Review Article

Effects of intraoperative recruitment maneuver in patients with obesity undergoing laparoscopic surgery: A narrative review

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Abstract

In this article, we explored 18 studies showing the impact of the intraoperative recruitment maneuver on patients with obesity undergoing laparoscopic surgery. A recruiting maneuver accompanied by a more significant positive end-expiratory pressure enhances intraoperative oxygenation and respiratory mechanics in obese patients undergoing surgery. They are safe and do not have unfavorable hemodynamic consequences.

Keywords: Laparoscopy, obesity, positive end-expiratory pressure, recruitment maneuver

Introduction

Obesity is now a global epidemic, and it poses a challenge to the perioperative management of patients by anesthesiologists. It is now recognized as a distinct risk factor for developing postoperative pulmonary complications (PPCs).[1] The incidence of PPCs has been reported to be 11.7% in patients with obesity, with independent associations with age, body mass index (BMI), and use of rescue recruitment maneuvers (RMs).[2]

In morbidly patients with obesity, respiratory function is impaired with anesthesia and laparoscopic surgery, further aggravating the problem. This is because of the combined effects of obesity, obesity hypoventilation syndrome, positioning during surgery, and pneumoperitoneum, which result in decreased functional residual capacity (FRC) and, consequently, the development of atelectasis. Because of this, patients with obesity are more prone to developing PPC and have a more extended hospital stay.[3-6]

There is a growing need to optimize ventilation strategies in patients with obesity planned for surgery as an increasing number of patients with obesity present for surgery. Intraoperative ventilator settings are known to affect oxygenation and compliance of the lungs, but the optimal strategy remains poorly defined in this group of patients.[2] Evidence-based strategies are needed to prevent atelectasis and PPC in patients with obesity.

The purpose of the present study was to conduct a literature review on RMs in obese patients undergoing laparoscopic surgery regarding enhanced oxygenation, respiratory mechanics, and a reduction in PPC.

Material and Methods

In the present review, the effects of intraoperative RM on the development of atelectasis in patients with obesity undergoing laparoscopic surgery following abdominal surgery were investigated. A literature review was performed using

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PubMed and Google Scholar, and articles published till December 31, 2022, were searched. Specific keywords were used for the literature review [Appendix 1]. Articles addressing the effects of intraoperative RMs in obese patients undergoing laparoscopic surgery were included. Exclusion criteria included duplicate articles and articles with RMs involving nonobese patients or patients undergoing open surgeries.

Results

Initially, 2760 records were identified using the search strategy. After removing duplicates, 2722 records were screened; subsequently, 2704 were excluded following the inclusion and exclusion criteria applied. Finally, 18 studies were included in the present review, as shown in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flowchart [Figure 1]. Data collection tables were constructed to determine each investigation's crucial and pertinent variables [Table 1].

After critically appraising and analyzing all the studies, 18 were found to offer the most pertinent information as per our objective of the present systematic review. The included studies' methodology and data collection procedures were the most comprehensive, but they had small sample sizes and were all single-center studies.

