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Intraoperative positive end-expiratory pressure evaluation using the intratidal compliance-volume profile

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Editor's key points

- The use of PEEP is beneficial in mechanically ventilated critically ill patients with acute lung injury.
- PEEP may also be useful during surgery under general anaesthesia, but the optimum levels are uncertain.
- In this small observational study, a PEEP setting of 5 cm H_2O was insufficient to prevent derecruitment and a reduction in compliance.
- Higher, individualized settings of PEEP are probably required for most patients, but prospective studies using a variety of PEEP settings are needed.

Background. Lung-protective mechanical ventilation during general surgery including the application of PEEP can reduce postoperative pulmonary complications. In a prospective clinical observation study, we evaluated volume-dependent respiratory system compliance in adult patients undergoing ear–nose–throat surgery with ventilation settings chosen empirically by the attending anaesthetist.

Methods. In 40 patients, we measured the respiratory variables during intraoperative mechanical ventilation. All measurements were subdivided into 5 min intervals. Dynamic compliance (C_{RS}) and the intratidal volume-dependent C_{RS} curve was calculated for each interval and classified into one of the six specific compliance profiles indicating intratidal recruitment/derecruitment, overdistension or all. We retrospectively compared the occurrences of the respective compliance profiles at PEEP levels of 5 cm H_2O and at higher levels.

Results. The attending anaesthetists set the PEEP level initially to 5 cm H_2O in 29 patients (83%), to 7 cm H_2O in 5 patients (14%), and to 8 cm H_2O in 2 patients (6%). Across all measurements the mean C_{RS} was 61 (11) ml cm H_2O^{-1} (40–86 ml cm H_2O^{-1}) and decreased continuously during the procedure. At PEEP of 5 cm H_2O the compliance profile indicating strong intratidal recruitment/derecruitment occurred more often (18.6%) compared with higher PEEP levels (5.5%, $P<0.01$). Overdistension was practically never observed.

Conclusions. In most patients, a PEEP of 5 cm H_2O during intraoperative mechanical ventilation is too low to prevent intratidal recruitment/derecruitment. The analysis of the intratidal compliance profile provides the rationale to individually titrate a PEEP level that stabilizes the alveolar recruitment status of the lung during intraoperative mechanical ventilation.

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Keywords: compliance–volume curve; elective surgery; lung compliance mechanical ventilation; respiratory system mechanics

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Postoperative pulmonary complications (PPC) after surgery under general anaesthesia result in longer hospital stays, impact on morbidity and mortality,[1–4] and appear to be promoted by unfavourable intraoperative ventilator settings.[5 6]

In anaesthetized patients undergoing major abdominal surgery, a lung-protective ventilation strategy was associated with improved clinical outcomes and reduced risk of PPC.[7] In recent studies, it was shown that the positive effects of lung-protective ventilation might not be noticeable during or shortly after the surgical procedure but occur later during the hospital stay.[8 9] Intermittent recruitment manoeuvres, low tidal volume, and positive end-expiratory pressure (PEEP) were considered beneficial for the patients in terms of less PPC. However, a standard approach for patient-individual settings of PEEP levels is not well defined.

During general anaesthesia and mechanical ventilation, sedation and paralysis of patients result in the collapse of alveoli predominantly in the dependent lung regions.[6 10] Therefore, there is an increased risk of repetitive opening and closing (i.e. recruitment/derecruitment of partially atelectatic lung parenchyma). A high PEEP prevents from intratidal recruitment/derecruitment, but may also lead to overdistension in the non-dependent areas. The problem of how to find a balance between these two extremes and how to find the best PEEP for each patient in the operating theatre remains.[11]

We hypothesized that the analysis of the intratidal respiratory system compliance would give insights into the recruitment state of the lungs and might provide the rationale for titrating a patient-individual PEEP level to keep the lung optimally recruited during intraoperative mechanical ventilation. As a secondary analysis, overweight *vs* normal weight patients, and smokers *vs* non-smokers were compared.

