

# Diaphragmatic Electrical Activity

## A New Tool to Assess Lung Hyperinflation?

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“EXPIRATION and slow decrease of light together reaching minimum together ... in about 10 s and immediately cry as before. Silence and hold for about 5 s.” In the script for his late play “Breath,” Samuel Beckett conveys in sound and light his awareness of long and vital expiratory times. His personal experience with emphysema might have provided some of the inspiration. In the current issue of *ANESTHESIOLOGY*, Bellani *et al.*<sup>1</sup> propose a new method to quantify the respiratory mechanical consequences of these required long exhalations in ventilated patients and to assess their response to positive end-expiratory pressure (PEEP).

Auto-PEEP is the positive alveolar pressure in excess of any applied PEEP present in some patients' lungs at the end of a passive exhalation. It results from incomplete pulmonary emptying due mainly to increased airway resistance and reduced lung elastic recoil, typical of chronic obstructive pulmonary disease, and potentially worsened postoperatively.<sup>2</sup> Auto-PEEP is related to dynamic lung hyperinflation, that is, end-expiratory volumes above the volume of lung elastic relaxation, with onset of spontaneous or mechanical inspiration characteristically during an ongoing exhalation.

The main determinants of auto-PEEP are minute ventilation, expiratory time, and time constant of the respiratory system (*i.e.*, the product of the respiratory system resistance and compliance). Increased dyspnea, muscle fatigue, barotrauma, hemodynamic compromise, and even cardiac arrest are some of the important clinical consequences.<sup>3</sup> In patients under assisted modes of mechanical ventilation and during ventilator weaning, auto-PEEP accounts for a substantial increase in patient's muscle energy expenditure<sup>4</sup> and is associated with ineffective efforts, that is, inspiratory muscle



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contraction insufficient to trigger a ventilator breath. This is due to the mechanical load added by auto-PEEP to the respiratory system, which hinders the achievement by the patient of usual triggers of ventilatory support, pressures or flows.

Despite its relevance, use of auto-PEEP as a variable to guide clinical practice in spontaneously breathing ventilated patients is limited due to the difficulty of its measurement which requires absence of expiratory muscle activity and placement of an esophageal balloon. Neurally adjusted ventilatory assist (NAVA) is a ventilatory mode that uses the electrical activity of the diaphragm (EAdi-derived from electrodes from a special esophageal catheter) to trigger assisted support. Because the trigger, cycling, and assistance level are all based on diaphragm electrical activity and not on pressures or flows, it has been shown to improve patient-ventilator synchrony.<sup>5</sup>

Bellani *et al.*<sup>1</sup> studied whether that electrical activity of the diaphragm could also be used to estimate auto-PEEP during two spontaneous modes of mechanical ventilation: pressure support ventilation (PSV) and NAVA. The authors measured the EAdi at the onset of inspiratory flow (denominated auto-EAdi) in 10 patients with suspected auto-PEEP and showed that auto-EAdi followed closely auto-PEEP in individual patient analysis. The variable relation between EAdi and the pressure generated by the respiratory muscles among patients was elegantly addressed by calibrating the EAdi to the negative deflection in the proximal airway pressure during an inspiratory effort against closed inspiratory and expiratory valves.<sup>6</sup> The authors concluded that the auto-EAdi provides a simple and reliable tool for continuously monitoring the presence of dynamic auto-PEEP at the bedside.

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In comparing auto-PEEP measurements during PSV and NAVA, it is important to note that during PSV the pressure generated by the inspiratory muscles allows for an estimate of auto-PEEP. This is because the deflection in esophageal pressure from the start of inspiratory effort to the onset of inspiratory flow is equal to or slightly greater than the pressure required to counterbalance auto-PEEP.<sup>7</sup> As well pointed out by the authors, the same is not true during NAVA when ventilatory support is triggered by the electrical activity of the diaphragm. In this case, the inspiratory esophageal pressure deflection represents a lower boundary and not the effective alveolar auto-PEEP, a likely contributing factor for the lower auto-PEEP during NAVA and distinct auto-PEEP *versus* auto-EAdi regression lines observed by the authors for the two ventilatory modes. Also relevant is the fact that the NAVA and PSV groups were matched by equivalent peak pressures. Thus, although it is tempting to argue in favor of a superiority of NAVA in this work, no specific optimization and individualization of PSV or NAVA settings was pursued. Accordingly, the results cannot be directly interpreted as a final comparison of the best performance of the studied ventilatory modes.

