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RESPIRATION AND THE AIRWAY

Effects of four intraoperative ventilatory strategies on respiratory compliance and gas exchange during laparoscopic gastric banding in obese patients

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Background. Respiratory function is impaired in obese patients undergoing laparoscopic surgery. This study was performed to determine whether repeated lung recruitment combined with PEEP improves respiratory compliance and arterial partial pressure of oxygen (Pa_{O_2}) in obese patients undergoing laparoscopic gastric banding.

Methods. Sixty patients with BMI >30 kg m^{-2} were randomized, after induction of pneumoperitoneum, to receive either PEEP of 10 cm H_2O (Group P), inspiratory pressure of 40 cm H_2O for 15 s once (Group R), Group R recruitment followed by PEEP 10 cm H_2O (Group RP), or Group RP recruitment but with the inspiratory manoeuvre repeated every 10 min (Group RRP). Static respiratory compliance and Pa_{O_2} were determined after intubation, 10 min after pneumoperitoneum (before lung recruitment), and every 10 min thereafter (after recruitment). Results are presented as mean (SD).

Results. Pneumoperitoneum decreased respiratory compliance from 48 (3) to 30 (1) ml cm H_2O^{-1} and decreased Pa_{O_2} from 12.4 (0.3) to 8.8 (0.3) kPa in all groups ($P<0.01$). Immediately after recruitment, compliance was 32 (1), 32 (2), 40 (2), and 40 (1) ml cm H_2O^{-1} and Pa_{O_2} was 9.1 (0.3), 9.1 (0.1), 11.9 (0.1), and 11.9 (0.1) kPa in Groups P, R, RP, and RRP, respectively ($P<0.01$). Ten and 20 min later, Pa_{O_2} in Group R decreased to 9.2 (0.1) kPa and compliance in Group PR decreased to 33 (2) ml cm H_2O^{-1}, respectively ($P<0.01$).

Conclusions. Group RRP recruitment strategy was associated with the best intraoperative respiratory compliance and Pa_{O_2} in obese patients undergoing laparoscopic gastric banding.

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Respiratory function is markedly impaired in morbidly obese patients undergoing laparoscopic surgery.[1 2] This has been attributed to the combined effects of supine position, muscle paralysis, and pneumoperitoneum on lung function, which result in reduced functional residual capacity, increased closing volume, and consequent atelectasis.[3 4] As a result, there is increased risk for postoperative respiratory complications[5] and prolonged hospital length of stay[6] in this patient population.

Various intraoperative ventilatory strategies have been studied to improve gas exchange in these patients including large tidal volume, high ventilatory frequency, or both,[7] PEEP,[8] and reverse Trendelenburg position;[9] however, the effects of these interventions have been variable. Recently, an alveolar recruitment manoeuvre using inspiratory pressure of 40 cm H_2O sustained for 15 s followed by PEEP of 8 cm H_2O has been shown to improve intraoperative arterial oxygenation in morbidly obese patients undergoing open bariatric surgery.[10] However, the effectiveness of this strategy has not been demonstrated in patients undergoing laparoscopic bariatric surgery. In addition, the effects of sustained inspiratory pressure of

40 cm H_2O, applied every 10 min intraoperatively, on respiratory compliance and oxygenation have not been previously determined. Therefore, a randomized, controlled study was undertaken to compare the effects of four intraoperative ventilatory strategies: PEEP, single inspiratory pressure manoeuvre alone, single inspiratory pressure manoeuvre followed by PEEP, and repeated inspiratory pressure manoeuvre along with PEEP on static respiratory compliance and arterial partial pressure of oxygen (Pa_{O_2}) in obese patients undergoing laparoscopic gastric banding under general anaesthesia. The aim of the trial was to determine which of these four strategies is associated with the best intraoperative static respiratory compliance and Pa_{O_2} in this patient population.

Methods

After institutional ethics committee approval, 60 American Society of Anesthesiologists' physical class II patients undergoing elective laparoscopic gastric banding under general anaesthesia gave written informed consent to participate in this randomized controlled study. Patients were considered for inclusion in the trial if they were 18–60 yr of age and had a BMI of >30 kg m^{-2}. They were excluded from the study if they had any of the following: asthma, chronic obstructive pulmonary disease, restrictive lung disease, increased intracranial pressure, and/or history of smoking. All drugs were administered based on ideal body weight.

