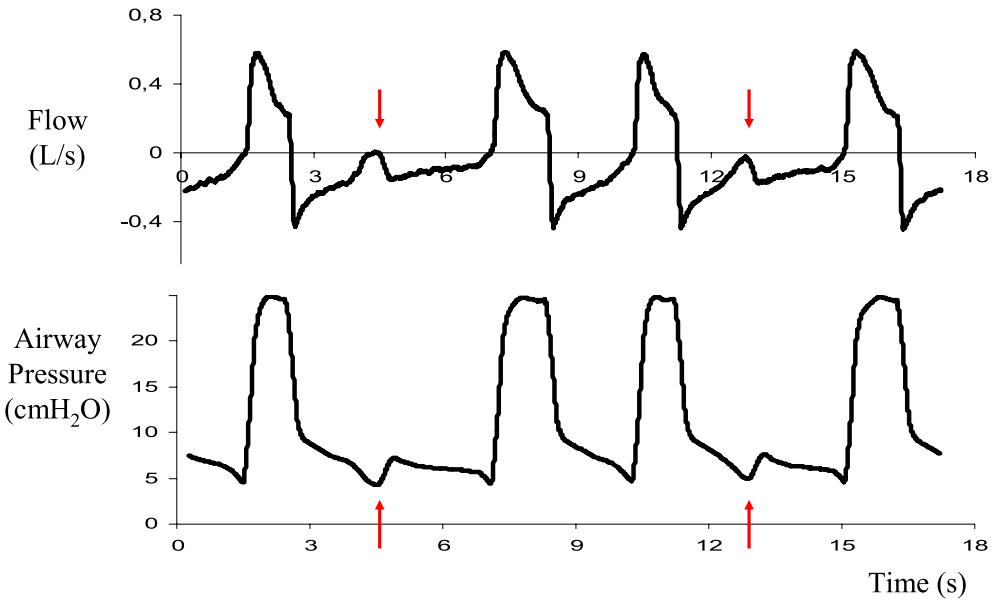

Fig. 1 Flow and airway-pressure signals from a patient exhibiting frequent ineffective triggering. The figure shows two ineffective breaths (*arrows*) detected as airway pressure drops coinciding with flow signal increases

Table 1 Characteristics of the 12 study patients (*BMI*, body mass index; *SAPS*, Simplified Acute Physiology Score; *PEEPi*, intrinsic positive end-expiratory pressure; *MV*, mechanical ventilation; *S*, survival; *D*, death; *COPD*, chronic obstructive pulmonary disease)

Patient no.	Sex	Age (years)	BMI	SAPS II	Underlying respiratory disease	PEEPi (cm H_2O)	MV duration time of study (days)	Total MV duration (days)	Extubation failure	Trache-ostomy	Outcome
1	M	52	40	41	COPD	7.2	2	7	Yes	No	S
2	M	75	17	69	None	2.5	29	35	Yes	Yes	D
3	M	83	25	41	COPD	0.7	6	32	No	No	D
4	F	77	24	52	COPD	5.0	5	8	Yes	No	D
5	F	54	31	39	Myasthenia gravis	2.0	19	31	Yes	Yes	D
6	F	78	29	43	COPD	1.3	3	8	Yes	No	D
7	M	83	28	36	Diaphragmatic paralysis	2.0	29	66	Yes	Yes	D
8	F	81	27	81	Diaphragmatic hernia	5.1	16	19	No	No	S
9	F	78	37	41	COPD	3.0	10	12	No	No	S
10	M	71	31	41	Critical illness neuromyopathy	1.7	22	40	Yes	No	D
11	M	82	29	45	COPD	7.0	5	8	No	No	S
12	M	63	22	85	Steroid-induced myopathy	2.5	8	42	Yes	No	D
Median	–	78 (69–81)	28 (25–31)	42 (41–56)	–	2.5 (1.9–5.0)	9 (5–20)	25 (8–37)	–	–	–

arterial pH was 7.47 (IQR 7.42–7.49), arterial PCO_2 43 mmHg (38–48), and PaO_2/FIO_2 229 mmHg (205–267). Their median Ramsay score was 2 (2–3), and a single patient was receiving continuous low-level sedation. Under the baseline condition with PEEP ineffective efforts represented 45% of respiratory efforts (36–52) and wasted muscle energy expenditure related to ineffective efforts represented more than 15% of the total PTP (11–27). Eight (66%) patients died, reflecting a very selected population.

