Recruitment of lung volume during surgery neither affects the postoperative spirometry nor the risk of hypoxaemia after laparoscopic gastric bypass in morbidly obese patients: a randomized controlled study


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Editor’s key points

- General anaesthesia causes a reduction in functional residual capacity (FRC) that can last several days.
- Obese patients can suffer more profound changes than non-obese patients.
- Recruitment manoeuvres reverse the reduction in FRC during the intraoperative phase.
- The current study investigated whether this improvement persists into the postoperative phase in obese patients.

Background. Intraoperative recruitment manoeuvres (RMs) combined with PEEP reverse the decrease in functional residual capacity (FRC) associated with anaesthesia and improve intraoperative oxygenation. Whether these benefits persist after operation remains unknown. We tested the hypothesis that intraoperative RMs associated with PEEP improve postoperative spirometry including FRC and reduce the incidence of postoperative hypoxaemia in morbidly obese (MO) patients undergoing laparoscopic gastric bypass.

Methods. After IRB approval and informed consent, 50 MO patients undergoing laparoscopic gastric bypass under volume-controlled ventilation (tidal volume 6 ml kg⁻¹ of IBW) were randomly ventilated with either 10 cm H₂O PEEP and one RM carried out after induction of pneumoperitoneum, and another after exsufflation. Anaesthesia and analgesia were standardized. Spirometry was assessed before operation and 24 h after surgery. Postoperative oxygenation and the apnoea–hypopnoea index (AHI) were recorded during the first postoperative night.

Results. Age, BMI, and STOP BANG score were similar in both groups. FRC decrease after surgery was minimal (0.15 (0.14) litre in control and 0.38 (0.19) litre in the RM group) and similar between the groups (P=0.35). FVC, FEV₁, mean SPO₂, percentage of time spent with SPO₂ below 90%, and AHI did not differ significantly between the groups.

Conclusions. This study demonstrates that when added to a protective mechanical ventilation combining low tidal volume and high PEEP, two RMs do not improve postoperative lung function including FRC, arterial oxygenation, and the incidence of obstructive apnoea in MO patients after laparoscopic upper abdominal surgery.

Clinical trial registration. EudraCT 2011-000999-33.

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General anaesthesia decreases functional residual capacity (FRC) and causes atelectasis. After upper abdominal surgery, FRC remains decreased in the immediate postoperative period and then recovers slowly over several days. Upper abdominal surgery is also associated with reductions in forced vital capacity (FVC) and forced expiratory volume after 1 s (FEV₁). However, the alteration in FRC is more clinically relevant since it can result in small airway closure and ventilation-perfusion mismatch, potentially leading to postoperative hypoxaemia and respiratory complications.

Morbidly obese (MO) patients undergoing abdominal surgery under general anaesthesia develop more perioperative atelectasis than healthy subjects. The decrease in lung volume secondary to obesity also favours velopharyngeal collapsibility, particularly in the case of pre-existing sleep-disordered breathing, a prevalent disorder in MO patients. Further reduction in FRC such as after upper abdominal surgery could therefore worsen episodes of upper airway obstruction in the case of sleep apnoea syndrome. Taken together, these perioperative pathophysiological ventilatory changes explain that MO patients
experience frequent episodes of postoperative hypoxaemia and seem to be at increased risk of postoperative pulmonary complications.9

Different strategies have been proposed to reduce atelectasis: induction of anaesthesia in the head-up position without or with a continuous positive airway pressure (CPAP)11 12 and use of intraoperative PEEP.13 However, the alveolar recruitment manoeuvre (RM) seems the most effective technique to reverse atelectasis.13 14 In MO patients undergoing laparoscopic surgery, recruitment of lung volume during surgery improves intraoperative respiratory mechanics and oxygenation.13 15 16 However, whether these benefits persist into the postoperative period is unknown.

We investigated the effect of an intraoperative alveolar recruitment strategy on postoperative FRC, and also on oxygenation and the incidence of obstructive apnoea during the first postoperative night in MO patients undergoing laparoscopic gastric bypass.