Ringers' lactate 12 ml kg^{-1} i.v. was administered over 15 min in all patients before induction of anaesthesia. Standard monitors were applied, a 20 gauge radial arterial catheter was inserted, and Bispectral Index^{TM} (BIS) monitor (Aspect Medical System, UK) was attached. Anaesthesia was induced with fentanyl 3 μg kg^{-1} i.v. and propofol 1–2 mg kg^{-1} i.v., and intubation was facilitated with rocuronium 0.6 mg kg^{-1} i.v. The trachea was intubated with size 7.5 mm oral tracheal tube. The lungs were ventilated with oxygen 30% and air 70% at a flow rate of 2 litre min^{-1}, with volume-control mode of ventilation, tidal volume 10 ml kg^{-1}, inspiratory to expiratory ratio 1:2, and zero end-expiratory pressure (Zeus^{TM} Anaesthesia machine, Software 4.n, Drager, Germany). After intubation, the ventilatory frequency was adjusted to keep end-tidal carbon dioxide (CO_2) levels at 4.7–5.3 kPa and was then left unchanged throughout the case. Anaesthesia was maintained with propofol infusion 100–200 μg kg^{-1} min^{-1} i.v. titrated to maintain a BIS value of 40–50, fentanyl 1 μg kg^{-1} i.v. q 30 min as needed, and rocuronium 0.2 mg kg^{-1} i.v. as needed to keep a single twitch on the train-of-four stimulation of the ulnar nerve (TOF-Watch SX^{TM}, Bluestar Enterprises Inc., Chanhassen, MN, USA). CO_2 pneumoperitoneum was induced, in the usual fashion, to an intra-abdominal pressure of 11–13 mm Hg in all patients, and the patient's head was elevated 30° afterward until the end of surgery. Ten minutes after pneumoperitoneum formation and before the start of surgery, patients were randomized, using a computer-generated randomization schedule and sealed opaque envelopes, to one of the four intervention groups. Group P received PEEP of 10 cm H_2O till the end of surgery, Group R had sustained inspiratory pressure of 40 cm H_2O for 15 s applied once, and Group RP had sustained inspiratory pressure of 40 cm H_2O for 15 s applied once followed immediately by PEEP of 10 cm H_2O till the end of surgery. Group RRP, on the other hand, received sustained inspiratory pressure of 40 cm H_2O for 15 s followed immediately by PEEP of 10 cm H_2O till the end of surgery. In addition, the inspiratory pressure manoeuvre was repeated every 10 min during the study period (Fig. 1). The inspiratory manoeuvre in Groups R, RP, and RRP was performed using a 1 litre anaesthesia machine manual ventilation bag and 10 litre min^{-1} flow of oxygen 30% and air 70% after setting the pressure release valve at 40 cm H_2O.

Measurements

All measurements were made with the patient head elevated at 30°. Heart rate, mean arterial pressure (MAP), and pulse-oximetry-measured oxygen saturation (Sp_{O_2}) were recorded every 5 min throughout the procedure. Respiratory system compliance was calculated automatically, on a breath-by-breath basis, by the anaesthesia machine (Zeus^{TM} anaesthesia machine, Software 4.n, Drager, Germany). This was done by dividing the exhaled tidal volume by plateau pressure after subtracting PEEP from the latter. Given an increase in default inspiratory time of 1 s in this machine, plateau pressure is measured at end inspiration, after the set tidal volume has been delivered and just before expiration ensues. Arterial blood gases were corrected for body temperature and were measured using ABL 510^{TM} blood gas analyzer (Radiometer, Copenhagen, Denmark). Respiratory system compliance and arterial blood gases were determined at the following time intervals; 5 min after tracheal intubation, 10 min after pneumoperitoneum formation (before the recruitment manoeuvre), and every 10 min thereafter (immediately after the recruitment manoeuvre) for a total of 50 min after the induction of pneumoperitoneum (Fig. 2). In the post-anaesthesia care unit (PACU), Sp_{O_2} was recorded every 10 min for a total of 1 h (SC9000 XL^{TM}, Siemens, Germany) by an observer blinded to patient's group assignment, and pain (visual analogue scale ≥4 out of 10) was treated with morphine 4 mg i.v. as needed. Chest radiography was performed in the PACU and 24 h later to detect potential adverse effects of the recruitment strategy. All adverse events were recorded including, but not limited to, barotrauma, oxygen desaturation (Sp_{O_2} <90%), and intensive care unit admission. Patients were discharged from hospital at the discretion of the surgeon who was blinded to patient's group assignment.