Physiological measurements

Flow was recorded using a Fleisch no. 2 pneumotachograph (Fleisch, Lausanne, Switzerland) inserted between the Y piece of the ventilator circuit and the endotracheal tube and connected to a differential pressure transducer (Validyne MP45, ±2.5 cm H_2O, Northridge, CA, USA). Airway pressure was measured at the distal end of the circuit using a differential pressure transducer (Validyne MP45, ±80 cm H_2O). Esophageal and gastric pressures were measured using a double-lumen catheter equipped with two balloons (Marquat, Boissy Saint-Léger, France). Each balloon was inflated with 1 ml air and connected to a differential pressure transducer (Validyne MP45, ±100 cm H_2O). Appropriate placement of the esophageal balloon was verified using an occlusion test [13]. All signals were recorded at 200 Hz using an analog/numeric data-acquisition system (MP100, Biopac Systems, CA, USA) and stored in a personal computer for subsequent analysis.

Breathing pattern and minute ventilation were determined from integrated flow signals. Respiratory muscle energy expenditure was quantified from the esophageal pressure-time product (PTP). The PTP was obtained by measuring the area under the esophageal pressure signal between the onset of the inspiratory effort and the end of inspiration. This area was referenced to the chest-wall static recoil pressure-time curve relationship [14]. A difference between the beginning of the negative esophageal-pressure deflection and the zero-flow point was taken as the intrinsic positive end-expiratory pressure (PEEPi) [15] and was corrected for any abdominal pressure activity [16]. PEEPi was also measured during ineffective breaths, although no flow was delivered by the ventilator, taking ΔP as the minimal PEEPi value (Fig. 2). PTP was measured per breath and per minute for both effective and ineffective inspiratory efforts.

Ineffective triggering events were identified from the esophageal pressure signal. Their frequency was expressed as the asynchrony index computed by dividing the number of ineffective efforts by the total respiratory rate equal to the sum of ventilator cycles and wasted efforts [10]. After insertion of esophageal catheter patients were ventilated during a 20-minute period to ensure a steady basal condition. Because of the potentially large number of experi-

