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Physiologic comparison of neurally adjusted ventilator assist, proportional assist and pressure support ventilation in critically ill patients

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ABSTRACT

To compare, in a group of difficult to wean critically ill patients, the short-term effects of neurally adjusted ventilator assist (NAVA), proportional assist (PAV+) and pressure support (PSV) ventilation on patient–ventilator interaction. *Methods*: Seventeen patients were studied during NAVA, PAV+ and PSV with and without artificial increase in ventilator demands (dead space in 10 and chest load in 7 patients). Prior to challenge addition the level of assist in each of the three modes tested was adjusted to get the same level of patient's effort. *Results*: Compared to PSV, proportional modes favored tidal volume variability. Patient effort increase after dead space was comparable among the three modes. After chest load, patient effort increased significantly more with NAVA and PSV compared to PAV+. Triggering delay was significantly higher with PAV+. The linear correlation between tidal volume and inspiratory integral of transdiaphragmatic pressure (PTPdi) was weaker with NAVA than with PAV+ and PSV on account of a weaker inspiratory integral of the electrical activity of the diaphragm ($\int$EAdi)–PTPdi linear correlation during NAVA [median (interquartile range) of r^2, determination of coefficient, 16.2% (1.4–30.9%)]. *Conclusion*: Compared to PSV, proportional modes favored tidal volume variability. The weak $\int$EAdi–PTPdi linear relationship during NAVA and poor triggering function during PAV+ may limit the effectiveness of these modes to proportionally assist the inspiratory effort.

1. Introduction

Assisted mechanical ventilation is a first line ventilatory strategy in critically ill patients able to undertake part of their respiratory work (Tobin, 2003). A priority of assisted ventilation is to ensure adequate blood gas exchange, harmonious patient–ventilator interaction and sufficient unloading of the respiratory muscles (Kondili et al., 2003). Accomplishment of these targets is often complex and represents one of the greatest challenges in the treatment of partially supported patients.

Pressure support ventilation (PSV) is a frequently used mode of assisted mechanical ventilation (Esteban et al., 1999). Nevertheless, with this mode an optimal level of assistance and/or a perfect patient–ventilator synchrony may not be achieved (Kondili et al., 2003). Moreover, ventilator assistance remains constant, a drawback in the face of changing patient's ventilatory demands. This is not the case with proportional modes, such as neurally adjusted ventilator assist (NAVA) (Sinderby et al., 1999) and proportional assist ventilation (PAV) (Younes, 1992), which permit the patient to modify the level of ventilator assistance. NAVA uses the signal of the electrical activity of the diaphragm (EAdi) to trigger the ventilator, guide pressure delivery and terminate mechanical inspiration (Sinderby et al., 1999). PAV delivers pressure proportional to the instantaneous flow (V′) and volume (V) and, hence, to respiratory muscles' pressure, provided that respiratory system elastance and resistance are known (Younes, 1992). The latter are automatically calculated by a ventilator software (PAV+, PAV with load adjustable gain factors) (Younes et al., 2001a,b; Kondili et al., 2006).

Several studies demonstrated that, compared to PSV, both PAV (Alexopoulou et al., 2013; Bosma et al., 2007; Xirouchaki et al., 2008) and NAVA (Colombo et al., 2008) improve patient–ventilator synchrony and unload the respiratory muscles without the risk of over-assistance. Nevertheless, a direct comparison of the three modes, PAV+, NAVA and PSV, has never been performed. In addition there are limited data on the performance of proportional modes in difficult to wean patients. The latter represents a challenging group

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of patients in whom different ventilatory strategies might have significant impact on weaning outcome. The aim of this study was to examine, in a group of difficult to wean critically ill patients, the breathing pattern and patient effort during PSV, NAVA and PAV+ at resting conditions and after an acute artificial increase in ventilator demand. In addition, because the ability of a ventilator mode to meet patient demand would require that tidal volume, which is partly determined by airway pressure, will match patient inspiratory effort, we examined the correlation between tidal volume with indices of inspiratory efforts such as transdiaphragmatic pressure (Pdi) and EAdi.

2. Methods (see also supplemental digital content, SDC)

2.1. Patients

Patients with difficult or prolonged weaning (Boles et al., 2007) were studied. PSV, NAVA and PAV+ were applied in all patients before and after an artificial increase in respiratory demand. The study was conducted in two time periods: In the first, the respiratory demand in all eligible patients was increased by the addition of 150 ml dead space in the ventilator circuit (dead space group) (Ranieri et al., 1985). Patients enrolled during the second period were tested before and after application of sandbags to the entire surface of the chest and abdominal wall (load group) (Kondili et al., 2006). The study was approved by the hospital ethics committee and informed consent was obtained from the patients or their families.

2.2. Measurements

V′, V and airway (Paw), esophageal (Pes), gastric (Pgas) and transdiaphragmatic (Pdi = Pgas − Pes) pressures were measured as described previously (Kondili et al., 2006, 2010). EAdi was recorded using the NAVA electrodes attached to a nasogastric tube (Maquet, Solna, Sweden) (Colombo et al., 2010). The proper position of the eosphageal and gastric balloons (to measure Pes and Pgas, respectively), and nasogastric tube (to record EAdi) was verified using standard tests and procedures (D'Angelo et al., 1991; Kondili et al., 2006). Each signal was sampled at 150 Hz and stored on a computer disk for later analysis.