Methods

After approval by the Institutional Ethics Committee of Centre Hospitalier Universitaire de Liege (Liege, Belgium; ref 2001-59: and registered with EudraCT 2011-000999-33), 50 consenting MO (BMI >35 kg m⁻²) ASA physical status II–III patients were included in this randomized double-blind controlled study (see Fig. 1 for CONSORT trial profile). All patients had a laparoscopic gastric bypass performed in the morning between December 2011 and May 2012. Exclusion criteria were: age <18 and >65, preoperative diagnosis of obstructive sleep apnoea (OSA) syndrome using polysomnography (our policy is to use CPAP or BiPAP after operation in these patients), a history of pneumothorax or right heart failure, or surgery scheduled on Friday since the spirometry laboratory is closed on Saturday. Patients were withdrawn from the study and replaced in the case of protocol violation and if intraoperative RM were necessary because of pulse oximetry below 90%.

Randomization and blinding

Patients were assigned to one of the two groups using a reproducible set of computer-generated random numbers: the RM group and the control group without RM. Investigators involved in recording postoperative parameters and patients were blinded to treatment allocation.

Anaesthesia

Anaesthesia was standardized in all patients. Patients were orally premedicated with alprazolam 0.5 mg, ranitidine 150 mg, and domperidone 10 mg 1 h before surgery. When in the operating theatre, patients were given a 300 µg clonidine i.v. infusion over 10 min together with an i.v. infusion of 500 ml of Volulyte®©, a balanced hydroxyethyl starch solution (Fresenius Kabi AG, Bad Homburg, Germany) to improve haemodynamic tolerance of head-up position, pneumoperitoneum, and RMs when used.11 Anaesthesia was induced i.v. using 10 µg sufentanil, 100 mg lidocaine, propofol 2 mg kg⁻¹ of IBW + 40% of weight excess. Tracheal intubation was facilitated with succinylcholine 1 mg kg⁻¹ of actual body weight. Anaesthesia was maintained with desflurane in an air:oxygen mixture with an FIO₂ of 0.8. After recovery from succinylcholine, muscle relaxation was maintained with rocuronium 0.6 mg kg⁻¹ of IBW followed by a continuous infusion of rocuronium started at 7 µg kg⁻¹ h⁻¹ of IBW + 40% of weight excess and titrated to keep a train of four of 0 until the end of the surgical procedure. At the end of surgery, neuromuscular block was antagonized using sugammadex 4 mg kg⁻¹ of IBW + 40% of weight excess. A continuous i.v. infusion of Plasmalyte®, a crystalloid solution (Baxter®© SA, Lessines, Belgium), was administered at a rate of 4 ml kg⁻¹ h⁻¹ of IBW intraoperatively.

Ventilation

Ventilation was standardized in all patients. Before induction, preoxygenation and denitrogenation were obtained by vital capacity manoeuvres with an FIO₂ of 1.0 and using a 10 cm H₂O CPAP until the FEO₂ becomes >0.9 in patients in ramp position. After tracheal intubation, lungs were ventilated using volume-controlled ventilation with a tidal volume of 6 ml kg⁻¹ of ideal body weight [IBW; IBW was calculated as the height (in cm) minus 100 in men and minus 105 in women] using an Aisys ventilator (GE Healthcare, Diegem, Belgium). The respiratory rate was adapted to maintain a PCO₂ between 4.7 and 6 kPa and a 10 cm H₂O PEEP was applied in all patients. In patients assigned to the RM group, two RMs consisting of maintaining the airway pressure at 40 mm Hg during 40 s were performed, one 5 min after creation of the pneumoperitoneum (14 cm H₂O) and one 5 min after its exsufflation. At the end of surgery and after reversal of muscle relaxation, patients were allowed to awaken from anaesthesia in the head-up position breathing a mixture of air:oxygen with an FIO₂ of 0.8. After emergence from anaesthesia, patients were placed in their bed 30° upright and given oxygen via a non-rebreathing facemask with reservoir bag in the recovery room. Non-invasive positive pressure ventilation was not used after operation.

