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High frequency percussive ventilation in burn patients: hemodynamics and gas exchange

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Abstract

High frequency percussive ventilation (HFPV) is a recent ventilatory mode, which combines conventional cycles with high frequency percussions.

HFPV was initially instituted as salvage therapy after acute respiratory failure following smoke inhalation injury achieving in each case a dramatic improvement of blood oxygenation, $PaCO_2$ and ventilatory pressures.

This study investigates the influence of HFPV on hesmodynamics, blood oxygenation and ventilatory parameters in eight stable ICU burn patients requiring artificial ventilatory support during a postoperative period following traumatic injury.

Periods of 2 h were analysed receiving conventional ventilation and HFPV with a high frequency of 400 and 800 cycles/min.

Hemodynamic data were not significantly modified; peak inspiratory pressure was significantly lower under HFPV but mean airway pressure was unchanged. Blood oxygenation and CO_2 elimination were significantly improved under HFPV. No side effects were noted.

These observations suggest that HFPV could improve pulmonary gas exchanges under lower peak pressures and without hemodynamic compromise. HFPV could represent an interesting alternative open lung strategy method to improve alveolar recruitment.

Keywords: Conventional ventilation; Barotrauma; Burns; Hypoxemia; High frequency percussive ventilation

1. Introduction

Current treatment modalities for respiratory failure include conventional artificial ventilation (volume cycled positive pressure ventilators) associated with supplemented oxygen, tracheobronchial toilet and antimicrobial therapy. Unfortunately conventional ventilatory support fails in some cases, after smoke inhalation or severe organ dysfunction after extensive burns for example, leading to excessive ventilatory pressures (and barotrauma), lack of elimination of carbon dioxide or impaired blood oxygenation [1].

An interesting alternative to the current ventilatory support methods is the 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 is the latest in high frequency ventilation and combines some advantages of high frequency with others of conventional support.

Inhalation injury represents a major complication for thermally injured patients which increases morbidity and mortality of burned patients: inhalation injury predisposes to the development of bacterial pneumonias in 8.8–86% of all patients and is also responsible for progressive respiratory insufficiency leading to acute respiratory failure [3–5]. Cioffi et al. describe in 1989 the use of HFPV as rescue ventilatory mode in patients with acute respiratory distress syndrome (ARDS) following inhalation injury [3].

The purpose of this study is to compare the effect of high frequency percussive ventilation on gas exchange, ventilatory parameters and hemodynamics in a stable population of burn patients admitted in ICU for postoperative ventilation after surgical reconstructive procedures.

2. Materials and methods

Eight burn patients (five men, three women; four smokers; three patients with medical history of pulmonary disease) admitted to the Critical Care Department of the Queen Astrid Military Hospital in Brussels for postoperative follow-up

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were involved in the present study. Mean age was 41 ± 10.7 years.

Maintenance fluids were administered at 25 ml/kg per day; colloids were started if necessary to maintain adequate filling pressures and packed red cells were given to restore blood volume and to maintain hematocrit above 25%.

Midazolam (0.1 mg/kg per h) and sufentanyl (0.1 μg/kg per h) infusions were used for sedation.

Antibiotic coverage was instituted when indicated for prophylaxis before surgery.

Hemodynamic variables were assessed through Swan-Ganz catheters (Arrows 7F) and arterial lines in all patients: PWP, CVP, HR, mPAP were systematically measured. Cardiac output (CO) was determined by the thermodilution method.

All the patients were hemodynamically stable with no need for vasoactive support; postoperative body temperature was also stable ($37.1 \pm 2\,^{\circ}C$).

All patients required artificial ventilatory support for surgical technical reasons or analgesia after surgical elective procedures. Conventional ventilation (CV) was instituted using a Dräger Evita 2 with a I:E ratio 1:2. Normocapnia (less than 42 mmHg) and arterial O_2 saturation greater than 85% were maintained. All patients were stable for more than 12 h with an inspired oxygen concentration lower than 40% under conventional ventilatory mode before the test. FiO_2, PEEP, $PaCO_2$ and PaO_2 were compared for 2 h periods under CV, during and after HFPV, under CV again; for each period four determinations were averaged to obtain representative values for hemodynamics, ventilation and pulmonary gas exchange.