Methods

The present study was approved by the local ethics committee of the University Medical Center Freiburg (EK 66/12). Forty patients presenting at the Department of Ear–Nose–Throat Surgery of the University Medical Center Freiburg undergoing elective surgery (ASA status I–III, aged 21–72 yr) were included in the study after obtaining informed written consent. Exclusion criteria defined a priori to the study were chronic obstructive pulmonary disease, repeated systemic corticosteroid therapy for acute exacerbations of chronic obstructive pulmonary disease, asthma, sleep disorders, pregnancy and abdominal surgery, thoracic surgery or neurosurgery. Midazolam (3.75–7.5 mg) was given as an oral premedication at least 1 h before induction of anaesthesia. Each patient was positioned in the supine position on the operating table with a standard pillow (5 cm in height) below the head. After routine monitoring was implemented (ECG, oxygen saturation- and non-invasive blood pressure measurement, Infinity Delta XL Dräger medical, Lübeck, Germany), an i.v. line was inserted and anaesthesia was induced following a standard protocol. All patients were pre-oxygenated with an $F_{I_{O_2}}$ of 0.8 before tracheal intubation. The $F_{I_{O_2}}$ was maintained at 0.4 for the duration of anaesthesia. Remifentanil was administered at a rate of 0.5 μg kg^{-1} min^{-1} (Glaxo Smith Kline, Germany) for 60 s and then reduced to 0.15–0.3 μg kg^{-1} body weight min^{-1}, Propofol (Fresenius Kabi, Germany) was given by target-controlled infusion (TCI) with target effect-site dose (ED) of 4–6 μg ml^{-1} (Agilia, Schnider model, Fresenius Kabi, Germany). Thereafter, anaesthesia was maintained with propofol (ED TCI between 2.5 and 5 μl ml^{-1}). Tracheal intubation was facilitated by *cis*-atracurium (0.2 mg kg^{-1}, Abbott, Switzerland). Tracheal tubes equipped with high-volume, low-pressure cuffs with an internal diameter of 7.0 mm for women and 8.0 mm for men (Mallinckrodt™ Hi-Contour tube, Covidien, Neustadt/Donau, Germany) were used. The cuff pressure was monitored continuously and maintained <20 cm H_2O.

The ventilation protocol consisted of controlled mechanical ventilation (Primus IE; Dräger medical, Lübeck, Germany) with an inspiration to expiration ratio of 1:2, tidal volume of 6–8 ml kg^{-1} predicted body weight (PBW) and a respiratory rate adjusted to maintain normocapnia (end-tidal carbon dioxide partial pressure between 4 and 5.3 kPa). The PBW was calculated from body height (*h*) following the ARDSnet recommendations:[12]

$$\mathrm{PBW_{Men}} = 50\,\mathrm{kg} + 0.9\,\mathrm{kg\,cm^{-1}}(h - 152.4\,\mathrm{cm}),$$

$$\mathrm{PBW_{Women}} = 45.5\,\mathrm{kg} + 0.9\,\mathrm{kg\,cm^{-1}}(h - 152.4\,\mathrm{cm}).$$

According to the department protocol a PEEP of 5 cm H_2O was used. Nevertheless, the attending anaesthetist, blinded in terms of the study design and the aim of the study, was allowed to set a higher PEEP according to his/her own judgement or at the surgeon's request.

For data acquisition the 'medibus-protocol' of the ventilator was activated and the anaesthesia machine connected to a laptop (Dell, Latitude E 6510, Round Rock, TX, USA) via the serial interface. Flow rate and airway pressure were retrieved by means of a custom-made software based on LabView (v7.1, Austin, TX, USA) at a sample rate of 62.5 Hz. In addition, oxygen saturation, heart rate, non-invasive blood pressure, and end-tidal partial pressure of carbon dioxide were recorded in 5 min intervals throughout the procedure.

After the measurements were collected, the raw data were transmitted to a workstation for further analysis. All analyses were conducted with the use of Matlab (R 2012, Natick, MA, USA) or Excel (Excel 2010, Microsoft, Redmond, WA, USA). For every individual patient, the mean compliance of the respiratory system (C_{RS}) was calculated. Furthermore, the volume-dependent compliance profiles were calculated using the gliding-SLICE method.[13 14] In brief, after calculating volume data by numerical integration of flow rate, the 10–90% volume range of the tidal pressure–volume curve was subdivided into 31 equidistant volume portions (slices). For each volume slice respiratory system, compliance was determined via multiple linear regression analysis of data lying within the volume range surrounding the slice by 1/6th of the tidal volume.[14]

The resulting intratidal compliance–volume curves were classified into one of the six compliance profiles (Fig. 1) as proposed by Mols and colleagues[14] and translated into a computer-based graphical user interface.[15 16] Within the range of vital capacity, the pressure–volume curve of the respiratory system can be described mathematically as a sigmoidal function.[17] The derivative of this function results in the compliance–volume curve (i.e. a downward opening parabolic function showing respiratory system compliance over the vital capacity). The intratidal compliance–volume curve is a cut

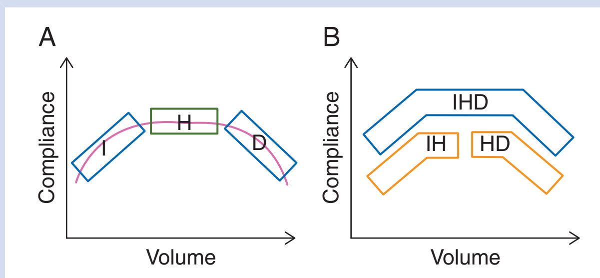

Fig 1 Schematic drawing of six compliance profiles classified on the basis of intratidal compliance–volume curve. H, horizontal compliance profile; I, merely increasing compliance profile; IH, increasing turning into horizontal compliance profile; D, merely decreasing compliance profile; HD, horizontal turning into decreasing compliance profile; IHD, increasing turning into horizontal and further turning into decreasing compliance profile.