Pressure-Control Ventilation: “Primum non nocere” — Options in Limiting Pulmonary Barotrauma

The application of mechanical ventilation is a practice in which the respiratory clinician may face widely varying conditions in a patient’s pulmonary compliance. Decreased compliance in the pulmonary system can lead to significant problems in providing mechanical ventilatory support. The clinician must try to obtain a balance in obtaining acceptable ventilation and oxygenation parameters and the consequences of the needed support on the patient’s lung parenchyma. To use a famous quote credited to Hippocrates: “As to diseases, make a habit of two things — to help, or at least do no harm.”

Pressure-control ventilation is most often prescribed for patients with severe adult respiratory distress syndrome (ARDS). ARDS is initially characterized by the formation of noncardiac pulmonary edema and, in later stages, by the formation of hyaline membrane and pulmonary fibrosis. These conditions lead to reduced pulmonary compliance, progressive atelectasis, and impaired gas exchange, especially oxygenation. Since severe physiologic shunting is the cause of this hypoxemia, it does not respond well to oxygen therapy. This leads to a classic clinical hallmark of ARDS called refractory hypoxemia. This type of patient requires high peak airway inspiratory pressures to deliver preset tidal volumes in the traditional volume-control modes of ventilation. A significant problem with ARDS is that the lung is not uniformly affected. While a majority of the lung fields may have low compliance due to atelectasis, hyaline membrane formation, surfactant deficiency, and pulmonary fibrosis, other lung fields may have normal compliance. By utilizing conventional volume ventilation, the majority of the delivered tidal volume is routed to these normal compliance lung fields. This can lead to over-distension of these areas and further insult to the lung parenchyma.

RTs must always be aware of the potential harm that may be caused while providing mechanical ventilation in any situation.

Pressure-control ventilation is an alternative mode of controlled ventilation. When a patient is placed on pressure-control ventilation, the clinician sets the rate, inspiratory time, positive end-expiratory pressure (PEEP), and, most importantly, the peak airway pressure limit. The ventilator acts as a constant pressure generator, limited to a preset value set by the clinician. Once this pressure is reached, it is held at that level till a limiting
factor (such as the end of the inspiratory cycle) occurs. A major advantage in utilizing pressure-control mode is that the patient can receive as much inspiratory flow as needed. These inspiratory flows can be as high as 120 to 200 L/min, dependent on the flow-limit capabilities of the ventilator.

By limiting the delivered peak airway pressure, the clinician helps limit the pulmonary barotrauma delivered to the lung. The peak alveolar pressure, which is a major factor in ventilator-induced injury, can climb no higher than the preset pressure.

Some researchers have suggested that, due to the relationship of lung injury to hyperinflation, the term barotrauma should be replaced by the term volutrauma. These researchers feel this volutrauma is not caused by the peak airway pressure or the PEEP level but the difference found across the alveolus known as the trans-alveolar pressure. In a normal subject, a transalveolar of 30–35 cm H₂O achieves the alveolar size associated with total lung capacity. Therefore, it is not surprising to associate trauma to alveolar membranes with repeated exposure to tidal transalveolar pressures greater than 35 cm H₂O. This mechanical ventilation-induced trauma produces alveolar membranes that are susceptible to becoming permeable to water and protein.

Initial settings

When the decision is made to institute pressure-control ventilation, many important clinical decisions must be made to ensure the new ventilator settings are not doing more harm than good. When pressure-control ventilation is instituted, the clinician must set the maximal delivered peak pressure, PEEP level, inspiratory time, and rate. Remember that in pressure-control ventilation, delivered tidal volume, minute volume, and alveolar ventilation is a product of the set peak pressure, inspiratory time, and compliance of the respiratory system. Determining the correct initial set peak pressure when converting to pressure-control ventilation from volume-control ventilation can be a challenge; the clinician must try to use a set peak pressure that will deliver approximately the same tidal volume that was being delivered during volume ventilation. This peak pressure level can be calculated by determining the difference in pressure between the end inspiratory plateau pressure and the set PEEP level during a volume-controlled breath. As stated earlier, set peak pressures greater than 35 cm H₂O should be avoided if possible to help decrease insult to the alveolar membranes.

Due to the heterogenous nature of the lung injury seen in ARDS, a minimal level of PEEP needs to be applied to prevent tidal end expiratory collapse of the edematous airway tissue. When this tissue collapses, there is a decrease in respiratory system compliance; and distinct points of inflection are noted on the static pressure volume curve. Application of PEEP levels above this lower point of inflection on the pressure volume curve known as the “Pflex” is thought to be beneficial, but determining an accurate value for the deflection point has been reported as imprecise when estimating it off static pressure volume curves.³ Providing this minimal level of PEEP support, it is felt, prevents the recurring process of alveolar tidal recruitment and subsequent collapse. It is also felt that this minimal PEEP level may help limit progressive microatelectasis and inactivation of surfactant.⁴ A minimum level of 7–12 cm H₂O has been suggested as a good starting point. If higher levels of PEEP are implemented, it is recommended that a pulmonary artery catheter be placed so that cardiac function may be accurately assessed.
The next parameter that is vital in determining delivered tidal volume is the set inspiratory time. A lot of the literature on pressure-control ventilation concerns the use of prolonged inspiratory times and inverse inspiratory-to-expiratory-time ratios (I:E). This facet of pressure-control ventilation helps increase delivered mean airway pressure ($P_{aw}$) and helps improve oxygenation.\(^5\) The downside to this is that it is very uncomfortable for the patient. Most have to be sedated and paralyzed in order to maximize the benefits.

The possible need for prolonged pharmacological paralysis can have severe long-term consequences, almost as severe as ARDS itself.

I had the privilege of hearing a lecture by Marshall L. Post, RRT, about pressure-control ventilation at the AARC International Respiratory Congress in New Orleans in 1997. In his lecture he described how he and his staff used graphics to optimize the set inspiratory time. By using this real-time diagnostic tool, they were able to maximize the set inspiratory time and delivered tidal volume without developing auto-PEEP. The set respiratory rate and inspiratory time were manipulated to allow both inspiratory and expiratory flow to reach baseline. It allowed them to pressure ventilate the patient without subjecting the patient to the possible long-term harm that could have been caused by prolonged paralysis and sedation.

Newer-generation ventilators now offer a combination of pressure-control and volume-control modes of ventilation. In this combined pressure-control volume-regulated mode, the delivered peak pressure is limited; but a set tidal volume and minute volume can be delivered. Then, even if compliance changes, set minute ventilation is guaranteed and peak pressure is limited.

For those of you who have read this article and have wondered what the phrase “primum non nocere” means, it is a tenet credited to Hippocrates and used in the Hippocratic oath. It means, “First Do No Harm.” We as respiratory clinicians must always be aware of the potential harm that may be caused while providing mechanical ventilation in any situation.

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REFERENCES
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