Blood gas analysis corrected for temperature and calculation of hemoglobin saturation was performed on an ABL300 (Radiometer—Copenhagen).

Group data are expressed as median and range. Statistical analysis was performed to assess differences between treatment periods (Student's *t*-test and Wilcoxon signed rank test). 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 percussive phase and baseline CPAP is adjusted following the results of blood oxygenation and CO_2 elimination. Peak airway pressure can be adjusted and also influence minute ventilation and CO_2 level. Frequency of HFPV periods was 600 and 900 cycles/min; FiO_2 was not modified and O_2 saturation remained greater than 85%.

Full humidification was performed through the ventilator system to prevent tracheo-bronchial injury. Ventilatory parameters were measured with a respirator-independent monitoring device (Bicore Monitoring Systems, Irvine, California—using a flow transducer and an oesophageal transducer) for the two ventilatory modes; the flow transducer was inserted between the Y piece of the ventilator circuit and the proximal end of the endotracheal tube.

The conventional ventilator was set in volume controlled mode delivered through square flow wave flow profile with Vt, respiratory rate (RR), FiO_2, inspiratory flow and respiratory time as previously selected by the attending physician. Initial HFPV settings were adjusted to obtain the same measured tidal volumes and PEEP values than under CV; HFPV settings were then adapted following blood gas results.

3. Results

Patients' characteristics are listed in Table 1.

A statistically significant increase of the PaO_2 and PaO_2/FiO_2 ratio was observed during the HFPV periods (Fig. 1). Concomitantly a significant decrease of $PaCO_2$ was also noted (Fig. 2): the conventional cycles of HFPV were adapted and conventional cycles frequency of HFPV periods had to be significantly reduced to prevent severe hypocarbia and respiratory alcalose (Fig. 3).

The PaO_2 increase and the $PaCO_2$ decrease were influenced by the high frequency percussions rate: 900 cycles/min induce a statistically significant for PaO_2 increase.

No statistical significance was noted between the CV and HFPV periods for hemodynamics.

Ventilatory pressures were also significantly influenced by the use of HFPV: PIP was lower under HFPV (Fig. 4) with no effect on mean airway pressure.

Reduction of PIP was also influenced by the percussions cycles rates.

PEEP levels were not significantly different before and after starting HFPV (7 ± 1.2 cm H_2O under CV and 6.4 ± 1.2 cm H_2O under HFPV 600)—Fig. 5). Intrinsic PEEP was also not significantly different under HFPV and CV.

No side effects (particularly barotrauma) were noted; hemodynamic tolerance remained excellent in all patients under percussive ventilation.

A thorax drain had to be placed in one patient for surgical reasons during conventional ventilation; the lung status remained unchanged under HFPV.

Comparison of the different measures before and after the use of HFPV ventilation shows no significant difference

Table 1
Population, distribution and characteristics

Patient no.	Age (years)	Sex	Trauma	Surgery
1	53	F	Explosion	Orthopedic
2	57	M	Burn + trauma	Vascular
3	27	M	Burn	Graft
4	48	M	Burn	Graft
5	33	F	Burn	Graft
6	32	M	Burn + trauma	Orthopedic
7	40	M	Explosion	Orthopedic
8	38	F	Burn	Graft

