Distribution of ventilation and oxygenation in surgical obese patients ventilated with high versus low positive end-expiratory pressure

A substudy of a randomised controlled trial

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BACKGROUND Intra-operative ventilation using low/physiological tidal volume and positive end-expiratory pressure (PEEP) with periodic alveolar recruitment manoeuvres (ARMs) is recommended in obese surgery patients.

OBJECTIVES To investigate the effects of PEEP levels and ARMs on ventilation distribution, oxygenation, haemodynamic parameters and cerebral oximetry.

DESIGN A substudy of a randomised controlled trial.

SETTING Tertiary medical centre in Geneva, Switzerland, between 2015 and 2018.

PATIENTS One hundred and sixty-two patients with a BMI at least 35 kg per square metre undergoing elective open or laparoscopic surgery lasting at least 120 min.

INTERVENTION Patients were randomised to PEEP of 4 cmH2O (n = 79) or PEEP of 12 cmH2O with hourly ARMs (n = 83).

MAIN OUTCOME MEASURES The primary endpoint was the fraction of ventilation in the dependent lung as measured by electrical impedance tomography. Secondary endpoints were the oxygen saturation index (SaO2/FIO2 ratio), respiratory and haemodynamic parameters, and cerebral tissue oximetry.

RESULTS Compared with low PEEP, high PEEP was associated with smaller intra-operative decreases in dependent lung ventilation [-11.2%; 95% confidence interval (CI) -8.7 to -13.7 vs. -13.9%; 95% CI -11.7 to -16.5; P = 0.029], oxygen saturation index (-49.6%; 95% CI -48.0 to -51.3 vs. -51.3%; 95% CI -49.6 to -53.1; P < 0.001) and a lower driving pressure (-6.3 cmH2O; 95% CI -5.7 to -7.0). Haemodynamic parameters did not differ between the groups, except at the end of ARMs when arterial pressure and cardiac index decreased on average by -13.7 mmHg (95% CI -12.5 to -14.9) and by -0.54 l min⁻¹ m⁻² (95% CI -0.49 to -0.59) along with increased cerebral tissue oximetry (3.0 and 3.2% on left and right front brain, respectively).

CONCLUSION In obese patients undergoing abdominal surgery, intra-operative PEEP of 12 cmH2O with periodic ARMs, compared with intra-operative PEEP of 4 cmH2O without ARMs, slightly redistributed ventilation to dependent lung zones with minor improvements in peripheral and cerebral oxygenation.

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Introduction

Up to 28% of European and 38% of American citizens are obese. Following major surgery, obesity is associated with prolonged hospital stay due to poor wound healing, surgical site infection, sepsis and myocardial infarction, as well as pulmonary complications. After anaesthesia induction in supine position, lung volume and oxygenation capacity are reduced, and these changes are amplified in morbidly obese patients. The reduced chest wall compliance results in a restrictive syndrome with heterogeneous distribution of the tidal volume (VT) that worsens during laparoscopic or robotic surgery due to abdominal gas insufflation. As peripheral airway closure occurs within a tidal breath, atelectasis and cyclic alveolar collapse tend to develop in the most dependent lung areas.

Application of positive end-expiratory pressure (PEEP) with periodic alveolar recruitment manoeuvres (ARMs) has been shown to be effective in preventing and reversing atelectasis formation and cyclic alveolar collapse. Thoracic electrical impedance tomography (EIT), cardiac output monitor using pulse contour analysis and near-infrared spectroscopy (NIRS) have emerged as effective and reliable tools to assess the distribution of ventilation through the lungs as well as systemic and regional oxygen delivery in anaesthetised mechanically ventilated patients.