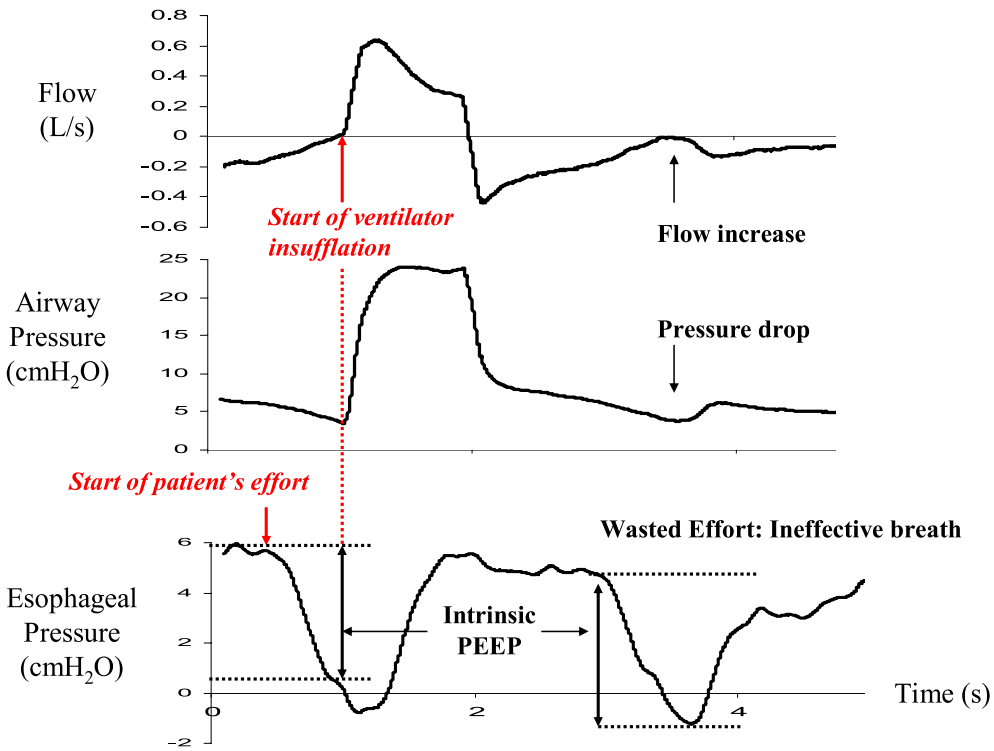

Fig. 2 Flow, airway-pressure, and esophageal-pressure signals showing intrinsic positive end-expiratory pressure (*PEEP*) defined as the pressure drop required before triggering the ventilator (first effort). Ineffective triggering occurs when an inspiratory effort fails to overcome the load induced by PEEPi and therefore fails to trigger a ventilator breath (second effort). During the second breath PEEPi is greater than the esophageal pressure drop generated by the patient

mental conditions and because the breathing pattern usually reaches its steady-state rapidly [17], we kept each period relatively short. In each condition breathing pattern was recorded for 10 min [18], and the asynchrony index and PTP were calculated over the last 5 min of this 10-min period. Periods were separated by 3–5 min spent with the baseline conditions. We checked that breathing pattern remained similar than during the preceding baseline period, and we recorded breathing pattern at the end of the study to verify that patients returned to their baseline condition.

Protocol for ventilator setting adjustment

All patients were ventilated using an AVEA ventilator (VIASYS Healthcare, Conshohocken, PA, USA) allowing adjustment of the cycling-off criterion from 5–45% of the peak inspiratory flow and adjustment of the maximal insufflation time. Both adjustments are useful for limiting the insufflation time during pressure support. The effects on asynchrony of the following ventilator setting adjustments were assessed in random order: (a) Baseline data were obtained without PEEP and after application of 5 cm H_2O of external PEEP. (b) The pressure-support level was gradually decreased in steps of 2 cm H_2O, starting at the baseline level with PEEP and continuing until ineffective triggering was eliminated or the patient showed poor tolerance defined as a respiratory rate greater than 35/min, a drop in SpO_2 below 90%, and/or sternocleidomastoid muscle activation. (c) The insufflation time was gradually reduced, starting at the baseline time with PEEP, by increasing the cycling-off criterion in steps of 10%; if ineffective triggering persisted at the highest value (45%), the insufflation time was further reduced by adjusting the maximal insufflation time in steps of 0.2 s from the mean insufflation time; this titration was stopped when ineffective triggering was eliminated or the patient showed poor tolerance as defined above.

After the experiments the patient was ventilated with the settings that produced the lowest asynchrony index, using external PEEP and the lowest level of pressure support possible without signs of poor tolerance. Arterial blood gases were measured after 2 h under these optimized conditions. Setting changes made by the attending physician over the next 24 h were recorded.

Statistical analysis

Data are reported as medians and IQRs. Measurements were compared across ventilator settings: zero end-expiratory pressure, PEEP, optimal pressure-support level, and optimal insufflation time. Nonparametric tests were used because of the small number of patients. To analyze variance we used the nonparametric Friedman test, and to perform pair wise comparisons we used the Wilcoxon test for each period. Differences with p values less than 0.05 were considered statistically significant.

Results

Effect of PEEP

Application of 5 cm H_2O of external PEEP led to a significant but small reduction in PEEPi (Table 2). However, the external PEEP level was greater than PEEPi in 8 of the 12 patients. PTP related to effective breaths decreased significantly ($p = 0.01$), and total PTP tended to decrease ($p = 0.07$). However, PEEP had no significant influence on the prevalence of ineffective triggering: the asynchrony index was 30% (16–53) without PEEP and 45% (36–52) under the baseline condition with PEEP ($p = 0.29$). Although minute-ventilation remained stable, tidal volume tended to be larger with than without PEEP ($p = 0.05$).

Optimization of the pressure-support level

The level of pressure support was gradually reduced without inducing signs of poor tolerance or further changes in alveolar ventilation. This reduction decreased the asynchrony index from 45% (36–52) to 0% (0–7, $p < 0.01$; Fig. 3). Ineffective triggering was completely eliminated in two-thirds of the patients (8/12) (Fig. 4). Table 3 reports arterial blood gases 2 h after the change in pressure-support level. PCO_2 remained stable, and pH declined slightly. The main changes in ventilatory parameters are shown in Table 2. Reducing the pressure-support level decreased tidal volume to approx. 6 ml/kg predicted body weight and also decreased PEEPi but left minute-ventilation unchanged. The respiratory rate indicated by the ventilator increased because most of the ineffective efforts were unmasked whereas the patients' true respiratory rate remained unchanged (Fig. 5). Patient effort was not changed by reducing the level of pressure support: PTP related to effective triggering increased slightly, whereas PTP related to ineffective efforts decreased.