Parameters

- Oxygenation – Arterial partial pressure of oxygen (PaO_2), PaO_2/FiO_2 (fraction of inspired oxygen) ratio, and oxygen saturation (SpO_2) were studied for improvement in oxygenation on using RM. All the studies in the present review reported a significant improvement in oxygenation in the intraoperative period using RM.[4-21] A lower alveolar to arterial oxygen gradient (O_2A-a) supported this arterial oxygen gradient and lower atelectasis score in the chest computed tomography (CT) scan.[6]
- Ventilation – Arterial partial pressure of carbon dioxide ($PaCO_2$) was measured, and an increase following pneumoperitoneum was reported, followed by a decrease after RM, more in the RM group.[7-10] The enhanced CO_2 elimination was attributed to improved ventilation/perfusion (V/Q) mismatch by RM.
- Respiratory mechanics
    - Peak and plateau airway pressure – Many studies reported a significant decrease in peak and plateau pressure in patients in the RM group.[8-14] Positive end-expiratory pressure (PEEP) after RM counterbalances the pneumoperitoneum-induced upward shift of the diaphragm, providing more space for lung expansion, hence reducing the peak and plateau pressure.
- Compliance – Many reported improved compliance, explained by the reversal of atelectasis and improved lung volumes.[5,7,11,14,15] In a study by Futier *et al*.,[8] an increase in compliance was noted, with a significant correlation between compliance and end expiratory lung volume (EELV).
- PEEP to zero end-expiratory pressure (ZEEP) expiratory volume delta (Delta VTE) – Tafer *et al*.[5] reported an increase in VTE, an indirect measure of an increase in lung volume and improvement of atelectasis.
- EELV – Futier *et al*.[8] and Elokda *et al*. studied the effect of PEEP alone and PEEP plus RM. They showed that PEEP with RM resulted in a higher increase in EELV, which is a sensitive indicator for airway collapse. There was a marked increase in oxygenation, which was also associated with improved elastance of the respiratory system, dead space, and difference in partial pressure of arterial and end-tidal carbon dioxide ($Pa - ETCO_2$). Ventilation at low EELV may result in the opening and closing of atelectatic lung regions.[8,13]
- Forced expiratory volume in 1 s (FEV1), forced vital capacity (FVC) – Remístico *et al*.[9] found a significant decrease in FEV and FEV_1 values in the non-RM group compared to the RM group on postoperative days 1 and 2. Contradictory results were reported by Defresne *et al*.,[12] who noted that the addition of intraoperative RMs had no effect on postoperative FRC, which was also measured at 24 h postoperatively. Additionally, regardless of intraoperative lung recruitment technique, FVC and FEV1 were similarly decreased the day following surgery. Also, in their study, arterial oxygenation and apnea hypopnea index measured during the first postoperative day were unaffected by intraoperative lung recruitment, which contradicts the results of other studies presented in the review. When closely analyzed, their results reveal that the decrease in FEV1 and FVC was only 25% on the first postoperative day in both groups, which is much smaller than that reported in patients with obesity in the literature.
- Diaphragmatic excursion (DE) and atelectasis area – Ellatif *et al*. studied the effect of RM on DE and atelectasis measured with ultrasound. They observed significantly lower DE in the control group compared to the PEEP 5 cm H_2O and PEEP 5 cm H_2O + RM group, but no difference was observed

