A Scanographic Assessment of Alveolar Recruitment and Overinflation during High Frequency Ventilation - Preliminary Results in Three Patients*

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SUMMARY

BACKGROUND AND OBJECTIVES: *High-frequency ventilation (HFV) may offer an attractive alternative to conventional strategies in the ventilation of the acute respiratory distress syndrome (ARDS) or acute lung injury (ALI) because it can minimize lung injury. Maintaining ventilation between lower and upper inflection points, it can warrant alveolar recruitment with probably reduced level of overinflation. The goal of this study was to compare alveolar recruitment and overinflation induced by HFV versus conventional mechanical ventilation with positive-end expiratory pressure (PEEP), in three patients with ALI/ARDS.*

METHODS: *This was a prospective study in an Intensive Care Unit of a University Hospital, evaluating three ALI/ARDS patients. Scanographic measurements were done, using special software (Lungview), during HFV and conventional ventilation with or without PEEP, in a randomised order. In HFV and PEEP mean airway pressure was kept constant. Lung density histograms were plotted. Alveolar recruitment was calculated as the percentages of air that entering in sick lung areas. Overinflation was calculated as lung volume under –900 Hounsfield units.*

RESULTS: *Lung density histograms were similar in both conditions. Alveolar recruitment was 49 ± 35% versus 48 ± 27% and overinflation was15 ± 5 ml (0.4 ± 0.1 %) and 2 ± 2 ml (0.1 ± 0.1%) in HFV and PEEP, respectively.*

CONCLUSIONS: *In the three patients evaluated application of HFV and conventional mechanical ventilation with PEEP showed, for the same mean airway pressure, similar lung density histograms as well as similar level of alveolar recruitment and lung overinflation.*

Key Words: *acute respiratory distress syndrome, acute lung injury, high frequency ventilation, positive-end expiratory pressure, alveolar recruitment, lung overinflation.*

Mechanical ventilation can have deleterious effects in patients with acute respiratory distress syndrome (ARDS) or acute lung injury (ALI)[1]. This has raised concerns about the conventional ventilatory management of this syndrome and high-frequency ventilation (HFV) may offer an attractive alternative to conventional strategies because it minimizes lung injury[2]. HFV is a form of mechanical ventilation in which small tidal volumes (1 to 5 ml per kilogram) are administered at high rates (60 to 3600 cycles per minute. While applying small and frequent tidal volumes, it maintains the respiratory system between the lower and the upper inflection points from the pressure-volumes (P-V) curves[2], making good physiologic sense in the management of ARDS. Clinical trials did not show benefits in mortality principally in adult patients with ALI or ARDS[3-8]. Nevertheless it has been used as a ventilatory mode for managing this syndrome not only in pediatric but also in adult patients[9-16].

The goals of mechanical ventilation in ARDS patients are to recruit damaged lung tissue causing the least lung overinflation in order to prevent barotrauma. Some studies have been done in the last years measuring alveolar recruitment and overinflation associated to conventional mechanical ventilation with positive end-expiratory pressure (PEEP), using CT scan measurements. It has been demonstrated that PEEP can induce alveolar recruitment[17,18] but also that, at least sometimes, it can be associated with lung overinflation[19-21], defining overinflation as lung volumes above –900 Hounsfield units (HU) in lung density histograms. There is no study, in our days, evaluating scanographic measurements of recruitment and overinflation induced by HFV.

The goal of this study was to compare alveolar recruitment and lung overinflation induced by HFV *versus* conventional mechanical ventilation with PEEP, in three patients with ALI or ARDS.

METHODS

The study was designed to include patients with ARDS or ALI, defined according to the consensus conference (22), with diffuse radiological manifestations in CT scans examinations and with a lower inflection point in P-V curves. Patients with hemodynamic instability, heart failure, acute coronary insufficiency, chronic obstructive pulmonary disease (COPD), severe head injury and having a chest tube with air leak were excluded.

