Lung and chest wall properties during mechanical ventilation

Akademisk avhandling
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Avhandlingen baseras på följande delarbeten:

I. Persson P., Lundin S., Stenqvist O.
Transpulmonary and pleural pressure in a respiratory system model with an elastic recoiling lung and an expanding chest wall
Intensive Care Medicine Experimental 2016 Dec; 4(1): 26-.

II. Persson P., Stenqvist O., Lundin S.
Evaluation of lung and chest wall mechanics during anaesthesia using the PEEP-step method
British Journal of Anaesthesia, 2018 Apr; 120(4):860-867

III. Persson P., Ahlstrand R., Gudmundsson M., de Leon A., Stenqvist O., Lundin S.
Detailed measurement of esophageal pressure during mechanical ventilation with an advanced high-resolution manometry catheter
Submitted

IV. Persson P., Stenqvist O., Lundin S.
The chest wall during mechanical ventilation – an experimental study in a pig model
In manuscript

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Abstract

Background: Mechanical ventilation causes injury to the lungs due to high pressures and high volumes. Pressure affecting the lungs, the transpulmonary pressure, needs to be monitored to minimise harmful side effects but then lung and chest wall mechanics need to be separately considered. The conventional method is based on measurement of esophageal pressures but the interpretation of these pressures is debated. A non-invasive "PEEP-step method" for calculation of transpulmonary pressure has been introduced and tested in pigs and in patients in the ICU but still it has not been generally accepted. The aim of this thesis was to (1) validate the PEEP-step method in patients, (2) assess factors influencing the conventional method using esophageal pressure measurements and (3) evaluate lung and chest wall mechanics during mechanical ventilation.

Methods: In a mechanical model, based on the classical description of the respiratory system with a recoiling lung and an expanding chest wall, the theoretical explanation for the PEEP-step method was tested. The PEEP-step method, involving changes of PEEP and calculation of changes in end-expiratory lung volume, was further evaluated by comparison with the conventional method, based on esophageal pressure, in 24 patients undergoing general anaesthesia. In the third study esophageal pressures were evaluated with an advanced High Resolution Manometry (HRM) catheter in 20 mechanically ventilated patients in the ICU and Operating theatre as well as in 17 awake spontaneous breathing patients in sitting and supine positions. HRM permits simultaneous measurements of pressure at all levels in esophagus. Finally chest wall mechanics during mechanical ventilation were studied in pigs using electric impedance tomography, esophageal pressures and measurement of the recoiling pressure after pneumothorax and of the thoracic volume before and after pneumothorax (determined with computer tomography).

Results: The respiratory system model with a recoiling lung inside an expanding chest wall connected to an abdomen with high plasticity behaved similarly to patients during tidal and PEEP-induced inflation. The change in end-expiratory lung volume after an increase in PEEP was determined by the elastance of the lung and the size of the PEEP-change. Elastance of the lung and transpulmonary pressure could be calculated from a PEEP-step manoeuvre. In patients, transpulmonary driving pressure calculated with the PEEP-step method and the conventional method showed good agreement (mean difference < 0.2 cmH_2O). The calculated change in end-expiratory pleural pressure was -0.1 cmH_2O after an increase of PEEP. When esophageal pressures were measured with HRM, there was a substantial variation within individual patients (mean difference between highest and lowest esophageal pressures within a patient was 23.7 cmH_2O) as well as a significantly higher mean pressure in supine compared to sitting position (mean difference 12.3 cmH_2O). In the supine position, larger cardiac artefacts were seen as well as simultaneous increases and decreases in esophageal pressures within a patient. In pigs, the distribution of a tidal inflation and a PEEP-induced inflation within the lung was similar. The recoiling pressure of the lung at functional residual capacity was 3.9 cmH_2O. Calculated end-expiratory chest wall elastance was low (0.6-2.3 cmH_2O/L) compared to tidal chest wall elastance (10.0-13.6 cmH_2O/L).

Conclusions: The PEEP-step method accurately measures transpulmonary driving pressure. After an increase of PEEP the chest wall expands and restores the negative pleural pressure at end-expiration and the change in end-expiratory lung volume is dependent on lung elastance. Esophageal pressures are affected by many factors and vary substantially within individual patients. An equally large tidal and PEEP-induced inflation have similar distributions within the lung and necessitates an equally large change in transpulmonary pressure. The chest wall exerts an expanding force on the lung at end-expiration, which causes the end-expiratory pleural pressure to remain negative also at higher PEEP levels.

Keywords: Mechanical ventilation, Respiratory mechanics, Ventilator induced lung injury, Esophageal pressure, Positive end-expiratory pressure

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