Optimization of insufflation time

Reducing the insufflation time decreased the asynchrony index from 45% (36–52) to 7% (3–15, ($p < 0.01$; Fig. 3) and also reduced PEEPi. With insufflation-time reduction ineffective triggering events represented fewer than 10% of respiratory efforts in two-thirds of the patients (8/12). In these, increasing the cycling-off criterion to 45% allowed minimization of ineffective triggering in six patients whereas a further reduction in insufflation time by decreasing maximal inspiratory time was necessary and well tolerated in two patients. However, ineffective triggering persisted in 75% of patients (Fig. 4). Insufflation-time reduction was the only ventilator adjustment that decreased the total patient effort by reducing ineffective PTP without increasing effective PTP (Table 2). Moreover, insufflation-time reduction decreased patient effort per triggered cycle to a lower value than did any of the other adjustments.

Table 2 Ventilator parameters (*VT*, tidal volume; *PBW*, predicted body weight; *RR*, respiratory rate; *Ti*, insufflation time; *PTP*, pressure-time product; *PS*, pressure-support; *ZEEP*, zero end-expiratory pressure; *PEEP*, positive end-expiratory pressure; *parentheses*, interquartile range)

	Baseline PS–ZEEP	Baseline PS–PEEP	Optimal PS	Optimal Ti
VT (ml)	458 (397–578)	571 (487–638)	349 (336–368)*	398 (357–491)*
VT (ml/kg, PBW)	7.8 (6.0–10.4)	10.2 (7.2–11.5)	5.9 (4.9–6.7)*	7.0 (5.9–7.9)*
RR ventilator (breaths/min)	18.4 (11.9–22.4)	16.1 (12.4–17.2)	22.4 (22.0–31.3)*	22.6 (20.1–30.1)*
RR patient (breaths/min)	27.0 (22.4–32.5)	26.5 (23.1–31.9)	29.4 (24.6–34.5)	28.3 (23.3–34.3)
Minute ventilation (l/min)	8.6 (7.7–10.4)	8.5 (7.8–9.9)	9.4 (8.4–11.1)	9.8 (7.8–11.4)
Ti ventilator (s)	1.3 (0.9–1.5)	1.3 (1.0–1.8)	0.8 (0.8–1.0)*	0.8 (0.6–1.0)*
Dynamic intrinsic PEEP (cm H_2O)	2.5 (1.9–5.0)**	1.8 (1.2–3.3)	1.1 (0.9–2.4)*	1.5 (1.0–2.3)*
PTP effective/cycle (cm H_2O/s per cycle)	4.3 (2.2–5.0)	3.5 (2.5–4.6)	2.9 (1.9–3.9)	2.2 (1.3–2.4)**
PTP effective minute (cm H_2O/s per minute)	67 (37–95)*	56 (43–70)	81 (58–106)*	51 (36–65)
PTP ineffective minute (cm H_2O/s minute)	9 (5–19)	10 (7–21)	0 (0–1)**	1 (0–5)*
PTP total minute (cm H_2O/s per minute)	84 (51–97)	61 (58–81)	82 (61–106)	51 (40–68)**

*$p < 0.05$ vs. baseline PS + PEEP, **$p < 0.05$ vs. all other conditions

Table 3 Arterial blood gas values 2 h afteroptimization of the pressure-support level (*PS*, pressure-support; *ZEEP*, zero end-expiratory pressure; *PEEP*, positive end-expiratory pressure)

	Baseline PS-PEEP	Optimal PS	*p*
Pressure-support level (cm H_2O)	20.0 (19.5–20.0)	13.0 (12.0–14.0)	< 0.01
PaO_2/FIO_2 (mm Hg)	229 (205–267)	213 (193–249)	0.80
PCO_2 (mm Hg)	43 (38–48)	43 (39–52)	0.24
pH	7.47 (7.42–7.49)	7.43 (7.39–7.45)	0.06

