High-Frequency Oscillatory Ventilation as a Rescue Therapy for Adult Trauma Patients

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Background
High-frequency oscillatory ventilation is an alternative ventilation mode that improves oxygenation in trauma patients in whom conventional ventilation strategies have been unsuccessful.

Objective
To evaluate the effect of high-frequency oscillatory ventilation on oxygenation, survival, and parameters predictive of survival in trauma patients.

Methods
A retrospective case series of 24 adult patients admitted to the trauma intensive care unit at a level I trauma center between November 2001 and July 2005 and treated with high-frequency oscillatory ventilation. Survivors and nonsurvivors were compared for mechanism and severity of injury, oxygenation parameters related to high-frequency oscillatory ventilation, and hospital course.

Results
Of the 8577 patients admitted during the study period, acute respiratory distress syndrome developed in 103 (1%). Of those 103 patients, 24 (23%) were treated with high-frequency oscillatory ventilation. Most of the patients treated with high-frequency oscillatory ventilation had sustained blunt trauma (79%). Oxygenation parameters improved significantly with high-frequency oscillatory ventilation in all patients, regardless of survival. Of the 24 patients treated with this ventilation mode, 15 (62%) survived. Survival did not correlate with improved oxygenation parameters but with the number of failed organ systems and injury severity.

Conclusion
Although high-frequency oscillatory ventilation improves oxygenation, severity of traumatic injury and organ failure, not respiratory parameters, are predictors of survival. High-frequency oscillatory ventilation should be considered for pulmonary rescue of severely injured patients with acute respiratory distress syndrome. (American Journal of Critical Care. 2009;18:144-148)
Acute respiratory distress syndrome (ARDS) remains a difficult problem in patients with severe traumatic injury. With reliable data indicating that reduced mortality is associated with lower tidal volumes, and experimental evidence supporting a ventilator-induced lung injury pathway as a source of inflammatory mediators contributing to the systemic inflammatory response syndrome, our trauma intensive care unit has emphasized lung-protective strategies in patients receiving mechanical ventilation. A subpopulation of severely injured patients, however, experience progressive pulmonary deterioration despite maximal conventional ventilator management that includes lung protection.

When faced with this difficult situation, we have used high-frequency oscillatory ventilation (HFOV) as a rescue maneuver to improve oxygenation while maintaining a lung protective strategy. HFOV provides high levels of mean airway pressure that result in lung recruitment and "open lung" ventilation. Although data on use of HFOV in neonates is plentiful, only a few descriptions of its use in adults and in traumatically injured patients have been published. We have reviewed our experience with HFOV in adult trauma patients to better characterize the population of patients treated with HFOV and the effects of HFOV on survival.

**Methods**

Our records were reviewed from November 2001 to July 2005 to identify adult trauma patients with ARDS who required HFOV. ARDS was defined as a ratio of $\frac{PaO_2}{FIO_2}$ to fraction of inspired oxygen that was 200 or less, the presence of pulmonary infiltrates, and a pulmonary artery occlusion pressure less than 18 mm Hg. Although the timing and criteria for initiation of HFOV were at the discretion of the attending trauma surgeon, our practice is a group-based practice with daily discussions of all patients and similar practice patterns among the members of the group. HFOV was instituted when standard ventilation resulted in progressive hypoxia in patients with peak inspiratory pressures exceeding 35 cm H$_2$O and positive end-expiratory pressures greater than 12 cm H$_2$O. Peak inspiratory pressures of 40 cm H$_2$O are related to lung injury, so pressures close to this level were avoided by changing ventilatory modes to HFOV when peak pressures consistently greater than 35 cm H$_2$O were reached.

Abdominal compartment syndrome is an important confounding variable in trauma patients. It is our practice to measure compartment pressures in all patients with elevated peak pressures and risk factors for compartment syndrome (abdominal surgery and/or volume of resuscitation ≥5 L). The abdomen is surgically decompressed in patients with the clinical triad of abdominal compartment syndrome (high peak ventilator pressures, oliguria, and hypotension) and abdominal pressures of 20 mm H$_2$O or in patients with an incomplete triad and pressures of 40 mm H$_2$O.

Oxygenation parameters were recorded immediately before HFOV and after initiation of HFOV (first blood gas determination, usually at 2 hours). Transition from HFOV to conventional ventilation occurred when the mean airway pressure had been lowered to less than 24 cm H$_2$O, with adequate oxygenation at a fraction of inspired oxygen of less than 0.50. Demographics and injury parameters, including abbreviated injury score, revised trauma score, injury severity score, and trauma-related injury severity score were recorded. Statistical analysis was completed with analysis of variance, paired $t$ test, and $\chi^2$ analysis, with statistical significance set at $P<.05$. An HFOV outcome assessment (futility score) was retrospectively completed for each patient to assess the utility of the assessment in trauma patients.

**Results**

A total of 8577 patients were admitted to the trauma service between November 2001 and July 2005, with 2456 of these patients (29%) admitted...
with HFOV; of these, 18 were male (75%), with a mean age of 28 years (range, 16-61 years). Injury mechanisms were blunt in 19 cases (79%) and penetrating in 5 cases (21%). Among the patients treated with HFOV, a source of infection could be attributed to the development of ARDS in 9 patients (38%), including ventilator-associated pneumonia in 5 patients, urinary tract infection in 3 patients, and catheter infection in 1 patient. A total of 7 patients (29%) had documented septic shock, and 14 patients required management of an open abdomen.

