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High frequency percussive ventilation and conventional ventilation after smoke inhalation: a randomised study

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Abstract

Inhalation injury and bacterial pneumonia represent some of the most important causes of mortality in burn patients. Thirty-five severely burned patients were randomised on admission for conventional ventilation (CV; control group) versus high frequency percussive ventilation (HFPV; study group). HFPV is a ventilatory mode, introduced 10 years ago which combines the advantages of CV with some of those of high frequency ventilation.

Arterial blood gases, ventilatory and hemodynamic variables were recorded for 5 days at 2 h intervals. Incident complications were classically managed. A statistical analysis (Student's *t*-test and Wilcoxon signed rank test) demonstrated a significant higher PaO_2/FiO_2 from days 0 to 3 in the HFPV group. No significant differences were observed for the other parameters. Our findings suggest that HFPV can improve blood oxygenation during the acute phase following inhalation injury allowing reduction of FiO_2. No significant differences were observed between groups for mortality nor incidence of infectious complications in this study.

Keywords: Acute respiratory failure; Smoke inhalation; Burns; Hypoxemia; High frequency percussive ventilation; Combined high frequency ventilation

1. Introduction

Inhalation injury represents a dramatic complication in thermally injured patients, increasing morbidity and mortality [1,16] by predisposing to the development of bacterial pneumonias. It frequently causes progressive respiratory insufficiency leading to acute respiratory failure [3].

Current treatment modalities for respiratory insufficiency from inhalation injury include support with artificial conventional ventilation (CV; volume-cycled positive pressure ventilators) associated with supplemented oxygen, frequent tracheo-bronchial toilet and anti-microbial therapy [1,16].

Unfortunately, CV support fails in many cases, leading to excessive ventilatory pressures and possible occurrence of volutrauma or barotrauma, lack of elimination of carbon dioxide or insufficient blood oxygenation [1,3].An interesting alternative to CV support methods is high frequency percussive ventilation (HFPV), which is a recent form of high frequency ventilation administered by a volumetric diffusive respirator (VDR) developed by Forest M. Bird [2]. This technique combines some advantages of high frequency with others of CV support.

The purpose of this randomised study is to compare the use of CV and HFPV in patients with inhalation injury associated with burn damage. This study represents the first randomised trial using this kind of ventilation in patients with inhalation injury.

2. Materials and methods

After this protocol was reviewed and authorised by the Institutional Review Board of our hospital, 35 patients admitted during a 20-month period to the Belgian Army Burn Centre of Brussels were enrolled in the protocol according to the following inclusion criteria: age >18 years, burned surface area >20% and presence of inhalation injury according to recognised criteria (closed space fire, facial burns, carbonaceous sputum, positive bronchial fibroscopy with soot in the airways), with need for mechanical ventilatory support. Pregnant women were excluded.

Patients were randomly allocated by a random number table to the control group with CV or the study group ventilated with HFPV. Inhalation injury was confirmed by analysis of clinical data, circumstances of burns and bronchoscopic examination (Table 1). Initial fluid resuscitation was calculated at 3 ml/kg per percent burned surface area per day (Parkland formula) [16,19].

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Table 1
Population: inhalation criteria in randomised groups

	Group I	Group II	*P*-value
Close space fire	15/17	16/18	NS
Facial burns	15/17	16/18	NS
Carbonaceous sputum	5/17	6/18	NS
Ventilatory support on the field	11/17	12/18	NS
Bronchoscopy (+)	15/17	16/18	NS

Group I receiving CV (Evita, Dräger) and group II receiving HFPV (VDR4, Percussionaire Corporation). NS: not significant.

Maintenance fluids were also administered with a severe restriction to 1 ml/(kg h). Colloids (human albumin 20%) were started 8 h after admission and packed cells were given to restore blood volume and to maintain hematocrit >25%. Midazolam (0.1 mg/(kg h)) and sufentanyl (0.1 mg/(kg h)) infusions were used for sedation and analgesia.

Antibiotic coverage was instituted when indicated by clinical, radiological and bacteriological data and adapted to the results of bacterial cultures.