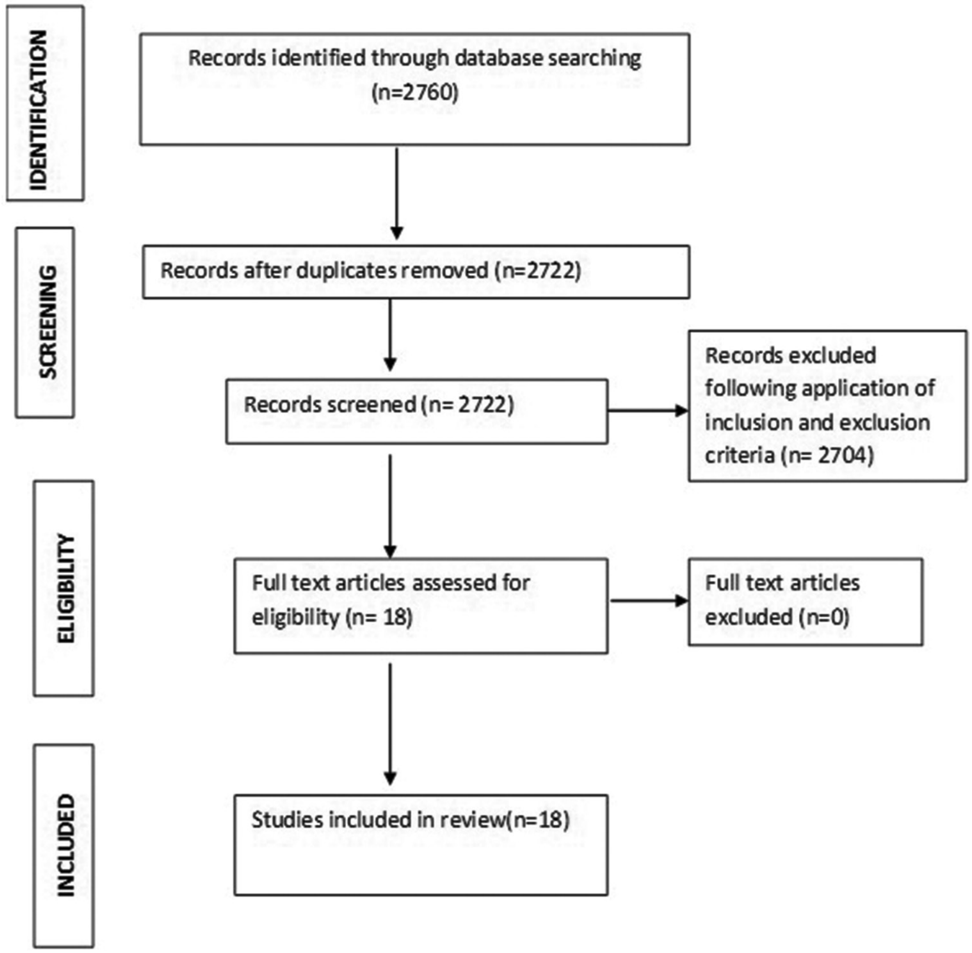

Figure 1: PRISMA flow chart

between the PEEP 5 cm H_2O and RM + PEEP 5 cm H_2O groups. This could be explained by a lower PEEP used in their study.[16-18]

- Clinical parameters – Remístico *et al*.[9] reported improved dyspnea Borg scale in the postoperative period in RM group patients. In addition, a higher incidence of pulmonary complications was identified in the control group on the chest radiograph. Severac *et al*.[19] showed a significantly lower incidence of pulmonary dysfunction in post anesthesia care unit (PACU) and on the first postoperative day with the use of RM.

Discussion

Patients with obesity have reduced chest wall and lung compliance because of fat deposition on the abdomen and chest and increased pulmonary blood flow. The reduced total pulmonary compliance results in decreased FRC, with the closing capacity approaching the decreased FRC. This leads to airway closure with normal tidal volume respiration, resulting in intrapulmonary shunting and V/Q mismatch. Supine position and general anesthesia independently worsen this V/Q mismatch, which is further exaggerated during laparoscopic surgery. The combination of decreased chest wall compliance, diaphragmatic tone, effects of general anesthesia, and laparoscopy surgery increases the risk of atelectasis. The decreased expiratory reserve volume and FRC renders the obese patient at an increased risk of rapid desaturation in the intraoperative and postoperative periods.[20-23]

In a study by Bendixen *et al*.,[24] PaO_2 fell by 22% and pulmonary compliance decreased by 15% without sigh breaths. After a few minutes of deep, slow, and sustained breaths, the average rise in PaO_2 was 150 mmHg, which reduced the shunt created by static V_T.[25]

What is an RM?

Hedenstierna and Rothen[26] described RMs as double tidal volume breaths, vital capacity breaths, and sigh breaths. Alveolar RMs act as sigh breath and provide increased pressure to reinflate the alveoli, which are collapsed and help to reverse atelectasis. RMs help to recruit alveoli, facilitate gas exchange by increasing the lung area, and improve alveolar oxygenation by maintaining an increase in airway pressure.

