Journal of Critical Care (2013) **28**, 534.e1–534.e5

ELSEVIER

Journal of Critical Care

Effectiveness of end-expiratory lung volume measurements during the lung recruitment maneuver for patients with atelectasis

Susumu Nakahashi PT, MS*, Satoshi Gando MD, PhD, Takehiko Ishikawa MD, PhD, Takeshi Wada MD, PhD, Yuichiro Yanagida MD, Nobuhiko Kubota MD, PhD, Shinji Uegaki MD, Mineji Hayakawa MD, PhD, Atsushi Sawamura MD, PhD

Division of Acute and Critical Care Medicine, Department of Anesthesiology and Critical Care Medicine, Hokkaido University Graduate School of Medicine, N15W7 Kita-ku, Sapporo 060-8638, Japan

Keywords:
Recruitement maneuver;
Atelectasis;
Functional residual capacity;
End-expiratory lung volume;
Respiratory therapy

Abstract

Purpose: The aim of this study was to determine whether the relative change in the end-expiratory lung volume (EELV) obtained by the recruitment maneuver (RM) can serve as an indicator of the change in the P/F ratio.

Materials and Methods: The effects of the intermittent stepwise increases in the RM (peak inspiratory pressure, 45, 50, and 55 cm H_2O) were compared in 21 patients with atelectasis under mechanical ventilation. The EELV, the ratio of arterial oxygen concentration to the fraction of inspired oxygen P/F ratio, and relative change rate (Δ) in these parameters were evaluated after each RM.

Results: A greater improvement in the EELV (1157 ± 344 mL vs 1469 ± 396 mL) and P/F ratio (250 ± 99 vs 320 ± 92) was observed after the RM. The ΔEELV was correlated with the ΔP/F ratio ($\rho = 0.73$, $P < .01$) and was identified as an accurate predictor of the improvement of the ΔP/F ratio by the receiver operating characteristic curve (the area under the curve, 0.93; $P < .01$).

Conclusions: These results suggest that the ΔEELV obtained by intermittent stepwise RM can serve as an indicator of the change in the P/F ratio.

1. Introduction

The lung recruitment maneuver (RM) is a method used for reinflation (recruitment) to achieve the recovery of lung volume by transiently increasing the transpulmonary pressure to reopen collapsed alveoli [1,2]. Recruitment is achieved in the inspiratory phase; however, insufficient inspiratory pressure fails to achieve reopening. On the other hand, the alveolar overinflation and increase in transpulmonary pressure induced by applying high pressure can cause lung injury [3] and circulatory depression, resulting in decreased cardiac output and arrhythmia. Therefore, safe and effective settings for the application of pressure are required. An assessment that could be performed during RM

* Corresponding author. Tel.: +81-011-7067377; fax: +81-011-7067378.
E-mail address: n14w4@s3.dion.ne.jp (S. Nakahashi).

0883-9441/$ – see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.jcrc.2012.11.003

was needed to determine whether the collapsed alveoli were reopened.

The most accurate assessment of the reopening of collapsed alveoli is provided by a computed tomographic (CT) scan, but this method is not a reasonable bedside system in the intensive care unit (ICU). Although an arterial blood gas analysis is also used as an indicator of reopening [4], it is invasive and cumbersome when it has to be measured frequently in a short period. In addition, it does not indicate the lung volume directly. Therefore, it is critical to develop a simple bedside method for evaluating the effects of the RM for reopening collapsed alveoli in the clinical setting.

Recently, it has become possible to measure the end-expiratory lung volume (EELV) automatically, and it is identical to the EELV measured by CT [5,6]. In addition, it is well known that the EELV increases when the collapsed alveoli are reopened after the RM [6-9]. However, no studies have discussed the effects of stepwise increases in the inspiratory pressure using the change in the EELV as an indicator for the improvement of the P/F ratio induced by the reopening of collapsed alveoli.