In a multicentre randomised clinical trial in adult obese patients undergoing elective abdominal surgery, the ‘PROBESE’ study, intra-operative ventilation with PEEP at 12 cmH₂O combined with periodic ARMs was not effective in reducing postoperative pulmonary complications (PPCs) compared with a lower PEEP (4 cmH₂O) without ARMs. It remains uncertain whether a ventilation strategy that uses higher PEEP and ARMs improves the distribution of VT without compromising cardiac output and cerebral oxygen delivery. Given the association between intra-operative cerebral oxygen desaturation and postoperative delirium, the effects of different ventilatory strategies on brain oxygenation needs to be examined. In the current substudy, therefore, we investigated the effects of the two ventilatory strategies on the distribution of ventilation in the dependent lungs, respiratory mechanics and haemodynamic parameters, as well as peripheral and cerebral oxygenation.

Materials and methods

Ethics

This substudy of the PROBESE multicentre trial was conducted from January 2015 to May 2018 at the University Hospital of Geneva, Switzerland. The protocols of the parent clinical trial, and this local prospective study were approved on 12 January 2015 by the Ethics Commission for Research of the Canton of Geneva (Chairperson Prof. Bernard Hirschel, rue Gabrielle-Perret Gentil 4, CH-1211 Genève) under the number CCER 14–238. All patients were informed about the research purposes along with the practical aspects and gave written informed consent prior to inclusion.

Patients

Selection criteria for this trial included a BMI at least 35 kg per square metre, elective open or laparoscopic surgery lasting at least 120 min and an intermediate to high risk of PPCs as indicated by the Assess Respiratory Risk in Surgical Patients in Catalonia (ARISCAT) score at least 26. Patients with previous lung surgery, chemotherapy or radiotherapy (within last 60 days) or mechanical ventilation (within last 30 days) were excluded.

Protocol and group allocation

After arrival in the operating room, nonpremedicated patients were connected to a multiparameter haemodynamic monitor (Philips IntelliVue X2, Amsterdam, the Netherlands) to measure mean arterial pressure (MAP), heart rate (HR) and arterial oxygen saturation (SaO₂). Continuous non-invasive arterial pulse wave analysis using finger cuff technology allowed determination of stroke volume (SV; CNAP Monitor 500; CN Systems Medizintechnik AG, Graz, Austria), whereas near-infrared oximetry (Foresight device; CAS Medical Systems Inc., Branford, Connecticut, USA) allowed monitoring of cerebral tissue oxygenation (SctO₂) in left and right frontal brain areas. To assess regional ventilation, a 16 electrode silicone belt of appropriate size to match chest circumference was placed at the level of the fourth or fifth intercostal space with a reference electrode on the anterior midline and connected to the EIT monitor (Pulmo-vista 500; Dräger Medical GmbH, Lübeck, Germany).
Balanced anaesthesia was administered using desflurane or sevoflurane, low-dose opiates and muscle relaxants targeting bispectral index values between 40 and 60. Intravenous crystalloids and vasopressors were given to support blood pressure. Following orotracheal intubation, volume-controlled ventilation (Asys CS2; GE Healthcare, Fairfield, Connecticut, USA) was provided with a \( V_T \) of 7 mld kg\(^{-1} \) predicted body weight (PBW), respiratory rate at 12min\(^{-1} \) and inspiratory oxygen fraction (\( FIO_2 \)) set to 0.4 and adjusted to keep \( SaO_2 \) at least 92%. The inspiratory to expiratory (I:E) ratio, inspiratory time and respiratory rate were adjusted to maintain end-tidal carbon dioxide partial pressure between 35 and 45 mmHg. Patients were randomly assigned to receive either a PEEP of 4 cmH\(_2\)O (low PEEP group) or a PEEP of 12 cmH\(_2\)O with ARMs started after endotracheal intubation and repeated hourly (high PEEP group). The randomisation process has been published elsewhere.\(^{11,15}\) The ARMs were achieved by stepwise increase of \( V_T \) (\(+4\) mld kg\(^{-1} \) of PBW) up to plateau pressure of 40 to 50 cmH\(_2\)O. All patients were planned to be extubated in the operating room at the end of surgery after reversal of neuromuscular blockade.