Postoperative analgesia

Patients received parecoxib 80 mg i.v. in the absence of contraindication after the induction of anaesthesia. Paracetamol 2 g (Paracetamol, Fresenius Kabi AG) and tramadol 100 mg (Contramol®, Grunenthal, Sint-Stevens, Woluwe, Belgium) were administered i.v. 30–60 min before the end of surgery. Piritramide, a synthetic opioid (Janssen Pharmaceutica, Beerse, Belgium), was titrated in the recovery room to provide a pain score inferior to 3 on a 0–10 verbal scale. When in the ward, patients received paracetamol i.v. 1 g every 6 h and a continuous i.v. infusion of 400 mg tramadol over 24 h.

Measurements

The primary endpoint of this study was the change in FRC at postoperative day 1. FRC was measured at the time of preoperative assessment and at postoperative day 1 by closed-circuit helium dilution (FRC<sub>pert</sub>) and whole body plethysmography (FRC<sub>pleth</sub>) (Vmax<sup>TM</sup> Autobox, Carefusion Corporation, Torrey...
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View Court, San Diego, CA, USA. All measurements were performed in the sitting position. For $\text{FRC}_{\text{pleth}}$, the mean of three measurements that agreed within 5% was reported. The result of one technically satisfactory measurement was used for $\text{FRC}_{\text{He}}$.

Secondary endpoints included changes in forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV₁) and postoperative arterial oxygen saturation and apnoea–hypopnoea index (AHI). FVC and FEV₁ were measured together with FRC in the sitting position before surgery and at postoperative day 1. AHI and arterial oxygen saturation were obtained from an ambulatory sleep recorder (Somnolter®, Nomics, Liege, Belgium) placed during the first postoperative night. During this recording, patients were lying in their bed with the head slightly elevated and with no supplemental oxygen.

The STOP BANG score was calculated during the preoperative visit. Durations of anaesthesia and of pneumoperitoneum were measured. Compliance of the respiratory system was recorded from the CARESCAPE monitor B850 connected to an Aisys ventilator (GE Healthcare) 5 min after creation of the

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**Fig 1** CONSORT diagram on patient recruitment, inclusion, and exclusion. RM, recruitment manoeuvre.
14 cm H₂O pneumoperitoneum, 5 min after exsufflation, and 2 min after each RM in patients assigned to the RM group. Finally, the length of hospital stay was recorded.

Statistics

No data being available with regard to postoperative change in FRC in MO patients undergoing upper abdominal laparoscopy, we extrapolated from published data reporting a 50% decrease in other spirometric parameters at postoperative day 1. Using data from Futier and colleagues about the impact of the same RM as used in our study on intraoperative changes in FRC, we estimated that a sample size of 22 patients per group would provide an 80% power for detecting a 30% difference in FRC between the groups at an α-level of 0.05. Fifty patients were included.

Normality of the data distribution was tested using the Shapiro–Wilk test. FRC values were normalized by log-transformation. The paired Student’s t-test and Wilcoxon matched-pairs signed-rank test were used for within-group comparisons as appropriate. The unpaired Student’s t-test and Mann–Whitney test were used for between-group comparisons. Data are presented as mean (so) or median (IQ 25–75) unless otherwise stated. P<0.05 was considered statistically significant.

Results

Patient characteristic data, STOP BANG score, durations of pneumoperitoneum, and anaesthesia were similar in both groups (Table 1). No RM needed to be interrupted for haemodynamic intolerance. One patient in the PEEP group required several RMs; he was withdrawn from the study and replaced (Fig. 1). Both RMs improved thoracopulmonary compliance, but the effect of the second RM was larger (Table 2). In both groups, pre- and postoperative values of FRC were similar (Fig. 2 and Table 3). The change in FRC_H2 after surgery, that is, preoperative FRC_H2 – postoperative FRC_H2, was 0.15 (0.14) litre in the control group and 0.38 (0.19) litre in the RM group (P=0.35; Table 4). Similar results were obtained for FRC_pleth (data not shown). Forced vital capacity and forced expiratory volume in 1 s were significantly decreased the day after surgery (Table 3). However, FEV₁ and FVC were similarly affected by surgery (Table 4). During the first postoperative night, the mean SpO₂, percentage of recording time with an SpO₂ below 90%, and the AH were not significantly different in both groups (Table 5). The length of hospital stay was similar in both groups: 2 (2–3) days in the RM group; 2 (2–2) days in the control group.