The protocol was approved by the Comité Consultatif de

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Protection des Personnes dans la Recherche Biomédicale of la Pitié-Salpêtrière Hospital (Paris, France) and written informed consent was obtained from each patient's next of kin. During the study, all patients were treated according to the routine from the Intensive Care Unit (ICU). They were sedated, paralyzed, orally intubated with a HI-Lo Jet number 8 Mallinckrodt tube (Mallinckrodt Inc; Argyle, NY, USA) and under mechanical ventilation. In all patients hemodynamic measurements were monitored using a fiberoptic thermodilution pulmonary artery catheter and a radial or femoral arterial catheter. P-V curves were obtained according to a constant flow technique[23] and used to determine the lower inflection point.

Patients were evaluated during conventional ventilation without (ZEEP) or with PEEP and during high frequency jet ventilation (HFV) in a randomised order. Conventional mechanical ventilation was performed with a César Ventilator, (Taema, France). Connections between the endotracheal tube and the ventilator were removed as well as the filter, replaced by a hot humidificator. Ventilatory parameters were: F_IO_2 1, I/E ratio 0.40, no inspiratory pause, respiratory rate at the limit of intrinsic PEEP, tidal volume between 6 and 8 mL/kg in order to keep $PaCO_2$ value between 35 and 45 mmHg, plateau pressure below 30 cmH_2O and PEEP 2 cmH_2O above the lower inflection point. A sigh was administered 4 times a minute using 1.5 times the tidal volume, in order to reproduce conditions from HFV. With those ventilatory parameters mean airway pressure (measured in the distal portion from the endotracheal tube) and $PaCO_2$ were unregistered and used as reference for HFV adjustments.

HFV was performed using an AMS 1000 ventilator (Acutronic Medical Systems AG, Hirzel, Switzerland). Rewarming and humidification of gases were provided by an HH-812 jet humidifier (Acutronic Medical Systems AG, Hirzel, Switzerland). Additional conventional ventilation was obtained using a CPU 1 ventilator (Ohmeda, Maurepas, France). In HFV pressure and I:E ratio were adjusted in order to achieve the reference mean airway pressure measured in conventional ventilation. In the same way, tidal volume and respiratory rate were adjusted to achieve the same $PaCO_2$ measured in conventional ventilation ± 5 mmHg. HFV was done in the proximal channel from the Mallinckrodt tube. Conventional ventilation was maintained with a volume of 100 mL, I/E ratio 1/15, respiratory rate 4 breaths per minute. Measurements of mean airway pressure in the distal portion from the endotracheal tube did not take in account the breaths from conventional ventilation.

Data collected were: age; *Simplified Acute Physiologic Score* (SAPS II)[24]; *Lung Injury Severity Score* (LISS)[25]; cardiorespiratory measurements as well as CT acquisition unregistered as in other previous protocols[19-21,23,26-28]. Scanographic assessment was done using specifically designed software (Lungview®) according to previous description[21,26-28]. Lung density histograms were plotted in the three conditions studied. Total and partial lung volumes and the volume of gas and tissue were measured and calculated as percentage of the total lung volume. As previously described[19,20] different lung regions were defined as: nonaerated (–100 to +100 HU), poorly aerated (–100 to –500 HU), normally aerated (–500 to –900HU) and overinflated (–900 to –1000 HU). Alveolar recruitment was calculated as the percentage of air going into sick lung areas, according to the method proposed by Malbouisson et al.[28].

Cardiorespiratory measurements were unregistered after one hour periods and CT acquisitions were taken after fifteen minute periods, in the following order, according to randomization: ZEEP, PEEP or HFV, ZEEP and PEEP or HFV. In PEEP and HFV they were compared in the same level of mean airway pressure.

RESULTS

During one year only three patients (mean age 47 ± 19 years, SAPS score 29 ± 10 and a LISS score 3 ± 0.6) fulfilled the inclusion and non-exclusion criteria. Two of them had ALI (PaO_2/FIO_2 = 258 and 247) and one ARDS criteria (PaO_2/F_IO_2 = 145). The three patients survived.

The mean airway pressure during PEEP or HFV was 21 ± 7 cm H_2O. The mean PEEP level used was 15 ± 5 cmH_2O. The tidal volume was 713 ± 80 mL in ZEEP, 647 ± 50 ml in PEEP and 122 ± 39 in HFV. The respiratory rate was 18 ± 6 in ZEEP, 19 ± 5 in PEEP and 187 ± 23 in HFV.