**Measurements**

Respiratory mechanical parameters were recorded from the ventilator display screen, including \( V_T \), PEEP, RR, \( SpO_2 \), \( FIO_2 \), end-tidal carbon dioxide fraction (\( FetCO_2 \)), peak inspiratory pressure and plateau pressure (\( P_{plateau} \)). Standard formulas were used to calculate the driving pressure (\( \Delta P = P_{plateau} - PEEP \)), dynamic compliance (\( C_{dyn} = V_T/\Delta P \)), cardiac index (CI = SV \times HR/body surface area) and a pulmonary oxygenation index (\( SaO_2/FIO_2 \)).\(^{16}\) Average tidal EIT-images were constructed from voltage profiles generated by cyclic injections of rotating electrical currents,\(^{17}\) and the impedance tidal variation (ITV) was calculated as the difference between the end-expiratory and the end-inspiratory relative impedance. Tidal EIT-images were subdivided into four horizontal regions of interest (from top to bottom: ROI-I, II, III and IV) and numerical values indicated the percentage of total ventilation in each layer within 15 s time periods. Tidal EIT-images in ROI-III and ROI-IV reflected ventilation of the dependent lung region (VDL) and EIT-images in ROI-I and ROI-II reflected regional ventilation of the nondependent lung. Before anaesthesia induction, patients were prompted to breathe steadily for 3 min at a regular pace (12 to 16 cycles per minute), and over the last minute of spontaneous respiration, all EIT measurements were obtained. Intra-operatively, EIT measurements were taken when the electrocautery was not used.

All respiratory and haemodynamic parameters were recorded at four (respiratory mechanics, \( FetCO_2 \)) or five (oxygenation index and EIT) time points (supplemental Figure 1, http://links.lww.com/EJA/A760): before anaesthesia induction (awake), 5 min after induction and intubation (postinduction) and 1, 2 and 3 h after intubation or at the end of surgery (H1, H2 and H3, respectively). In the high-PEEP group, additional respiratory and haemodynamic measurements were done at the end of each ARM.

**Endpoints**

The primary endpoint was the fraction of VDL as measured by EIT; secondary endpoints included the \( SaO_2/FIO_2 \) ratio, respiratory and haemodynamic parameters as well as \( SctO_2 \).

**Statistical analysis**

The sample size calculation indicated that 72 patients per group were required to detect a relative increase of 10% in VDL in the high PEEP group, given the observed VDL values in the low PEEP group and the corresponding covariance matrix of the cohort (assuming an \( \alpha = 0.05 \) and a power of 80%). Continuous variables were reported as means with standard deviations (SD) or 95% confidence interval (CI) or median with interquartile range [IQR], and categorical variables as frequencies (%). Continuous variables were compared using a Student’s \( t \)-test or Wilcoxon rank-sum test and categorical variables using \( \chi^2 \) test or Fisher exact test. Standardised differences (STDs) were used to assess imbalances between baseline characteristics between the two groups. Repeated-measures mixed models were used to estimate the between and within-individual effects of high PEEP on ventilatory and haemodynamic parameters. Pairwise comparisons with Sidak-Bonferroni correction were carried out to analyse the treatment effect at each time point. The effect of ARMs on haemodynamic and ventilatory parameters in the high PEEP group was estimated using repeated-measures mixed models and paired \( t \)-tests. All analyses were performed using STATA 17 software (Stata Corp, College Station, Texas, USA).

**Results**

**Study population**

A total of 249 patients were enrolled and measurements of EIT, haemodynamic, respiratory and oximetric parameters were obtained in 162 patients who were included in this substudy (Fig. 1). Patient characteristics and intra-operative procedural features did not differ between the two groups (Table 1). As in the parent study, the incidence of PPCs, the need for respiratory therapy and the hospital length of stay did not differ between the two groups (supplemental Table 1, http://links.lww.com/EJA/A760). The intra-operative volume of crystalloids infused and the need for vasopressors was similar in the two groups (supplemental Table 2, http://links.lww.com/EJA/A760).

