

## RESPIRATION AND THE AIRWAY

# 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<sub>2</sub>O 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<sub>2</sub>O and at higher levels.

**Results.** The attending anaesthetists set the PEEP level initially to 5 cm H<sub>2</sub>O in 29 patients (83%), to 7 cm H<sub>2</sub>O in 5 patients (14%), and to 8 cm H<sub>2</sub>O in 2 patients (6%). Across all measurements the mean  $C_{RS}$  was 61 (11) ml cm H<sub>2</sub>O<sup>-1</sup> (40–86 ml cm H<sub>2</sub>O<sup>-1</sup>) and decreased continuously during the procedure. At PEEP of 5 cm H<sub>2</sub>O 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<sub>2</sub>O 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.

**Trial registration number.** DRKS00004286.

**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,<sup>1–4</sup> and appear to be promoted by unfavourable intraoperative ventilator settings.<sup>5,6</sup>

In anaesthetized patients undergoing major abdominal surgery, a lung-protective ventilation strategy was associated with improved clinical outcomes and reduced risk of PPC.<sup>7</sup> 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.<sup>8,9</sup> 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.<sup>6,10</sup> 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.<sup>11</sup>

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. Remifentanyl was administered at a rate of  $0.5 \mu\text{g kg}^{-1} \text{min}^{-1}$  (Glaxo Smith Kline, Germany) for 60 s and then reduced to  $0.15\text{--}0.3 \mu\text{g kg}^{-1} \text{body weight min}^{-1}$ . Propofol (Fresenius Kabi, Germany) was given by target-controlled infusion (TCI) with target effect-site dose (ED) of  $4\text{--}6 \mu\text{g ml}^{-1}$  (Agilia, Schnider model, Fresenius Kabi, Germany). Thereafter, anaesthesia was maintained with propofol (ED TCI between  $2.5$  and  $5 \mu\text{l ml}^{-1}$ ). Tracheal intubation was facilitated by *cis*-atracurium ( $0.2 \text{ mg kg}^{-1}$ , 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  $<20 \text{ cm H}_2\text{O}$ .

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  $6\text{--}8 \text{ ml kg}^{-1}$  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:<sup>12</sup>

$$\text{PBW}_{\text{Men}} = 50 \text{ kg} + 0.9 \text{ kg cm}^{-1}(h - 152.4 \text{ cm}),$$

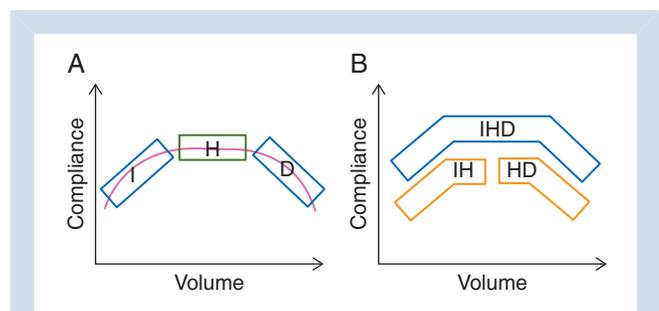
$$\text{PBW}_{\text{Women}} = 45.5 \text{ kg} + 0.9 \text{ kg cm}^{-1}(h - 152.4 \text{ cm}).$$

According to the department protocol a PEEP of  $5 \text{ cm H}_2\text{O}$  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.<sup>13 14</sup> 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.<sup>14</sup>

The resulting intratidal compliance–volume curves were classified into one of the six compliance profiles (Fig. 1) as proposed by Mols and colleagues<sup>14</sup> and translated into a computer-based graphical user interface.<sup>15 16</sup> Within the range of vital capacity, the pressure–volume curve of the



**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.

respiratory system can be described mathematically as a sigmoidal function.<sup>17</sup> 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 out from the total compliance–volume curve. Depending on its position on the total compliance–volume curve, the intratidal compliance can show an increasing, a horizontal, or a decreasing profile, indicating intratidal recruitment/derecruitment, constant respiratory system mechanics, and tissue overdistension, respectively (Fig. 1A). From these basic profiles three mixed ones can be derived: increasing turning into horizontal, horizontal turning into decreasing, and increasing turning into horizontal and then decreasing (Fig. 1B). This implies the following concept: an increasing compliance profile indicates strong or weak recruitment/derecruitment, respectively. A decreasing compliance profile indicates strong or weak overdistension, respectively. A horizontal compliance profile indicates the presence of neither recruitment/derecruitment nor overdistension, and a compliance profile including increasing and decreasing parts indicates recruitment/derecruitment in the low volume range and overdistension in the high-volume range.<sup>15 16 18</sup> In this study the respective compliance profiles were identified by an automated computer sequence as described by Bühler and colleagues.<sup>15</sup> In brief, a parabola with negative curvature was fitted into the compliance curve. A horizontal compliance profile was assumed if the parabola varied by <20% within the volume range of the compliance curve. An increasing or decreasing profile part was assumed if the parabola increased or decreased by >20% within the volume range of the compliance curve, respectively. A partly horizontal profile was assumed if the parabola was increasing or decreasing and its maximum lay within the volume range of the compliance curve.

