Intensive Care Med (1999) 25: 1297–1301

BRIEF REPORT

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Safety and efficacy of a sustained inflation for alveolar recruitment in adults with respiratory failure

Received: 12 February 1999
Accepted: 8 September 1999

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Abstract *Objective:* To assess the safety and efficacy of a sustained inflation, used as a lung volume recruitment maneuver in ventilated patients with hypoxemic respiratory failure.
Design: Prospective data collection as part of a quality assurance program following introduction of a lung volume recruitment guideline in the intensive care unit.
Setting: Academic medical-surgical critical care unit.
Patients: Hypoxemic patients with bilateral pulmonary infiltrates. Patients with chronic obstructive pulmonary disease, pulmonary barotrauma and hemodynamic instability were excluded.
Interventions: A sustained inflation using a pressure of 30 to 45 cmH_2O was applied for 20 s. The pressure was determined as the lesser of 45 cmH_2O or the peak pressure while ventilated at a tidal volume of 12 ml/kg. Intra-arterial blood pressure and pulse oximetry were monitored continuously.
Measurements and results: Significant improvement in oxygenation occurred in the majority of patients within 10 min. The mean oxygen saturation improved from 86.9 ± 5.5 to 94.3 ± 2.3 % ($p < 0.01$). No significant adverse effects were noted: hypotension and mild oxygen desaturation occurred in some patients during the 20-s inflation, reversing rapidly after inflation was terminated. No barotrauma occurred.
Conclusions: A sustained inflation is a safe, clinically applicable method of lung volume recruitment which improves oxygenation in selected patients and may have a role in ventilatory management.

Key words Mechanical ventilation · Respiratory distress syndrome, adult · Lung physiopathology · Lung recruitment

Introduction

Based on increasing evidence that mechanical ventilation may induce lung injury [1], pressure-limited ventilatory strategies have been developed to reduce pulmonary baro- and volutrauma. Recent data have shown that routine limitation of inspiratory pressure does not necessarily improve outcome [2, 3]. These studies did not utilize a ventilatory strategy that prevented derecruitment of lung units, an approach which has been shown in animal studies to improve gas exchange and prevent lung injury caused by the shear stresses of the repetitive opening and closing of alveolar units [4]. In contrast, a study by Amato and colleagues suggested that an adequate lung volume recruitment strategy may be an important, and perhaps critical, component of a non-injurious pressure-limited strategy in humans [5]. This study based their lung protective ventilatory strategy on measurements of the pressure-volume (PV) characteristics of the respiratory system. In the group ventilated with the protective strategy, the positive end-expiratory pressure (PEEP) level was individualized to each patient at a value 2 cmH_2O greater than the lower inflection point (Pflex) of the PV curve. Concerns with this approach include the difficulty in measuring static PV curves and the potential risks to the patient of paralysis and loss of PEEP during the maneuver. Furthermore, the measured respiratory system Pflex may differ significantly from the actual lung Pflex, especially in patients with decreased chest wall compliance [6, 7].

In animal studies, a sustained inflation maneuver reverses the derecruitment associated with low pressure ventilation [8]. PEEP can then be used as a means of maintaining rather than producing recruitment. In the present study, we implemented a ventilation protocol in our intensive care unit (ICU) using a strategy to recruit the lungs through a sustained inflation and PEEP. In this report, we describe the safety and efficacy of this sustained inflation recruitment maneuver, as applied to patients with hypoxemic respiratory failure of various causes.

Patients and methods

Based on available laboratory and clinical data [5, 8, 9], guidelines for lung recruitment using a sustained inflation maneuver were developed and implemented in our ICU. These were applied in patients with hypoxemia on mechanical ventilation, at the discretion of the attending intensivist. Data were collected to assess the acute physiological benefit and adverse effects of this maneuver as part of an ICU quality assurance program, and this study reviews data from the first 14 patients.