**Primary endpoint**

Pre-operatively, VDL under spontaneous ventilation in supine position did not differ between the two groups (49.3%; 95% CI 48.0 to 50.7 vs. 50.5%; 95% CI 49.4 to 51.7

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in high-PEEP and low-PEEP groups, respectively). Following anaesthesia induction and initiation of mechanical ventilation, the reduction in VDL was smaller in the high PEEP than in the low PEEP group (-11.2%; 95% CI -8.7 to -13.7 vs. -13.9%; 95% CI -11.7 to -16.5 resulting in higher VDL (+2.7%; 95% CI 1.3 to 4.1, Fig. 2). At the end of periodic ARMs, VDL increased on average by 5.4% (95% CI 4.3 to 6.5) without reaching baseline values. After head-up positioning and gas insufflation in the abdomen, there were no changes in the distribution of VT and VDL remained stable till the end of surgery. The distribution of tidal EIT in the four ROI is illustrated in supplemental Figures 2 and 3, http://links.lww.com/EJA/A760.

Secondary endpoints and posthoc analysis

Compared with baseline, SaO₂/FIO₂ decreased in both groups after starting mechanical ventilation (-49.6%; 95% CI -48.0 to -51.3 and -51.3%; 95% CI -49.6 to -53.1 in the high and low PEEP group, respectively) but remained slightly higher in the high PEEP group compared with the low PEEP group (+2.7%; 95% CI 1.3 to 4.1) (Fig. 3). At the end of each periodic ARM, there was a small increase in SaO₂/FIO₂.

As summarised in Table 2, the high PEEP group exhibited higher mean P_{Plateau} than the low PEEP group with lower ΔP and higher C_{Dyn} after 180 min of mechanical ventilation, C_{Dyn} decreased in the low PEEP group, whereas it remained unchanged in the high PEEP group. There was no correlation between intra-operative measurements of ΔP and VDL in the two groups (R² = 0.0002 and 0.0074 in the low and high PEEP group, respectively) (supplemental Figure 4, http://links.lww.com/EJA/A760). Likewise, transient gains in VDL following ARMs (<10%, 10 to 25% or >25%) were not associated with significant reductions in ΔP (supplemental Figure 5, http://links.lww.com/EJA/A760).

Intra-operatively, haemodynamic parameters did not differ between the two groups (Fig. 4). ARMs transiently decreased MAP (-13.7 mmHg; 95% CI -12.5 to -14.9) and CI (-0.541 min⁻¹m⁻²; 95% CI -0.49 to -0.59).
Intra-operatively, ScTB2 in the right and left sides remained unchanged in the high PEEP group and small decreases in ScTB2 occurred over time in the low PEEP group (Fig. 4). Following ARMs, ScTB2 increased slightly (3.0 and 3.2% on left and right front brain, respectively).

Discussion

In this cohort of obese patients undergoing abdominal surgery and at risk of PPCs, a ventilatory strategy using low/physiological VT and a PEEP of 12 cmH2O with periodic ARMs compared with a PEEP of 4 cmH2O without ARMs resulted in minor redistribution of ventilation in the dependent part of the lungs, with transient further gain during ARMs; higher Pplat with reduction in ΔP but no correlation between the fall in ΔP and improved VDL; and similar haemodynamics and minor improvements in ScTB2, with transient decreases in CI and MAP during ARMs.

In this large sample of obese patients, EIT allowed real-time non-invasive imaging of regional lung aeration and it was used to compare the effects of higher to lower PEEP levels on the distribution of VT through the lungs. Analysis of tidal impedance variations has been validated in mechanically ventilated patients against spirometry for VT measurements and computed tomography to detect atelectasis formation, alveolar recruitment and overdistension.18,19 Placing the EIT belt at the fourth to fifth intercostal space generates a 5 to 10 cm wide cross-section in the thorax and represents a valuable compromise to describe the distribution of VT through the middle part of the lungs while avoiding interferences due to surgical manipulation.20 Respiratory mechanics, systemic and cerebral oxygenation variables were collected at different times during surgery as well as before and after ARMs. This made possible to explore the association between the changes in regional lung aeration, respiratory mechanical function, and haemodynamic parameters at two levels of PEEP with or without periodic ARMs.