During this observational study, the anaesthetist in charge set PEEP based on his/her own judgement. Therefore, the total measurements from all patients were subdivided into 5 min intervals within which the PEEP remained constant and the mean compliance and the compliance profile including the respective compliance profile for each 5 min interval was calculated by averaging the compliance profiles from all breaths within the respective interval.

For retrospective analysis of the influence of PEEP on the compliance profile, data were subdivided into data from 5 min intervals with PEEP of 5 cm H<sub>2</sub>O (low PEEP group) and PEEP >5 cm H<sub>2</sub>O (high PEEP group). Furthermore, for retrospective analysis of the influence of BMI on the compliance profile, patients with a BMI <25 kg m<sup>-2</sup> were allocated to the normal weight group and patients with a BMI ≥25 kg m<sup>-2</sup> were allocated to the overweight group.

### Statistics

Data are given as mean (SD) if not indicated otherwise. To compare frequencies of compliance profiles chi-square tests were applied. For comparisons of differences in mean compliance between groups, Student's *t*-tests were performed. A *P*-value of <0.05 was considered statistically significant.

## Results

Data were recorded and analysed from August to November 2012. Forty consecutive patients presenting for elective ear–nose–throat surgery were included in the study. In one patient technical problems during measurement occurred and in four patients pressure-controlled ventilation was used. For better comparability, data from these patients were excluded from the study. Patient characteristic data of the remaining 35 patients included in the study are given in Table 1.

The attending anaesthetists set the PEEP level initially to 5 cm H<sub>2</sub>O in 29 patients (83%), to 7 cm H<sub>2</sub>O in 5 patients (14%), and to 8 cm H<sub>2</sub>O in 2 patients (6%) (Table 2).

### Mean compliance

The average C<sub>RS</sub> across all measurements was 61 (11) ml cm H<sub>2</sub>O<sup>-1</sup>. The mean C<sub>RS</sub> decreased continuously during surgery (Fig. 2) and was reduced to 94% of the initial value after 60 min, to 91% after 1 h, and to 88% after 2 h.

### Compliance profiles

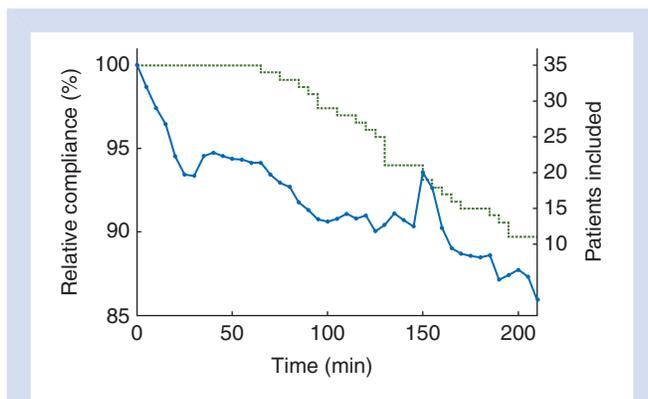
After dividing the measurements from 35 patients into 5 min intervals, 1235 analysable data sets were retrieved. Three intervals were excluded from the analysis as PEEP transitions

**Table 1** Patient (n=35) and clinical characteristics. Smoking status was unknown in four patients

Age [yr, (median, range)]	51 (21–73)
Smoker [n (%)]	14 (45)
Non-smoker [n (%)]	17 (55)
ASA I [n (%)]	13 (36)
ASA II [n (%)]	19 (58)
ASA III [n (%)]	3 (8)
Body weight [kg (median, range)]	75.4 (50–114)
Body height [cm (median, range)]	169 (153–185)
BMI [kg m <sup>-2</sup> , (median, range)]	26.3 (17.9–42.9)