Table 1: Pulmonary RM effects on patients with obesity undergoing laparoscopic surgery

Authors	Sample and population	Groups	Type of RM	Timing of RM	Variables	Result	Conclusion
Whalen *et al*. 2006[4]	Twenty American Society of Anesthesiologists (ASA) class 2 or 3 patients, between 25 and 65 years old, undergoing laparoscopic bariatric Roux-en-Y operations	1) Control group- PEEP 4 2) RM + PEEP 12	Increasing PEEP in a stepwise fashion – first to 10 cm H_2O (three breaths), then to 15 cm H_2O (three breaths), and finally to 20 cm H_2O (10 breaths)	After pneumoperitoneum	PaO_2/FiO_2, respiratory mechanics, and hemodynamics	Significant increase in intraoperative PaO_2, respiratory system dynamic compliance in the RM group, but soon after tracheal extubation, all the beneficial effects on oxygenation disappeared	Use of alveolar recruitment may be an effective mode of improving intraoperative oxygenation in morbidly obese patients. In addition, it showed the effect to be short lived and associated with more frequent intraoperative use of vasopressors
Tafer *et al*. 2009[5]	Twenty-six patients with obesity (BMI >40 kg/m²) undergoing laparoscopic bariatric surgery	1) PEEP 2) RM + PEEP	Controlled pressure ventilation with I/E 1:1, freq. -7/min, insufflation pressure 40 cm H_2O, PEEP 20 cm H_2O	After intubation and before insufflation of pneumoperitoneum	Lung compliance (FRC) was estimated measuring delta VTE (delta expiratory volume) during a PEEP to ZEEP maneuver	In the RM group, significant improvement in compliance was seen. No difference in delta VTE was noted between the groups at the end of the intervention	In patients with morbid obesity undergoing laparoscopic bariatric surgery, an RM conducted before pneumoperitoneum improves the lung mechanics
Talab *et al*. 2009[6]	Sixty-six adult patients with obesity (BMI 30 and 50 kg/m²) underwent laparoscopic bariatric surgery	1) RM + ZEEP 2) RM + PEEP (5 cm H_2O) 3) RM + PEEP (10 cm H_2O)	Vital capacity maneuver for 7–8 s	Immediately after intubation	Arterial oxygen saturation and alveolar-arterial PaO_2 gradient (A-a PaO_2), length of stay in PACU, and the use of a nonrebreathing O_2 mask (100% FiO_2) or reintubation, CT scan	Patients in the RM + PEEP 10 group had better oxygenation both intraoperatively and postoperatively in PACU, lower atelectasis score on chest CT scan, and less postoperative pulmonary complications than the ZEEP and PEEP 5 groups	Intraoperative alveolar recruitment with vital capacity maneuver(VCM) followed by PEEP 10 cm H_2O is effective in preventing lung atelectasis and is associated with better oxygenation, shorter PACU stay, and fewer pulmonary complications
Almarakbi *et al*. 2009[7]	Sixty patients with BMI >30 kg/m² undergoing LSG	1) Group P-PEEP 10 H_2O 2) Group R-RM + 3) Group RP-RM + PEEP 10 H_2O_4) Group RRP-RM + PEEP 10 H_2O	Sustained inspiratory pressure of 40 cm H_2O for 15 s	Every 10 min	Respiratory compliance, PaO_2, $PaCO_2$	Static compliance improved in groups RRP and RP. PaO_2 improved in group RP, but was sustained in group RRP . $PaCO_2$ increased gradually in all groups except in group RRP	RM plus PEEP was associated with the best intraoperative respiratory compliance and $Pa(O_2)$ in patients with obesity undergoing laparoscopic gastric banding
Futier *et al*. 2010[8]	Sixty adult patients (30 obese, 30 healthy weight) underwent laparoscopic surgery in reverse Trendelenburg position	1) PEEP + RM 2) PEEP	Continuous positive airway pressure (40 cm H_2O/40 s)	20 min after pneumoinsufflation	EELV, static elastance , respiratory mechanics , dead space, and gas exchange (PaO_2, $PaCO_2$), mean arterial pressure (MAP)	RM combined with 10 cm H_2O of PEEP improved EELV, respiratory mechanics, and oxygenation during pneumoperitoneum, whereas PEEP alone did not	RM with PEEP induces sustained improvements in EELV, gas exchange, and respiratory mechanics

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Table 1: Contd...