2.3. Study protocol

The patients were studied in semi-recumbent position (>30°). Initially, their nasogastric tubes were replaced by a nasogastric tube equipped with NAVA electrodes (16 French diameter, 125 cm long; Maquet Critical Care, Sölna, Sweden) and the gastric content was drained. Subsequently, thin, latex balloon-tipped catheter systems were inserted into the middle third of the esophagus and stomach to measure Pes and Pgas, respectively.

Two ventilators were used for the purpose of the study: (1) a Servo-i® (Maquet Critical Care, Solna, Sweden) to deliver NAVA and PSV and (2) a Puritan Bennett 840 (Covidien, USA) to deliver PAV+. Inspired fraction of oxygen (FiO_2), flow trigger sensitivity and external positive end-expiratory pressure (PEEP) selected by the primary physician prior to patient inclusion on the baseline mode (PAV+ or PSV), remained unaltered throughout the study. Pdi swings (Pdi_{swings}) on baseline mode were used to adjust the ventilator assist level, such as to obtain comparable steady-state Pdi_{swings} among the three modes. In each ventilator mode the patients underwent two 20-min sessions, without (no challenge) and with (challenge) artificial increase in ventilatory demands. Arterial gas samples were obtained at the end of each experimental condition (see Fig. S1 in SDC for study protocol).

2.4. Data analysis

The last 3 min of each 20-min period were analyzed and averaged to give the breath variables corresponding to each experimental condition. Breaths with low quality Pdi signal (i.e. cough, peristaltic waves on Pes signal) were excluded. Pdi were reported as changes from end-expiratory value (Kondili et al., 2006). Since with NAVA and PSV EAdi and Pdi were recorded by two different systems (Maquet and Windaq, respectively), an end-inspiratory pause was performed prior to NAVA or PSV recordings, to allow the offline synchronization of the two recordings using Paw and V′ as reference signals (see Fig. S2). Synchronization of EAdi cycles to Pdi cycles was not feasible with PAV+ as we could not acquire Paw and V′ waveforms from 'Maquet system' when the patients were ventilated on PAV+ (see SDC).

To evaluate the breathing pattern, inspiratory tidal volume (V_T), patient respiratory rate (RR), minute ventilation (V_E), Pdi-derived (Ti_{Pdi}) and flow-derived (Ti_{mech}) inspiratory times, Pdi-derived total respiratory cycle duration (Ttot) and the duty cycle (Ti_{Pdi}/Ttot) were measured as previously described (see Fig. S3) (Kondili et al., 2006, 2010). Breathing pattern variability was expressed as the coefficient of variation of V_T and RR.

Patient inspiratory effort per breath was quantified by measuring the pressure-time area under the Pdi signal (PTPdi/b) between the onset of inspiratory effort and the end of neural inspiration, i.e. from the beginning of Pdi increase to the point at which Pdi started to decline rapidly (Kondili et al., 2006; Spahija et al., 2010; Fig. S3). PTPdi per minute (PTPdi/min) and per liter of minute ventilation (PTPdi/L) were also calculated. The inspiratory effort dissipated to trigger the ventilator ($PTPdi_{trig}$) was estimated as the time integral of Pdi from the beginning of inspiration to the nadir value of Paw. The rate of rise of Pdi (dPdi/dt) and the level of intrinsic PEEP (PEEPi) were also computed (Kondili et al., 2006, 2010).

In addition to Pdi-derived indices, the corresponding EAdi-derived indices were computed [EAdi inspiratory time (Ti_{EAdi}, Fig. S3), $EAdi_{swings}$, the integral of EAdi over Ti_{EAdi} (∫EAdi/b), ∫EAdi/min, ∫EAdi/L and dEAdi/dt].

Respiratory system elastance and resistance were measured with and without the challenge using the automatic technique of end-inspiratory airway occlusion during PAV+ mode (Kondili et al., 2006).

Asynchrony, although not the primary aim of the study, was also computed during the 3 min recording period (Georgopoulos et al., 2006) (see SDC).

2.5. Statistical analysis

Data were analyzed using non-parametric tests. Continuous variables were expressed as medians (25–75th interquartile range, IQR). Variables were compared using the Friedman test for repeated measurements followed, when indicated, by a pairwise comparison with Wilcoxon signed rank using Bonferroni post hoc correction. Categorical variables were compared using the Fisher's exact test.

Linear regression analysis was used and the coefficient of determination (r^2) was calculated to examine the relationship among ∫EAdi/b, PTPdi/b and V_T. The relationship between ∫EAdi/b and V_T could not be examined during PAV+ since the synchronization of EAdi and Pdi cycles was not feasible (see SDC). In the dead space group and for a given mode the regression analysis was performed using all analyzed breaths (with and without dead space); each patient had one value of r^2 for any examined correlation at each tested mode. In the load group, since respiratory mechanics were altered by the load, the correlation analysis was performed separately for breaths without and separately for breaths with load application and each patient had two r^2 for a given correlation and a given mode (one with and one without challenge) (see SDC for

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