**Table 2** Intraoperative data. *Pe*'CO<sub>2</sub>, end-tidal CO<sub>2</sub> partial pressure; SpO<sub>2</sub>, peripheral capillary oxygen saturation; PBW, predicted body weight

Variable	Value
Heart rate, bpm	54 (8)
Ventilation frequency, bpm	11 (1)
Tidal volume, ml	518 (70)
Tidal volume uncorrected, ml kg <sup>-1</sup>	7.1 (1.1)
Tidal volume PBW, ml kg <sup>-1</sup>	8.4 (1.2)
Compliance, ml cm H <sub>2</sub> O <sup>-1</sup> (mean)	61 (11)
Mean blood pressure, mm Hg	70 (7)
PetCO <sub>2</sub> , kPa	4.8 (0.3)
SpO <sub>2</sub> , %	99 (1)
Surgery duration, min (mean, range)	184 (70–420)



**Fig 2** Relative compliance change during ongoing surgery (solid line). During surgery the compliance decreased continuously. Note that reasoned by variable surgery duration the number of patients included for a certain time point decreases with time (dotted line). During the first 60 min data from all 35 patients were available. After 120 min, data from 26 patients could be used and after 200 min only 11 patients contributed to the curve.

occurred between the low PEEP group ( $=5$  cm H<sub>2</sub>O) and high PEEP group ( $>5$  cm H<sub>2</sub>O). Exemplary data are shown in Figure 3. We observed horizontal compliance profiles in 90 (7.3%) analysed intervals (Table 3). A merely increasing compliance profile was observed in 163 (13.2%) intervals. An increasing turning into horizontal compliance profile was observed in 975 (79.7%) intervals. Decreasing compliance profiles were never observed. An increasing to decreasing compliance profile was observed in only four (0.3%) intervals.

In the retrospective analysis separating the data from 5 min intervals into the low PEEP (PEEP= $5$  cm H<sub>2</sub>O) and high PEEP group (all intervals with PEEP  $>5$  cm H<sub>2</sub>O) we observed horizontal profiles ( $P=0.32$ ) and, increasing turning into horizontal ( $P<0.01$ ) more often, and purely increasing profiles less often ( $P<0.01$ ) compared with the low PEEP group (Table 3).

In the overweight patients (BMI  $\geq 25$  kg m<sup>-2</sup>;  $n=20$ ) mean  $C_{RS}$  [ $56.6$  (9.9) ml cm H<sub>2</sub>O<sup>-1</sup>] was lower compared with the patients with normal (BMI  $<25$  kg m<sup>-2</sup>;  $n=15$ ) weight [ $66.2$  (10.7) ml cm H<sub>2</sub>O<sup>-1</sup>,  $P<0.001$ ]. In our study, overweight patients received higher PEEP [ $5.6$  (1.0) cm H<sub>2</sub>O] than patients with normal weight [ $5.1$  (0.7) cm H<sub>2</sub>O,  $P=0.04$ ]. Weak, but significant correlations between  $C_{RS}$  and the BMI ( $R^2=0.1736$ ,  $P<0.01$ ) and  $C_{RS}$  and body height ( $R^2=0.2174$ ,  $P=0.01$ ) were found. Smokers (45%) tended to have a lower  $C_{RS}$  [ $57.8$  (9.7) ml cm H<sub>2</sub>O<sup>-1</sup>] than non-smokers [ $64.2$  (12.0) ml cm H<sub>2</sub>O<sup>-1</sup>,  $P=0.055$ ]. No significant influence of age on  $C_{RS}$  was observed. Smokers and overweight patients showed lesser intervals with horizontal and more intervals with merely increasing compliance profiles compared with the non-smokers and normal weight patients (Table 4).

## Discussion

Anaesthetists mechanically ventilate patients with a non-injured respiratory system for elective surgery on a daily basis. Our aim was to investigate the situation of the respiratory

system compliance in patients with healthy lungs during mechanical ventilation undergoing general anaesthesia.