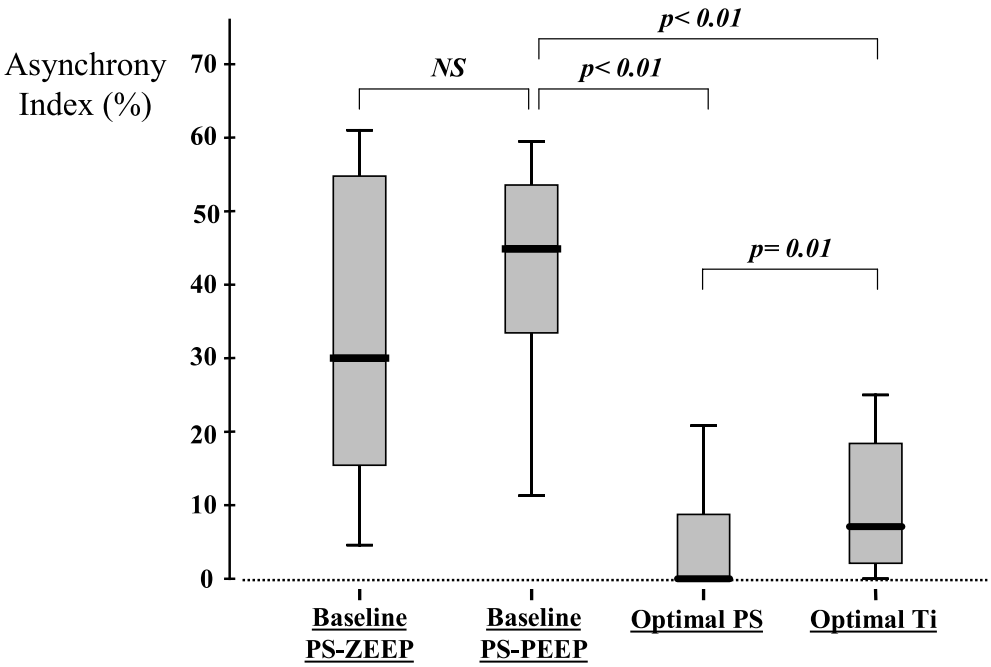

Fig. 3 Median (interquartile range) values of the asynchrony index with the various ventilator settings. Gradually reducing the pressure-support level or ventilator insufflation time (by increasing the cycling-off criterion) significantly minimized ineffective triggering events. Applying external PEEP had no influence on the frequency of ineffective triggering. *ZEEP*, Zero end-expiratory pressure; *PEEP*, positive end-expiratory pressure; *PS*, pressure-support; *Ti*, insufflation time

