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Respiration and the Airway

Detection of optimal PEEP for equal distribution of tidal volume by volumetric capnography and electrical impedance tomography during decreasing levels of PEEP in post cardiac-surgery patients

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Abstract

Background: Homogeneous ventilation is important for prevention of ventilator-induced lung injury. Electrical impedance tomography (EIT) has been used to identify optimal PEEP by detection of homogenous ventilation in non-dependent and dependent lung regions. We aimed to compare the ability of volumetric capnography and EIT in detecting homogenous ventilation between these lung regions.

Methods: Fifteen mechanically-ventilated patients after cardiac surgery were studied. Ventilator settings were adjusted to volume-controlled mode with a fixed tidal volume (Vt) of 6–8 ml kg^{-1} predicted body weight. Different PEEP levels were applied (14 to 0 cm H_2O, in steps of 2 cm H_2O) and blood gases, Vcap and EIT were measured.

Results: Tidal impedance variation of the non-dependent region was highest at 6 cm H_2O PEEP, and decreased significantly at 14 cm H_2O PEEP indicating decrease in the fraction of Vt in this region. At 12 cm H_2O PEEP, homogenous ventilation was seen between both lung regions. Bohr and Enghoff dead space calculations decreased from a PEEP of 10 cm H_2O. Alveolar dead space divided by alveolar Vt decreased at PEEP levels ≤6 cm H_2O. The normalized slope of phase III significantly changed at PEEP levels ≤4 cm H_2O. Airway dead space was higher at higher PEEP levels and decreased at the lower PEEP levels.

Conclusions: In postoperative cardiac patients, calculated dead space agreed well with EIT to detect the optimal PEEP for an equal distribution of inspired volume, amongst non-dependent and dependent lung regions. Airway dead space reduces at decreasing PEEP levels.

Key words: capnography; mechanical ventilation; peep; ventilator induced lung injury

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Editor's key points

- This pilot study compared volumetric capnography and electrical impedance tomography (EIT) in detecting distribution of ventilation after cardiac surgery.
- EIT values approximated to calculated dead space and detected optimal PEEP to equalize gas distribution in dependent and non-dependent lung regions.
- At 12 cm H_20 PEEP, ventilation was distributed homogeneously between dependent and non-dependent regions.
- However, excessive PEEP applied to healthy lungs caused airway distension rather than improving alveolar ventilation.

Ventilator-induced lung injury (VILI) is a well-recognized complication of mechanical ventilation, which occurs in both patients with acute respiratory distress syndrome (ARDS)[1] and healthy lungs.[2 3] The deleterious effects of mechanical ventilation are caused by large amounts of stress and strain acting on lung tissue, as a result of inhomogeneous ventilation of the lungs.[4–6] Although, protective lung strategies using low tidal volumes have been strongly recommended to prevent the development of VILI, the amount of PEEP that should be applied is still under debate.[7 8] The positive effect of PEEP depends on the recruitability of lung tissue, which varies between patients,[9 10] but also from day to day. Therefore, setting the PEEP level without a reliable tool to estimate the distribution of inspiratory tidal volume (Vt) at the bedside is a challenging activity.

Volumetric capnography (Vcap) is a non-invasive technique that describes the CO_2 exhalation during one breath, and can be used to calculate alveolar and airway dead space.[11] Because elimination of CO_2 depends on alveolar ventilation and pulmonary perfusion, V/Q mismatches in either hyperinflated or collapsed lung areas will affect the amount of exhaled CO_2 and thereby Vcap. Recently, a multi-centre observational study showed that an increased dead space fraction in patients with ARDS was associated with an increased mortality.[12] Several studies showed the capability of Vcap in detecting optimal PEEP level during mechanical ventilation in various lung pathological conditions.[13–15] Böhm and colleagues[14] showed in 11 morbidly obese patients undergoing bariatric surgery, Slope III (S_{III}) has a high sensitivity and specificity to detect lung recruitment. They concluded that S_{III} was useful for identifying appropriate levels of PEEP in those patients. In 20 obese patients undergoing laparoscopic bariatric surgery Tusman and colleagues[13] found that both Vcap and pulse-oximetry, as compared with respiratory compliance, are accurate parameters for the detection of alveolar collapse. Fengmei and colleagues[15] found that best PEEP based on dead space fraction corresponded well with best PEEP according to highest respiratory compliance, in 23 ARDS patients. Therefore, Vcap is a promising technique to detect alveolar collapse and recruitment at the bedside.