Discussion

This study demonstrates first that laparoscopic upper abdominal surgery in MO patients with intraoperative protective mechanical ventilation does not result in significant decrease in FRC 24 h after operation. Secondly, adding intraoperative lung RMs to protective ventilation does not affect postoperative FRC. Thirdly, FVC and FEV₁ are similarly reduced the day after surgery, whether intraoperative lung recruitment was used or not. Finally, arterial oxygenation and AH measured during the first postoperative night were not affected by the use of intraoperative lung recruitment.

The absence of decrease in FRC at postoperative day 1 in the present study contrasts with previous data which identified obesity as a risk factor for low postoperative FRC after laparoscopic cholecystectomy. This is unlikely to result from technical issues. Indeed, FRC_H2 was measured using the closed-circuit helium dilution technique like in other similar studies. The preoperative FRC measurements we report are consistent with previous data in MO patients. Moreover, analysis of FRC values provided by whole body plethysmography gives similar results. Only FRC_H2 was reported to avoid redundancy and might have limited lung derecruitment. The postoperative decrease in FRC might also have fully recovered at

Table 1 Patient data, STOP BANG scores, durations of pneumoperitoneum, and anaesthesia. Data are presented as median (range) or numbers. RM, recruitment manoeuvre

<table>
<thead>
<tr>
<th>Table 2 Thoracopulmonary compliance (ml cm H₂O −1) during surgery. Data are means (so). RM1, first recruitment manoeuvre 5 min after creation of pneumoperitoneum; RM2, second recruitment manoeuvre 5 min after exsufflation; RM, recruitment manoeuvre</th>
<th>Pre-RM</th>
<th>Post-RM</th>
<th>P-value</th>
<th>Pre-RM</th>
<th>Post-RM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (n = 25)</td>
<td>32 (8)</td>
<td>NA</td>
<td>NA</td>
<td>35 (10)</td>
<td>38 (11)</td>
<td>0.09</td>
</tr>
<tr>
<td>RM1</td>
<td>32 (8)</td>
<td>NA</td>
<td>NA</td>
<td>35 (10)</td>
<td>38 (11)</td>
<td>0.09</td>
</tr>
<tr>
<td>RM2</td>
<td>41 (11)</td>
<td>NA</td>
<td>NA</td>
<td>45 (13)</td>
<td>65 (18)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
postoperative day 1. Accordingly, Ali and Gana\textsuperscript{25} reported an early FRC recovery after laparoscopic cholecystectomy. Since FRC was not significantly decreased in the control group after operation, not surprisingly intraoperative lung recruitment had no effect on postoperative FRC.

FEV\textsubscript{1} and FVC decreased similarly and approximately by 25% in both groups on the first postoperative day. This reduction is less than what we previously reported in a similar population of MO patients.\textsuperscript{19} One potential explanation is the use of a protective mechanical ventilation in the present study. Indeed, Severgnini and colleagues\textsuperscript{26} reported that protective ventilation combined with RMs improved postoperative pulmonary function tests after laparotomy, but their study does not allow to distinguish between the effect of low tidal volume ventilation with PEEP and the effect of lung recruitment. Our study showed no additional benefit of lung recruitment when combined with protective ventilation on the postoperative changes in FVC and FEV\textsubscript{1}.