Authors	Sample and population	Groups	Type of RM	Timing of RM	Variables	Result	Conclusion
Remístico *et al*. 2011[9]	30 patients	1) Control group 2) RM group	Positive end-expiratory pressure of 30 cm H_2O and inspiratory plateau pressure of 45 cm H_2O	2 min after pneumoperitoneum defiation	FEV_1, FVC, Peak expiratory flow (PEF), maximal voluntary ventilation (MVV), mid-expiratory flow (FEF25-75%), heart rate (HR), respiratory rate (RR), MAP, SpO_2, partial pressure end-tidal carbon dioxide ($PETCO_2$)	Significant decrease in spirometric values and higher incidence of pulmonary complications on chest radiograph in the control group. Significant improvement in dyspnea Borg scale in the RM group	RM resulting in more favorable radiologic and spirometric findings in the RM group compared to the control group
El–Sayed *et al*. 2012[10]	The study included 60 patients with BMI >50 kg m^2 undergoing laparoscopic bariatric surgery	1) RM + 10 cm H_2O PEEP + O_2 postoperatively; 2) RM + PEEP 15 cm H_2O and O_2 postoperatively; 3) RM + PEEP 15 + BiPAP	Sustained inspiratory pressure of 40 cm H_2O for 15 s follow by PEEP till extubation	After intubation	Intraoperative oxygenation, ventilation, respiratory mechanics, hemodynamics, postoperative oxygenation, vasopressor doses, length of ICU stay, and postoperative pulmonary complications	Static compliance improved significantly after recruitment in the PEEP 15 groups. PaO_2/FiO_2 was significantly higher in PEEP 15 groups and BIPAP group. ICU stay was significantly shorter in the PEEP + BiPAP group	RM followed by PEEP 15 cm H_2O improved oxygenation and respiratory mechanics during intraoperative and early postoperative periods in morbidly obese patients
Ahmed *et al*. 2012[11]	Sixty patients with BMI >35 undergoing LSG	1) Control group- no RM 2) Single RM + PEEP 3) Repeated RM + PEEP	Vital capacity maneuver	Group 2-5 min after pneumoperitoneum, group 3- every 30 min after creation of pneumoperitoneum	PaO_2, PaO_2/FiO_2, respiratory mechanics	Repeated RM with PEEP resulted in significant improvement in arterial oxygenation and static compliance, but the effects of RM did not last in the perioperative period	Repeated VCM in addition to PEEP 10 cm H_2O can be used to maintain the beneficial effects of alveolar recruitment in patients with obesity undergoing bariatric surgery
Defresne *et al*. 2014[12]	50 morbidly obese patients undergoing laparoscopic gastric bypass	1) PEEP 2) PEEP + RM	40 mmHg for 40 s	One after induction of pneumoperitoneum and another after exsufflation	FRC (FEV1) , postoperative arterial oxygen saturation and AHI	FRC decrease after surgery similar between the groups. FVC, FEV_1, mean SpO_2, percentage of time spent with SpO_2 below 90%, and AHI did not differ significantly between the groups	PEEP with two RMs did not improve postoperative lung function, including FRC, arterial oxygenation, and the incidence of obstructive apnea in morbidly obese (MO) patients
Elokda *et al*. 2014[13]	Fifty adults ASA I–II, BMI (40–50 kg/m^2) elective laparoscopic gastric banding	1) PEEP 2) PEEP + RM	40 cm H_2O for 45 s	Immediately after intubation	Heart rate, mean blood pressure, respiratory mechanical parameters: peak airway pressure, plateau pressure, and end-expiratory lung volume, PaO_2, PaO_2/FiO_2, and SpO_2	PaO_2 and PaO_2/FiO_2 ratio increased significantly in the RM group. Peak and plateau airway pressures increased significantly in the PEEP only group. End-expiratory lung volume increased significantly in the RM group	Preemptive RM with PEEP of 15 cm H_2O was effective in preventing pneumoperitoneum-induced intraoperative hypoxemia and respiratory mechanics changes

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Table 1: Contd...

