Original Article

Lung recruitment maneuver effects on respiratory mechanics and extravascular lung water index in patients with acute respiratory distress syndrome

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BACKGROUND: Animal experiments showed that recruitment maneuver (RM) and protective ventilation strategy of the lung could improve oxygenation and reduce extravascular lung water. This study was to investigate the effects of RM on respiratory mechanics and extravascular lung water index (EVLWI) in patients with acute respiratory distress syndrome (ARDS).

METHODS: Thirty patients with ARDS were randomized into a RM group and a non-RM group. In the RM group, after basic mechanical ventilation stabilized for 30 minutes, RM was performed and repeated once every 12 hours for 3 days. In the non-RM group, lung protective strategy was conducted without RM. Oxygenation index ($\text{PaO}_2/\text{FiO}_2$), peak inspiratory pressure (PIP), Plateau pressure (Pplat), static pulmonary compliance (Cst) and EVLWI of patients before treatment and at 12, 24, 48, 72 hours after the treatment were measured and compared between the groups. Hemodynamic changes were observed before and after RM. One-way ANOVA, Student's *t* test and Fisher's exact test were used to process the data.

RESULTS: The levels of $\text{PaO}_2/\text{FiO}_2$ and Cst increased after treatment in the two groups, but they were higher in the RM group than in the non-RM group ($P < 0.05$). The PIP and Pplat decreased after treatment in the two groups, but they were lower in the RM group than in the non-RM group ($P < 0.05$). The EVLWI in the two groups showed downward trend after treatment ($P < 0.05$), and the differences were significant at all time points ($P < 0.01$); the EVLWI in the RM group was lower than that in the non-RM group at 12, 24, 48 and 72 hours ($P < 0.05$ or $P < 0.01$). Compared with pre-RM, hemodynamics changes during RM were significantly different ($P < 0.01$); compared with pre-RM, the changes were not significantly different at 120 seconds after the end of RM ($P > 0.05$).

CONCLUSIONS: RM could reduce EVLWI, increase oxygenation and lung compliance. The effect of RM on hemodynamics was transient.

KEY WORDS: Lung recruitment maneuver; Acute respiratory distress syndrome; Respiratory mechanics; Extravascular lung water index; Hemodynamics; Lung protective ventilation; Oxygenation index

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INTRODUCTION

In patients with acute respiratory syndrome (ARDS), disturbance of ventilation-perfusion ratio caused by redundant extravascular lung water may

cause severe hypoxemia and a high fatality rate.^[1] Mechanical ventilation, as the primary treatment of ARDS, can effectively improve the oxygen content and reduce lung injury. Low-tidal-volume ventilation

can reduce the fatality rate and shorten the duration of mechanical ventilation, but it may cause some alveolar collapse and even refractory hypoxemia. Animal experiments showed that both recruitment maneuver (RM) and protective ventilation of the lung could improve oxygenation and reduce extravascular lung water.^[2] The present study was to detect the effects of RM on respiratory mechanics and extravascular lung water index in patients with ARDS.

METHODS

Patients and methods

In this prospective randomized study, 30 patients with ARDS admitted to ICU of the First Affiliated Hospital of Nanchang University from April 2007 to December 2008 were enrolled. The patients met the diagnostic criteria of ARDS set by the Society of Critical Diseases of the Chinese Medical Association,^[3] but patients with instable hemodynamics were excluded.

Mechanical ventilation in all patients was conducted with Puritan Bennett 840 breathing machine (USA). The patients were divided into a non-RM group and a RM group. In the non-RM group ($n=15$), the lungs of the patients were ventilated with basic mechanical ventilation: square wave ventilation, VT 6-8 mL/kg IBW, ratio of inspiratory to expiratory 1:2; PEEP was adjusted according to inspired oxygen concentration,^[4] which was to maintain PEEP at a minimum level. In the RM group ($n=15$), patients' lungs were initially ventilated with the same respiratory variables. After the basic mechanical ventilation stabilized for 30 minutes, lung recruitment maneuver was performed: inspiratory pressure (pressure above PEEP) 20 cmH₂O, ratio of inspiratory to expiratory 1:1 remained at the same level, while lungs were recruited by increasing the PEEP in a stepwise fashion, first to 10 cmH₂O (3 breaths), then to 15 cmH₂O (3 breaths), and finally to 20 cmH₂O (10 breaths). The performance of RM needed about 2 minutes, and it was repeated once every 12 hours and lasted 3 days. After the RM, all parameters were adjusted to the original levels. During the whole course of treatment, PaO₂ 60-80 mmHg, SpO₂ 90%-95%, pH 7.30-7.45, and plateau pressure less than 30 cmH₂O were required.

Parameters

The levels of PaO₂ and FiO₂ were recorded before treatment and at 12, 24, 48, 72 hours after the treatment.

Oxygenation index was calculated according to the ratio of PaO₂ and FiO₂. The peak inspiratory pressure (PIP), peak plateau pressure (Pplat) and quasi-static compliance (Cst) were recorded before treatment and at 12, 24, 48, 72 hours after the treatment with ventilators (Puritan Bennett 840, USA). The extravascular lung water index (EVLWI) of the two groups were monitored at different time points by a PICCO monitor, and heart rate (HR), mean arterial pressure (MAP), central venous pressure (CVP) and cardiac insufficiency (CI) of the RM-group were recorded before, during and at 60, 120, 300 seconds after lung recruitment.

Statistical analysis

All data were analyzed with SPSS 16.0. Measurement data were expressed as mean $\pm$ standard deviation (SD). The data among different time points were compared using one-way analysis of variance (ANOVA). The difference between time points was determined by the Dunnett-t test, and between the groups by Student's *t* test. Fisher's exact test was used to process the enumeration data. A $P < 0.05$ was considered statistically significant.