Following anaesthesia induction, mechanical ventilation with physiological VT resulted in a moderate shift of ventilation from dependent to nondependent lung areas with reduction in pulmonary oxygen uptake reflecting
greater ventilation-perfusion mismatch, as previously reported in cardiac and visceral surgery.\textsuperscript{5,21,22} In our patients, pre-operative oxygenation with FIO\textsubscript{2} of 1.0 promoted absorption atelectasis in the dependent well perfused lung parts, whereas the reverse Trendelenburg position favoured caudal displacement of the diaphragm, along with some preservation of lung volumes in the dorso-caudal pulmonary regions.\textsuperscript{23} Compared with low PEEP at 4 cmH\textsubscript{2}O, moderate PEEP at 12 cmH\textsubscript{2}O coupled with periodic ARMs resulted in slightly higher P\textsubscript{Plateau} (+1.7 cmH\textsubscript{2}O) with a marginal gain in dorsal ventilation (+2.7\%) and lesser stress on lung structures as

\textbf{Fig. 2} Effect of intra-operative high positive end-expiratory pressure with recruitment manoeuvres vs. low PEEP on ventilation of the dependent lung part in obese patients.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig2}
\caption{Effect of intra-operative high positive end-expiratory pressure with recruitment manoeuvres vs. low PEEP on ventilation of the dependent lung part in obese patients.}
\end{figure}

Treatment effect, \( P = 0.029 \); Recruitment effect, \( P < 0.001 \); Interaction, \( P = 0.335 \)

\begin{table}
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\begin{tabular}{lcc}
\hline
 & Before induction & After induction \\
\hline
Low PEEP & \textsuperscript{P} = 0.890 & \textsuperscript{P} = 0.757 \textsuperscript{< 0.001} \\
High PEEP & \textsuperscript{P} = 0.046 & \textsuperscript{P} = 0.486 \textsuperscript{< 0.001} \\
Recruitment manoeuvre & \textsuperscript{P} = 0.067 & \textsuperscript{P} = 0.067 \textsuperscript{< 0.001} \\
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\end{tabular}
\end{table}

\textbf{Fig. 3} Effect of intra-operative high positive end-expiratory pressure with recruitment manoeuvres vs. low PEEP on the ratio of pulsed-oxygen saturation (SaO\textsubscript{2})/fractional inspired oxygen (FIO\textsubscript{2}) in obese patients.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig3}
\caption{Effect of intra-operative high positive end-expiratory pressure with recruitment manoeuvres vs. low PEEP on the ratio of pulsed-oxygen saturation (SaO\textsubscript{2})/fractional inspired oxygen (FIO\textsubscript{2}) in obese patients.}
\end{figure}

Treatment effect, \( P < 0.001 \); Recruitment effect, \( P < 0.001 \); Interaction, \( P = 0.039 \)

\begin{table}
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 & Before induction & After induction \\
\hline
Low PEEP & \textsuperscript{P} = 0.997 & \textsuperscript{P} = 0.086 \textsuperscript{< 0.001} \\
High PEEP & \textsuperscript{P} = 0.001 & \textsuperscript{P} = 0.001 \textsuperscript{< 0.001} \\
Recruitment manoeuvre & \textsuperscript{P} = 0.001 & \textsuperscript{P} = 0.001 \textsuperscript{< 0.001} \\
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\end{table}
reflected by lower driving pressure (-6.3 cmH2O) and lung recruitment in obese individuals with uninjured pulmonary oedema.27 Altogether, lung imaging and physiological measurements (PPlateau - PEEP) is a poor indicator of optimal ventilation and that disturbances induced by anaesthesia and mechanical ventilation trial) or an end-expiratory transpulmonary pressure of 0 cmH2O (oesophageal pressure) or by minimising lung collapse and overdistension (EIT lung imaging).6,8,28,29 Application of such open-lung ventilation strategy requires higher PEEP levels (~15 to 23 cmH2O) than in our study and has been shown effective at lowering mechanical stress, increasing oxygenation and end-expiratory lung volume with more homogeneous VT distribution as evidenced by lesser collapsed and distended lung areas in obese patients during abdominal surgery.31,32,33 However, the intra-operative respiratory benefits of higher PEEP levels with periodic ARMs disappear shortly after anaesthesia emergence and do not translate into better clinical respiratory outcomes.8,22,31 Although current evidence suggests that the use of low/physiological tidal volume or physiological VT improves clinical outcomes,7 the role of ΔP for titrating ventilation and the optimal settings of PEEP with periodic ARMs in obese patients remain unclear and deserve further investigation.