Hemodynamic variables were assessed using invasive central venous and arterial monitoring; pulmonary artery catheters were used in 17 patients (eight in group I and nine in group II). All of the patients needed mechanical ventilatory support before or on admission to maintain normocapnia (<45 mmHg) and an arterial O_2 saturation >85% with adaptation of the inspired oxygen concentration.

During the first 5 days following injury, FiO_2, PEEP, $PaCO_2$ and PaO_2 were measured at 2 h intervals.

Blood gas analysis and calculation of haemoglobin saturation were performed on an ABL300 radiometer (Copenhagen) and ventilatory parameters were measured using the on line system of the ventilator. The airway pressure was measured between the Y-piece of the ventilator circuit and the proximal end of the endotracheal tube. Side effects and incidence of pulmonary infections were noted.

Table 2
Population: age and burn surface area in randomised groups

	Group I	Group II	*P*-value
Patients	17	18	
Mean age (years)	41.3 ± 22	41.3 ± 15	NS
Burn surface area (%)	46.2 ± 22.3	51.7 ± 21.3	NS

Group I receiving CV (Evita, Dräger) and group II receiving HFPV (VDR4, Percussionaire Corporation). NS: not significant.

Group data were expressed as median and range. Statistical analysis was performed to assess differences between groups (unpaired Student's *t*-test and Wilcoxon signed rank test). Conventional volume-controlled ventilation was delivered through a conventional respirator (Evita 2, Dräger Vt 7) 10 ml/kg; respiratory rate (RR) 12–18 breaths/min). The conventional ventilator was set in volume-controlled mode delivered through square flow wave flow profile with tidal volume, RR, FiO_2, inspiratory flow and respiratory time selected by the attending physician to maintain adequate gas exchanges (arterial saturation higher than 85%).

HFPV was delivered by a high frequency pulse generator (Bird Space Technologies, Percussionaire Corporation, Sand Point, ID). Gas from a pulse generator is administered through a non gated venturi connected to an endotracheal tube; the venturi entrains humidified gas from the ventilator.

The system combines high frequency volume breaths with a variable *I*/*E* ratio; periodically the flow is interrupted to return to baseline CPAP.

The ratio between the percussive phase and baseline CPAP is adapted following the results of blood oxygenation and CO_2 elimination. Peak airway pressure can be adjusted to influence CO_2 level [1,2].

HFPV frequency was always between 600 and 800 cycles/min; FiO_2 and PEEP were adjusted to obtain an O_2 saturation >85%.

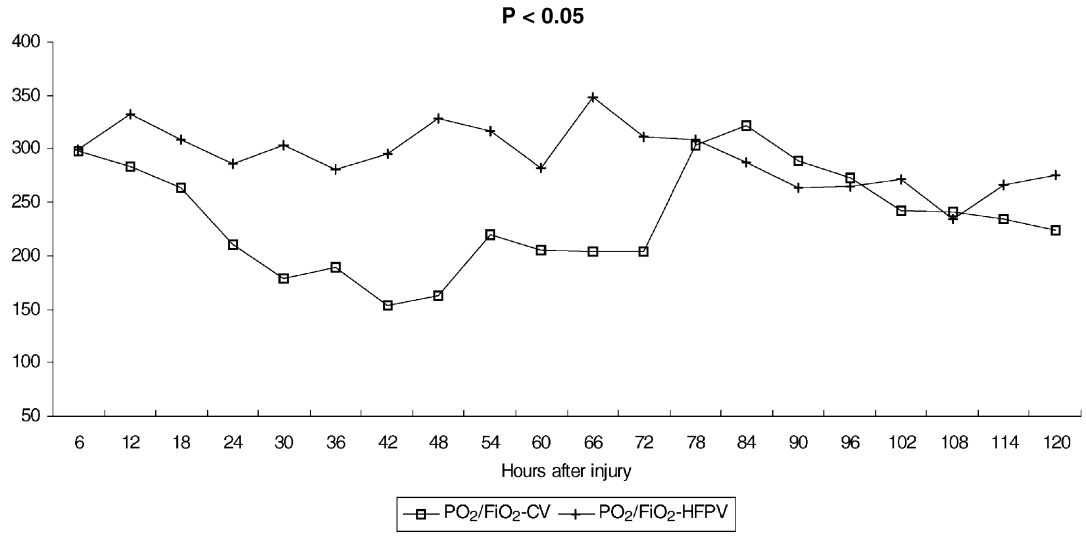

Fig. 1. Evolution of PaO_2/FiO_2 in CV and HFPV groups (data are expressed as median).