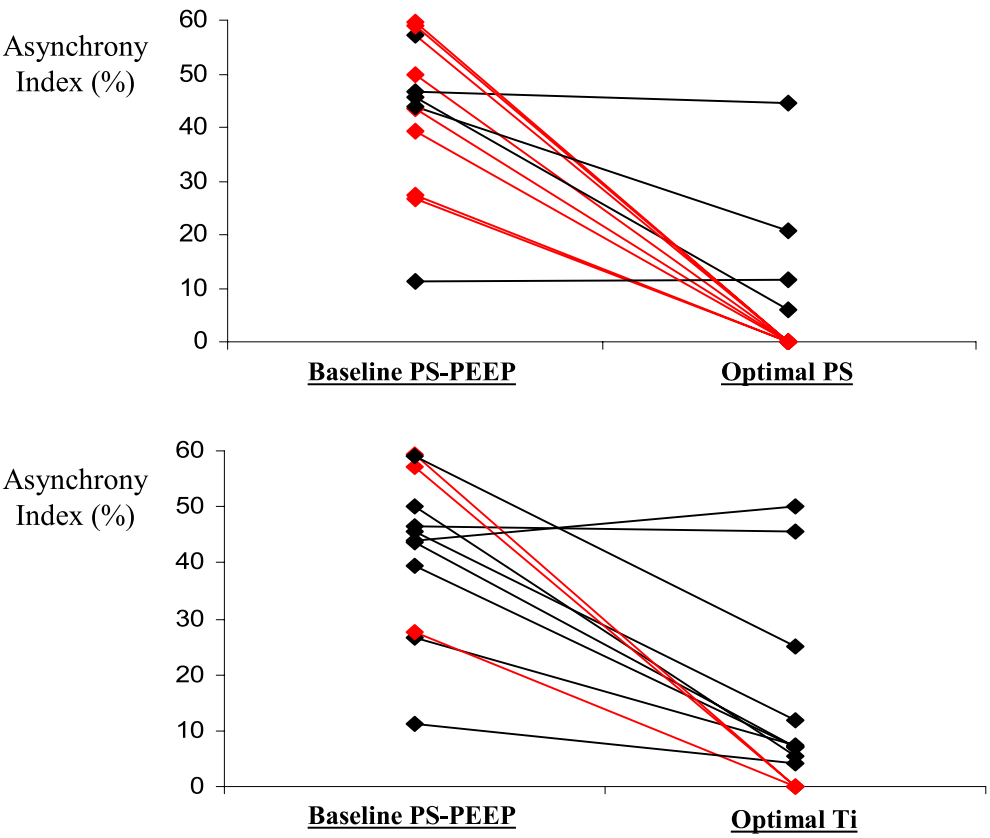

Fig. 4 Individual values of the asynchrony index under the baseline condition and after optimization of the pressure-support level (*top*) and ventilator insufflation time (*bottom*). Among the 12 patients ineffective triggering events were completely eliminated (*red line*) in eight patients using optimal PS and in three patients using optimal Ti. *PEEP*, Positive end-expiratory pressure; *PS*, pressure-support; *Ti*, ventilator insufflation time

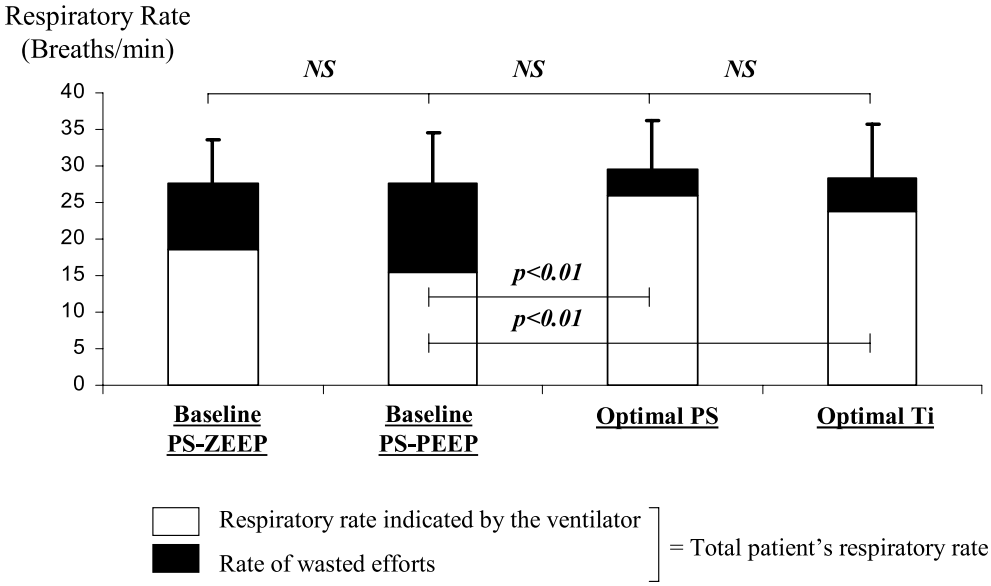

Fig. 5 Mean ± SD values of true total patient respiratory rate, computed as the sum of the ventilator respiratory rate (*open squares*) and ineffective breaths (*black squares*), for the various ventilator settings. Although respiratory rate indicated by the ventilator increased after reduction in the pressure-support level or insufflation time, because wasted efforts were unmasked, the true total patient respiratory rate remained unchanged. *ZEEP*, Zero end-expiratory pressure; *PEEP*, positive end-expiratory pressure; *PS*, pressure-support; *Ti*, insufflation time

Clinical tolerance of optimized ventilatory settings

After the experiments patients were ventilated using the optimal pressure-support level determined during the study. Within the next 24 h the pressure-support level was increased by the attending physician in 3 of the 12 patients, decreased in 2, and remained unchanged in 7. Consequently the mean pressure-support level remained unchanged [13.0 cm H_2O (12.0–14.0) vs. 13.0 (11.8–16.5), $p = 0.24$), reflecting the good tolerance of the titrated pressure support reduction.