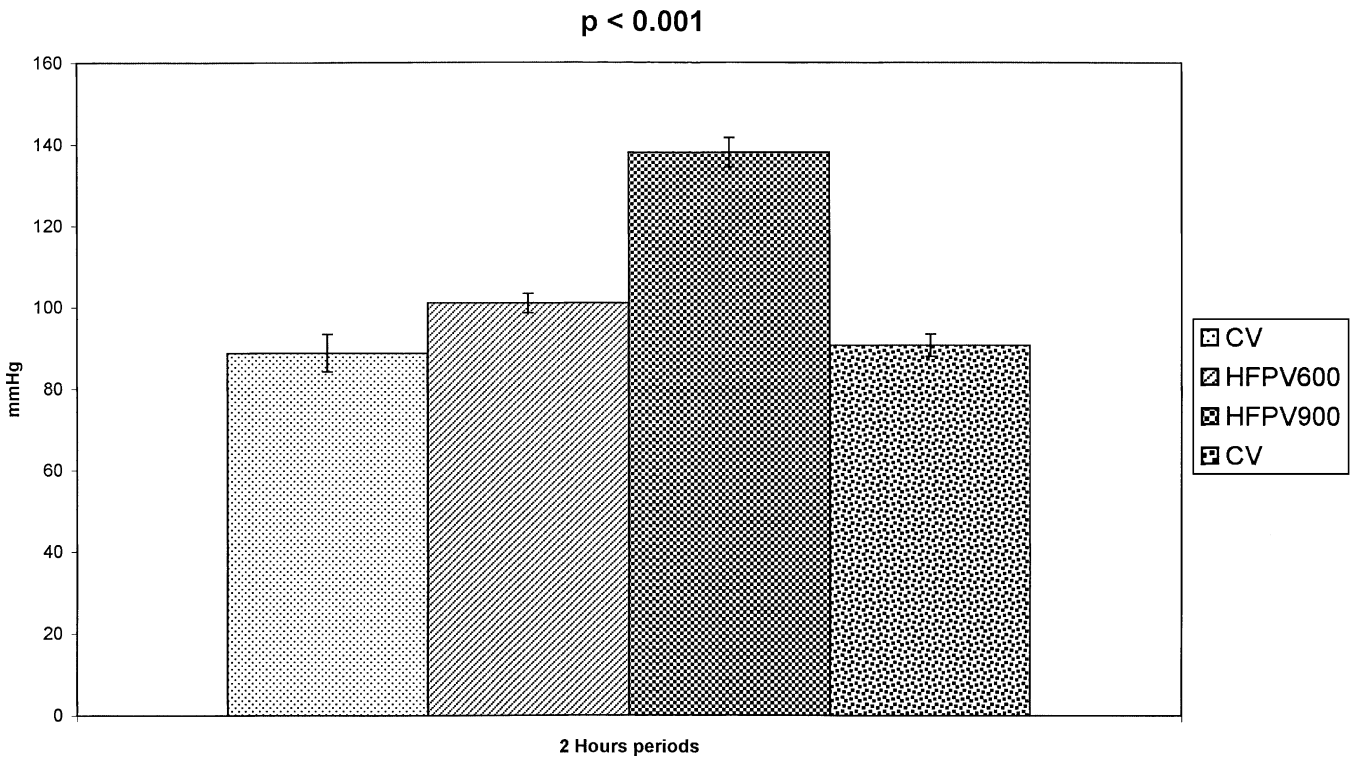

Fig. 1. PaO_2 evolution (values are expressed as means and standard deviation).

