**Setting the Tidal Volume In Adults Receiving Mechanical Ventilation:
Lessons Learned From Recent Investigations**

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Introduction
Selecting the optimum tidal volume for adult patients on ventilatory support is critical to achieving the best clinical outcomes. Over the years, guidelines about tidal volumes have varied including times when sigh breaths were set to prevent the development of atelectasis. The purpose of this article is to describe the transition that examination committees have made over the last several years in which lung protection has become the primary goal when making decisions about mechanical ventilation.

Ventilator Induced Lung Injury
Since the introduction of mechanical ventilatory support over 60 years ago, there has been an increasing body of evidence that this form of potentially life-saving support, may also be the source of further lung damage and have potential deleterious impact outside of the respiratory system.(1,2) Studies in a variety of experimental animals, using large tidal volumes and/or high inflation pressures demonstrated physiologic and pathologic changes similar to the diffuse alveolar damage seen in the acute respiratory distress syndrome, which was termed ventilator induced lung injury.(1) The comparable scenario in humans was termed ventilator associated lung injury by an international consensus conference.(3) The primary insult was overstretching the alveolus, either by large tidal volumes or excessive inspiratory plateau pressures (>30 cmH$_2$O) and was termed volutrauma and barotrauma, respectively.(2) In addition, the realization that systemic injury could also result from the elaboration of various inflammatory molecules, including reactive oxygen radicals and/or the translocation of bacteria or air into the systemic circulation to invoke a systemic inflammatory response was recognized as a potential cause of biotrauma.(2) The application of positive end-expiratory pressure (PEEP) was found to be protective in a number of experimental circumstances and could also prevent the shear stress injury associated with repetitive recruitment-derecruitment (termed atelectotrauma).(2)

The concept of ventilator associated lung injury, or specifically damage from alveolar over-distention by large tidal volumes and/or elevated end-inspiratory plateau pressures challenged the common conventional ventilatory support practice of setting tidal volumes at 10-15 mL/kg measured body weight with a goal of achieving "normal values for acid base status, P$_a$O$_2$, and P$_a$CO$_2$. Recognition of this relationship gave rise to clinical investigations designed to evaluate whether outcome could be improved by limiting the potential for ventilator associated lung injury and using a lung protective ventilatory support strategy employing a smaller tidal volume and paying close attention to keeping the end-inspiratory plateau pressure under 30 cmH$_2$O.(4-8) Adopting the lung protective strategy would have to compromise the prior goals of ventilatory support. Primary emphasis is on maintaining adequate oxygenation, while accepting an increase in P$_a$CO$_2$ and resultant respiratory acidosis, as a consequence of the controlled hypoventilation or permissive hypercapnia.(4) This ventilatory support strategy had been utilized with obstructive airway disease to avoid dynamic hyperinflation and high levels of occult PEEP and resulted in improved outcomes compared to conventional ventilatory support.(9) In experimental models of lung injury there is evidence of

decreased inflammation and lung water as a consequence of "therapeutic" hypercapnia.(10)

Clinical Trials in ALI and ARDS

The adoption of lung protective ventilation strategies by clinicians was slowed by conflicting results from different studies that were published between 1994 and 1999. Hickling (4) and Amato (5) demonstrated improved survival while limiting tidal volume and inspiratory pressure. However, Brochard (7) and Brower (8) found no difference in outcome could be associated with similar ventilation strategies although Brower expressed concern that the study sample may have been too small, which could have underpowered statistical analyses. Finally, the seminal work of the ARDS network established by the National Heart Lung and Blood Institute of the National Institute of Health published the results of a large, prospective, multicentered trial of lung protective ventilatory support using tidal volumes of 6 mL/kg ideal body weight and end-inspiratory plateau pressures < 30 cm H2O vs 12 mL/kg ideal body weight and plateau pressure < 50 cm H2O in 861 patients with acute lung injury or ARDS.(11) The trial was stopped early because of the impact on mortality. The large tidal volume group had significantly higher mortality (39.8% vs 31.0%) and significantly fewer days of being alive and off of ventilatory support.(11) The beneficial response was noted in ARDS from various risk factors.(12)

Subsequent network studies evaluated the benefits of higher and lower PEEP support, conservative vs liberal fluid management, guidance of therapy based on central venous catheters vs PA catheters, and continued to support the concept of providing lung protective ventilatory support to improve patient outcome.(13-15) Implementing lung protective ventilatory support for ARDS patients was also reported by other centers as a way to improve survival compared to historical controls.(16) These results changed the standard of care for ventilatory support for patients with ARDS and extended the concept of lung protective ventilatory support as the guiding principle for all forms of ventilatory support. The paradigm governing ventilatory support also switched from one of normalizing arterial blood gas results to one of maintaining "adequate oxygenation" and providing lung protection.