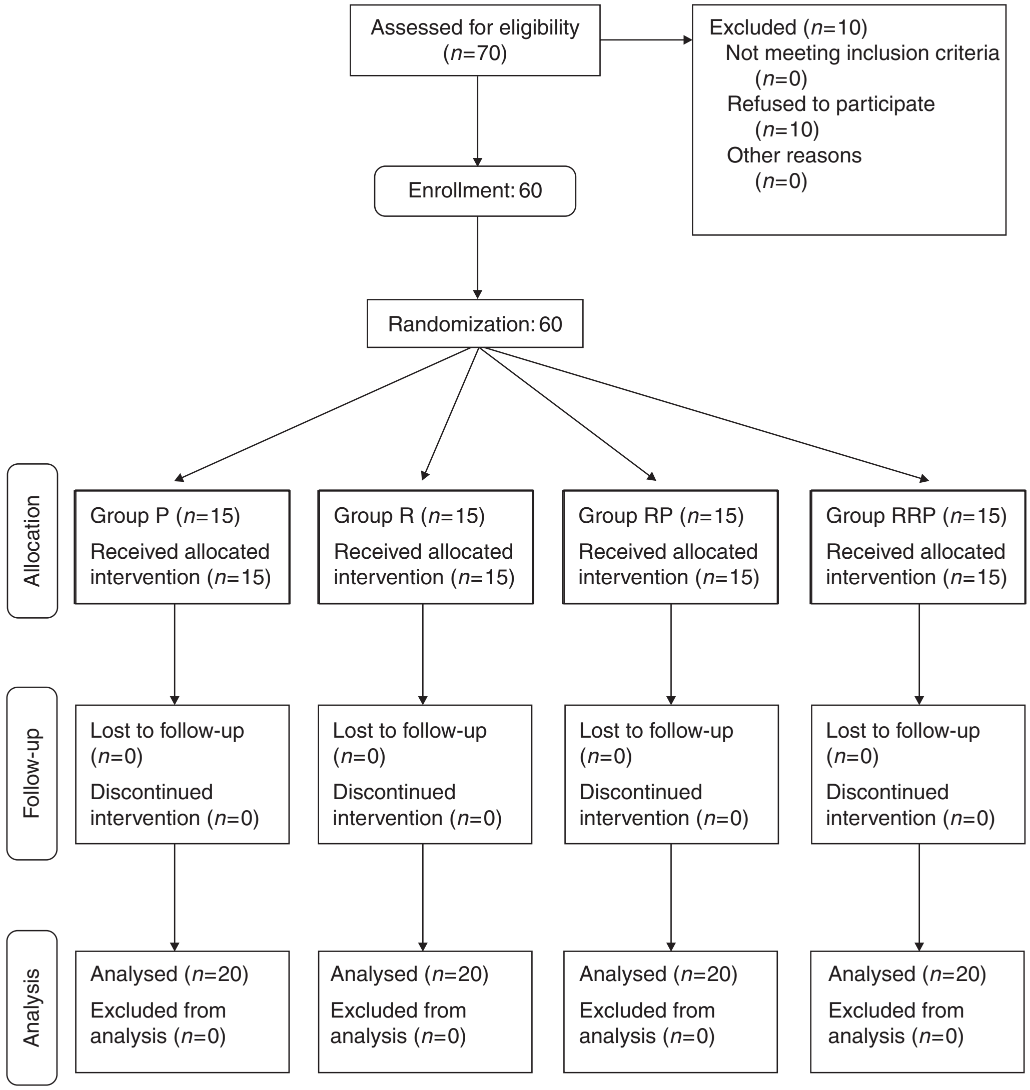

Fig 1 A CONSORT flow chart showing the flow of patients through the trial.

Statistical analysis

On the basis of a two-sided α of 0.05, 80% power, a population variance of 5, and a clinically relevant difference in respiratory system compliance of 5 ml cm H_2O^{-1}, a total of 60 patients were required for the conduct of the study. All analyses were performed on an intention-to-treat basis. Continually measured data were analysed using repeated measures analysis of variance, and non-continuous data using analysis of variance. *Post hoc* pair-wise comparisons were performed, where appropriate, using Tukey's test. Continually measured data met the underlying statistical assumptions for repeated measures analysis of variance. Statistical procedures were performed using SPSS® statistical package (SPSS Inc., Chicago, IL, USA), version 16.0, for Windows® except for sample size calculation which was performed using PS Power and Sample Size Calculations Program®, version 2.1.31 (© 1997 by WD Dupont and WD Plummer10). Results are presented as mean (SD), unless otherwise indicated, and statistical significance was defined as $P<0.05$.

