High Frequency Percussive Ventilation in Pediatric Patients With Inhalation Injury

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The objective of this study was to present data that showed high frequency percussive ventilation (HFPV) was superior to traditional mechanical ventilation for the treatment of children with inhalation injuries. Inhalation injuries continue to be the number one cause of death of patients with thermal injuries in the United States. Therapy for this condition has consisted of conservative pulmonary toilet and mechanical ventilation. Despite improvements in the management of burn injury, patients with inhalation injury develop pneumonia and pneumothorax, leading to adult respiratory distress syndrome. Unfortunately, inhalation injury that is complicated by pneumonia has been shown to increase mortality by 60% in these patients. Cioffi has shown that prophylactic use of HFPV in adult patients with inhalation injury has been a successful method of reducing the incidence of pneumonia and mortality. The effects of HFPV on the incidence of pneumonia, peak inspiratory pressures, and arterial partial pressure of oxygen/fraction of inspired concentration of oxygen (P/F) ratios were retrospectively studied in 13 children with inhalation injuries and compared with historic controls treated with conventional mechanical ventilation. All patients were treated with our standard inhalation injury protocol and extubated when they met standard extubation criteria. Patients ranged in age from 6 to 9 years, and most had burns covering greater than 50% of their total body surface areas. No deaths occurred in either group, but the patients who were treated with HFPV had no cases of pneumonia ($P < .05$), better P/F ratios ($P < .05$), lower peak inspiratory pressures, and less work of breathing ($P < .05$) as compared with our control group. On the basis of our clinical experience and data, the use of HFPV seems to be an effective treatment for the reduction of pulmonary morbidity in pediatric patients with inhalation injuries. (J Burn Care Rehabil 1999;20:232-5)

Pulmonary injury from smoke inhalation continues to be one of the major causes of morbidity and mortality in the patient with burns.[1,2] Ever since the development of advanced treatment in burn care, patients who would have normally died from this disease are now being saved. However, even with these therapeutic advances, smoke inhalation injury continues to frustrate many investigators.[3]

Mortality from smoke inhalation alone is low (0% to 11%), but smoke inhalation in combination with cutaneous burns has been reported to be fatal in 30% to 90% of patients.[4,5]

We know that it is the stimulus of the inflammatory mediators that is responsible for the initial pulmonary damage,[6,7] yet we have not been able to find a therapeutic modality or a satisfactory drug regimen that will attenuate this response. Pneumonia increases burn mortality by 40%, and the combination of inhalation injury and pneumonia leads to a 60% increase in deaths.[8] This is especially true in children and in the elderly, who are especially prone to pneumonia because they have a limited physiologic reserve.

Current approaches to the management of inhalation injury include assessment and securing of the airway, vigorous airway clearance, pharmacologic management, aggressive prevention and treatment of pneumonia, and mechanical ventilatory support when indicated.[9]

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Despite all conservative efforts to support unassisted ventilation, pediatric patients with inhalation injury often develop respiratory failure and require mechanical ventilatory support.[10] Present day ventilatory management for patients with inhalation injury includes volume control, synchronized intermitted mandatory ventilation and pressure support (SIMV+PS), pressure control to reverse inspiratory to expiratory ratios, permissive hypercapnia, and high frequency ventilation.[11,12] Unfortunately, although the number of options available to the clinician has increased exponentially, well-controlled clinical trials defining the specific role of each of the modes of ventilation and comparing them with other modes of ventilation have not been forthcoming, particularly in the pediatric population.

Cioffi et al[13] reported that optimal ventilation and survival of adults with inhalation injury may be attained with high frequency percussive ventilation (HFPV), as compared with conventional (volume limited) ventilation. Significant decreases in the incidence of pneumonia and mortality in adult patients with inhalation injury were also noted when high frequency percussive ventilation was used instead of conventional ventilation. However, no such study has been done in the pediatric burn patient with inhalation injury. Thus the purpose of this study was to investigate the effect of high frequency percussive ventilation on mortality, incidence of pneumonia, arterial partial pressure of oxygen/fraction of inspired concentration of oxygen (P/F) ratios, and peak inspiratory pressures of children with inhalation injury.

METHODS

Twenty-six pediatric patients admitted to the Galveston Shriners Hospital for Children Burns Institute participated in this study. The effects of high frequency percussive ventilation on mortality rate, incidence of pneumonia, and peak inspiratory pressures were studied in 13 children with burns who had documented inhalation injury and were admitted between January 1995 and January 1996. These results were compared with those of an historic cohort treated with conventional mechanical ventilation during the same period of time. Both groups received the same inhalation injury treatment protocol except for the method of mechanical ventilation. Patients in the conventional mechanical ventilation (CMV) group were ventilated with the Servo 900C ventilator (Siemens-Elema, Danvers, Mass) in the SIMV and pressure support mode. Initial ventilator settings included tidal volumes of 12 to 15 mL/kg, SIMV of 14 to 24, and pressure support of 10 cm H_20. Respiratory rate, fraction of inspired concentration of oxygen (FiO_2), and positive end expiratory pressure (PEEP) levels were adjusted to meet the clinical demands and comfort of each patient. Patients in the HFPV group were ventilated with the Volumetric Diffusive Respirator (VDR) (Percussionaire Corp,

Table 1. Demographics (N = 26)

	CMV (n = 13)	HFPV (n = 13)
Age (y)	6.5 ± 4	8 ± 5
% total body surface area burned	55% ± 20%	51% ± 18%
% body surface area with third-degree burn	38% ± 32%	45% ± 19%
Length of stay (days)	52 ± 36	41 ± 18
Mortality	0	0

Data presented as mean ± standard deviation.