Discussion

We found that optimizing the ventilator settings improved patient-ventilator synchrony by minimizing ineffective triggering during pressure-support ventilation, without increasing respiratory muscle effort in a selected population of ventilator-dependent patients with weaning difficulties. This is the first systematic comparison of three strategies: gradual reduction in the pressure-support level, gradual reduction in the ventilator insufflation time, and application of external PEEP. Reducing the pressure-support level completely eliminated ineffective triggering in two-thirds of the patients and decreased the tidal volume to approx. 6 ml/kg predicted body weight. There was no clinically detectable increase in respiratory-muscle energy expenditure, and alveolar ventilation remained unchanged, suggesting that the ineffective efforts were caused by excessive ventilatory support. Reducing the insufflation time produced a smaller decrease in ineffective triggering events than did reducing the level of pressure support but yielded a greater decrease in patient effort. Of note, both settings reduced insufflation time and tidal volume. External PEEP had no influence on ineffective triggering.

Effect of PEEP on asynchrony

External PEEP has been shown to decrease ineffective triggering in patients with high PEEPi [9, 10] by reducing the work of breathing needed to trigger the ventilator [19–21]. By titrating an optimal external PEEP level Nava et al. [9] significantly reduced ineffective triggering in patients with COPD and high levels of PEEPi. By contrast, we found that 5 cm H_2O of external PEEP failed to decrease ineffective triggering. Similarly, Vitacca et al. [22] found that applying 5 cm H_2O of external PEEP at various pressure-support levels had no influence on ventilatory patterns or ineffective triggering rates. In patients with PEEPi the external PEEP level should ideally be set below the dynamic PEEPi level to avoid hyperinflation [23]. This adjustment is difficult to achieve because PEEPi changes across cycles, depending on tidal volume and strength of the patient's efforts [4, 7]. Moreover, accurate determination of dynamic PEEPi requires esophageal pressure measurement, which cannot be performed in everyday clinical practice. Consequently the mean PEEP level usually applied in patients with COPD is about 5 cm H_2O [24]. This value may be excessive in many patients and may fail to decrease ineffective triggering. In our study the external PEEP level selected by the clinician (5 cm H_2O) was greater than PEEPi in 8 of the 12 patients. We believe that a low initial level of external PEEP may be applied (around 3 cm H_2O), and that a better possible titration may be a gradual increase in PEEP level to set

the minimal value minimizing ineffective triggering as previously suggested [11].

Adjusting the pressure-support level

Chao et al. [10] found that the most effective method for eliminating asynchrony consisted in reducing the level of ventilator support and noted that applying external PEEP reduced, but did not eliminate ineffective triggering. Two physiological studies showed that diminishing the pressure-support level minimized ineffective triggering by decreasing the tidal volume and insufflation time, lengthening the expiratory time, and limiting potential PEEPi [7, 9]. Moreover, a high level of ventilatory support reduced respiratory drive and patient effort, further promoting ineffective breaths [7]. We recently observed that ineffective triggering was associated not only with high tidal volumes and high pressure-support levels but also with more alkalotic pH values, suggesting that patients with high rates of ineffective triggering received excessive pressure support [6]. However, a marked reduction in pressure support may also increase the work of breathing, leading to poor clinical tolerance with respiratory acidosis [9]. We found that a gradual reduction in pressure support eliminated or decreased ineffective triggering without inducing excessive work of breathing and without changing alveolar ventilation as reflected by $PaCO_2$. Effective efforts increased slightly because of the lower pressure-support level, but this effect was canceled out by a decrease in wasted work of breathing related to ineffective breaths. Moreover, the true patient respiratory rate (including effective and wasted efforts) remained nearly unchanged, in keeping with previous data [25]. The combination of a small reduction in PEEPi and of a mild increase in patient's effort probably explains the reduction in ineffective efforts.

Adjusting the insufflation time

With pressure-support ventilation the insufflation time is not adjustable and depends only partially on the patient's ventilatory demand [26]. The ventilator insufflation time tends to be longer than the patient's neural inspiratory time, and this delayed cycling is more pronounced with higher levels of pressure support and in patients with COPD [5]. Tassaux et al. [11] found that increasing the expiratory trigger to 70% of the peak inspiratory flow improved patient-ventilator synchrony and decreased ineffective efforts without changing inspiratory muscle effort or alveolar ventilation. Similarly we found that ineffective triggering was less frequent with a high expiratory trigger [6]. Tidal volume and ventilator insufflation time were reduced, decreasing PEEPi. Consequently the effort developed during triggered ventilator breaths was smaller, and the total respiratory effort was also reduced, in line with previous findings [11].