Patients eligible for the recruitment protocol were those with hypoxemic respiratory failure and bilateral pulmonary infiltrates, who had been ventilated for less than 72 h. Those with obstructive airways disease, pulmonary barotrauma or hemodynamic instability were excluded. All patients were well sedated and neuromuscular blockade was given where clinically indicated for ventilatory management, but was not necessary for the recruitment protocol. All ventilatory parameters were set by the attending physician, including PEEP, for which our ICU does not have a specific protocol. Following a period of stable ventilation for 1 h, a brief standardized ventilation protocol, described below, was used to determine an appropriate recruitment inflation pressure. Patients were ventilated in a volume control mode with a tidal volume of 12 ml/kg and previously set PEEP for several breaths, and peak airway pressure was recorded. The recruitment inflation pressure was chosen as the lesser of 45 cmH_2O or the peak pressure at 12 ml/kg tidal volume. This allowed for an individualized recruitment pressure, so that patients with poor respiratory system compliance received a higher pressure, to a maximum of 45 cmH_2O. Because the initial PEEP levels varied, this method did not produce an identical recruitment volume in each patient. A pressure of 30 cmH_2O was used in the first 4 patients as an initial safety measure.

The ventilator was then adjusted to deliver a sustained inflation, by switching to the continuous positive airway pressure (CPAP) mode and increasing the pressure to the desired inflation pressure. This inflation pressure was maintained for 20 s, following which the CPAP was reduced to the original PEEP level and ventilation recommenced at baseline settings. The following parameters were monitored continuously during and after the inflation: oxygen saturation by pulse oximetry (SpO_2), arterial blood pressure and mixed venous oxygen saturation when available. Data were recorded at four time points: (i) immediately prior to recruitment; (ii) at the end of the 20-s inflation; (iii) 10 min post-recruitment; and (iv) 4 h post-recruitment. Fractional inspired oxygen (FIO_2) was not changed during this 4-h period. Patients who desaturated during this 4-h period were considered for repeat recruitment maneuvers. Patients were monitored continuously during the 4-h period and intermittently for 24 h, for the development of adverse events such as barotrauma (pneumothorax, subcutaneous emphysema), hypotension or desaturation.

Data are given as the mean (± standard deviation). Comparison of the mean saturation data between time periods was performed using a paired *t*-test. A p value < 0.05 was considered significant.

Results

Fourteen patients underwent the sustained inflation maneuver, and their diagnoses and ventilatory data are given in Table 1. Neuromuscular blockade was used in 4 patients. The recruitment pressure varied from 30 to 45 cmH_2O. The mean SpO_2 for the study group was 86.9 ± 5.5 % prior to the maneuver and decreased slightly to 86.0 ± 4.5 % at the end of the 20-s recruitment maneuver. The maximum decrease in saturation noted was 4 % (Fig. 1). By 10 min, mean saturation had improved to 94.3 ± 2.3 % ($p < 0.01$). Only 3 patients had pulmonary artery catheters in place, and mixed venous oxygen saturation in each of these increased within 10 min of the recruitment maneuver (mean 53 % increasing to 63 %). The improved level of oxygen saturation was maintained in 10 of the 14 patients for at least 4 h (Fig. 1). In the remaining 4 patients, a decrease in SpO_2 toward pre-recruitment levels occurred within 4 h. All 4 patients had a PEEP level less than or equal to 10 cmH_2O. Subsequent recruitment maneuvers with an increase in PEEP level were performed in 3 of these patients. A sustained improvement in oxygenation was noted (Fig. 2). One patient was considered too hemodynamically unstable for a repeat maneuver.

No significant adverse effects occurred and the procedures were well tolerated. The 20-s recruitment maneuver was completed in all patients. The arterial blood pressure decreased during the 20-s inflation (mean systolic decrease of 6.9 ± 9.5 mmHg), but in only 3 patients did the systolic level drop below 85 mmHg transiently. Bradycardia occurred in 1 patient. All these effects reversed rapidly after the inflation was terminated. Several patients who had not received neuromuscular blockade developed coughing during the inflation. No barotrauma was documented in follow-up for 24 h.