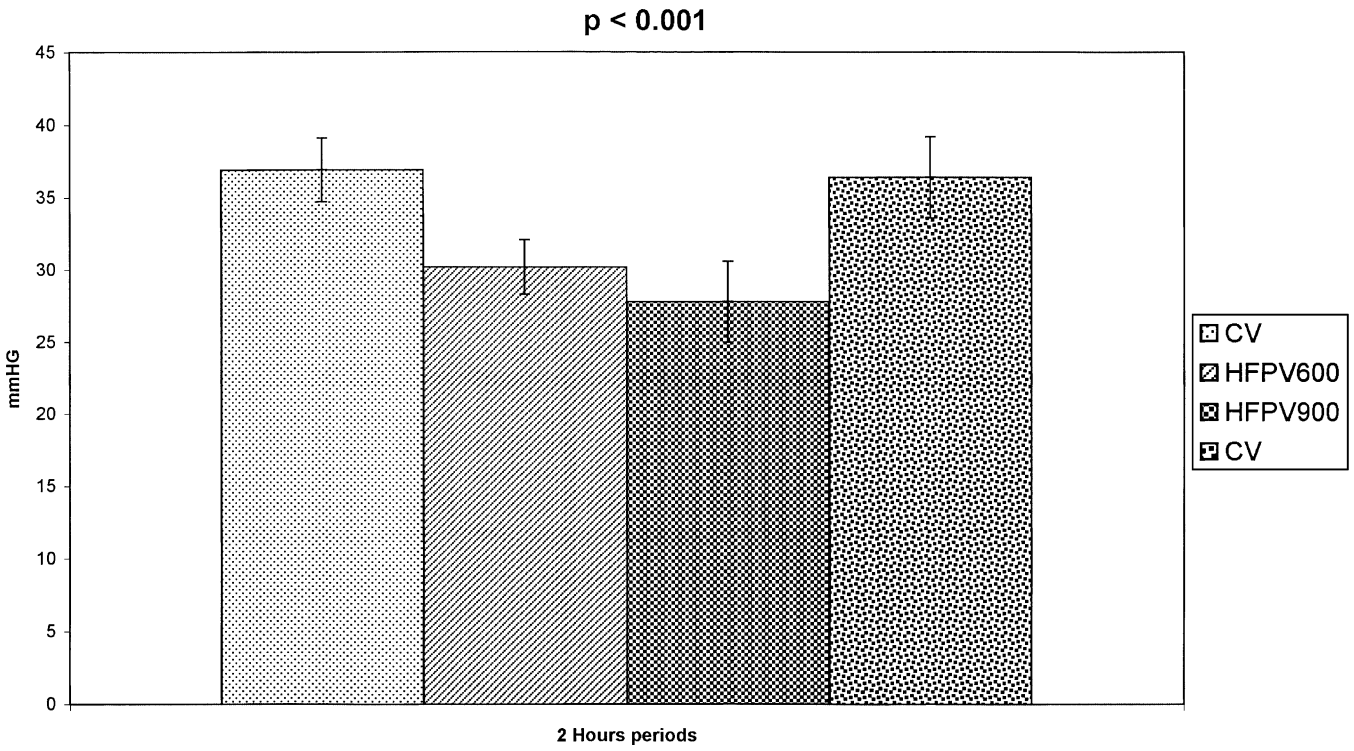

Fig. 2. $PaCO_2$ evolution (values are expressed as means and standard deviation).