MO patients experience frequent episodes of postoperative hypoxaemia.\textsuperscript{27} The first postoperative night seems to be a particularly high-risk period of hypoxaemia because of surgery-induced sleep disturbances.\textsuperscript{28, 29} We found no effect of intraoperative lung recruitment on arterial oxygen saturation measured continuously during the first postoperative night. This lack of effect fits the absence of benefit of lung recruitment on FRC. Indeed, a correlation was recently established between decreased lung volumes and hypoxaemia during the first postoperative night after bariatric surgery.\textsuperscript{30} Severgnini and colleagues\textsuperscript{26} reported higher arterial oxygen saturation during the first five postoperative days when a protective ventilation combined with lung recruitment was used. But since their control group did not receive protective ventilation, their study does not allow to separate the effect of lung recruitment from low tidal volume ventilation with high PEEP. Moreover, they excluded patients with a BMI $\geq 40$ kg m\textsuperscript{-2}. Our data suggest that the benefit of intraoperative lung recruitment on postoperative oxygenation after laparoscopic surgery in obese patients, if any, is transient and limited to the immediate postoperative period. Accordingly, Almarakbi and colleagues\textsuperscript{31} reported higher postoperative arterial oxygen saturations in patients assigned to repeated RMs and PEEP in a study limited to the first two postoperative hours.

Besides decreased lung volumes, upper airway obstruction is the other major cause of postoperative hypoxaemia in obese patients.\textsuperscript{32} Indeed, morbid obesity is a risk factor for OSA.\textsuperscript{13} Reduced lung volume favours pharyngeal collapsibility in MO patients, particularly those with OSA.\textsuperscript{7} Since lung volumes were expected to be decreased after upper abdominal surgery, we found relevant to investigate the incidence of postoperative obstructive apnoea after laparoscopic gastric bypass and the potential benefit of lung RM reported to increase lung volumes. Patients with an established preoperative diagnosis of OSA therapy were excluded from the present study because our policy is to use CPAP or BiPAP in these patients after operation. However, this disorder remains largely under-diagnosed and we probably included unrecognized OSA patients. The median STOP-BANG score was 4 in both groups, which is associated with a low probability of moderate or severe OSA syndrome.\textsuperscript{34} Accordingly, the postoperative AHI was low in both groups. In our study, intraoperative lung

![Fig 2 Combined dot and box and whiskers plot of FRC before and after surgery in both groups. Open circles represent individual patients. FRC, functional residual capacity; PRE, preoperative; POST, postoperative; RM, recruitment manoeuvre.](image)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control ($n = 21$)</th>
<th>RM ($n = 23$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preop Day 1</td>
<td>P-value</td>
</tr>
<tr>
<td>FRC (litre)</td>
<td>2.05 (0.56)</td>
<td>1.9 (0.82)</td>
</tr>
<tr>
<td>FVC (litre)</td>
<td>3.7 (0.74)</td>
<td>2.9 (0.74)</td>
</tr>
<tr>
<td>FEV\textsubscript{1} (litre)</td>
<td>2.96 (0.6)</td>
<td>2.28 (0.6)</td>
</tr>
</tbody>
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recruitment did not affect AHI. This is in agreement with the fact that intraoperative lung recruitment did not improve lung volumes after operation. However, we cannot extend those results to a population of OSA patients.

The present study has three main limitations. First, postoperative spirometric measurements were only performed once at postoperative day 1. Therefore, potential benefits of recruitment during the early postoperative period and their durations were not explored. However, the clinical relevance of short-lasting (a few hours) postoperative benefits is questionable in our opinion. Secondly, we did not measure FRC intraoperatively. Like others, we used the changes in thoracopulmonary compliance as a surrogate for the efficacy of our intraoperative RM. This latter was extensively studied and was shown to effectively improve end-expiratory lung volume and to increase FRC in MO patients. Accordingly, the thoracopulmonary compliance increased after alveolar recruitment in our study. Inefficacy of our RM is therefore unlikely to account for the negative results of our study. Thirdly, we did not record oxygen saturation and the AHI before surgery. This would have been interesting to document the changes in these parameters induced by laparoscopic upper abdominal surgery and to identify patients’ subgroups benefiting from alveolar recruitment.

In conclusion, intraoperative lung recruitment does not improve postoperative lung function including FRC at postoperative day 1 after laparoscopic gastric bypass surgery when protective ventilation is used intraoperatively. It has no effect on arterial oxygenation and the incidence of upper airway obstruction during the first postoperative night either. Together with the recent literature, our results suggest that protective ventilation including the use of a low tidal volume and a PEEP is sufficient for optimizing postoperative lung function and to prevent postoperative respiratory complications. This needs further confirmation.

### Authors’ contributions


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### Declaration of interest

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