Proportional Assist Ventilation and Neurally Adjusted Ventilatory Assist

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Abbreviations

EAdi Electrical activity of the diaphragm
NAVA Neurally adjusted ventilatory assist
PAV Proportional assist ventilation

Historically, patients in need of mechanical ventilation were often heavily sedated or paralyzed and placed on time-cycled modes of ventilation. There is now clear evidence showing that reduced sedation and spontaneous breathing improve patient outcome in terms of days on ventilation and mortality [1]. Under these conditions (less sedation and more spontaneous breathing), unless the patient ‘entrains’ themselves to the rate of the breath delivery, time-cycled modes may not be the most appropriate, especially in light of the recent work demonstrating that patient-ventilator asynchrony increases the duration of mechanical ventilation and mortality [2].

Two new modes of mechanical ventilation are now available on the market that can synchronize not only the timing, but also the level of assist to the patient’s own effort, PAV and NAVA. This article describes the concepts related to PAV and NAVA, their similarities and their differences, and the recent physiological studies. For a more detailed review of this topic, the reader is referred to Sinderby and Beck [3].

Patient-Ventilator Interaction

Ideally, a mechanical ventilator should behave as a respiratory prosthesis, providing air in tandem with the patient’s breathing in terms of timing and the magnitude of the inspiration. The prevalence of patient-ventilator asynchrony has recently been revealed [2] and it is now readily accepted that during conventional ventilation, such as pressure support ventilation, poor patient-ventilator asynchrony does occur [4, 5]. Patient-ventilator asynchrony ranges at its worst from completely missed patient efforts (so-called wasted efforts) and auto-triggering in the absence of spontaneous efforts, to delays in ventilator triggering and cycling-off. Modes with fixed levels of assist (such as assist control, pressure control, and pressure support ventilation)
may also be asynchronous since the ventilator cannot respond to changes in patient demand on a breath-by-breath basis. Patient-ventilator asynchrony has now been shown to affect patient outcome in terms of prolonged weaning [6], poorer sleep quality [7], longer duration of mechanical ventilation and tracheotomy [2], and in infants, higher incidence of pneumothorax [8].

**From Brain to Breath: Spontaneous Breathing**

A simplified schematic of the chain of events that occur during spontaneous breathing is presented in figure 1. The signal for spontaneous breathing originates in the respiratory centers (Step 1) and in the case of the diaphragm – the most important muscle of respiration – travels down the phrenic nerves, then passes through the neuromuscular junction (Step 2) to activate the diaphragm electrically (Step 3). It is only after this step of electrical activation of the diaphragm, that cross-bridge cycling is initiated and the muscle contracts (Step 4). Contraction of the diaphragm results in lung expansion (Step 5), resulting in flow and volume at the airway (Step 6). Depending on the type and severity of the disease, the final output of airflow and volume at the airway may not represent the true neural respiratory output.

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**Proportional Assist Ventilation**

In PAV [9], the ventilator generates airway pressure in proportion to instantaneous flow and volume (Step 6). The flow assist, which is a percentage of the airway resistance, dictates how much airway pressure is delivered per unit of flow. The volume assist, which is a percent of the pulmonary elastance, dictates how much pressure is delivered per unit of volume. The degree of assist can range to provide unloading between 0 and 100%. During PAV, knowledge about respiratory system mechanics and endotracheal tube resistance are required. This is especially important in preterm neonates as there is a large breath-to-breath variability in resistance and compliance of the respiratory system. Recently, ‘PAV+’, with updated measurements of resistance and elastance and implementation of load-adjustable gain factors, has the potential to account for this.

With regard to physiological studies [for a review, see 3], PAV has been shown to improve patient comfort, improve patient-ventilator interaction, improve sleep quality, and allows greater variability in breathing pattern (i.e. more physiological) in comparison with pressure support. In both adults and neonates, PAV has been demonstrated to unload the respiratory muscles, with lower mean airway pressures than pressure support ventilation – with similar clinical short-term outcomes (gas exchange and hemodynamics). Recently, PAV with load-adjustable gain factors has been shown to be feasible in critically ill patients, and to require fewer interventions with respect to sedation and ventilator settings [10] compared to pressure support.

**Neurally Adjusted Ventilatory Assist**

NAVA uses the EAdi (Step 3) – a signal representative of the output from the respiratory centers – to control both the timing and the magnitude of delivered pressure [11]. The EAdi is obtained
by an array of miniaturized sensors placed on a conventional nasogastric (or orogastric) feeding tube. The electrode array is positioned in the esophagus at the level of the gastroesophageal junction, where the spontaneous activity of the crural diaphragm is sensed. Standardized signal processing algorithms automatically take into account diaphragm displacement, motion artifacts, filtering of the electrocardiogram, and cross-talk from other active muscles [12]. The processed signal, known as the EAdi waveform, can be characterized by its amplitude on inspiration (phasic EAdi) and expiration (tonic EAdi) as well as its timing (neural inspiratory time, neural expiratory time, neural respiratory rate). When compared to the airway pressure waveform in other modes of ventilation, the EAdi provides information about patient-ventilator synchrony. 