Full humidification was performed through the ventilator system to protect the tracheo-bronchial mucosa.

3. Results

Patients' characteristics are listed in Table 2. There was no significant difference between the two groups for age and burn surface area. A statistically significant increase of the PaO_2/FiO_2 ratio was observed in the HFPV group during the first 3 days post-injury (Fig. 1): FiO_2 in the CV group was significantly higher than in the HFPV group (Fig. 2), while no statistical significance was noted between the two groups for CO_2 elimination (Fig. 3), PaO_2 (Fig. 4), ventilatory pressures PIP and MAP (Figs. 5 and 6) and hemodynamic data.

We observed neither a significant difference in mortality nor incidence of pulmonary infections between the CV and HFPV groups.

Fourteen patients survived in the two groups (78 and 82%, respectively), 10 patients developed microbial pneumonia in the HFPV group (59%) and 11 in the CV group (61%).

One patient died during the study period in each group (multiple organ failure related to sepsis; burned surface area, 46 and 52%; age, 42 and 46 years); use of the other ventilatory mode did not improve the respiratory and hemodynamic status of these patients. Mean PEEP levels were not significantly different ($9 \pm 2.4\,cmH_2O$ under CV and $8.5 \pm 2.1\,cmH_2O$ under HFPV). No side effects (particularly barotrauma) were noted in either group.

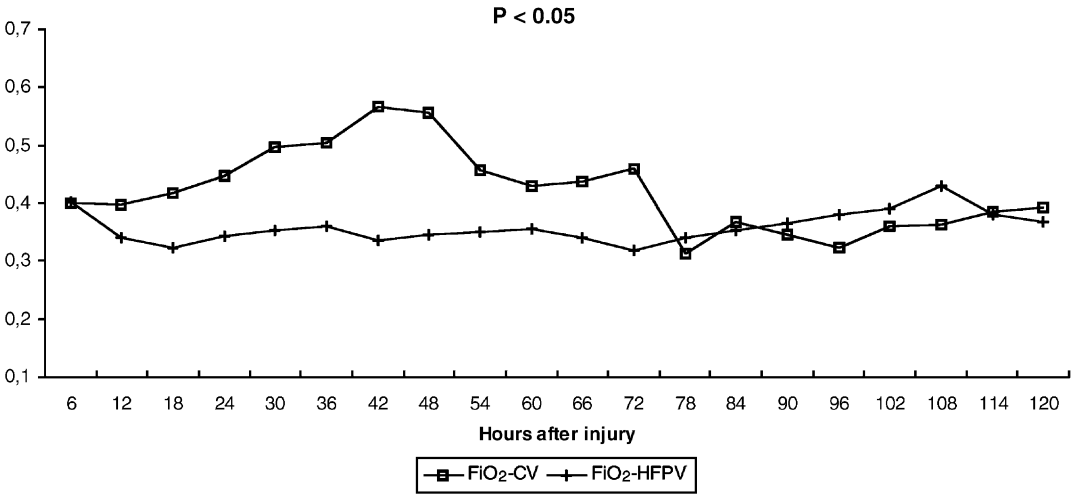

Fig. 2. Evolution of FiO_2 values in CV and HFPV groups (data are expressed as median).