Discussion

The major finding of this study is that a sustained inflation of up to 45 cmH_2O for 20 s can be effective in im-

Table 1 Diagnoses and oxygenation characteristics of the 14 patients (*FIO_2* fractional inspired oxygen, *PaO_2* arterial oxygen tension, *SpO_2* oxygen saturation, *ARDS* acute respiratory distress syndrome)

Patient and diagnosis	Duration of ventilation (h)	FIO_2	PEEP (cmH_2O)	PaO_2/FIO_2	Initial SpO_2 (%)	Recruitment pressure (cmH_2O)
1. Bone marrow transplant/ARDS	1	1.0	12	175[a]	84	30
2. Negative pressure pulmonary edema	1	0.5	10	242[a]	88	30
3. Heart failure	28	0.4	10	175	95	30
4. Aspiration/ARDS	16	0.5	10	136	95	30
5. Sepsis/ARDS	72	0.6	9	107	89	45
6. Post-cardiac arrest/ARDS	4	1.0	7	52	87	30
7. Heart failure	20	0.9	8	100	88	35
8. Heart failure	3	0.5	5	118	87	40
9. Sepsis/ARDS	9	0.6	9	97	88	45
10. Viral pneumonitis	14	0.65	16	106	87	45
11. Bone marrow transplant/ARDS	2	1.0	20	42	85	40
12. Sepsis/ARDS	72	0.55	14	163	88	35
13. Bone marrow transplant/ARDS	1	0.90	15	63	71	40
14. Pneumonia/ARDS	2	0.60	12	146[a]	87	40

[a] PaO_2/FIO_2 post-recruitment: no pre-recruitment arterial blood gas determination performed

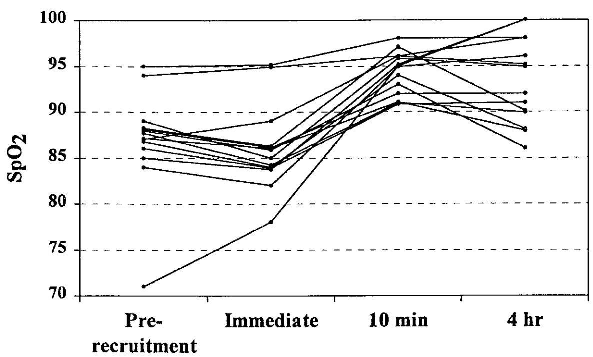

Fig. 1 Graph of oxygen saturation *SpO_2* against time period for the 14 patients. *Pre-recruitment* = immediately prior to the recruitment maneuver; *Immediate* = at the end of the 20-s inflation; *10 min* = at 10 min following recruitment maneuver; *4 h* = 4 h following recruitment maneuver

proving oxygenation in a select group of ventilated patients with persistent hypoxemia and bilateral airspace disease. We do not mean to imply that this is the optimum approach to recruitment, but it is one approach that is clinically applicable at the bedside in all ICUs. For this reason, we implemented this strategy in our ICU and evaluated its safety. The present study indicates that this approach is safe and is applicable to patients with various underlying conditions, but requires monitoring of SpO_2 and arterial blood pressure. Recruitment will lead to increased lung volume, increased pleural pressure and may decrease cardiac output and blood pressure. While an improvement in SpO_2 occurred in all our patients, these were selected subjects early in their clinical course, and this benefit may not apply in all hypoxemic patients.

The methodology employed in our protocol was developed empirically, using an inflation pressure of 30 to 45 cmH_2O, a range that was likely to produce recruitment but unlikely to cause alveolar overdistension, based on available animal and clinical data. In rabbits with stiff lungs induced by lung lavage, a recruitment effect was demonstrated using pressures as low as 30 cmH_2O [8]. Clinical studies have shown that a sustained pressure of 40 cmH_2O was necessary to reverse atelectasis in patients with general anesthesia-induced atelectasis [10] or a plateau pressure of 46 cmH_2O in subjects with the acute respiratory distress syndrome (ARDS) [9]. An inflation pressure of 30 to 45 cmH_2O was used in Amato's clinical trial of "open lung" ventilation [5]. It is likely, however, that patients who have stiff chest walls (e. g., massive ascites) will require higher sustained inflation pressures to ensure recruitment [6]. In addition to an adequate pressure level, a critical duration of application is needed to improve oxygenation and pulmonary mechanics [11]. Reported studies have used 15- to 20-s inflations effectively [5, 8, 10]. The use of a 20-s inspiratory hold potentially allows the opening of lung units with long time constants, at moderate pressures. We used the ventilator to apply the inflation, rather than an external anaesthetic bag, for better control of the administered pressure and to avoid the potential for derecruitment during ventilator disconnection.