Authors	Sample and population	Groups	Type of RM	Timing of RM	Variables	Result	Conclusion
Michal Stankiewicz-Rudnicki *et al.* 2016[14]	57 morbidly obese patients	1) PEEP 0 2) PEEP 10 + RM	Two sustained inflations for 10 s, each with peak inspiratory pressure of 40 cm H_2O	After intubation	IR, intraoperative respiratory mechanics, and pulse oximetry values	Respiratory system compliance, plateau pressure, and pulse oximetry values were higher in PEEP 10 + RM group	In patients with obesity, PEEP level of 10 cm H_2O preceded by an RM improves respiratory compliance and oxygenation, but does not prevent atelectasis
Nestler *et al.* 2017[15]	54 patients	(1) RM + individualized PEEP titrated using EIT (PEEPIND) or (2) no RM and PEEP of 5 cm H_2O (PEEP 5)	Peak pressure 50 cm H_2O, PEEP 30 cm H_2O, respiratory rate 6 bpm, for 10 cycles	After intubation , pneumo, and before extubation	PaO_2/FiO_2, EELV, ventilation distribution	RM and higher PEEPIND restored EELV, regional ventilation distribution, and oxygenation during anesthesia, but these differences did not persist in the postoperative period	In patients with obesity, an RM and higher PEEPIND restored EELV, regional ventilation distribution, and oxygenation during anesthesia, but these differences did not persist after extubation. Lung protection strategies should be extended in the postoperative period
Ke Wei *et al.* 2018[16]	Thirty-six obese adult patients with BMI >40 kg/m² who were scheduled for LSG	1) Control group- no RM 2) RM + ZEEP 3) RM + PEEP	Increasing PEEP in a stepwise manner- first to 5 cm H_2O, then to 10 cm H_2O, and then to 15 cm H_2O with three breaths on each point	Every 30 min	Arterial oxygenation, respiratory mechanics, hemodynamics, and postoperative outcomes were investigated	Patients in the two RM-treated groups had lower driving pressure during pneumoperitoneum and better arterial oxygenation in the emergence stage compared to control group. No difference in incidence of PPCs	Repeated ARMs, either with or without PEEP, improve early postoperative oxygenation and shorten time to extubation. ARMs without PEEP result in lower airway pressure and less hemodynamic impairment in patients who undergo bariatric surgery
Sümer *et al.* 2020[17]	Sixty morbidly obese patients undergoing LSG surgery	1) No RM 2) RM	40 cm H_2O pressure for 40 s	5 min after desufflation with 100% oxygen	pO_2, pCO_2, respiratory compliance	In group RM, PaO_2 was significantly high, while $PaCO_2$ was significantly low. The compliance in the recruitment group was higher	RM to PEEP administration for morbidly obese patients undergoing LSG surgery is considered to be effective in improving respiratory mechanics and arterial blood gas values

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Table 1: Contd...