In this study, haemodynamic parameters and cerebral oxygenation were similarly preserved at higher and lower PEEP. During ARMs, hyperventilation and limitation in arterial CO2 (pCO2) were similarly preserved at higher and lower PEEP levels with periodic ARMs disappear shortly after anaesthesia emergence and do not translate into better clinical respiratory outcomes.8,22,31 Although current evidence suggests that the use of low/physiological tidal volume or physiological VT improves clinical outcomes,7 the role of ΔP for titrating ventilation and the optimal settings of PEEP with periodic ARMs in obese patients remain unclear and deserve further investigation.

This study has limitations. Firstly, as designed in the original PROBESE study, we compared the effects of two levels of PEEP that were lower than those reported in individualised PEEP trials wherein larger improvements in dependent lung aeration with higher respiratory driving pressure increased dorsal lung aeration overcompensated the hypoxic vasoconstriction within the cerebral autoregulatory range (e.g. MAP maintained above 70 mmHg). These favourable findings differ from those reported in patients undergoing carotid endarterectomy and in mechanically ventilated patients with brain injury or acute respiratory distress syndrome, in whom ARMs are often associated with impaired systemic haemodynamic and worsened cerebral oxygenation with no improved systemic oxygenation.35-37 In summary, these results suggest that ARMs may transiently increase cerebral oxygenation in normovolaemic patients with preserved cerebrovascular autoregulation and no elevated intracranial pressure.38 Optimising oxygen delivery to the brain is clinically relevant, as avoidance of cerebral oxygen desaturation has been associated with less postoperative cognitive dysfunction.39

Table 2 Effect of high positive end-expiratory pressure with recruitment manoeuvres vs. low positive end-expiratory pressure on respiratory parameters in obese patients