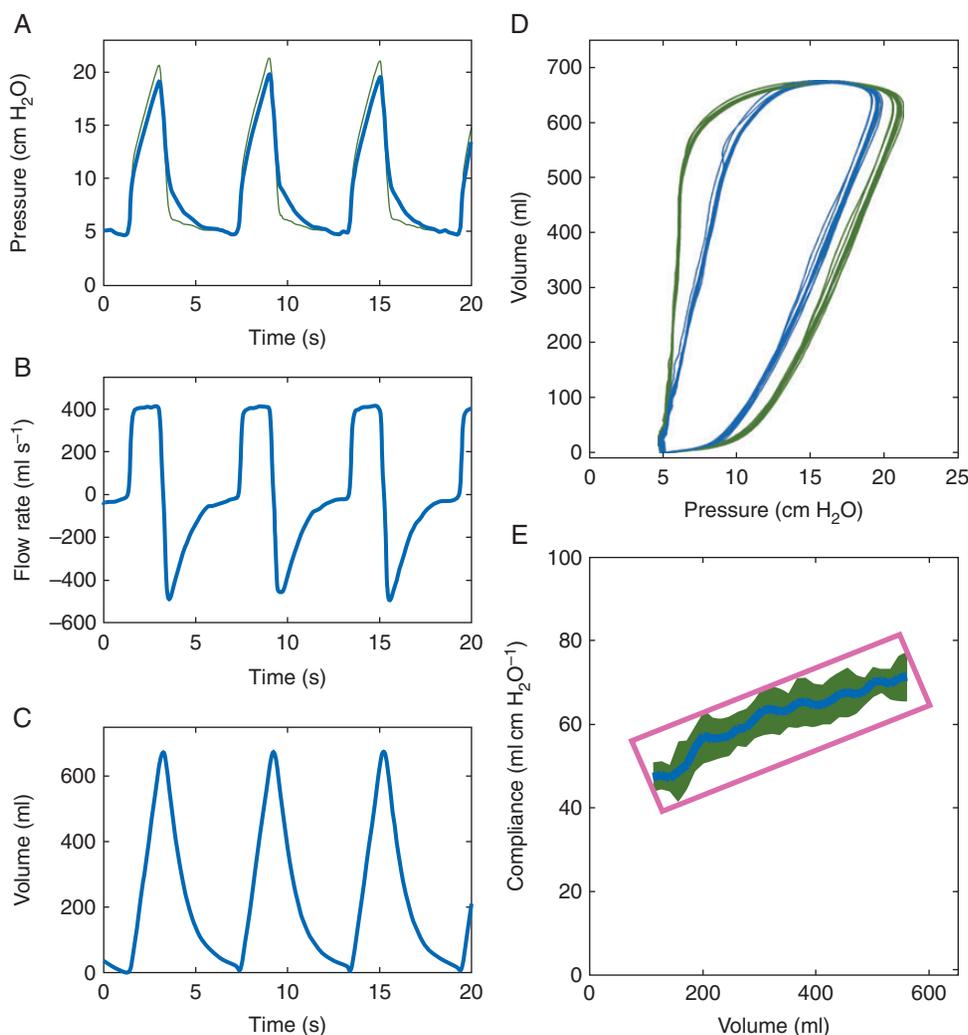
The main findings of our study are that during elective surgery with empirically set PEEP (a) the analysis of intratidal compliance–volume profile indicates that mechanical ventilation is predominantly associated with intratidal recruitment/derecruitment while overdistension very rarely occurs, (b) with higher PEEP (7 cm H<sub>2</sub>O and above) the degree of intratidal recruitment/derecruitment is reduced and (c) nicotine abuse, BMI, and body height but not age influenced the respiratory system compliance significantly.

In patients with acute respiratory distress syndrome, lung-protective ventilation has been shown to reduce mortality and is now considered best practice in the management of critically ill patients.<sup>19–21</sup> Because in most patients no complications occur during the procedures in which the anaesthetists are involved, ventilator settings seem to be given less consideration in these patients. However, recent studies have demonstrated that lung-protective ventilation settings are also important in patients without lung injury. Intraoperative lung-protective ventilation settings reduce the risk of postoperative complications which occur as late as the third day of postoperative hospital stay.<sup>8,9</sup> The risk of postoperative pulmonary complications depends on the type of anaesthesia, the surgical procedure, and the individual patient constitution.<sup>5,22,23</sup> Many of these factors cannot be influenced. Mechanical ventilation settings are however directly controllable by the anaesthetist and, as a recent study clearly demonstrated, contribute to postoperative complications and even influence mortality after elective surgery.<sup>24</sup> Lung-protective ventilation settings should therefore be used in all mechanically ventilated patients and not only in those patients with lung injury.