The present study was conducted to test the hypothesis that the change in the EELV (ΔEELV) obtained by RM can serve as an accurate indicator of the change in the P/F ratio.

2. Materials and methods

2.1. Patient selection

The present study was approved by the Human Ethics Committee of the Hokkaido University Hospital, and written informed consent was obtained from each patient's next of kin. This study was conducted between July 2010 and December 2011. Twenty-one postoperative mechanically ventilated patients with atelectasis on their chest radiograph in the ICU of Hokkaido University Hospital were enrolled in this study. Patients were excluded if they had a chronic obstructive lung disease, interstitial lung disease, pneumothorax, pulmonary thromboembolism, pneumonia, acute respiratory distress syndrome (ARDS), the ratio of arterial oxygen concentration to the fraction of inspired oxygen (P/F ratio) P/F ratio less than 100, hemodynamic instability, or copious secretion retention (need for suctioning >3 times/2 h or the need for bronchofiberscopy) or if they were receiving percutaneous cardiopulmonary support and extracorporeal membrane oxygenation. Additional exclusion criteria were the deterioration of the general condition of the patient during the study period and hemodynamic instability (change in the blood pressure and/or heart rate ≥ 15%) caused by the RM.

2.2. Ventilator settings and measurements

During the study period, the patients were ventilated with an EC ventilator (GE Healthcare, Madison, Wis) with a COVX module (GE Healthcare, Helsinki, Finland). The patients were initially ventilated in a synchronized-intermittent mandatory ventilation mode with volume control, with a tidal volume of 8 mL/kg ideal body weight, an inspiratory/expiratory (I/E) ratio of 1:2 without an inspiratory pause, a respiratory rate adjusted to achieve normocapnia, and appropriate levels of positive end-expiratory pressure (PEEP) based on the experienced clinical judgment of their physicians (baseline ventilation conditions). The patients were ventilated under deep sedation (Richmond Agitation Sedation Scale −5) and had no spontaneous breathing efforts during the study period because EELV measurements are affected by spontaneous breathing variations. No muscle relaxants were used.

The RM composed of consecutive 3 breaths with a PEEP of 20 cm H_2O and a peak inspiratory pressure (PIP) of 45, 50, or 55 cm H_2O were performed 3 times [10,11]. A schematic diagram of the protocol is shown in Fig. 1. Owing to the accurate control of inspiratory pressure, we changed the ventilatory mode from the volume-controlled mode to the pressure-controlled mode during the RM. The EELV was

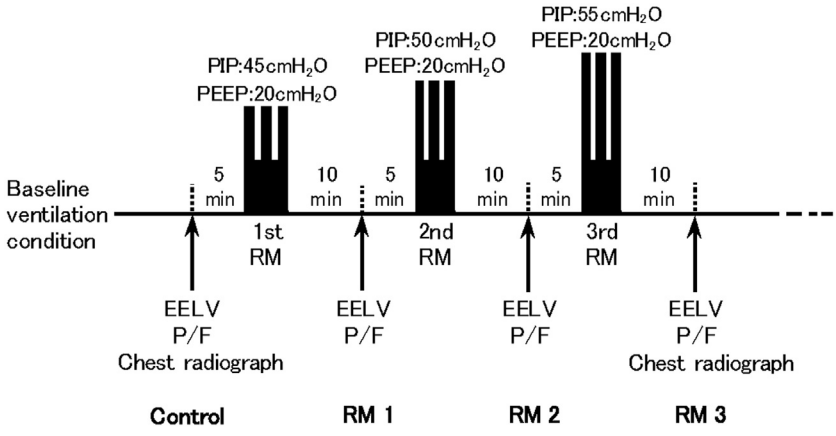

Fig. 1 The study protocol. The RM was conducted under pressure-controlled ventilation with a PEEP of 20 cm H_2O and a PIP of 45, 50, or 55 cm H_2O. The EELV and P/F ratio were measured 10 minutes after each RM (RMs 1, 2, and 3) and 5 minutes before the first RM.