The most important cardiorespiratory and lung volume measurements in ZEEP, PEEP and HFV are shown in table 1. The measurements obtained in HFV and in PEEP were similar, but some small differences could be seen when both conditions were compared: arterial pressure and systemic vascular resistance were slightly lower; pulmonary pressure, pulmonary vascular resistance, $PaCO_2$ and Qs/Qt were slightly higher in HFV. Alveolar recruitment was the same in HFV and PEEP. The volume of overinflation was slightly greater with HFV but similar when calculated in percentage over total lung volume. The lung density histograms obtained in the three conditions are shown in figure 1. There was no difference comparing HFV and PEEP, in the three patients described.

DISCUSSION

In the three patients studied application of conventional mechanical ventilation with PEEP and HFV had, for a same mean airway pressure, the same level of alveolar recruitment and overinflation.

Previous results concerning clinical studies with HFV demonstrated very good results concerning oxygenation, being better than conventional ventilation with PEEP and, sometimes, lifesaving. It is true both when it is done as high frequency jet ventilation[14] or as high frequency oscillation[11,13]. Considering its physiological basis, HFV is a ventilatory strategy that maintains the respiratory system between the lower and the upper inflection points from pressure-volume curves[2]. Taking in account this information one could hypothesize that HFV can induce the same or greater alveolar recruitment than PEEP with less risk of overinflation. This hypothesis was not observed in the three patients described here.

Despite the small number of patients, this report was the first one showing lung density histogram during HFV and trying to quantify alveolar recruitment and lung overinflation with this ventilatory strategy, using the same sca-

Table 1 – Cardiorespiratory Parameters and Lung Volumes in ZEEP, HFV and PEEP in the Three Patients Studied

	ZEEP	HFV	PEEP
HR (bpm)	90 ± 20	88 ± 18	84 ± 22
MAP (mmHg)	93 ± 13	83 ± 14	89 ± 19
MPAP (mmHg)	29 ± 4	34 ± 1	29 ± 4
PAOP (mmHg)	16 ± 4	15 ± 5	12 ± 5
CI ($L.min^{-1}.m^{-2}$)	4.0 ± 1.6	3.2 ± 0.5	3.1 ± 0.7
SVR ($dynes.s.cm^{-5}.m^2$)	2004 ± 1383	1845 ± 791	2200 ± 1232
PVR ($dynes.s.cm^{-5}.m^2$)	303 ± 151	489 ± 210	449 ± 152
$PaCO_2$ (mmHg)	38 ± 10	46 ± 8	38 ± 4
PaO_2 (mmHg)	217 ± 62	283 ± 56	295 ± 20
PaO_2 + $PaCO_2$ (mmHg)	254 ± 66	329 ± 64	333 ± 22
DO_2 ($mL.min^{-1}.m^{-2}$)	500 ± 165	417 ± 41	405 ± 66
VO_2 ($mL.min^{-1}.m^{-2}$)	111 ± 35	109 ± 10	121 ± 13
Qs/Qt (%)	35 ± 5	30 ± 6	24 ± 4
Total lung volume (mL)	1630 ± 459	2555 ± 883	2729 ± 725
Overinflated volume (mL)	0 ± 0	15 ± 5	2 ± 2
(%)*	0 ± 0	0.4 ± 0.1	0.1 ± 0.1
Normally aerated volume (mL)	402 ± 270	1764 ± 683	1965 ± 501
(%)*	26 ± 15	68 ± 5	72 ± 6
Poorly aerated volume (mL)	705 ± 248	335 ± 58	329 ± 69
(%)*	44 ± 9	14 ± 3	12 ± 2
Non-aerated volume (mL)	523 ± 266	442 ± 138	433 ± 217
(%)*	31 ± 9	18 ± 3	16 ± 5
Recruitment** (%)*		49 ± 35	48 ± 27