Not all patients with auto-PEEP respond equally to external PEEP. Whereas overinflation is usually expected to follow the application of PEEP in obstructive patients, a significant proportion of these may show a “paradoxical” response with decreased functional residual capacity, plateau pressure, and total PEEP.<sup>8</sup> Indeed, even in the same patient not all lung regions respond equally to PEEP,<sup>9</sup> consistent with the redistribution of regional lung ventilation in chronic obstructive pulmonary disease.<sup>10</sup> Some regions can actually deflate with higher PEEP, a finding indicative of regional flow limitation.<sup>9</sup> The individual response to PEEP will depend on the magnitude of auto-PEEP and on the relative contribution of regions with and without flow limitation. That deflation with application of PEEP actually portrays ultimately the main goal of external PEEP in the presence of auto-PEEP: airway recruitment. If this is not achieved, PEEP will only produce hyperinflation and its consequences.

For these reasons, Bellani *et al.*'s<sup>1</sup> findings of diaphragmatic unloading directly proportional to increases in external PEEP should be interpreted cautiously. Even though they might suggest that higher external PEEP was always beneficial by reducing auto-PEEP, total PEEP, and the possibility of hyperinflation should be considered. Whereas individual measurements of total PEEP as a function of external PEEP were not presented, on average increasing external PEEP from 0 to 14 cm H<sub>2</sub>O caused only a modest (approximately 2 cm H<sub>2</sub>O) reduction of auto-PEEP, with the net result of an increased total PEEP. Accordingly, the benefits of external PEEP could be offset by the side effects of hyperinflation. At the bedside, stable or reduced plateau pressures in volume-cycled ventilation or increased tidal volumes in pressure-cycled ventilation resulting from careful PEEP up-titration indicate a favorable response to

external PEEP in the presence of auto-PEEP.<sup>3</sup> In fact, the changes in tidal volume with PEEP reported in the study suggest an optimal PEEP lower than the applied maximum (14 cm H<sub>2</sub>O). Bellani *et al.*<sup>1</sup> expand those bedside resources by offering the auto-EAdi and the inspiratory delay between the onset of diaphragmatic electrical activity and inspiratory flow as novel clinical measurements to assess diaphragmatic workload and optimize ventilatory assistance.

The typical airway pressure tracing during NAVA in the presence of auto-PEEP identified by the authors is another contribution worth of attention. It presents an abrupt increase in airway pressures at the onset of inspiration caused by closure of the expiratory valve and likely related to the magnitude of auto-PEEP, followed by a transient pressure reduction with low flow before further increase in pressure. Such tracing reveals that despite early triggering of inspiration during NAVA, there is also the possibility of muscle activity with minimal air flow in this mode. Such wasted energy could lessen the benefits of earlier triggering of NAVA as compared with PSV. Further comparisons of those modes in terms of energy expenditure and accessory inspiratory and expiratory muscle function, particularly relevant in more severe chronic obstructive pulmonary disease, will bring further information to the field.

In conclusion, Bellani *et al.*<sup>1</sup> demonstrated that it is possible to use the diaphragmatic electrical activity recorded by the NAVA catheter to estimate auto-PEEP during assisted modes of ventilation and to assess the effect on auto-PEEP of changing external PEEP. Neuromuscular activity breeds and reveals mechanical function. This knowledge strengthens the methods for investigation and bedside practice on the important clinical goal of minimizing patients' auto-PEEP.

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