Authors	Sample and population	Groups	Type of RM	Timing of RM	Variables	Result	Conclusion
Ellatif *et al*. 2020[18]	69 patients with obesity undergoing LSG	1) No PEEP/RM 2) PEEP 3) PEEP + RM	40 cm H_2O for 40 s	Four times (postinduction of anesthesia , after completion of pneumoperitoneum, after Trendelenburg position, after exsufflation)	DE. Secondary outcomes atelectasis area, FVC , FEV_1, PIP, and any complications	DE significant lower in the control group. Atelectasis volume was significantly increased in the control group compared to the other two groups. FVC and FEV_1 were markedly decreased in the control group	The application of RM and PEEP is helpful for preserving DE and improving lung aeration during LSG
Severac *et al*. 2021[19]	Two hundred and thirty patients were included: 115 in the RM group and 115 in the control group	1) Control group- no RM 2) RM	30 cm H_2O during 30 s every 30 min	After intubation, every 30 min	Clinical criterion of pulmonary dysfunction including oxygen saturation, oxygen needs and dyspnea, RM tolerance, pulmonary and non-pulmonary complications, length of hospital stay, ICU admission	Patients in the RM group had significantly lower rate of pulmonary dysfunction. No significant differences were found in secondary outcomes between the two groups	RM is safe and effective in reducing early pulmonary dysfunction in patients with obesity undergoing bariatric surgery
Wang *et al*. 2022[20]	80 patients	1) RM + PEEP-EIT arm 2) PEEP-EIT arm	Peak pressure of 40 cm H_2O for 20 s	After intubation , pneumo, and before extubation	PaO_2/FiO_2, ROI distribution, respiratory mechanics	Patients in the RM+PEEP-EIT arm had a significantly higher intraoperative PaO_2/FiO_2. However, at 5 min before leaving PACU and on postoperative day 1, there was no great difference in PaO_2/FiO_2	Individualized optimal PEEP combined with regular lung RM effectively improves intraoperative oxygenation and increases dynamic lung compliance (Cydn), but may not reduce postoperative pulmonary complications compared to individualized PEEP alone
Ellenberger *et al*. 2022[21]	162 patients	1) PEEP 4 2) PEEP 12 + RM	Stepwise increase of tidal volume (+4 ml kg^{-1} of PBW) up to plateau pressure of 40–50 cm H_2O	After intubation and repeated every 1 h	Fraction of ventilation in the dependent lung measured by EIT, oxygen saturation index (arterial oxygen saturation (Sao_2)/ FIO_2 ratio), respiratory and hemodynamic parameters, and cerebral tissue oximetry	High PEEP+RM was associated with smaller intraoperative decreases in dependent lung ventilation, oxygen saturation index, and a lower driving pressure. Hemodynamic parameters did not differ between two groups with a minor increase in cerebral tissue oximetry IN PEEP 12 + RM	In patients with obesity undergoing abdominal surgery, intraoperative PEEP of 12 cm H_2O with periodic ARMs, compared to intraoperative PEEP of 4 cm H_2O without ARMs, slightly redistributed ventilation to dependent lung zones with minor improvements in peripheral and cerebral oxygenation

AHI=apnea–hypopnea index, BMI=body mass index, CT=computed tomography, DE=diaphragmatic excursion, EELV=end-expiratory lung volume, EIT=electric impedance tomography, ICU=intensive care unit, IR=impedance ratio, LSG=laparoscopic sleeve gastrectomy, $PaCO_2$=arterial partial pressure of carbon dioxide, PaO_2=arterial partial pressure of oxygen, PEEP=positive end-expiratory pressure, PEEPIND=PEEP titrated using electrical impedance tomography, PIP=peak inspiratory pressure. PPCs=postoperative pulmonary complications, ROI=region of interest, RM=recruitment maneuver

Which RM is to be used?

