High Tidal Volume Decreases Adult Respiratory Distress Syndrome, Atelectasis, and Ventilator Days Compared with Low Tidal Volume in Pediatric Burned Patients with Inhalation Injury

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BACKGROUND: Inhalation injury, which is among the causes of acute lung injury and acute respiratory distress syndrome (ARDS), continues to represent a significant source of mortality in burned patients. Inhalation injury often requires mechanical ventilation, but the ideal tidal volume strategy is not clearly defined in burned pediatric patients. The aim of this study was to determine the effects of low and high tidal volume on the number of ventilator days, ventilation pressures, and incidence of atelectasis, pneumonia, and ARDS in pediatric burned patients with inhalation injury within 1 year post burn injury.

METHODS: From 1986 to 2014, inhalation injury was diagnosed by bronchoscopy in pediatric burned patients ($n = 932$). Patients were divided into 3 groups: unventilated ($n = 241$), high tidal volume (HTV, 15 ± 3 mL/kg, $n = 190$), and low tidal volume (LTV, 9 ± 3 mL/kg, $n = 501$).

RESULTS: High tidal volume was associated with significantly decreased ventilator days ($p < 0.005$) and maximum positive end expiratory pressure ($p < 0.0001$) and significantly increased maximum peak inspiratory pressure ($p < 0.02$) and plateau pressure ($p < 0.02$) compared with those in patients with LTV. The incidence of atelectasis ($p < 0.0001$) and ARDS ($p < 0.02$) was significantly decreased with HTV compared with LTV. However, the incidence of pneumothorax was significantly increased in the HTV group compared with the LTV group ($p < 0.03$).

CONCLUSIONS: High tidal volume significantly decreases ventilator days and the incidence of both atelectasis and ARDS compared with low tidal volume in pediatric burned patients with inhalation injury. Therefore, the use of HTV may interrupt sequences leading to lung injury in our patient population. (J Am Coll Surg 2015;220:570–578. © 2015 by the American College of Surgeons)

Approximately 1.25 million individuals in the United States suffer from thermal injury, which results in 3,400 deaths each year.[1] Approximately 23,000 of these burned patients suffer concomitant injury from smoke inhalation. Despite advances in critical care and wound management, inhalation injury remains a major source of mortality and morbidity in burn patients.[2,3] A recent 10-year review from the National Burn Repository documents that mortality was greater for burned patients with inhalation injury (27.3%) than for those without inhalation injury (4.5%). Additionally, the incidence of inhalation injury along with pneumonia increased the probability of death by 60% in burned patients.[4]

Inhalation injury is associated with the formation of casts in the airway and the reduction of surfactant in the alveoli.[5,6] The pathophysiology of inhalation injury may

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Abbreviations and Acronyms

ALI	=	acute lung injury
HTV	=	high tidal volume
LTV	=	low tidal volume
PEEP	=	positive end-expiratory pressures
PaO_2:FiO_2	=	partial pressure of oxygen to fraction inspired of oxygen
PIP	=	peak inspiratory pressures
TBSA	=	total burned surface area

also cause decreased pulmonary compliance and increased airway resistance, which often necessitates mechanical ventilation. Often, severe inhalation injury results in acute lung injury (ALI), which frequently develops into ARDS in burned patients.[7] The ARDS is associated with protein-rich pulmonary edema, which reflects injury of the lung endothelium and epithelium and impairs carbon dioxide release.[6] The clinical definition of ARDS according to the 1994 American-European Consensus Conference includes acute onset, bilateral lung infiltrates by radiography, and a partial pressure of oxygen to fraction inspired of oxygen ratio (PaO_2:FiO_2) of less than 200 mmHg.[8] In 2012, the ARDS Definition Task Force revamped the definition to the Berlin Definition, which classified ARDS solely based on the PaO_2:FiO_2. Mild ARDS was classified by a PaO_2:-FiO_2 of between 200 and 300 mmHg, while moderate ARDS was classified by a PaO_2:FiO_2 of 100 to 200 mmHg, and severe ARDS was classified by a PaO_2:FiO_2 of less than 100 mmHg.[9]

Burned patients with inhalation injury often require mechanical ventilation support. Traditionally, high tidal volume ventilation (HTV) was used in the burned pediatric population at the Shriners Hospitals for Children—Galveston from 1986 to 1996 to improve oxygenation and to achieve normal values for partial pressure of arterial carbon dioxide and for pH. However, the ARDS Network Study then showed that low tidal volume ventilation (LTV) decreased mortality in nonburned patients with ARDS.[10] Additionally, HTV was shown to cause over-distended alveoli, alveolar capillary membrane disruption, and increased inflammation in nonburned patients.[11] The outcomes studies of patients treated with HTV identified residual pulmonary abnormalities,[12] and the standard of care at SHC was then modified to an LTV protocol for ventilated patients from 1997 to 2014.

The optimal ventilation strategy for patients with burns and inhalation injury is not well defined.[13] The ARDS Network Study has shown a significant decrease in mortality when low tidal volumes are used for the treatment of ARDS. However, these studies excluded pediatric patients and patients with greater than 30% total burned surface area (TBSA), and whether the results hold true for patients with inhalation injury and burned patients has yet to be determined in a large scale study. We hypothesize that LTV compared with HTV in burned pediatric patients with inhalation injury will improve pulmonary outcomes, including decreased ventilator days and decreased incidence of ARDS and atelectasis. Our study compared 3 groups of burned pediatric patients (unventilated, HTV, LTV) with inhalation injury, who were admitted to the Shriners Hospital for Children—Galveston from 1986 to 2014.

METHODS

Patient demographics and injury characteristics

Inclusion criteria for the study were as follows: 0 to 18 years of age at the time of the admission, diagnosis with inhalation injury, and the need for ventilation (Fig. 1). Patient age, sex, ethnicity, TBSA, and third-degree TBSA were recorded at the time of admission. Age-appropriate diagrams were used to determine burn size.[14] Approval was obtained by the Institutional Review Board from the University of Texas Medical Branch for our retrospective study.

Inhalation injury diagnosis

Inhalation injury was confirmed by bronchoscopy in all patients. Findings included soot deposits, erythema, edema, mucosal blisters and erosion, and hemorrhage.

Atelectasis and ARDS diagnosis

Atelectasis was determined by radiologic interpretation of the chest x-ray; ARDS was also diagnosed by the radiologic interpretation of the chest x-ray, as well as a PaO_2:FiO_2 ratio of less than 200 mmHg.

Pneumonia diagnosis

Pneumonia was defined using the criteria set by the National Trauma Data Bank: presence of fever, which was defined as $<96.8°F$ or $>102.2°F$; leukocytosis, which was defined by a white blood cell count $>1200/\mu L$; Gram stain of sputum with a predominant organism and moderate to many white blood cells; chest radiograph with a pneumonic infiltrate; and culture of sputum demonstrating a pathogen.

Statistical analysis

Multiple linear regression was used to model the relation of ventilator days, maximum positive end-expiratory pressures (PEEP), and peak inspiratory pressures (PIP), plateau pressure, and admission nadir PaO_2 and PaO_2/FiO_2 ratio as functions of age, TBSA, treatment group