Lung Protection for Everyone

The concept of protecting the lung from harm and from additional systemic insult by employing a lung protective ventilatory support strategy spread into other clinical scenarios. A meta-analysis published in 2009 concluded that low tidal volume ventilation was beneficial for patients with acute lung injury and ARDS.(17) In addition to the mortality benefits of lung protective ventilatory support, a meta-analysis of 20 publications (over 2800 patients) found that the low tidal volume strategy was associated with decreased pulmonary infections and shorter hospital length of stay, despite the associated increase in P_aCO_2 and decrease in pH.(18) Using lung protective ventilation in 400 patients undergoing abdominal surgery who were judged to be at intermediate and high risk for developing post operative pulmonary complications resulted in significantly less major pulmonary and extra-pulmonary complications in the first 7 days post surgery with the use of lung protective ventilation.(19) In addition, the

lung protective ventilation group had less need for noninvasive ventilatory support , less need for invasive or noninvasive ventilatory support in the 30 day follow up period, and a shorter hospital stay. These findings have led some editorialists to suggest "low tidal volumes for all?"(20) Dr. Ferguson goes on to conclude that "in the ICU the ventilator should be set to a target tidal volume of 6-8 mL/kg in most patients receiving mechanical ventilation".(20) If a patient's spontaneous efforts result in a larger tidal volume than the volume provided by mandatory breaths, should sedation or even paralytic agents be administered?" (20) This question sets the stage for future controversies.

Determining Ideal or Predicted Body Weight

As mentioned previously, the new paradigm is to use ideal body weight as opposed to actual patient weight. The ideal body weight is based on height as lung volume does not change based on gaining or losing weight. Ideal body weight is determined by a calculation by gender and height. The candidate is expected to know these formulas for calculating the ideal or predicted body weight in Kg.

Male: 50 + (0.91) [height (cm) – 152.4] or 50 + 2.3[height (inches) – 60]
Female: 45.5 + (0.91) [height (cm) – 152.4] or 45.5 + 2.3[height (inches) – 60]

Controversy for the Future

Recognizing the concepts of lung protective ventilatory support has given rise to debate over the potential of tidal volumes over 6-8 mL/kg to produce lung injury, even in the setting of low inflation pressures and/or spontaneous breathing efforts. Debates have been conducted to find agreement as to whether the stress response of a large tidal volume is equivalent in a normal versus an unhealthy lung. There is speculation whether a large volumes supported by low levels of pressure support will produce the negative outcomes that were described above. (21,22) Discussants have argued over the importance of volume vs pressure for alveolar overdistention and the stress forces in the lung.(21,22) Dr. Gattinoni argues that the ideal tidal volume for a patient should be determined by measuring the lung volume and transpulmonary pressure (which is impractical in the critically ill patient).(22)

Summary

The convention of providing tidal volumes of 10 to 15 mL/kg of actual body weight regardless of airway pressure and aiming for normalization of arterial blood gases has been replaced by a new paradigm of lung protective ventilatory support. The maximum tidal volume has been dropped to 8 ml per kilogram ideal or predicted body weight based on the patient's height and sex. Lung protection also places an equal importance on maintaining an end-inspiratory plateau pressure ≤ 30 cm H2O to avoid alveolar overdistention and lowering the targeted tidal volume below 8 ml/kg if that pressure is exceeded. In the setting of ARDS, PEEP plays a therapeutic role in decreasing the potential for recruitment-derecruitment injury (atelectotrauma). Controversy continues as to whether increased tidal volumes or increased inflation pressures pose the greatest risk for lung injury and whether pressure controlled or volume controlled modes of ventilation offer distinct benefits. The jury is still out on this question, but the verdict is

clearly one in favor of using lung protective ventilatory support. For now the goal of lung protection with set tidal volumes of 6-8 mL/kg ideal body weight seems to fit the right answer for just about everyone, but there will likely be refinements in the future.

A candidate taking an NBRC examination should look for opportunities to use a lung protective strategy by delivering tidal volumes of no more than 8 mL/kg, holding plateau airway pressures below 30 cmH_2O, and including an appropriate PEEP level. If blood gases can be normalized at the same time, then do so. However, doing so is secondary to the volume and pressure limits. NBRC examination committees have migrated test content to follow these guidelines over the last several years. Our purpose in writing this article was to document this fact so that educators can be confident about guiding students' learning in this area.

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