### Continuous and intratidal derecruitment

The application of adequate PEEP is an important factor for a lung-protective ventilation strategy. However, a general rationale on how to set PEEP does not yet exist. Oxygenation is often used as an indicator for adequate ventilation settings. However, arterial blood gas analysis is an invasive method and only indicated in a minority of patients undergoing elective surgery. It furthermore does not give continuous information. Oxygen saturation is also only of limited value in this context as in most patients with healthy lungs it is usually close to 100% and frequently there is no direct correlation between the intraoperative PEEP and oxygen saturation.

In this study we observed that during intraoperative mechanical ventilation the compliance decreases continuously. Paralyzing medication might have been a reason for decreasing  $C_{RS}$ , however, other studies have shown, that paralyzing patients does not have influence on  $C_{RS}$ .<sup>25,26</sup> Furthermore, we would not have expected medication to decrease compliance in a continuous fashion. Studies using electrical impedance tomography have demonstrated that an insufficient PEEP level is associated with continuous alveolar derecruitment in obese patients during laparoscopic surgery.<sup>27</sup> Therefore, we rather assume that the development of atelectasis, reasoned



**Fig 3** Exemplary respiratory signals representing a cutout from a 5 min measurement interval. (A) Airway pressure (green) and tracheal pressure (blue); (B) flow rate; (C) volume; (D) airway pressure–volume (green) and tracheal pressure–volume (blue) loops from 12 breaths; (E) intratidal volume-dependent compliance curve (blue curve) averaged from the 12 breaths shown in D, the surrounding green area shows the pointwise standard deviation. The presented compliance curve was classified as merely increasing compliance profile (pink box).

**Table 3** Frequencies of compliance profiles from 35 patients. 1232 intervals of 5 min duration could be analysed. \* $P < 0.001$  compared with PEEP=5 cm H<sub>2</sub>O

Group	Compliance profiles					
	Horizontal	Merely increasing	Increasing to horizontal	Horizontal to decreasing	Merely decreasing	Increasing to decreasing
Total (n=1232)	90 (7.3%)	163 (13.2%)	975 (79.1%)	0	0	4 (0.3%)
PEEP=5 cm H <sub>2</sub> O (n=726)	31 (4.2%)	135 (18.6%)	558 (76.9%)	0	0	2 (0.3%)
PEEP>5 cm H <sub>2</sub> O (n=506)	59 (11.7%)	28 (5.5%)*	417 (82.4%)	0	0	2 (0.4%)

by insufficient PEEP (which was 5 cm H<sub>2</sub>O in most investigated time periods) caused the decreasing C<sub>RS</sub> in our patients.<sup>28</sup>

Levin and co-workers showed in their recent study clearly, that intraoperative mechanical ventilation with low PEEP (up to 4 cm H<sub>2</sub>O) is associated with increased mortality compared

with higher PEEP, suggesting that ventilation with low tidal volumes is beneficial only when used with higher PEEP.<sup>24</sup> This speculation is also supported by our analysis of intratidal C<sub>RS</sub> profiles. We found that most time periods the PEEP level was set too low to prevent intratidal recruitment/derecruitment

**Table 4** Frequencies of compliance profiles depending on smoking and overweight status. \* $P < 0.001$  compared with smokers, † $P = 0.018$  compared with overweight patients

Status	Compliance profiles					
	Horizontal	Merely increasing	Increasing to horizontal	Horizontal to decreasing	Merely decreasing	Increasing to decreasing
Non-smokers (n=638)	58* (9.1%)	69 (10.8%)	511 (80.1%)	0	0	0 (0%)
Smokers (n=466)	3 (0.62%)	83 (17.8%)	376 (80.7%)	0	0	4 (0.3%)
Non-overweight (n=469)	43† (9.2)	58 (12.4)	368 (78.5)	0	0	0 (0%)
Overweight (n=729)	41 (5.6%)	103 (14.1%)	581 (78.4%)	0	0	4 (0.5%)
Smokers and overweight (n=266)	1 (0.4%)	56 (21.1%)	205 (77.1%)	0	0	4 (1.5%)

(indicated by increasing compliance profiles). Furthermore, this was clearly more pronounced when the PEEP level was set at 5 cm H<sub>2</sub>O compared with higher levels. At higher PEEP levels the frequency of merely increasing compliance profiles was clearly reduced and that of horizontal compliance profiles was increased. Owing to the fact that we found very little decreasing compliance profiles in our patients which we associate with lung overdistension, we conclude that a PEEP of 5 cm H<sub>2</sub>O is too low and that a higher PEEP should be set for most patients during general anaesthesia without the risk of overdistension. However, the rare occurrences of horizontal compliance profiles at low PEEP demonstrate the necessity of a patient-individual ventilation setting that require a continuous bedside monitoring tool to identify the individual situation of lung mechanics in our patients.