Electrical Impedance Tomography (EIT) is a non-invasive, radiation-free, real time imaging modality, which has proved to correlate well with Computed Tomography (CT), according to assessment of changes in gas volume and tidal volume.[16–18] Recently, we showed that the intratidal gas distribution calculated from EIT measurements, is able to define a patient specific PEEP level, at which the lungs are homogeneously ventilated among dependent and non-dependent lung regions. This parameter was evaluated in both experimental studies and in patients,[19–21] but also during pressure support ventilation (PSV), Neurally Assisted Ventilatory Assist (NAVA) and pressure control ventilation (PCV).[22 23] In addition, EIT has been used to visualize hyperinflation in the non-dependent region at a certain PEEP level when pixel-compliance is decreased.[24 25]

Suter and colleagues[26] defined optimal PEEP as the balance of adequate Pa_{O_2} levels, good compliance and elimination of CO_2. However, we believe that stress and strain are important contributors to lung injury, as both factors increase with inhomogeneous ventilation.[5 6] Therefore, the main goal of this study was to compare the results of Vcap measurements with that of EIT in finding the optimal PEEP, with an equal distribution of the inspiratory volume among the dependent and the non-dependent regions.

Methods

Study population

In this pilot-study, 15 mechanically ventilated patients, who had undergone coronary-artery bypass grafting and/or cardiac-valve surgery, admitted to the cardiothoracic intensive care unit (ICU) were included. The local medical ethical committee approved the study protocol and written informed consent was obtained from each patient or their relatives. Data were collected between January and July 2014.

The inclusion criteria were age >18 yrs, written informed consent, haemodynamically stable. Exclusion criteria were: presence of a cardiac pacemaker, pneumothorax, thoracic deformations and severe airflow limitation (defined as forced expiratory volume in 1 s below 70% of forced vital capacity).

Study protocol

For Vcap measurements a mainstream CO_2 sensor was placed between the tracheal tube and ventilator tubing's, and was connected to a NICO-capnograph (Novametrix, Wallinford, Connecticut, USA). Specific software (Analysis plus, Novametrix, Wallinford, Connecticut, USA) was used to record all Vcap data. In order to perform electrical impedance tomography (EIT) measurements, a silicon belt with 16 electrodes was placed around the thoracic cage between the 5th and 6th intercostal space (Pulmovista 500, Dräger, Lübeck, Germany). Ventilator settings were set to volume-controlled mode (Evita-infinity, Dräger, Lübeck, Germany), with a fixed tidal volume of 6–8 ml kg^{-1} predicted body weight and inspiration/expiration (I/E) ratio of 1:2. We deliberately choose volume control in order to avoid a change in the min volume because of differences in lung compliance at different levels of PEEP. The initial setting of the respiratory rate and fraction of inspired oxygen was adjusted to maintain an end-tidal carbon dioxide tension and oxygen saturation within a range of 35–45 mm Hg and 97–100%, respectively. PEEP was set according to the attending physician. Vt, respiratory rate (RR), I/E ratio remained unchanged throughout the entire study period.

We are reluctant to apply high levels of PEEP (>15 cm H_2O) in postoperative patients after cardiac surgery who obviously have no ALI or ARDS, as these patients are generally prone to haemodynamic instability. Therefore, the patients were not subjected to recruitment manoeuvers. After baseline measurements of Vcap and EIT, the PEEP level was increased to 14 cm H_2O. This PEEP level was maintained for 15–20 min in order to reach a steady state situation, as assessed by a stable signal of the volume of exhaled carbon dioxide (VCO_2). Thereafter, the PEEP was decreased from 14 to 0 cm H_2O PEEP in steps of 2 cm H_2O. Each PEEP level was applied for five to 10 min depending on haemodynamically stability. Blood gas analysis, Vcap and EIT were measured during each PEEP step.