The mean day of initiation of HFOV was hospital day 7 (range, 0-14 days). Significant improvement in oxygenation was achieved with HFOV (Table 1). Improvement in oxygenation was seen within 1 or 2 hours of initiation of HFOV and continued throughout the use of HFOV. One patient had clinically significant worsening of oxygenation after return to conventional ventilation and required an additional course of HFOV (not included in this analysis); this patient eventually died.

Lengths of stay in the hospital and in the ICU were not influenced by HFOV but were determined by patient survival (Table 2). Patients received HFOV for a mean of 5 days (range, 1-18 days). Two patients had HFOV stopped earlier than clinically indicated because of the need for transport and 1 because of mechanical failure of the ventilator. A total of 15 patients (62%) ultimately survived their injuries to leave the hospital, and 9 patients (38%) did not. All 9 deaths occurred in patients with injuries due to blunt trauma. The duration of HFOV did not differ significantly between survivors and nonsurvivors (5.6 vs 4.1 days). Upon return to conventional ventilation, 11 survivors (73%) required tracheostomy. The total days of ventilation, total ICU days, and total hospital days were significantly longer in the survivors than in the nonsurvivors.

Survival does not appear to be influenced by use of HFOV, but remains dependent on the extent of initial injury, as indicated by the significant differences between survivors and nonsurvivors in injury severity score, number of failed organ systems, and trauma-related injury severity score (Table 3). Scores calculated for the HFOV outcome assessment did not differ significantly between survivors and nonsurvivors. Adjunctive oxygenation therapies used during HFOV included nitric oxide (1 patient) and prone positioning with nitric oxide (1 patient). No complications were attributed directly to the oscillating ventilator. Therapy was discontinued in 2 patients for transportation reasons and in 1 patient because of ventilator malfunction. Similar conditions have occurred with standard ventilation; specifically,
the need to change the ventilator or mode because of mechanical malfunction or transportation requirements. We routinely use transport ventilators for critically ill patients, but these ventilators have limited modes available, a situation that leads to transient changes in mode during transportation.

Discussion

Our HFOV experience encompasses patients with a wide spectrum of blunt and penetrating trauma. The purpose of our review was to identify the subset of patients in whom HFOV was used and to assess the utility of the practice. Nearly all reported experience with HFOV in adults has come from patients in medical and surgical intensive care units. In these groups, a preponderance of data supports the finding that HFOV improves oxygenation parameters better than conventional ventilation does in patients with ARDS culminating in oxygenation failure.4,7

Unfortunately, improved oxygenation has not significantly improved survival rates. In a recent randomized controlled trial,7 30-day survival did not differ significantly between patients treated with conventional mechanical ventilation and those treated with HFOV, although a trend in favor of HFOV was noted. Studies of sufficient size to show a significant improvement in survival in patients treated with HFOV have yet to be performed.8 Results of other studies suggest that early use of HFOV may improve survival rates, but our experience does not suggest any significant difference in outcome according to the day of initiation of HFOV in trauma patients. HFOV is also a safe alternative to conventional ventilation, with no significant complications outside of pneumothorax in the medical and surgical patients.8,9

To date, little experience with HFOV in adult trauma patients has been reported. Salim et al10 described 10 patients with traumatic brain injury and ARDS who were treated with HFOV; in those patients, not only did oxygenation parameters improve, but intracranial pressure decreased. Mortality was only 10%, much less than predicted on the basis of the injury severity score, suggesting that HFOV may offer a survival benefit to patients with traumatic brain injuries. The design of the study, however, did not allow any conclusive analysis of outcome.10 Use of HFOV as rescue therapy for burn patients with severe ARDS has also been explored. According to an initial report11 on 6 burn patients in whom HFOV was used as rescue therapy for oxygenation failure, rapid and significant improvement in oxygenation occurred. Although 5 of 6 patients died, none of the deaths were due to failure to oxygenate.11 An exception in burn patients appears to be patients with inhalation injury. These patients had only limited and significantly delayed improvements in oxygenation compared with burn patients without inhalation injury.12

No data are currently available on the utility of the HFOV outcome assessment tool in adults with traumatic injuries. In our limited experience, we found no significant difference in outcome score between survivors and nonsurvivors. The mean score in each group fell within the moderate anticipated mortality bracket, suggesting that the HFOV outcome assessment tool is not reliable in trauma patients.

Although HFOV offers no clear survival benefit in adult trauma patients, the length of survival was clearly increased in patients treated with HFOV, as indicated by the mean days in the intensive care unit and in the hospital. This increase also translates to an increase in resource utilization, but it is impossible to determine prospectively which patients will eventually survive. By increasing oxygenation and by “buying time,” some patients may recover sufficiently to be eventual survivors and have neurological function preserved. Hence, use of HFOV is a reasonable maneuver to attempt in trying to sustain an extremely ill patient.

Conclusion

High-frequency ventilation is a safe alternative ventilation strategy that should be considered as a rescue therapy for oxygenation failure in severely injured patients with ARDS. Survival, however, is related to the extent of initial injury and is unlikely to be affected by the use of HFOV.

REFERENCES


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