Results

Seventy patients were assessed for eligibility to be included in the trial; however, only 60 gave written informed consent to participate in this study, were randomized in equal numbers to four study groups, completed the study without protocol violations, and were analysed in the group to which they were randomized (Fig. 1). Baseline characteristics were similar among the study groups (Table 1). Static respiratory system compliance decreased in all study groups 10 min after pneumoperitoneum was induced (Fig. 3A; $P<0.01$ for F-test of within-subject effects). After lung recruitment, respiratory system compliance improved in Groups RRP and RP, whereas there was no change in Groups P and R (Fig. 3A; $P<0.01$ for F-test of

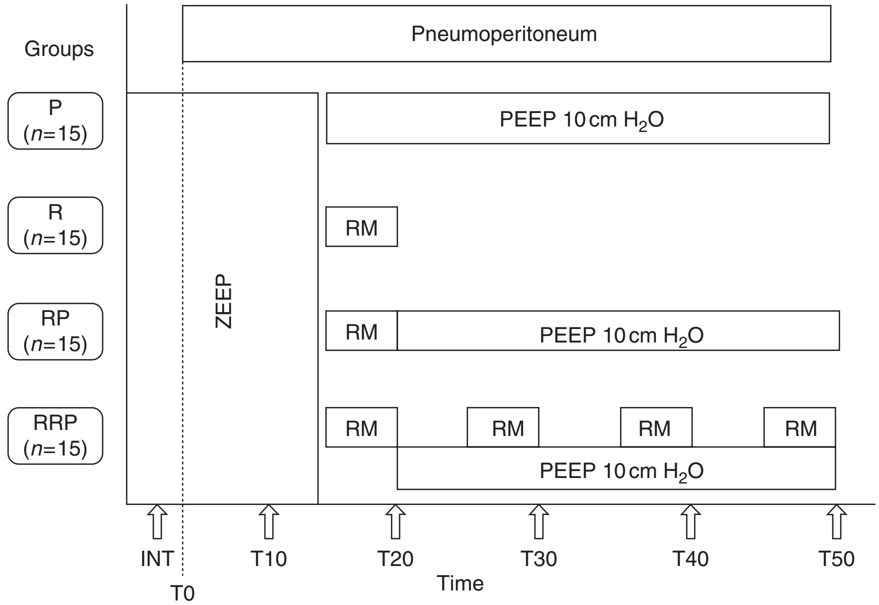

Fig 2 Outline of the study protocol. P, Group PEEP; R, group single recruitment manoeuvre; RP, group single recruitment manoeuvre followed by PEEP; RRP, group repeated recruitment manoeuvre with PEEP; ZEEP, zero end-expiratory pressure; RM, recruitment manoeuvre; INT, tracheal intubation; T*n*, *n* min after induction of pneumoperitoneum.

Table 1 Baseline subject characteristics. ASA, American Society of Anesthesiologists; M, males; F, females; Hb, haemoglobin. Data shown as mean (SD) (range) or absolute numbers

Variable	Group P (n=15)	Group R (n=15)	Group RP (n=15)	Group RRP (n=15)
Age (yr)	38 (3) (32–43)	38 (3) (33–43)	38 (3) (33–43)	38 (4) (33–46)
BMI (kg m^{-2})	33 (2)	33 (1)	34 (1)	33 (1)
Gender (M/F)	8/7	9/6	7/8	8/7
Preoperative Hb (g dl^{-1})	14.2 (0.7)	14.3 (0.6)	14.3 (0.7)	14.0 (0.7)
Anaesthesia time (min)	93 (12)	91 (10)	95 (10)	93 (12)

