

# High-frequency oscillation: How high should we go?\*

In patients with acute lung injury, mechanical ventilation with lower tidal volumes has been shown to decrease mortality, minimizing ventilator-induced lung injury by reducing tidal alveolar over-distension (*volutrauma*) (1). This *biotrauma* of ventilator-induced lung injury may also be added to by repetitive alveolar opening and closing (*atelectrauma*), although the clinical importance of this remains controversial (2–4). Advances in patient outcomes have certainly been made using conventional mechanical ventilation; alternative strategies, such as prone positioning and/or high-frequency oscillation (HFO), might provide still further improvement.

HFO is a relatively new ventilatory mode to the adult intensive care unit (ICU), although it has been used in neonatal and pediatric settings for close to 20 yrs. Data from several case series and two randomized trials strongly suggest that HFO is safe and effective as rescue therapy, improving oxygenation in patients with acute respiratory distress syndrome (ARDS) who have failed conventional strategies (5–9). However, another reason for enthusiasm over the introduction of adult HFO is that this ventilator is theoretically ideal for minimizing ventilator-induced lung injury, targeting prevention of both volutrauma and atelectrauma. During HFO, pressure oscillations are delivered with high frequency around a relatively constant mean airway pressure, providing very small tidal volumes. This could allow clinicians to use higher pressures to open and maintain aerated lung volume, while simultaneously avoiding tidal hyperinflation.

Tidal volumes with HFO have been previously shown to be inversely related to frequency (10). With frequencies ap-

plied in the neonatal ICU (10–15 Hz), delivered tidal volumes are very small. When HFO was introduced into the adult ICU, lower frequencies (3–6 Hz) were recommended to facilitate gas exchange, with the assumption that delivered tidal volumes would still be small. Importantly, however, the currently available adult HFO ventilator does not provide monitoring capabilities for tidal volume.

The size and safety of tidal volumes delivered with adult HFO settings were first called into question by Sedek and co-workers (11), who studied them in an ovine model of lung injury. At high levels of pressure amplitude and lower frequencies (4 Hz), they measured potentially concerning tidal volumes of approximately 4 mL/kg using an inline pneumotachograph. The article by Dr. Hager and colleagues (12), published in this issue of *Critical Care Medicine*, is, therefore, a welcome next step in this line of investigation.

These investigators systematically studied the effects of six different HFO parameters on the magnitude of tidal volumes delivered to a test lung, as measured using a hotwire anemometer, a technique they previously validated for this purpose (13). Of more immediate clinical relevance, they also examined the effect of changes in frequency and pressure amplitude on the tidal volumes delivered to seven adult patients with ARDS during HFO (12).

In both the test lung and in patients, tidal volumes showed significant variability across the different ventilator settings. Overall, however, the magnitude of delivered tidal volumes was generally small and usually less than the anatomical dead space. Indeed, in many of the patients assessed, baseline tidal volume approached 1 mL/kg predicted body weight. Therefore, one of our conclusions from this study is that it is, indeed, possible and feasible to deliver very small tidal volumes to adults using HFO.

The parameter that had the greatest effect on tidal volume was frequency. It is important to note that in patients receiving the lowest frequencies (3–4 Hz), tidal volumes were not negligible in the ranges

of 210 mL or 3.3 mL/kg predicted body weight. In our point above, notwithstanding, this suggests that it is also possible to deliver tidal volumes that are larger than anatomical dead space, which may be large enough to contribute to cyclic tidal over-distension of alveoli.

Although it might be ideal for critical care clinicians to be able to monitor tidal volumes at the bedside during HFO, this is not currently feasible. The ventilator itself does not have this capability, and the monitoring system used by Dr. Hager and colleagues (hotwire anemometer) is expensive, requires calibration, and is likely too complex to be implemented at the bedside of each patient receiving HFO (13).

Regardless of our ability to measure tidal volume directly in adults receiving HFO, the results of this study suggest that we should be cognizant of the need to minimize tidal volumes delivered with this device. This reinforces the concept that the manner in which a tool (or ventilator mode) is used is as important, if not more so, than the choice of tool (or mode) itself. We believe that clinicians using HFO should do so while utilizing the highest frequency possible that still achieves acceptable ventilation and arterial pH, taking advantage of the alternative mechanisms of gas exchange as much as possible (14, 15).

The study by Dr. Hager and colleagues (12) has limitations, as acknowledged by the authors in their discussion. Most notably, translating findings from the relatively simple test lung system to adults with ARDS may be problematic. In addition, it is important to recognize that all of the patients studied had been stabilized or were already improving on HFO; they were not in the throes of a “rescue” attempt. Nevertheless, although it may not be as easy or feasible to achieve these high frequencies in these sicker patients, we believe that the same physiologic principles apply. Delivering the lowest tidal volume possible is of most importance in patients who are receiving the highest mean airway pressures, as they are at most risk of tidal over-distension.

\*See also p. 1522.

Key Words: high-frequency oscillation; acute respiratory distress syndrome; tidal volume; mechanical ventilation

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In conclusion, whereas HFO should at present remain a rescue ventilation strategy in routine clinical use, it can also be considered a method to be applied early in ARDS to reduce ventilator-induced lung injury. At the current time, the latter represents a research hypothesis built on a strong physiologic foundation, which will be addressed in future clinical trials. Both in these future studies and in our clinical use today, we should use our increasing understanding of the physiology of HFO in adults to deliver the most lung-protective strategy possible, one component of which should be a very low tidal volume.

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# Endotracheal tube cuff leak: Can optimum management of cuff pressure prevent pneumonia?\*

One of the most well-established mechanisms of pneumonia in the intensive care unit (ICU) environment is oropharyngeal bacterial colonization and

silent aspiration of subglottic secretions around the endotracheal tube (ETT) cuff (1). As a result of this targeted mechanism, intensivists came up with various approaches for the prevention of pneumonia, such as head-of-the-bed (HOB) elevation, (2) subglottic continuous suctioning of secretions above the ETT cuff, (3) oropharyngeal decontamination by antiseptics, (4) and the application of antiseptic-impregnated endotracheal tubes (5). Within the proposed mechanistic pathway, aspiration of colonized oropharyngeal and subglottic secretions appear as the key element. Thus, perfect control of ETT cuff pressure may serve as the main prevention target. Controlling the ETT cuff by high volume or pressure would have been an easy solution to the problem, but high pressures threaten mucosal perfusion

and integrity (6, 7). ETT cuff pressure was recommended to be managed within 20–30 cm H<sub>2</sub>O to provide a sufficient seal without compromising mucosal perfusion (8).

In this issue of *Critical Care Medicine*, Dr. Valencia and colleagues (9) present a randomized controlled trial in which they assess the efficacy of an automatic ETT cuff pressure control device to optimize cuff pressures and to prevent pneumonia formation. It is an elegantly designed study around a simple preventive idea. In this study, investigators could control the ETT cuff pressures at the target range (20–30 cm H<sub>2</sub>O) in approximately 80% of the treatment group patients. Only 0.7% of the treatment group patients had cuff pressures <20 cm H<sub>2</sub>O compared with approximately 45% in the control group. This might mean that

\*See also p. 1543.

Key Words: ventilator-associated pneumonia; endotracheal tube; oropharyngeal; subglottic secretion; aspiration; antiseptic; chlorhexidine; semirecumbent; tracheo-bronchitis

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