Loss of the beneficial effects of the recruitment maneuver during the 4-h follow-up was noted in 4 patients. This may be the result of a PEEP level insufficient to maintain recruitment in these 4 patients, who all had PEEP levels less than or equal to 10 cmH_2O (mean 7.5 cmH_2O). The subsequent sustained improvement in oxygenation in the 3 patients who had repeat recruitment maneuvers and institution of higher PEEPs is in

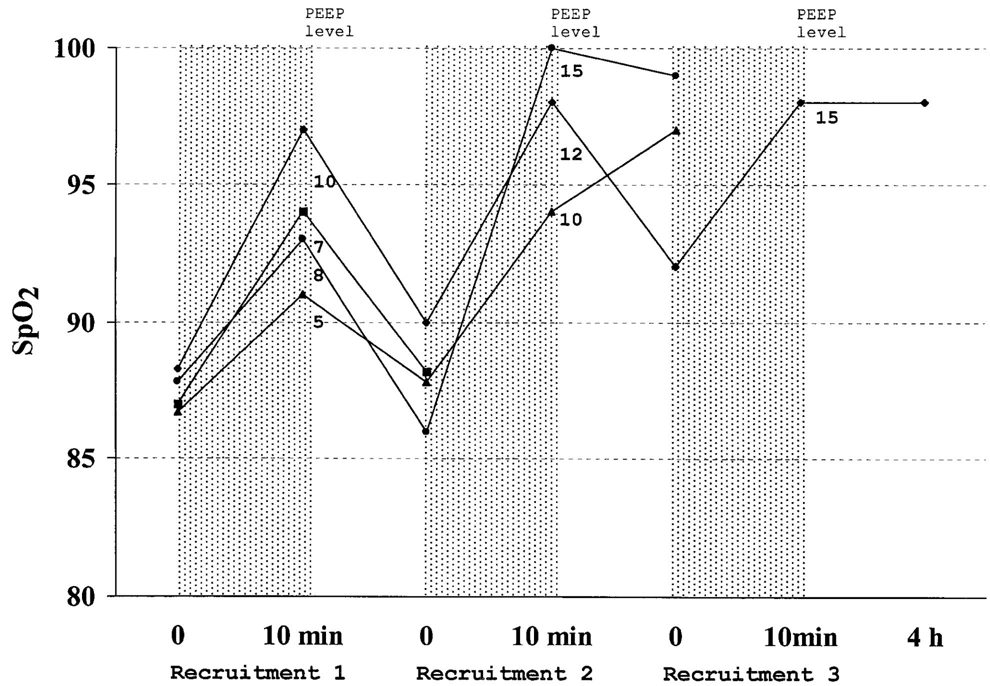

Fig. 2 Oxygen saturation levels *SpO_2* in the four patients who desaturated within 4 h of the initial recruitment maneuver *Recruitment 1.* Successive recruitment maneuvers *Recruitment 2 & 3* were performed in three patients at the same inflation pressure. The time period between recruitment maneuvers varied from 30 to 120 min. PEEP level was increased after each maneuver as indicated. One patient was too hemodynamically unstable for subsequent maneuvers. For each recruitment maneuver:
Time 0 = pre sustained inflation, 10 min = 10 minutes post-sustained inflation

accord with this hypothesis. The composition of inspired gas may also play a role in maintaining the recruitment effect, with more rapid derecruitment occurring at a higher FIO_2 [12].

Our clinical practice is to monitor SpO_2 after recruitment, and if the oxygenation benefit is not maintained the sustained inflation is repeated with an increase in the subsequent PEEP level. FIO_2 should be reduced to the lowest acceptable level, to prevent lung injury as well as to reduce the rate of derecruitment. The recruitment maneuver should be performed after all ventilator disconnects (e.g., suctioning). A sustained inflation recruitment maneuver may be an important component of a pressure-limited ventilation strategy, to improve oxygenation and prevent ventilator-induced lung injury [5, 8]. It is not known whether this maneuver has a benefit over other recruitment interventions, such as high PEEP levels or prone positioning. The optimal duration, pressure level and frequency of the sustained inflation remain to be determined, and the long-term clinical benefit of lung volume recruitment strategies is unknown.

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