Clinical consequences

The ideal dose of ventilatory support during assisted ventilation in general and pressure support in particular is unknown. If the hypothesis holds true that an excessive dose of support can cause both asynchronies and an excess in the duration of ventilation, our data provide a possible means to titrate ventilatory support and address this problem. It has been suggested that pressure support should be adjusted to obtain both clinical comfort and a tidal volume around 8 ml/kg [8] or a respiratory rate less than 30/min [27]. A PTP lower than 120 cm $H_2O\ s^{-1}\ min^{-1}$, as observed in our patients, is probably reasonable and far from the values observed in patients with weaning failure [27]. There is probably no advantage at trying to further decrease respiratory effort in this range.

In our patients with prolonged durations of mechanical ventilation and weak efforts, reducing the dose of ventilatory support improved synchrony while maintaining PTP within a reasonable range. The true patient respiratory rate remained unchanged and above 25 breaths/min on average regardless of the ventilatory support level, whereas the adjusted pressure-support level resulted in a tidal volume of about 6 ml/kg, close to the values proposed for protective ventilation in patients with acute respiratory distress syndrome [28]. Ineffective triggering may be a marker for excessive ventilator support, and gradually reducing the level of pressure support may be a valid method for determining the optimal level of pressure support. Targeting a tidal volume of 6 ml/kg predicted body weight may be a simple means of adjusting pressure support. In our study gradually reducing the insufflation time by increasing the expiratory trigger allowed asynchrony to be minimized while decreasing patient effort. However, expiratory-trigger adjustment is not available on all ventilators, whereas pressure support adjustment is simple and, according to our data, more likely to eliminate ineffective breaths. Empirical adjustment of external PEEP level up to 5 cm H_2O may lead to excessive PEEP in many patients and seems unable to improve patient-ventilator synchrony. Ideally PEEP should be titrated based on dynamic PEEP measured using the esophageal pressure signal [9, 20, 21], static PEEP measurements during end-expiratory occlusion [9, 23], or airway occlusion pressure (P0.1) measured by the ventilator [20].

Limitations

We evaluated patient-ventilator synchrony in a very specific population of patients with prolonged mechanical ventilation and weaning difficulties and therefore a high

mortality. Considering the small sample of patients and selected population, our results may not apply to all intensive care unit patients treated with pressure-support ventilation. A reason for excessive ventilation is that most clinicians choose to increase pressure-support level when respiratory rate is around 30 breaths per minute. Our study is one of the first showing that a gradually reduction in pressure support is not associated with excessive levels of work of breathing on patient's effort. Although in our study the ideal dose of ventilation reached a tidal volume of 6 ml/kg, our study design does not allow recommendation of an adjustment in pressure support to reach this targeted value in all patients. More importantly, the goal of optimization was gradually to reduce pressure support to minimize ineffective triggering by individually titrating tidal volume. As shown previously, a high rate of asynchrony is associated with prolonged mechanical ventilation and high mortality [6, 10]. Our data suggest that optimizing the ventilatory settings improves patient-ventilator synchrony during difficult weaning, but further studies are needed to evaluate effects on the duration of mechanical ventilation.

Conceivably the pressure-support level that minimizes ineffective triggering without inducing clinical signs of poor tolerance could constitute an ideal dose of ventilation at the time of titration but not over longer periods of time. In a study that used closed-loop control of the pressure-support level to maintain the patient in a comfort zone, the level of pressure support was modified 56 ± 40 times over a 24-h period [29]. This suggests that the pressure-support level may need to be modified repeatedly to avoid both excessive work of breathing and excessive ventilatory assistance. In our study the pressure-support level was increased in only 3 of 12 patients within 24 h after optimization, suggesting good tolerance of the level identified during the study.

Conclusion

In patients with prolonged ventilation and experiencing major weaning difficulties optimizing ventilator settings can reduce ineffective efforts while decreasing tidal volume (down to approx. 6 ml/kg predicted body weight in this study) and without inducing excessive respiratory muscle effort to breathe. This indirectly suggests that ineffective triggering is related to excessive ventilatory support. Reducing pressure support does not eliminate ineffective triggering in all patients. Reducing the insufflation time alone may also improve ineffective triggering but also decrease patient effort.

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