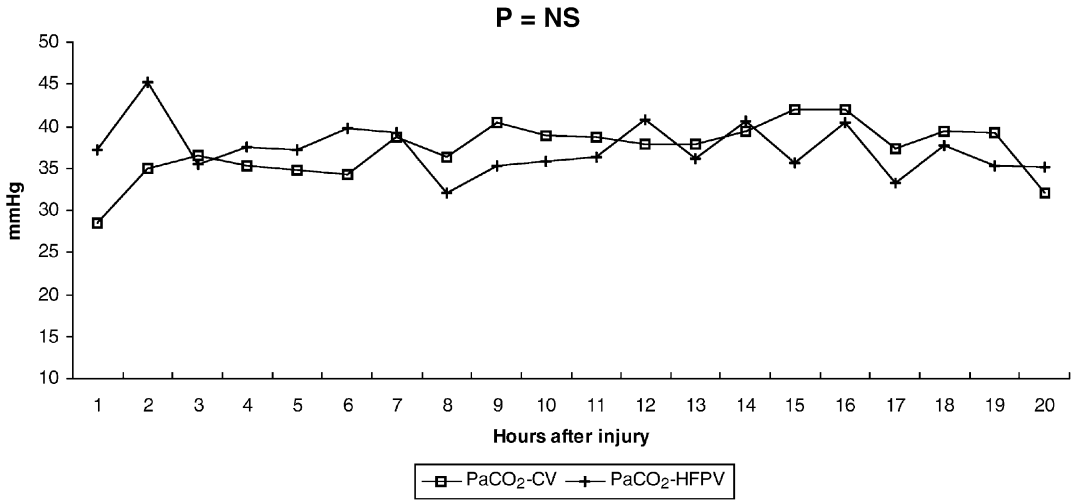

Fig. 3. Evolution of $PaCO_2$ values in CV and HFPV groups (data are expressed as median).

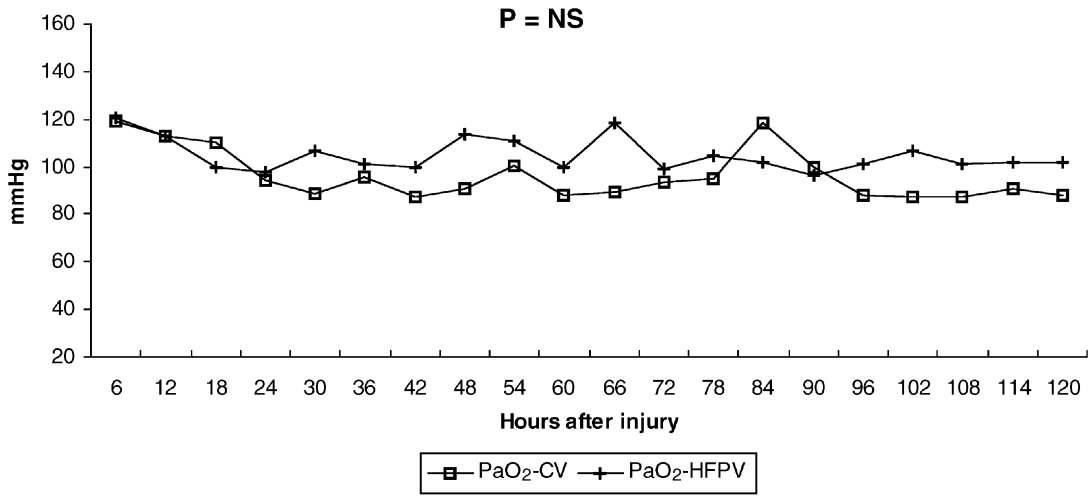

Fig. 4. Evolution of PaO_2 in CV and HFPV groups (data are expressed as median).