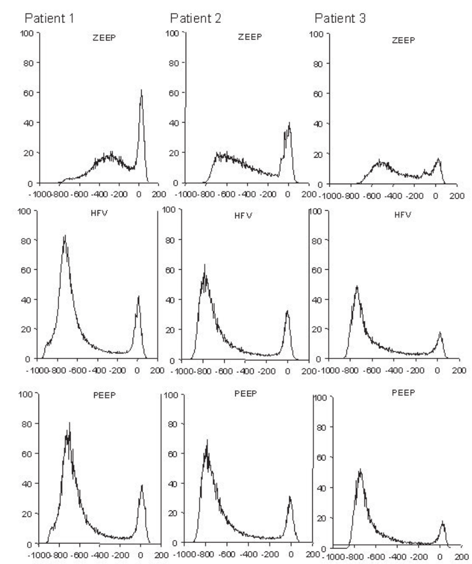
ZEEP= Zero PEEP; PEEP= Positive end-expiratory pressure; HFV= high frequency ventilation; HR = heart rate; MAP = mean arterial pressure; MPAP = mean pulmonary artery pressure; PAOP = pulmonary artery occlusion pressure; CI = cardiac index; SVR = indexed systemic vascular resistance; PVR = indexed pulmonary vascular resistance; $PaCO_2$ = arterial pressure of CO_2; PaO_2 = arterial pressure of oxygen; DO_2 = oxygen delivery; VO_2 = oxygen consumption; Qs/Qt = pulmonary shunt; * percentages over the total lung volume; ** recruitment calculated according to Malbouisson et al [Malbouisson, 2001 #1988].

nographic methods previously described for conventional ventilation with PEEP[19,20,28]. Maintaining the same mean airway pressure, lung density histograms were superimposable as well as the calculated volume of recruitment and overinflation.

The limitations of this report are that, till now, only three patients were included. Therefore, no definitive conclusion could be established from the observations described. A greater number of patients have to be enrolled in order to confirm the tendency observed here. In the same way, other protocols have to be considered using, for instance, the same plateau pressure instead of the same mean airway pressure.

In conclusion, we have described three patients in whom HFV was compared by CT scan methods with conventional mechanical ventilation with PEEP and, for the same mean airway pressure, both ventilatory methods showed similar lung density histograms as well as the same amount of alveolar recruitment and lung overinflation.

Figure 1: Individual lung density histograms in the 3 conditions; ZEEP = Zero PEEP; PEEP = Positive end-expiratory pressure; HFV = high frequency ventilation.



RESUMO

JUSTIFICATIVA E OBJETIVOS: A ventilação de alta freqüência (HFV) pode oferecer uma alternativa às estratégias ventilatórias convencionais em pacientes com síndrome da angústia respiratória aguda (SARA) ou lesão pulmonar aguda (LPA), pois pode minimizar a lesão pulmonar. Como mantém a ventilação entre os pontos de inflexão inferior e superior, pode assegurar recrutamento e reduzir a possibilidade de hiperinflação. O objetivo deste estudo foi comparar o recrutamento alveolar e a hiperinflação induzidos pela HFV *versus* ventilação mecânica convencional com pressão expiratória final positiva (PEEP), em três pacientes com LPA/SARA.

MÉTODO: Foi realizado um estudo prospectivo em uma Unidade de Tratamento Intensivo de um Hospital Universitário, avaliando três pacientes com LPA/SARA. Medidas tomográficas foram realizadas, utilizando um programa especial (Lungview), durante HFV e ventilação convencional com ou sem PEEP, em ordem aleatória. Durante HFV e PEEP a pressão média de vias aéreas era mantida constante. Foram comparados os histogramas de densidade pulmonares. O recrutamento alveolar foi calculado como a quantidade de ar que penetrava nas áreas pobremente e não aeradas. A hiperinflação foi calculada como o volume pulmonar com densidade abaixo de –900 unidades Hounsfield.

RESULTADOS: Os histogramas pulmonares foram similares em HFV e em PEEP. O percentual de recrutamento foi de 49 ± 35% *versus* 48 ± 27% e os valores de hiperinflação foram 15 ± 5 ml (0.4 ± 0.1 %) e 2 ± 2 ml (0,1 ± 0,1%), respectivamente em HFV e PEEP.

CONCLUSÕES: Nos três pacientes estudados, a aplicação de HFV ou de ventilação mecânica convencional com PEEP mostrou, para a mesma pressão média de via aérea,

histogramas de densidade pulmonares similares, bem como níveis semelhantes de recrutamento alveolar e de hiperinflação pulmonar.

Unitermos: Síndrome da angústia respiratória aguda; lesão pulmonar aguda; ventilação de alta freqüência; pressão expiratória final positiva; recrutamento alveolar, hiperinflação pulmonar.

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