between-subject effects). Group RRP had the best improvement in static respiratory system compliance ($P<0.01$, Tukey's test), followed by Group RP ($P<0.01$, Tukey's test). Pa_{O_2} decreased in all study groups after the induction of pneumoperitoneum (Fig. 3B; $P<0.01$ for F-test of within-subject effects) and increased after the recruitment manoeuvre in Groups RP and RRP only ($P<0.01$ for F-test of between-subject effects). However, Pa_{O_2} improvement was temporary in Group RP but was sustained in Group RRP (Fig. 3B, $P<0.01$, Tukey's test). In all study groups, pneumoperitoneum resulted in an increase in Pa_{CO_2} that decreased immediately after the recruitment manoeuvre (Fig. 3C; $P<0.01$ for F-test of within-subject effects). Subsequently, however, Pa_{CO_2} increased gradually over time in all groups except in Group RRP ($P<0.05$, Tukey's test) where it remained relatively unchanged throughout the case (Fig. 3C; $P=0.02$ for F-test of between-subject effects).

In the PACU, oxygen saturation was highest in Group RRP followed by Group RP during the first hour of recovery (Fig. 4; $P<0.01$ for between-subject effects). However, oxygen saturation did not change appreciably within each study group (Fig. 4; $P=0.19$ for within-subject effects). There were no episodes of desaturation (oxygen saturation $\leq$90%) or hypotension (MAP <65 mm Hg) at any time during the observation period. In addition, none of the patients required postoperative ventilatory assistance or had intensive care unit admission, barotrauma, or major adverse events. Hospital length of stay was different among the study groups ($P<0.01$ for ANOVA F-test). Patients in Group RRP were discharged from the hospital earlier [29.5 (1.6) h ($P<0.01$, Tukey's test)] than those in Groups RP [52.8 (12) h, ($P<0.01$, Tukey's test)], R [69 (9.5) h], and P [64.9 (12.7) h].

Discussion

Lung recruitment using inspiratory pressure of 40 cm H_2O for 15 s repeated every 10 min and combined with PEEP of 10 cm H_2O was associated with the best respiratory system compliance and best Pa_{O_2} in obese patients undergoing laparoscopic bariatric surgery, when compared with PEEP of 10 cm H_2O alone, inspiratory pressure of 40 cm H_2O applied once for 15 s, or both. These results are in keeping with the concept of 'opening up the lung and