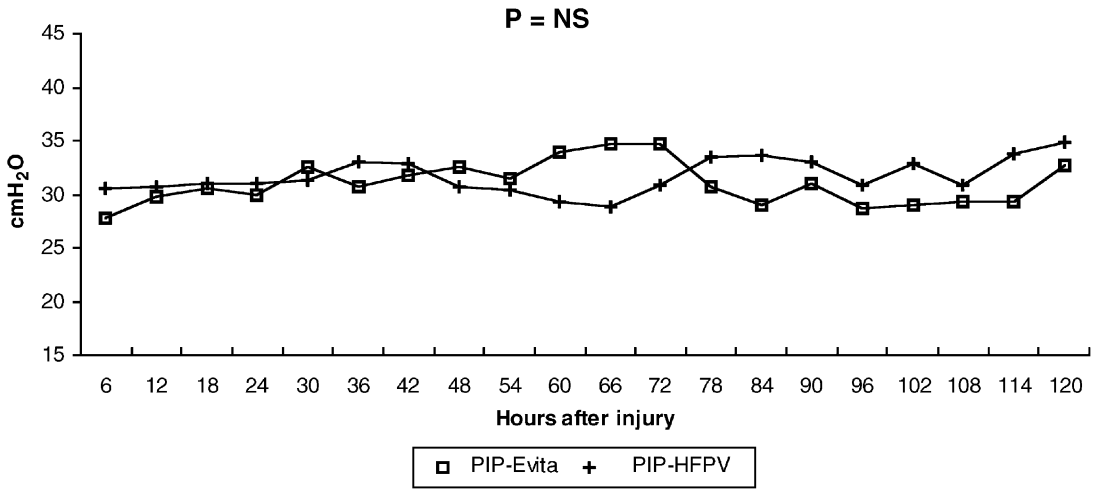

Fig. 5. Evolution of PIP in CV and HFPV groups (data are expressed as median).

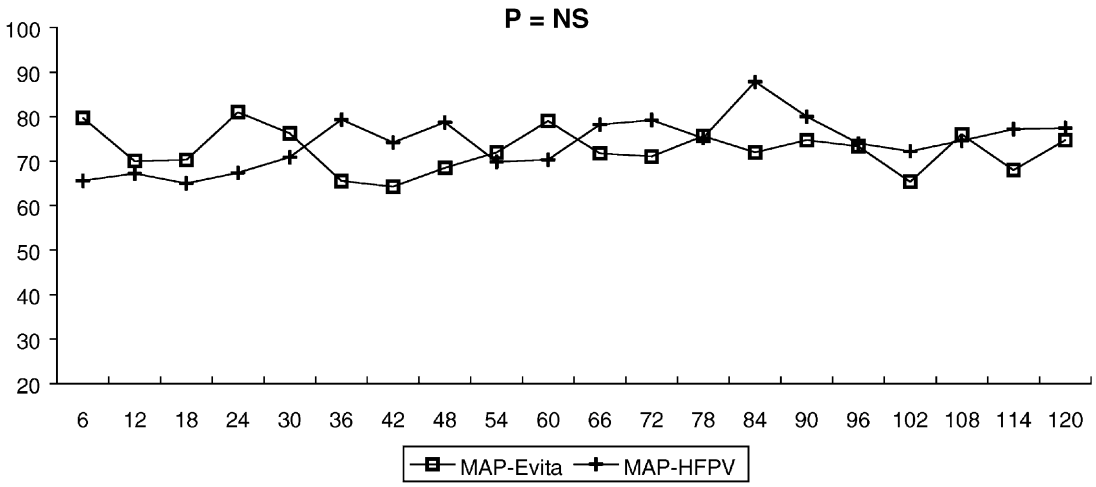

Fig. 6. Evolution of MAP in CV and HFPV groups (data are expressed as median).

4. Discussion

Smoke inhalation is frequently associated with burn injury and seems to be the first cause of death on the site of the disaster (30–90% in all populations). Several physio-pathological mechanisms for inhalation injury toxicity have been proposed (toxins, anoxia, airway obstruction, etc.) [16,17,24].

Cioffi et al. report a 20–40% increase in mortality in burn patients in presence of inhalation injury [1]. The mechanisms of this phenomenon are complex and not fully understood [1,6,22].

Tracheo-bronchial injury impairs the normal mucociliary clearance of the lung and leads to distal atelectasis favouring microbial infections and development of hypoxaemia by alterations of ventilation/perfusion ratios [5]. Barotrauma or volutrauma due to CV support could also be result from alterations of the epithelial integrity or exudative phenomena leading to a ball valve effect and air trapping [7].

