J Anesth (2007) 21:116–117
DOI 10.1007/s00540-006-0472-z

Journal of Anesthesia

Recent advances in strategy for prevention and treatment of lung injury: prevention of ventilator-associated lung injury

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In patients with acute lung injury (ALI) and those with acute respiratory distress syndrome (ARDS), inappropriate mechanical ventilation further damages the lungs, and lung protective strategies have been recommended. We evaluated the effects of a lung protective strategy in 14 patients who developed ALI after pulmonary thromboendarterectomy (PTE) surgery for chronic thromboembolic pulmonary hypertension (CTEPH) [1]. Because ALI may start immediately after the weaning from cardiopulmonary bypass in these patients, we presume that a lung protective strategy should be more effective than that in other ALI/ARDS patients.

Limitation of tidal volume/plateau pressure

The limitation of tidal volume to 6 ml·kg^{-1} improved survival in ALI/ARDS patients, compared to a tidal volume of 12 ml·kg^{-1} [2]. However, Eichacker et al. [3] proposed that the difference was due to high plateau pressure in the control group. Although limiting tidal volume below 6 ml·kg^{-1} and plateau pressure below 30 cmH_2O is commonly accepted, it is still controversial which restriction is more important, tidal volume or plateau pressure. By re-analyzing ARDSnet data, Deans et al. [4] suggested that an increase in tidal volume was associated with decreased mortality in a subgroup with high compliance (>0.6 ml·cmH_2O^{-1}·kg^{-1}), whereas the increase was associated with increased mortality in a subgroup with low compliance (<0.6 ml·cmH_2O^{-1}·kg^{-1}).

In patients after PTE surgery, we initially applied a large tidal volume (12.5 ± 1.4 ml·kg^{-1}). We adopted this setting because large tidal volume is thought to be helpful in avoiding hypercapnia-induced pulmonary hypertension after the surgery. In fact, the plateau pressure in these patients remained low (25.1 ± 3.8 cmH_2O) and seemed safe because their compliance was high (0.70 ml·cmH_2O^{-1}·kg^{-1}).

Recruitment maneuver

The recruitment maneuver is the application of high airway pressure for short duration to open peripheral airways and alveoli that were previously occluded. After PTE surgery, we performed the recruitment maneuver by increasing the positive end-expiratory pressure (PEEP) to 30 cmH_2O for 1 min under pressure control ventilation. This improved Pa_{O_2} at $F_{I_{O_2}}$ 1.0 from 240 ± 62 mmHg to 470 ± 93 mmHg (Fig. 1). However, the clinical implications of the recruitment maneuver need to be clarified.

High PEEP

A recent clinical study compared a higher PEEP (13.2 ± 3.5 cmH_2O) with a conventional PEEP setting (8.3 ± 3.2 cmH_2O) [5]. When tidal volume was kept at 6 ml·kg^{-1}, there was no difference in patient survival or length of mechanical ventilation between the two set-

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Received: August 3, 2006

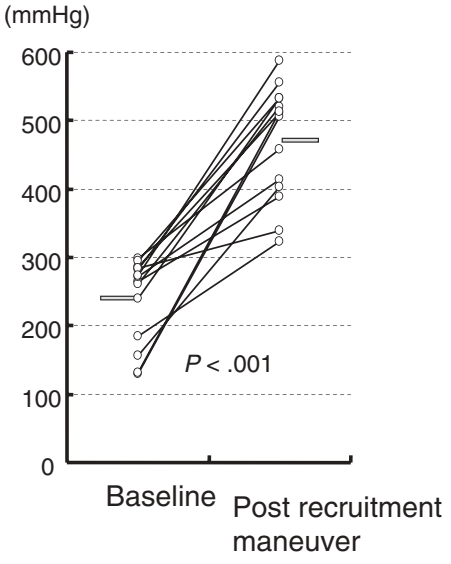

Fig. 1. Oxygenation in each patient before and after the recruitment maneuver. The recruitment maneuver improved Pa_{O_2} in each patient. Average Pa_{O_2} (*thick bars*) significantly increased from 240 ± 62 mmHg at the baseline to 470 ± 83 mmHg ($P < 0.001$). $F_{I_{O_2}}$ was held at 1.0 throughout the measurement

tings of PEEP. However, we believe this result can be interpreted in a different way: higher PEEP at least did not worsen the prognosis of ALI/ARDS patients.

It is still controversial how to set the optimal PEEP. It is simple to use the PEEP/$F_{I_{O_2}}$ table that ARDSnet used. However, evaluation of a pressure-volume curve may offer more appropriate adjustment of PEEP in individual patients. For our patients after PTE surgery, for whom we decreased the PEEP level in a stepwise manner after the recruitment maneuver, we determined the minimal PEEP, at which oxygenation and compliance were maintained.

Timing of the application of lung protective strategy

Many animal studies suggest that the early application of a lung protective strategy improves oxygenation and aids in the prevention of lung injury. Accordingly, we extended our lung protective strategy to the intraoperative management of PTE surgery: PEEP was elevated to 8–10 cmH_2O soon after the weaning from cardiopulmonary bypass. Since the introduction of the respiratory management protocol, the median length of mechanical ventilation has been shortened from 40 h to 22 h. This observation may support the concept of the early initiation of lung protective strategy.

In conclusion, in all patients who developed ALI after PTE surgery for CTEPH, the recruitment maneuver and high PEEP in the early period was effective in improving oxygenation and probably in weaning from mechanical ventilation. We need to search for the best protective lung strategy method by resolving the following questions: (1) whether the restriction of plateau pressure is more important than decreasing tidal volume, (2) whether the recruitment maneuver really has benefit, and (3) the way we should adjust PEEP.

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