RESULTS

There were no significant differences in age, gender, etiology of ARDS or APACHE II score between the two groups ($P > 0.05$). Before treatment, no significant differences were observed in PaO₂/FiO₂, Cst, PIP or Pplat between the two groups ($P > 0.05$). After treatment, the levels of PaO₂/FiO₂ and Cst in the two groups increased, but they were higher in the RM group than in the non-RM group ($P < 0.05$); after treatment, the levels of PIP and Pplat decreased in the two groups, but they were lower in the RM group than in the non-RM group ($P < 0.05$) (Figures 1-4).

There were also no significant differences in EVLWI between the two groups before treatment ($P > 0.05$), but after treatment, the EVLWI in the two groups decreased ($P < 0.05$), and the differences were significant at all time points ($P < 0.01$). Patients in the RM group had a significantly higher EVLWI at 12, 24, 48, 72 hours ($P < 0.05$ or $P < 0.01$) (Table 1).

During RM, the levels of MAP and CI decreased, but those of HR and CVP increased. Compared to pre-RM, the changes of these parameters were significantly different ($P < 0.01$), whereas compared to pre-RM, the changes were not significantly different at 120 seconds after the end of RM ($P > 0.05$) (Figure 5).

Table 1. Comparison of EVLWI at different time points between the two groups (mean $\pm$ SD, ml/kg)

Groups	0 h	12 h	24 h	48 h	72 h
RM	15.18 $\pm$ 1.22	13.32 $\pm$ 1.13*	12.57 $\pm$ 0.98*	12.22 $\pm$ 0.92*	11.96 $\pm$ 1.03*
Non-RM	15.06 $\pm$ 1.13	14.14 $\pm$ 1.02	13.66 $\pm$ 1.10*	13.28 $\pm$ 1.15*	13.02 $\pm$ 1.06*
<i>t</i>	0.280	-2.082	-2.873	-2.787	-2.780
<i>P</i>	0.781	0.047	0.008	0.009	0.010

Compared with 0 h, **P*<0.01 **Figure 1.** Comparison of PaO₂/FiO₂ between the two groups. **Figure 2.** Comparison of PIP between the two groups. **Figure 3.** Comparison of Pplat between the two groups. **Figure 4.** Comparison of Cst between the two groups. **Figure 5.** Changes of HR, MAP, CVP, and CI in patients with ARDS according to recruitment maneuver.

DISCUSSION

In ARDS patients, the disturbance of ventilation-perfusion ratio caused by redundant extravascular lung water can contribute to serious hypoxemia and

a high fatality rate. Low-tidal-volume ventilation as a fundamental treatment of ARDS can reduce the mortality of severe ARDS and also lead to some alveolar hyperventilation, and even alveolar collapse.^[5,6] Animal experiments showed that RM and protective ventilation of the lung in ARDS rabbits improved oxygenation and reduced extravascular lung water index.^[7-9] Pulse contour continuous cardiac output (PICCO) is the only technology that can provide a quantitative indicator of EVLW at the bedside.^[10] In this study, we used PICCO to observe the effects of RM on respiratory mechanics and EVLWI in ARDS patients.

The results of the study showed that the levels of PaO₂/FiO₂ and Cst in the RM group were higher than those in the non-RM group at each time point, but the levels of PIP and Pplat were lower than those of the non-RM group (*P*<0.05). Clearly, RM effectively increased lung compliance and improved oxygenation. It was

possible that RM kept a high airway pressure at the end of inspiration so as to make the different alveolar compliance to achieve balance, promoted more collapsed alveolar re-opening, and improved gas distribution and ventilation/perfusion ratio.^[11-13] RM gradually made alveolar open at different time points, and also extended the time for gas exchange. EVLWI in the RM group decreased after treatment, but in the RM group it was lower than that in the non-RM group at 12, 24, 48 and 72 hours ($P<0.05$ or $P<0.01$). Hence RM increased the clearance of extravascular lung water, as was reported elsewhere.^[8,14] Possibly, RM improved gas distribution in the lung, increased lung water clearance area, and reduced pulmonary blood flow. At the same time, RM decreased the loss of pulmonary surfactant protein, the pulmonary inflammatory response, the injury of alveolar epithelial cells and lung endothelial cells, and improved pulmonary vascular barrier function.^[15,16] Moreover, RM increased the mRNA expression of surfactant protein in the lung.^[17] In the non-RM group, EVLWI decreased after treatment because of the use of lung protective ventilation, the treatment of primary disease and the negative fluid balance. There is no clear answer to how much pressure should be selected in RM, but at present 30-50 cmH₂O is considered as the best.^[18] In this study 15 patients in the RM-group received pressure control ventilation with positive end-expiratory pressure of 20 cmH₂O and pressure control above positive end-expiratory pressure of 20 cm H₂O for 2 minutes (pressure control recruitment maneuver). All these patients in the RM-group didn't develop pneumothorax, mediastinal emphysema and other complications. Transient hypotension and change of cardiac index were also seen during RM possibly because of a marked right-ventricular dysfunction. Systolic blood pressure, heart rate, or cardiac index was not changed significantly at 120 seconds after RM. This finding proved that RM is safe in clinical practice, as was reported in the literature.^[19,20]

In summary, lung recruitment maneuver can improve oxygenation in patients with ARDS, lower EVLWI, increase lung compliance, and decrease airway pressure. In addition, lung recruitment maneuver is safe in clinical treatment.

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Ethical approval: This study was approved by the Ethics Committee of the hospital.

Conflicts of interest: No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

Contributors: Zhang JG proposed and wrote the study. All authors contributed to the design and interpretation of the study and to further drafts.

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