In the absence of the EAdi signal (and the catheter position has been deemed appropriate), it is an indication of central apnea, or suppression of spontaneous breathing activity. Hence, the EAdi signal has monitoring capabilities as well as controlling the ventilator.

In infant and adult patients, NAVA has been shown to significantly improve patient-ventilator interaction compared to conventional modes of assist [4, 5, 13], in terms of both improved timing and proportionality. Neural triggering and cycling-off on non-invasive (helmet) ventilation in healthy adults has demonstrated that this improved synchrony improves comfort [14].

During NAVA, the assist levels are adjusted by changing the proportionality between the EAdi and delivered pressure (the so-called ‘NAVA level’). Stepwise increases in the NAVA level cause a gradual reduction in respiratory drive, and therefore the expected increase in pressure is not necessarily achieved. Due to this physiological down-regulation of the EAdi signal, airway pressure and tidal volume ‘plateau’ at adequate levels of unloading [15].

Since the EAdi controller signal for NAVA is pneumatically independent, application of NAVA with excessively leaky non-invasive interfaces does not affect patient-ventilator synchrony.

Discussion

The similarities and differences between PAV and NAVA can only be discussed theoretically as there are no studies in the literature comparing these two modes of ventilation. The lack of a single device providing both modes of ventilation is likely the responsible factor.

In principle, NAVA and PAV are similar in that they are both modes of assisted ventilation where the applied airway pressure is servo-controlled continuously throughout spontaneous inspiration, changing in proportion to the patient's breathing effort and allowing the patient to control the extent and timing of lung inflation. During both NAVA and PAV, the amplification ‘gain’ between patient effort and delivered pressure can be adjusted, in order to achieve more or less unloading of the respiratory muscles. This is very different from modes of ventilation that are volume- or pressure-targeted, where fixed levels of assist are delivered independent of patient effort.

Both PAV and NAVA require that the patient is spontaneously breathing. However, it should be noted that NAVA uses the neural output signal (EAdi), whereas PAV has no monitoring capabilities for quantifying respiratory drive. This means that, similar to other patient-triggered modes of ventilation, a back-up mode of ventilation is required in the case of central apnea. As well, upper pressure limits should be adjusted accordingly, in the case of large and central respiratory drive. The fact that PAV and NAVA require some degree of spontaneous breathing may actually be a clinical advantage, in that the respiratory muscles are encouraged to be used during partial ventilator assist. Inactivity of respiratory muscles during mechanical ventilation (due to too high levels of sedation or too high levels of assist) has a
negative impact on diaphragm muscle fiber integrity and prolongs the duration of mechanical ventilation [16].

Unlike pressure support ventilation, increasing levels of assist with PAV and NAVA have little effect on respiratory rate and tidal volume when unloading is sufficient. In modes of ventilation that allow the patient the freedom to control the rate and depth of inspiration, it seems that there is a desired minute ventilation, rate and volume. When unloading is adequate to satisfy the patient’s demand, if the assist is increased during PAV or NAVA, patient effort decreases and therefore, so does the amount of assist.

The major differences between these two modes lie in how the disease processes affect the controller signals. During NAVA, the EAdi (the neural respiratory drive to the diaphragm from the respiratory centers, Step 3 in figure 1) is the controller signal. PAV uses airway flow and volume (Step 6), which is a surrogate measurement of respiratory drive, and further down the chain of events involved with spontaneous breathing.

In the presence of a leak – for example in infants with leaks around the endotracheal tube, or during non-invasive ventilation – the flow and volume signal in Step 6 will be misinterpreted as patient flow and volume. For triggering and delivering proportional assist during PAV, the leak may auto-cycle the ventilator and may call for increased flow delivery during inspiration. In sharp contrast, NAVA, using a neural trigger, is not affected by leaks for obtaining synchrony. Depending on the size of the leak, an increase in the NAVA level however may be required to unload the respiratory muscle sufficiently.

The major difference between NAVA and PAV might be observed in the case of dynamic hyperinflation, where shortening of the respiratory muscles affects the force output for a given neural activation. In fact, any disease process affecting the contractile properties of the diaphragm (Step 4) will in theory cause an ‘uncoupling’ between neural respiratory drive (Steps 1–3) and patient flow and volume (Step 6). In the case of dynamic hyperinflation, if the respiratory drive stays the same (i.e. same EAdi), the flow and volume will be lower, and the controller signal for PAV may reduce the airway pressure delivery.

**Conclusion**

PAV and NAVA are both modes of partial ventilator assist delivering assist in proportion to patient effort. During NAVA, the diaphragm electrical activity – a true signal of neural respiratory output – is the controller signal for delivered ventilation. During PAV, a surrogate measurement of respiratory drive is used to control the ventilator. The inherent benefits of these two modes lie in the fact that these modes require spontaneous breathing and offer synchronized delivery of assist.

**Recommendations**

- Implement spontaneous mode of ventilation as soon as possible/tolerable.
- Ensure that respiratory drive is not suppressed by too high levels of sedation or too high levels of assist, i.e. ensure that patients are spontaneously breathing.
- Optimize patient-ventilator synchrony.
References