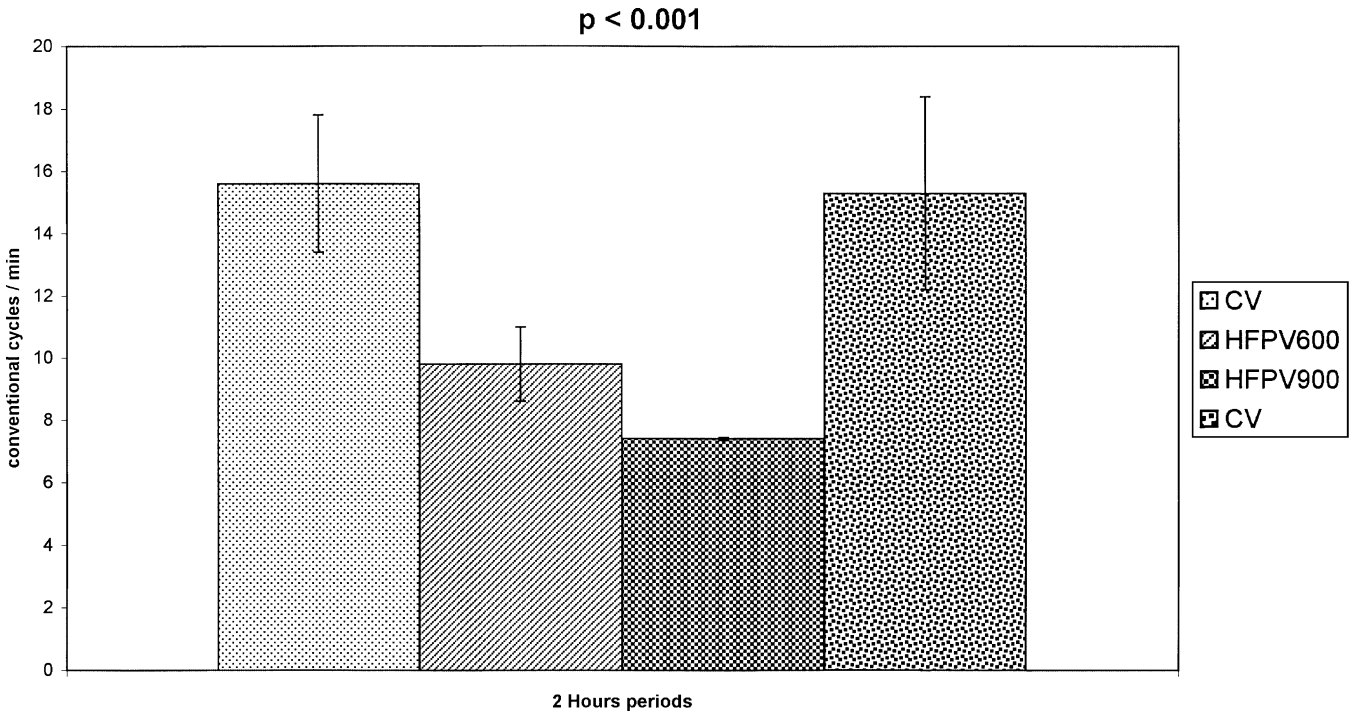

Fig. 3. Conventional frequency of ventilatory cycles (CVF) evolution (values are expressed as means and standard deviation).

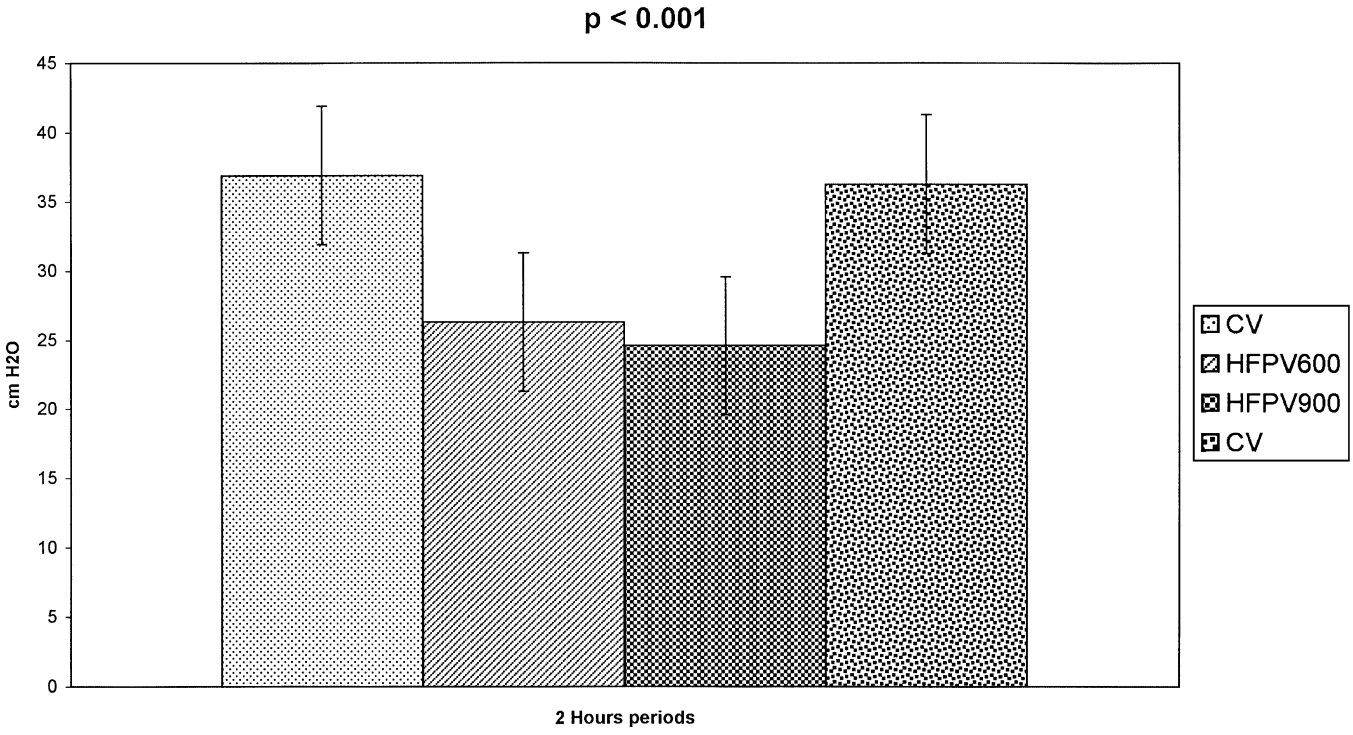

Fig. 4. Peak inspiratory pressure (PIP) evolution (values expressed as means and standard deviation).

between these two periods under conventional ventilation for blood gas results, ventilatory parameters and hemodynamics: patients were stable and remained stable after percussive ventilation periods.