The gliding-SLICE method allows a detailed view of non-linear intratidal mechanics of the respiratory system. It gives detailed insights into the intratidal profile of a patient's individual respiratory system compliance during the dynamic conditions of uninterrupted mechanical ventilation. We therefore suggest that displaying intratidal respiratory system mechanics on a breath-by-breath basis<sup>14 16 29</sup> might be a valuable tool for titration of a lung-protective PEEP during perioperative mechanical ventilation.

### Patient groups

Patients with a BMI of more than 25 kg m<sup>-2</sup> had a 10 ml cm H<sub>2</sub>O<sup>-1</sup> lower mean C<sub>RS</sub> compared with patients with a lower BMI. Obesity causes *per se* significant changes in respiratory system mechanics because of the large mass loading the respiratory system.<sup>30 31</sup> Furthermore, the cranial shift of the end-expiratory position of the diaphragm reduces end-expiratory lung volume and predisposes patients to airway closure and collapse of dependent lung regions.<sup>32 33</sup> A higher PEEP level seems to be indicated in such patients. We observed significant, however only a weak correlation between BMI and set PEEP.

As expected, the mean C<sub>RS</sub> increased with increasing body height. This has also been described in recent studies.<sup>34</sup>

Elderly patients undergoing a surgical procedure should be considered as a high-risk population concerning postoperative respiratory failure, especially if they are smokers.<sup>35</sup> Gunnarson and co-workers found age-dependent deterioration in arterial oxygenation during anaesthesia, because of increasing

dispersion of ventilation/perfusion ratios.<sup>36</sup> Other studies found that C<sub>RS</sub> decreases with age.<sup>37 38</sup> This however was not the case in our study.

In smokers we found a clearly reduced mean C<sub>RS</sub> compared with non-smokers. One might have expected higher compliances in smokers compared with non-smokers. However, as we included only patients without a known history of lung disease, the study contains only a certain subgroup of smokers who do not suffer from COPD.

### Limitations of the study

Owing to the observational character of this study, our study design did not include a standardized protocol for fluid administration. As none of the patients received more than 1000 ml of fluid during the procedure, it is unlikely that this limitation affected our results.

From an analytical point of view it would have been of interest to investigate the correlation between mechanical ventilation status and arterial oxygenation. However, in our study measurement of arterial oxygen partial pressure was not justifiable because of the invasiveness of such a measurement.

The choice of PEEP was left to the discretion of the attending anaesthetist. We cannot exclude that intraoperative adjustments to PEEP might have affected subsequent lung mechanics. In our retrospective analysis, we arbitrarily separated the data in periods in which a PEEP of 5 cm H<sub>2</sub>O was set from those in which a PEEP > 5 cm H<sub>2</sub>O was set. This is reasoned by the fact that in our medical centre a PEEP of at least 5 cm H<sub>2</sub>O is recommended. Higher PEEP levels may be set based on the decision of the attending anaesthetist. However, we observed that mostly a PEEP of 5 cm H<sub>2</sub>O was set and PEEP > 5 cm H<sub>2</sub>O occurred only non-systematically. Therefore, a further separation of the data at higher PEEP levels was not suitable. A PEEP below 5 cm H<sub>2</sub>O was never set in this study. For a systematic investigation of the effects of various PEEP settings, a large-sample randomized controlled trial, generating more balanced PEEP groups, would be required.

Quantification of alveolar collapse would have reinforced our findings. However, loading the patients with computed tomography would not have been justified for our study. The use of electrical impedance tomography might be an interesting alternative for that purpose in future clinical studies.<sup>39</sup>

In conclusion, our data demonstrate that a PEEP of 5 cm H<sub>2</sub>O results in more dynamic intratidal changes in compliance indicating recruitment/derecruitment than a higher level of PEEP. This suggests that the analysis of individual patient lung mechanics may result in a choice of higher PEEP. The analysis of the intratidal compliance–volume profile provides the methodological requirement to set an adequate PEEP from the perspective of the lung mechanics at the bedside.

## Authors' contributions

All authors drafted the article and added substantial intellectual content; S.W.: study design, data acquisition, and data analysis; M.B.: data acquisition and data analysis; J.S.: data analysis and interpretation; J.G.: study design and technical developments S.S.: study design, technical developments, experimental assistance, and data analysis.

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## Declaration of interest

None declared.

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