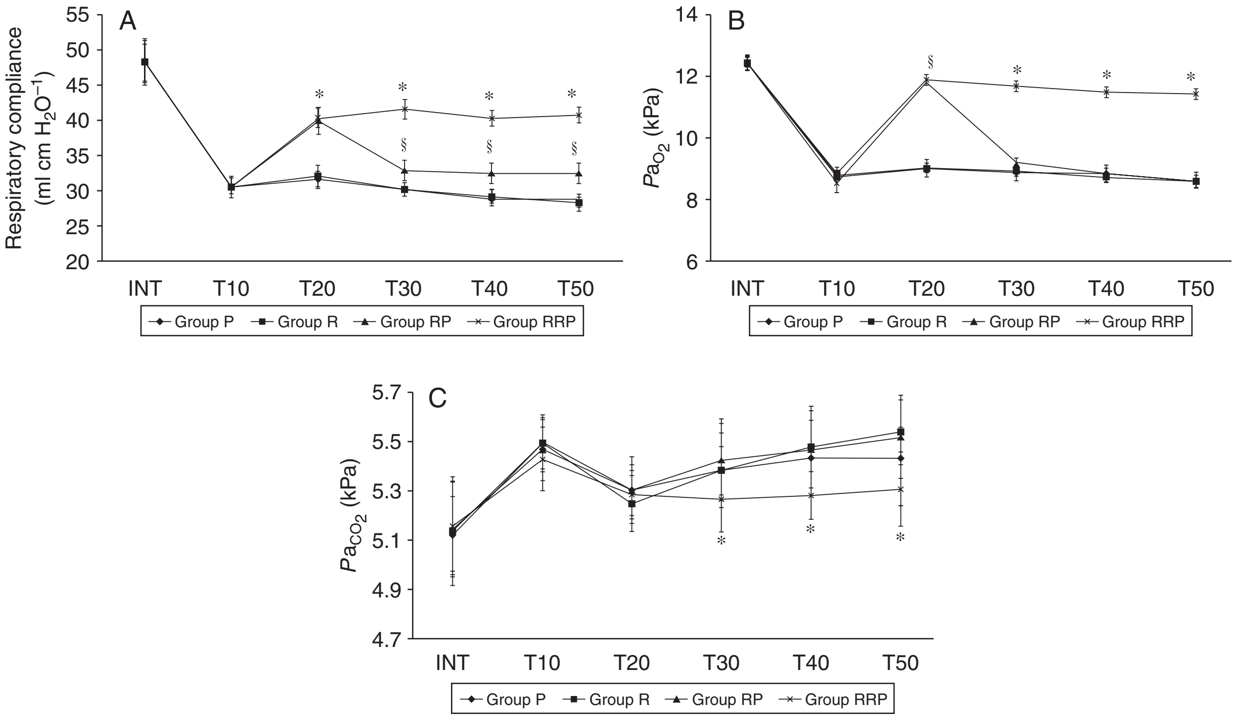

Fig 3 Intraoperative changes in respiratory compliance, arterial partial pressure of oxygen (Pa_{O_2}), and arterial partial pressure of carbon dioxide (Pa_{CO_2}) during the observation period. Respiratory compliance and arterial blood gas trends between groups. INT, 5 min after intubation; T*n*, *n* min after induction of pneumoperitoneum; P, Group PEEP; R, group single recruitment manoeuvre; RP, group single recruitment manoeuvre followed by PEEP; RRP, group repeated recruitment manoeuvre with PEEP. (A) After the recruitment manoeuvre, respiratory compliance improved most in Group RRP (*P<0.01, between the groups) followed by Group RP ($^§P$<0.01, between the groups), but there was no improvement in Groups P and R. (B) Pa_{O_2} decreased in all groups 10 min after pneumoperitoneum induction and remained so in Groups P and R (P<0.01). Recruitment manoeuvre increased Pa_{O_2} in Groups RP and RRP ($^§P$<0.01, between the groups); however, this improvement was sustained only in Group RRP (*P<0.01, between the groups). (C) Pa_{CO_2} increased in all groups after pneumoperitoneum induction and it decreased after the recruitment manoeuvre. However, Pa_{CO_2} increased again at T30 and continued to rise until T50 in Groups P, R, and RP (P<0.01, within the groups).

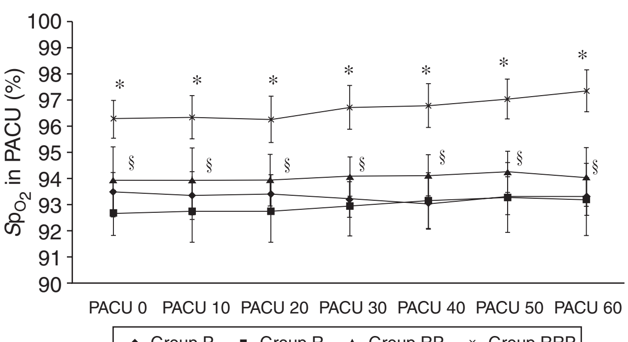

Fig 4 Postoperative changes in pulse-oximetry-measured oxygen saturation (Sp_{O_2}) during the first hour of recovery. Oxygen saturation trends between groups in the post-anaesthesia care unit (PACU); PACU*n*, *n* min after PACU admission; P, Group PEEP; R, group single recruitment manoeuvre; RP, group single recruitment manoeuvre followed by PEEP; RRP, group repeated recruitment manoeuvre with PEEP. On admission to PACU, Group RRP had the highest oxygen saturation followed by Group RP, which persisted through the first hour of recovery when compared with the other groups (*P<0.01 and $^§P$<0.01, between the groups, respectively).

keeping it open'[11] by alveolar recruitment achieved via a high inspiratory pressure manoeuvre with alveolar derecruitment minimized by applying PEEP.

Similar to previous reports in both obese[1 2] and non-obese individuals,[12 13] pneumoperitoneum in the current study impaired respiratory mechanics and gas exchange in all study groups. These effects could be attributed to development of atelectasis and reduced lung volumes which have been previously confirmed on spiral computed tomography in patients undergoing laparoscopic surgery.[14] The decrease in respiratory system compliance and Pa_{O_2} was significantly reverted by the application of sustained inspiratory pressure combined with PEEP, but not by either intervention alone. These results are consistent with those of Dyhr and colleagues[15] who demonstrated that both a lung recruitment manoeuvre and PEEP are required to maintain increased lung volume and Pa_{O_2}. In contrast, Pelosi and colleagues[8] showed that PEEP of 10 cm H_2O alone increases lung compliance and Pa_{O_2} in morbidly obese but not in normal weight individuals. However, patients in that study had higher BMI [51 (8) kg m^{-2}] than those in the current study and there was no pneumoperitoneum,[8] which could explain the disparity in the results of the two studies. It is also possible that the level of PEEP applied in Group P in the current trial was insufficient by itself for effective lung recruitment in the presence of pneumoperitoneum. In support of this are the findings of Whalen and colleagues[16] who applied incremental levels of PEEP, up to 20 cm H_2O, then decreased it to 12 cm H_2O and observed sustained beneficial effects on arterial oxygenation in the majority of obese patients undergoing laparoscopic bariatric surgery. Nevertheless, a few patients required repeating the recruitment manoeuvre to maintain its beneficial effect on arterial oxygenation.[16]