4. Discussion

Current strategies for the ventilatory management of critically ill patients propose limiting peak alveolar pressures to

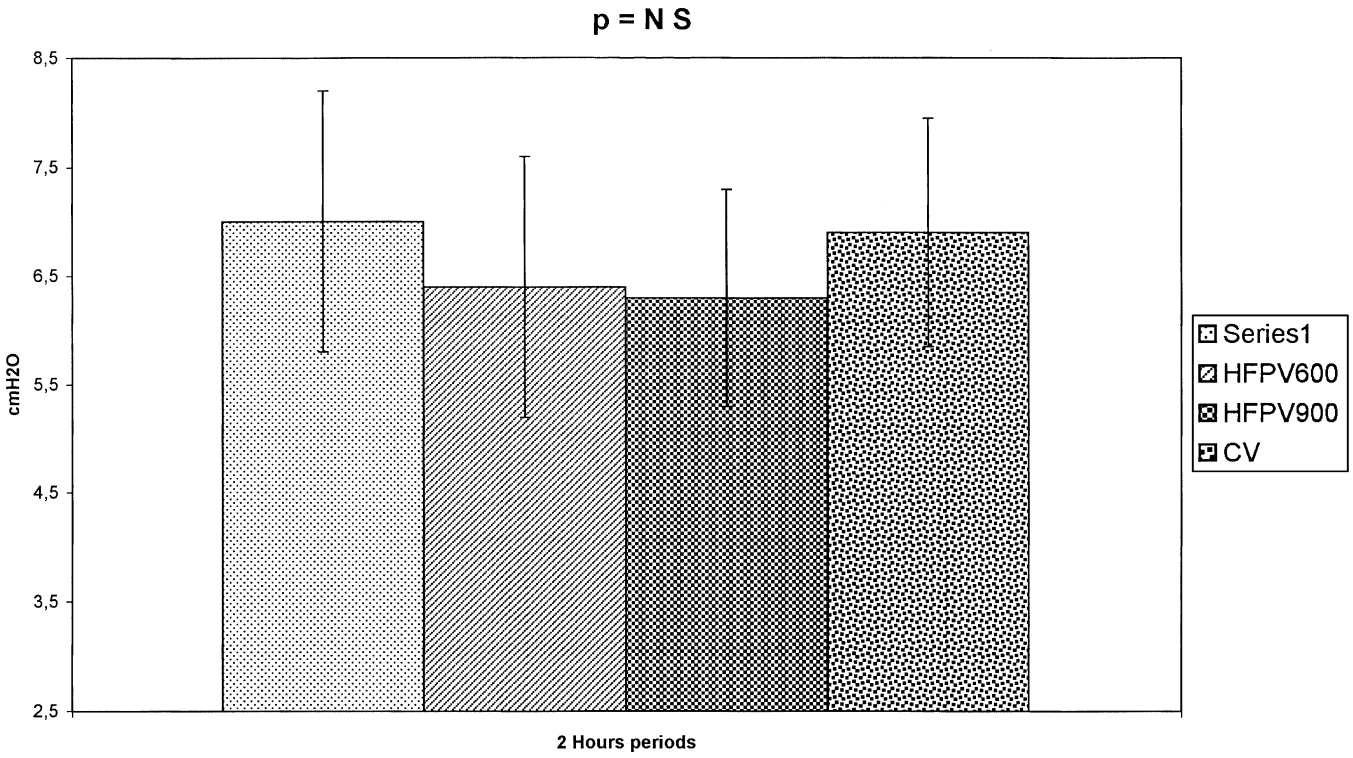

Fig. 5. PEEP evolution (values are expressed as means and standard deviation).

levels suggested as safe while optimizing alveolar recruitment [6]. The use of low tidal volumes and relatively high PEEP levels has been therefore suggested; supra-normal values of $PaCO_2$ must be tolerated and high PEEP should prevent loss of lung volumes and compliance due to atelectasis achieving better alveolar recruitment in ventilated patients and particularly in ARDS patients [1].