Table 2. Pulmonary data (N = 26)

	CMV (n = 13)	HFPV (n = 13)
Ventilator days	11 ± 26	9 ± 8
Pneumonia	6	0*
P/F ratios	380 ± 107	463 ± 83*
Peak inspiratory pressure	42 ± 14	27 ± 5*

Data presented as mean ± standard deviation.
* $P < .05$.

Table 3. Study variables (N = 26)

Normal values	CMV (n = 13)	HFPV (n = 13)
Lung compliance (50 to 100 mL/cm H_20)	19 ± 10	27 ± 22
Airway resistance (2 to 5 cm H_20/L/sec)	23 ± 9	34 ± 9
Work of breathing (3 to 6 joules/L)	2.2 ± 0.6	0.11 ± 0.06*

Data presented as mean ± standard deviation.
* $P < .05$.

Table 4. Intake and output data (N = 26)

	HFPV (n = 13)	CMV (n = 13)
Weight (Kg)	38 ± 26	29 ± 20
Intake (cc/24 hours)	4048 ± 2198	4689 ± 2524
Output (cc/24 hours)	2537 ± 1251	2973 ± 2154

Data presented as mean ± standard deviation.

Sandpoint, Idaho). Initial ventilator settings included a pulsatile flow rate (PIP) of 20 cm H_20, a pulse frequency of 400 to 600, an oscillatory PEEP of 5, a respiratory rate of 5 to 20, and a 2:1 inspiratory to expiratory ratio. Oxygenation was improved by setting the ventilator to a more diffusive mode, and carbon dioxide clearance was enhanced with the use of a more convective mode, thus allowing for semi-independent control of oxygenation and ventilation. With both groups of patients, ventilator settings were manipulated to achieve the best possible oxygenation and ventilation at the lowest possible peak inspiratory pressures, FiO_2, and PEEP levels.

Patients were included in the study if the following criteria were met: (1) the patient had an inhalation injury documented by bronchoscopy, (2) the patient required ventilatory support, (3) the patient was admitted within 48 hours of the burn, and (4) the patient was between 0 and 18 years old. Bronchoscopic findings of inhalation injury in both groups included erythema, edema, soot deposits, and tracheobronchial cysts. The criteria for determining ventilatory support included P/F ratio < 250, increasing hypercarbia, and increasing respiratory distress.

Study variables included number of ventilator days, incidence of pneumonia, P/F ratios, and peak inspiratory pressures. Pneumonia was diagnosed by positive sputum cultures and x-ray findings.

STATISTICS

Data were analyzed with the use of a standard Student *t* test.

RESULTS

Twenty-six pediatric patients meeting the entrance criteria were retrospectively reviewed. An analysis of the demographic data (Table 1) showed no significant difference between the 2 groups with regard to age, percent total body surface area burned, percent of body surface area with third-degree burn, and mortality. Study variables (Table 2) showed a significantly lower incidence of pneumonia (6 in the CMV vs O in the HFPV group), peak inspiratory pressures (42 in the CMV group vs 27 in the HFPV group), and P/F ratios (380 in the CMV group vs 463 in the HFPV group). The work of breathing (Table 3) was significantly lower for pediatric patients treated with HFPV as compared with those treated with CMV. To exclude a differential occurrence of pulmonary edema as a cause of outcome difference, Table 4 shows weight, intake, and output data. Patients in the HFPV group were an average of 2 years old than those in the CMV group, and this explains th physiologic difference in weight.

DISCUSSION

Despite improvements in the management of burn injury, pediatric patients with inhalation injury often develop pneumonia and require long-term mechanical ventilatory support.[10] Several studies have shown that inhalation injury complicated by pneumonia increases mortality by up to 60%.[4-6,8] Cioffi et al,[13] in their study of HFPV, showed that prophylactic use of HFPV in adult patients with burns and inhalation injury has successfully reduced the incidence of pneumonia and mortality. Arnold,[14] in his prospective study that compared CMV with high frequency oscillating ventilation (HFOV) in pediatric patients who had diffuse alveolar disease or air leak syndrome, found that HFOV offered rapid and sustained oxygenation and ventilation without increasing barotrauma. Both of these studies emphasized that reducing the barotrauma caused by over-distention of alveoli by conventional ventilators was the key to preventing chronic lung disease. Mlcak et al[15] showed that those burn patients diagnosed with an inhalation injury and that required mechanical ventilation had long-term restrictive lung disease; this was thought to be caused by the reactive process initiated by the products of combustion in smoke and by the barotrauma caused by mechanical ventilators.

By retrospectively studying the effects of HFPV and CMV in the pediatric patient with inhalation injury, we found that those patients treated with HFPV showed a decrease in the incidence of pneumonia, a lower peak inspiratory pressure, and an improvements of P/F ratio. This indicates that the management of these patients by this mode of ventilation is an improvement from traditional treatment with CMV. To clearly explore this retrospectively observed difference, we have started a randomized controlled prospective study that is comparing the different types of conventional ventilation with HFPV. This comparison is particularly important because other modes of mechanical ventilation that make use of permissive hypercapnea and that reverse inspiratory to expiratory ratios have been tried successfully in pediatric patients with lung disease.[11]

Initial findings from our prospective study (Table 3) showed that those patients treated with HFPV had a reduced work of breathing with this mode of ventilation as compared with those patients treated with CMV, possibly indicating a reduction in the oxygen

consumption of these hypermetabolic patients whose oxygen and energy demands are quite high. Additionally, none of the patients treated by HFPV developed signs and symptoms of tracheobronchitis.

In summary, we can conclude from our data that those pediatric patients with smoke inhalation injuries should be treated with HFPV and pulmonary toilet at the start of their therapy.

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