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Lung Protective Ventilator Strategies: Beyond Scaling Tidal Volumes to Ideal Lung Size*

Neil R. MacIntyre, MD
Department of Respiratory Care
Duke University Medical Center
Durham, NC

Over the past three decades, our understanding of alveolar injury induced by tidal and end-inspiratory overstretching forces from mechanical ventilators has grown dramatically. The simple concept of excessive tidal volumes (referenced to ideal lung size) and excessive end inspiratory airway pressures (plateau pressures or P_{plat} >30 cm H_2O) being the major determinants of overstretch injury has been enhanced by at least two important developments. First has been an awareness that transpulmonary pressure (TPP = alveolar pressure minus pleural pressure) is a more appropriate reflection of alveolar stretch (1). Thus, a P_{plat} that seems excessive may, in fact, be acceptable if global pleural pressures are high (a consequently low TPP). Second has been the appreciation that global effects may not be reflective of regional effects. Specifically, in heterogeneous lung injury, the distribution of delivered tidal volume (VT) may result in poor/absent volume delivery to diseased units and produce overstretching in healthier units (2). Simply scaling delivered tidal volume to an ideal lung size (i.e. , reflected by ideal body weight [IBW]) does not take this into account. Thus, a "normal" tidal volume (e.g., 6 mL/kg IBW) may be excessive in heterogeneous lung injury where the lung units with the best mechanics receive the bulk of the tidal breath resulting in regional overstretch injury.

These concepts are changing our way of managing patients on mechanical ventilators. No longer is the P_{plat} necessarily the upper threshold for injury—instead, the TPP at end inspiration is being considered the appropriate parameter to reflect potential overstretch injury. Ideally, esophageal pressure measurements (P_{es} is an approximation of P_{pl}) should be used to calculate an end inspiratory TPP (P_{plat}–P_{es}) (1). Unfortunately, esophageal manometry is technically challenging and is rarely used clinically. Nevertheless, clinicians are increasingly aware of the concept of TPP and often empirically adjust their upper P_{plat} limits accordingly in patients with known processes that elevate P_{pl} (e.g., anasarca, obesity, and abdominal compartment syndrome). The approach to VT settings is also changing. Simply scaling the tidal volume on an ideal lung size (i.e., VT/kg IBW) has increasingly been challenged as inappropriate. Specifically, many investigators, primarily using visual techniques such as CT scans, have described the "baby lung" concept of functional lung volume in diffuse lung injury (3, 4). They have argued that measurements of actual functional lung volume, which take into account the heterogeneous loss of lung tissue in lung injury, would be a more appropriate scaling factor for VT than for ideal lung volume

In this issue of *Critical Care Medicine*, Beitler et al (5) address these concepts through a re-analysis of data obtained in a study of positive end-expiratory pressure interactions with respiratory system mechanics (6). Forty two of the subjects in this study had simultaneous measurements of volume, airway pressure, and esophageal pressures during a recruitment maneuver (RM) at a pressure of 40 cm H_2O for 30 seconds. These RMs produced an average maximal TPP of 21 cm H_2O and were thus a rational upper physiologic limit. The volume delivered during the RM (V_{RM}) was used as an index of lung volume potentially available for ventilation (functional or recruitable lung volume). All of these subjects were ventilated with tidal volumes targeted to an ideal lung size with an average of 7.6 mL/kg IBW.

Two endpoints in this study were mechanical indicators of excessive end-inspiratory global stress (TPP at end inspiration) and tidal stress (TPP change over the tidal breath). Although there is some controversy about the interpretation of TPP changes over a tidal breath (7), the end-inspiratory TPP is certainly a reasonable reflection of end inspiratory global stress and stretch. Not surprisingly, low values for V_{RM} reflected poor respiratory system compliance (C_{rs}) and high end inspiratory lung stress. Furthermore, low values for V_{RM} were also associated with increased mortality. Importantly, low values for V_{RM} when coupled with tidal volumes scaled to IBW produced high values for VT/V_{RM}, which were found to be more predictive of end inspiratory lung stress than either VT/kg IBW or VT/C_{rs}.

*See also p. 91.

Key Words: recruitment maneuvers; tidal volumes; transpulmonary pressure; ventilator induced lung injury

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These results are consistent with other studies suggesting benefit to scaling tidal volumes to functional lung size rather than ideal lung size. Chiumello et al (8) have argued that functional lung size should be measured directly (gas dilution or other methods to determine functional residual capacity [FRC]), and tidal volume should be scaled accordingly as V_T/FRC. Amato et al (9) in a re-analysis of several large trials evaluating positive end-expiratory pressure protocols in patients with acute respiratory distress syndrome suggested that scaling the V_T to respiratory system compliance C_{rs} would be a useful indirect way to incorporate functional lung size into the tidal volume selection (smaller functional lung equals worse C_{rs}). They expressed this as a driving pressure ($DP = V_T/C_{rs}$) and found it to be more closely linked to a mortality outcome than P_{plat} or V_T/kg IBW.

That all of these analytic approaches seem superior to V_T/kg IBW should not be surprising. Whether it be V_T/FRC, V_T/C_{rs}, or V_T/V_{RM}, all are using a more physiologically sound denominator or scaling factor reflective of the functional lung available for safe ventilation. It is probably time to re-think our tidal volume strategies for these patients. Limiting regional overstretch injury—both end inspiratory and tidal—likely requires tidal breaths scaled to actual rather than ideal lung size. Which method is best adapted to the bedside remains to be determined. In the meantime, clinicians would be wise to lower their 6 mL/kg IBW settings in the setting of very noncompliant lungs with visual evidence of "baby lungs." Although the acute respiratory distress syndrome network rules (10) tends to recognize this by recommending dropping V_T when P_{plat} approaches 30 cm H_2O, perhaps this ought to be considered at P_{plat} in the 25 cm H_2O or lower range or when these newer ways to scale V_T suggest excessive tidal volume delivery.

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