The lung protective strategy has been proposed to improve the outcome of these patients but high PEEP levels may also impair cardiac function, decrease renal perfusion and increase risk of barotrauma [7–11].

Lung opening maneuvers such as sighs or deep breaths are known to improve compliance and oxygenation in anesthetized or ARDS patients and represent an interesting alternative to the use of high PEEP to increase alveolar recruitment. ARDS and acute lung injury have been characterized by a tendency to alveoli and small airways collapse [12,13].

Many experimental and clinical studies have shown that techniques using the open lung approach with the aim of keeping a maximum of respiratory tissues open and available for ventilation could markedly improve gas exchanges [13,14].

Alveolar recruitment is now considered as one of the important elements which conditions gas exchanges in patients with acute lung injury [15].

Foti et al. recently showed that volume recruitment maneuvers could improve pulmonary gas exchanges significantly without impairing cardiac function [16].

High frequency percussive ventilation is a recent form of high frequency ventilation administered by a VDR [2,3].

This technique is the latest in high frequency ventilation and combines some advantages of high frequency ventilation with others of conventional support: conventional cycles are combined with high frequency percussions.

These superimposed high frequency cycles could represent an interesting form of lung opening maneuver leading to a better alveolar recruitment.

Cioffi et al. describe in 1989 the use of this ventilatory method as rescue ventilatory mode in burn patients with ARDS following inhalation injury [3].

Cioffi and coworkers also report a 20–40% increase in burn population mortality in presence of inhalation. Smoke inhalation injury explain the high incidence of distal atelectasis and pulmonary infections (8.8–60%) in burn people and the development of hypoxemia and hypercarbia with alteration of the ventilation/perfusion ratio, like seen in acute respiratory failure of other origin [3–5]. The goals of the ventilatory support of acute lung injury would ideally supply the pathologic changes encountered with minimal superimposed side effects.

Conventional ventilation with volume cycled positive pressure ventilators does not always seem to be the best solution for this purpose: clearance of lung secretions is not enhanced and the tendency to atelectasis formation leading to lower compliance, gas exchanges disturbances and arterial hypoxemia remains difficult to counterbalance [17–19]. In our study HFPV induces more efficient gas exchanges with

lower peak airway pressures, no circulatory interference and allows to maintain a superimposed continuously varying positive endotracheal pressure throughout the respiratory circle. HFPV could represent a new approach of the open lung concept and could allow to limit peak alveolar pressures to safe levels while enhancing alveolar recruitment.

All these factors are beneficial for the ventilatory support of patients with acute respiratory failure [10–13,19,20].

The study of Carlon et al. [21] confirms the benefits of HFPV versus conventional ventilation in 309 randomized patients with ARDS but without influence on mortality.

Cioffi et al. describe an improvement in survival rate and decrease in the incidence of pneumonia in burned patients treated with prophylactic use of HFPV after smoke inhalation injury [5].

Our study confirms the ability of high frequency percussive ventilation to improve gas exchanges in stable ICU burn patients under conventional ventilation, under lower ventilatory pressures, without side effects and hemodynamic interference in this stable population. Limits of this technique is related to the poor monitoring capacities which necessitate the use of complementary external measure device of ventilatory parameters and end tidal CO_2.

To conclude, high frequency percussive ventilation represents an interesting alternative approach to provide ventilatory support to patients with acute respiratory failure not sufficiently responding to conventional ventilation. Combination of high frequency positive pressure cycles could propose another lung opening method leading to better alveolar recruitment, better gas exchanges and better lung compliance. Further investigations are necessary to determine whether percussive ventilation can really open previously closed airspaces or distends already open units. Optimal frequency of percussions phases and influence on the other forms of ventilator induced lesions like barotrauma or surfactant production impairment must also be determined.

More clinical data are required to determine if HFPV represents a hopeful alternative for lung protective strategy and could reduce mortality and morbidity in the critically ill populations with acute respiratory failure specially after smoke inhalation and burn injuries.

Acknowledgements

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