Monitoring Respiratory Drive and Respiratory Muscle Unloading during Mechanical Ventilation

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Introduction

Since Galen’s description 2000 years ago that the lungs could be inflated artificially, mechanical ventilation has become a primary intervention for life support [1]. The common indication for mechanical ventilation is respiratory failure, defined as a major abnormality in gas exchange [2]. According to Esteban et al. [3], how the assist is delivered in terms of volume and respiratory rate varies widely among centers. Recent randomized clinical trials have suggested that limitation of tidal volume reduces the risk of ventilator-induced lung injury (VILI) [4].

Given that the positive pressure ventilator solely pumps air or medical gas into the lungs (negative pressure ventilation will not be discussed), one must assume that mechanical ventilation either substitutes or partially assists the respiratory muscles’ function of inflating the lungs. If the patient is heavily sedated and/or paralyzed, the ventilator’s delivery of positive pressure substitutes the respiratory muscles, and the settings for pressure, tidal volume and respiratory rate are decided upon by the caregiver.

New evidence indicates that the practice of deep sedation has a negative impact on care and increases both the duration of hospital stay and mortality [5] (for an excellent overview see Burchardi [6]). Algorithms for sedation, therefore, increasingly favor reduced levels and daily interruption of sedation [7].

If sedation is limited, patients will likely be breathing spontaneously, involving respiratory muscle activity, and allowing tidal volumes and breathing frequency to be controlled by the patient. Intuitively, one would anticipate that the ventilator should adapt to and follow the patient’s breathing pattern. This is, however, not always the case. Poor interaction between the ventilator and the patient is commonly reported and has been suggested to increase the need for sedation [8, 9].

Respiratory Drive and Respiratory Muscle Unloading

To understand the underlying issues that cause poor patient-ventilator interaction, it is important to discuss how mechanical ventilation unloads the patient and controls respiratory drive. Unloading of the respiratory muscles is an indistinct term and several factors are involved in the process; these are discussed below.

The first aim during respiratory failure should be to reduce the underlying source that causes the increased load. For example, during acute bronchoconstriction, the aim would be to reduce airway resistance (reducing resistive load), which
would reduce dynamic hyperinflation (improves inspiratory muscle strength), and also increase compliance (reducing elastic load). Another manner in which the respiratory muscles can be unloaded is by reducing the respiratory drive with sedation and analgesia, which will reduce respiratory muscle pressure generation. To maintain adequate ventilation during sedation, an increase in the level of ventilatory assist may be necessary to compensate for the reduced patient work. Since mechanical ventilation is applied to increase ventilation, this in itself will of course reduce respiratory drive and pressure generation if it successfully reduces CO$_2$ levels. If the mechanical ventilator delivers the assist when the patient’s inspiratory muscles actively try to inhale, the mechanical ventilator can be considered an artificial inspiratory muscle, aiding the inspiratory muscles to generate sufficient ventilation.

### How Synchronous is Mechanical Ventilation?

In published clinical trials on outcome from mechanical ventilation, the differences between controlled ventilation vs partial ventilatory assist should be interpreted with caution, as it is not always stated what modes of ventilation are used or if the patient is spontaneously breathing. There have not yet been any clinical studies about the role of synchronized mechanical ventilation on patient outcome, where the assist is truly synchronized to patient effort. For example, the Cochrane review [10] on synchronized modes of mechanical ventilation does not include any quantitative index of patient ventilator interaction. In fact, the Cochrane reviewers call for evidence that modes that manufacturers refer to as ‘synchronous’ actually do provide synchronized assist.

In fact, reports on patient-ventilator interaction suggest that triggered modes of partial mechanical ventilation (e.g., pressure support ventilation) frequently are asynchronous to patient’s efforts [11], especially when assist levels are high [12–14]. Patient-ventilator asynchrony may cause the patient to ‘fight the ventilator’ increasing both inspiratory and expiratory muscle activity (e.g., [15]), as seen in Figure 1. Since poor patient-ventilator interaction is inherent to the use of pneumatic triggering and cycling-off algorithms, intuitively, improved trigger and cycling-off could resolve issues related to patient’s fighting the ventilator.

As asynchrony is usually manifested by the patient making an effort to inhale when the inhalation valve is closed or the patient is exhaling when the inhalation valve is open, it is interesting to observe how newer modes like bilevel positive airway pressure (BiPAP) and airway pressure release ventilation (APRV) overcome these shortcomings by simply not occluding the patient [16, 17]. These modes simply deliver time-cycled assist switching between two pressure levels. The patient can breathe freely during both the high and low pressure level such that one part of the minute ventilation is produced by the ventilator’s pressure cycling and one part is obtained by the patient’s spontaneous breathing [16, 17]. Evidently, the avoidance of occlusions reduces the load on the respiratory muscles. The delivery of assist with these modes is, however, not synchronized to patient effort and it is unclear how they differ from conventional (non-triggered, time-cycled) modes in terms of unloading.

Patient-ventilator asynchrony can also be manifested by the patient being passive and triggering with minimal use of the inspiratory muscles. Figure 2 shows an example of ventilator breaths that are triggered by small efforts, followed by a period of assist throughout which the diaphragm is not active. Inevitably, this pattern of