The decline in Pa_{O_2} in Group RP 10 min after the recruitment manoeuvre could be attributed to partial alveolar derecruitment. This is supported by the concomitant decline in respiratory compliance in the same group. On the other hand, alveolar derecruitment was likely minimized by the repeated inspiratory manoeuvre in Group RRP, which would explain the sustained improvement in respiratory compliance and Pa_{O_2} values in this group compared with the other groups. In support of this are the results of Sprung and colleagues[17] who observed a sustained improvement in Pa_{O_2}/FI_{O_2} and respiratory dynamic compliance in patients undergoing laparoscopic bariatric surgery when an incremental increase in PEEP manoeuvre was applied hourly. In addition, a sustained increase in Pa_{O_2} for 2 h was reported by Tusman and colleagues[18] after a recruitment strategy in which tidal volume was increased to achieve a peak inspiratory pressure of 40 cm H_2O followed by PEEP of 15 cm H_2O for 10 breaths, then PEEP of 5 cm H_2O.

The increase in Pa_{CO_2} after pneumoperitoneum induction could be attributed, at least in part, to CO_2 uptake secondary to CO_2 insufflation, and, in part, to atelectasis formation and consequent ventilation/perfusion mismatch. In keeping with the results of Tusman and colleagues,[19] PEEP alone and other recruitment strategies in this study resulted in a decrease in Pa_{CO_2} to near baseline values after its initial increase. The subsequent increase in Pa_{CO_2} over time in Groups P, R, and RP could be attributed to worsening of ventilation/perfusion mismatch in conjunction with ongoing CO_2 uptake and relatively constant CO_2 elimination in these groups. In contrast, the repeated inspiratory manoeuvre in Group RRP had likely enhanced CO_2 elimination by minimizing ventilation/perfusion mismatch through alveolar recruitment, and thus Pa_{CO_2} remained relatively stable in this group.

Recruitment manoeuvre using high inspiratory pressure could result in hypotension and increased requirement for vasopressors[16] which was not observed in the current study and which could be explained by the fluid bolus administered before anaesthesia induction and/or by the relatively lower peak inspiratory pressure used compared with that reported by others.[16]

After operation, some studies have shown no beneficial effects of intraoperative recruitment strategies on Pa_{O_2} after tracheal extubation.[16 20] In contrast, the current study showed sustained improvement in Sp_{O_2} in Group RRP into the first hour of recovery. This could be attributed to optimal alveolar recruitment and improved regional ventilation as a result of the repeated inspiratory pressure manoeuvre applied intraoperatively. In support of this are the results of Dyhr and colleagues[21] who reported maintenance of Pa_{O_2} for 30 min after discontinuation of PEEP in cardiac surgical patients and improved regional lung ventilation after lung recruitment.[21]

Study limitations

Respiratory system compliance was used as a surrogate for lung compliance. However, since all study patients were paralysed and the intra-abdominal pressure was maintained within a narrow range (11–13 mm Hg) intraoperatively, one could assume that chest wall compliance remained relatively unchanged throughout the study period and hence changes in respiratory system compliance reflected changes in lung compliance. The finding that hospital discharge time was shorter in Groups RRP and RP suggests that these patients had better postoperative respiratory function than their counterparts, given that there were no reported major adverse events in any group. Unfortunately, Sp_{O_2} was not measured on the ward, and hospital discharge criteria were not standardized. Therefore, this remains to be studied in a future trial.

In conclusion, repeated inspiratory pressure manoeuvre combined with 10 cm H_2O of PEEP increased respiratory system compliance and Pa_{O_2}, and decreased Pa_{CO_2} in obese patients undergoing laparoscopic gastric banding without adverse events. Moreover, the beneficial effects on oxygenation continued into the early recovery period.

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