Inhalation injury also impairs surfactant production by type II pneumocytes and inhibits the phagocytic capacities of the macrophages while granulocytes are being activated releasing various mediators altering the integrity of the capillary membrane [8].

All these alterations may explain the high incidence of pulmonary infection (8.8–60%), the development of hypoxemia and hypercarbia, and the alteration of the ventilation/perfusion ratio, observed in acute respiratory failure in burned patients [5,7,8].

Bacterial infection represents one of the leading causes of death in severely burned people, the totality of respiratory complications being the most frequent cause of death in this population, responsible for 18–24% of all deaths [1,3,16]. The elderly seem more prone to these deleterious effects [3,18].

Therefore, the goals of treatment would ideally be to correct these pathological changes with minimal side effects. CV with volume-cycled positive pressure ventilators does not seem to be the best solution for this purpose: clearance of lung secretions is impaired and high ventilatory peak pressures (associated or not with high FiO_2) are actually recognised as being poor prognostic factors for the recovery of lung function and final outcome of these critically ill patients [3,8,12–14,23].

HFPV represents an interesting alternative: HFPV could induce a more efficient gas distribution with lower peak airway and transpulmonary pressures, less impact on circulation and lower positive endotracheal pressure throughout the respiratory circle [9–11,15].

All these factors could be beneficial for the ventilatory support of patients with severe inhalation injury and acute respiratory failure. HFPV could also allow ventilation at lower inspired oxygen concentration (FiO_2); a high FiO_2 is suspected to increase the pulmonary sensitivity to infection [3].

The use of superimposed high frequency cycles on conventional cycles could also represent an interesting form of lung opening manoeuvre leading to a better alveolar recruitment which is now considered as one of the important elements which conditions gas exchanges in patients with acute lung injury.

Lung opening manoeuvres, such as sighs or deep breaths are known to improve compliance and oxygenation in anaesthetised or ARDS patients and represent an interesting alternative to the use of high PEEP to increase alveolar recruitment.

Carlton et al. confirm these benefits of HFPV versus CV in a randomised trial including 309 patients with ARDS but without influence on mortality [4] and Velmahos et al. observe during HFPV an improvement of blood oxygenation in patients with acute respiratory failure at higher mean airway pressures [20].

Cioffi et al. describe an improvement in survival rate and a decrease in the incidence of pneumonia in burned patients treated with prophylactic use of HFPV after smoke inhalation injury in comparison with a predicted mortality calculated on a previous group of patients and applied to the study group [3]. Cortiella et al. also confirm the interest of HFPV in paediatric patients with inhalation injury [21].

Our study represents the first randomised trial in severely burn patients suffering from inhalation injury. These results suggests the ability of HFPV to improve blood oxygenation in severely burned patients with smoke inhalation during the first 72 h following injury. However, this study fails to show a positive effect on global mortality and on the incidence of pulmonary infections.

This observation could be explained by different factors. The evolution of severely burned patients is influenced by the burn characteristics (depth), by the incidence of various complications (septic, metabolic, etc.) and by comorbidities which will influence the clinical course.

This study fails also to confirm the theoretically expected beneficial effects on ventilatory pressures as it was suggested by the study Rodeberg et al. [25]. This could be explained by the poor quality of the monitoring section of the VDR4: precise measurements of ventilatory pressures and spirometric data are difficult to obtain and not available at this moment.

This study also confirms that HFPV is well tolerated and the absence of relevant haemodynamic interference in patients with inhalation injury.

Further controlled studies are required to investigate the effects of HFPV on ventilatory parameters and mortality. Adequate respiratory monitoring should be obtained by independent ventilatory monitoring which allows to measure spirometric and mechanical parameters under HFPV.

The data presented in this study confirm and extend earlier data in the literature demonstrating that HFPV represents an alternative means for providing of ventilatory support to patients with burns and lung damage. Further investigations are necessary to determine whether percussive ventilation can reduce lung damage related to positive pressure ventilation.

Acknowledgements

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