| Variable                  | Low PEEP (n = 79) | High PEEP (n = 83) | High PEEP End recruitment | P * |
|---------------------------|------------------|-------------------|---------------------------|-----|
| Tidal volume ml kg⁻¹ PBW⁻¹  | Post induction   | 7.2 ± 0.9         | 7.3 ± 0.8                  | 14.2 ± 2.4 | 0.824 |
|                           | 60 min           | 7.2 ± 0.9         | 7.3 ± 0.8                  | 14.5 ± 2.4 | 0.616 |
|                           | 120 min          | 7.2 ± 0.9         | 7.2 ± 0.8                  | 14.3 ± 2.5 | 0.840 |
|                           | 180 min          | 7.3 ± 0.9         | 7.4 ± 0.9                  | 13.9 ± 3.0 | 0.462 |
| Plateau pressure, cmH2O   | Post induction   | 24.2 ± 4.4        | 26.1 ± 4.0                  | 35.0 ± 4.1 | 0.004 |
|                           | 60 min           | 24.4 ± 4.2        | 26.1 ± 4.2                  | 35.4 ± 3.8 | 0.012 |
|                           | 120 min          | 25.1 ± 4.1        | 26.4 ± 4.0                  | 35.5 ± 5.0 | 0.038 |
|                           | 180 min          | 25.0 ± 4.3        | 26.7 ± 3.8                  | 35.4 ± 4.7 | 0.008 |
| Fractional inspiratory oxygen concentration, % | Post induction   | 0.45 ± 0.06       | 0.44 ± 0.05                  | 0.44 ± 0.05 | 0.215 |
|                           | 60 min           | 0.45 ± 0.06       | 0.41 ± 0.02                  | 0.41 ± 0.02 | 0.001 |
|                           | 120 min          | 0.45 ± 0.06       | 0.41 ± 0.02                  | 0.41 ± 0.02 | < 0.001 |
|                           | 180 min          | 0.45 ± 0.06       | 0.41 ± 0.01                  | 0.41 ± 0.01 | < 0.001 |
| End-tidal carbon dioxide fraction, % | Postinduction    | 5.4 ± 0.4         | 5.4 ± 0.4                   | 5.0 ± 0.2  | 0.825 |
|                           | 60 min           | 5.5 ± 0.4         | 5.5 ± 0.4                   | 5.0 ± 0.3  | 0.845 |
|                           | 120 min          | 5.6 ± 0.4         | 5.5 ± 0.5                   | 4.9 ± 0.3  | 0.876 |
|                           | 180 min          | 5.7 ± 0.3         | 5.6 ± 0.4                   | 5.0 ± 0.3  | 0.892 |
| Driving pressure, cmH2O   | Post induction   | 20.2 ± 4.4        | 21.4 ± 4.0                  | 23.0 ± 4.1 | < 0.001 |
|                           | 60 min           | 20.4 ± 4.2        | 21.4 ± 4.2                  | 23.4 ± 3.8 | < 0.001 |
|                           | 120 min          | 21.1 ± 4.1        | 21.5 ± 4.2                  | 23.5 ± 5.0 | < 0.001 |
|                           | 180 min          | 21.0 ± 4.3        | 21.7 ± 3.8                  | 23.4 ± 4.7 | < 0.001 |
| Compliance, ml cmH2O⁻¹  | Post induction   | 26.4 ± 7.0        | 31.6 ± 9.1                  | 38.9 ± 10.6 | < 0.001 |
|                           | 60 min           | 25.6 ± 5.5        | 32.5 ± 11.2                 | 39.0 ± 10.2 | < 0.001 |
|                           | 120 min          | 24.2 ± 4.5        | 30.8 ± 8.4                  | 39.2 ± 10.0 | < 0.001 |
|                           | 180 min          | 22.8 ± 4.2        | 30.2 ± 7.5                  | 39.8 ± 9.9  | < 0.001 |

Data are presented as mean ± standard deviation. PBW, predicted body weight.
*High PEEP vs. low PEEP.
compliance were reported in anaesthetised obese patients.6–9,27,28 Secondly, different protocols of ARMs using continuous positive pressure over 30 to 60 s or stepwise increase in VT or PEEP levels could yield different haemodynamic and respiratory effects.40 Thirdly, our results obtained this single-centre substudy with obese patients undergoing laparoscopic surgery lasting on average 4 h in reverse Trendelenburg position could not be extrapolated in other type of surgery and in patients with diseased/injured lungs. Although higher (compared with lower) levels of PEEP are associated with physiological improvements and clinical benefits in critically ill patients with or without acute respiratory distress syndrome, the impact of obesity in adjusting well tolerated levels of PEEP has not been explored so far.41,42 Given the worldwide obesity epidemic, further well designed and powered studies are needed to examine the optimal ventilatory strategy in the increasing numbers of obese patients who may require emergency surgery following trauma or sepsis.

In conclusion, in obese anaesthetised patients undergoing abdominal surgery in reverse Trendelenburg position, intra-operative application of a PEEP at 12 cmH2O with periodic ARMs compared with a PEEP at 4 cmH2O without ARMs, slightly redistributed ventilation to dependent lung areas along with minor improvements in respiratory mechanics as well as peripheral and cerebral oxygenation.

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Full protocol accessible by request to the corresponding author.

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