Each included study used a different amount of pressure and RM. The RMs used were as follows:

- Continuous positive airway pressure of 40 cm H_2O for 40 s
- Increasing PEEP in a stepwise manner – first to 10 cm H_2O (three breaths), then to 15 cm H_2O (three breaths), and finally to 20 cm H_2O (10 breaths)
- Vital capacity maneuver for 7–8 s
- There was sustained inspiratory pressure of 40 cm H_2O for 15 s, followed by PEEP till extubation.
- Two sustained inflations for 10 s each, with a peak inspiratory pressure of 40 cm H_2O
- Peak pressure 50 cm H_2O, PEEP 30 cm H_2O, respiratory rate 6 bpm, for 10 cycles
- Stepwise increase in tidal volume (+4 ml/kg of predicted body weight (PBW)) up to plateau pressure of 40–50 cm H_2O
- Controlled pressure ventilation with inspiratory to expiratory (I/E) ratio 1:1, freq.- 7/min, insufflation pressure 40 cm H_2O, PEEP 20 cm H_2O

None of the studies conducted on patients with obesity compared the different RMs. However, beneficial effects were observed with all types of RMs used.

RM with/without PEEP?

All studies in the review concluded that RM with PEEP was more effective in improving oxygenation and respiratory mechanics in patients with obesity undergoing laparoscopic surgery. According to the findings of each trial, recruitment combined with PEEP improved oxygenation more than either recruitment or PEEP alone.[4-21]

Single versus repeated alveolar recruitment manoeuvres (ARMs)?

In a study by Almarakbi *et al.*,[7] RM was performed every 10 min. They reported increased oxygenation and compliance in group RPR, which received RM every 10 min. Most importantly, they reported an increase in oxygenation, which persisted for an hour postoperatively and a significantly earlier home discharge in the repeated RM group. The repeated inspiratory pressure resulted in optimal alveolar recruitment and improved ventilation. Ahmed *et al.*[11] compared the effect of single versus multiple RMs on arterial oxygenation and lung compliance in patients with obesity undergoing laparoscopic surgery. They concluded that a single RM with PEEP led to a temporary improvement in PaO_2 and static compliance, which lasted only 30 min after recruitment and then gradually decreased. So, repeated RMs are needed to prevent the collapse of the lung. In addition, in their study, Ahmed *et al.*[11] reported no difference in oxygenation in PACU between the RM and non-RM groups. It may be attributed to the removal of PEEP. The results contradict those of Almarakbi *et al.*,[7] who reported a sustained improvement in oxygen saturation in the repeated RM group in the first hour of recovery, possibly due to the increased recruitment frequency. Also, Severac *et al.* used RM every 30 min. Their results showed a significantly lower incidence of pulmonary dysfunction in PACU and on the first postoperative day, contrary to the results of other studies, which showed that the beneficial effects of RM vanished in the postoperative period.[11,19] There is still limited evidence to recommend single versus multiple RMs.

High/low/individualized PEEP?

The quantity of PEEP required is based on the patient's BMI and positioning during surgery, and thus can vary significantly, particularly among obese patients.[22] Talab *et al.*[6] compared zero end-expiratory pressure (ZEEP) + RM, PEEP 5 + RM, and PEEP 10 + RM. They concluded that PEEP 10 + RM was more effective in improving oxygenation, lowering A-aO_2 gradient, and lowering atelectasis score on CT scan. El Sayed *et al.*[10], in a study on 60 patients, concluded that RM with PEEP 15 caused significantly more significant improvement in PaO_2/FiO_2 and respiratory compliance compared to RM with PEEP 10. The amount of PEEP used remains unknown. The results of Talab *et al.*[6] and El Sayed *et al.* suggested that higher PEEP may be more beneficial in improving oxygenation and respiratory mechanics.[7-10] Nestler *et al.*[15] studied the effects of individualized PEEP titrated using electrical impedance tomography (PEEPIND) compared to a standard PEEP. They identified an average PEEP of 18.5 cm H_2O, and PEEPIND led to improved oxygenation, EELV, ventilation distribution, and lung mechanics. The results contradict those of Stankiewicz-Rudnick *et al.*,[14] who demonstrated a similar ventilation distribution in PEEP 0 and PEEP 10 with the RM group. The difference could be due to the lower PEEP applied by Stankiewicz-Rudnick *et al.*[14] and the position of the electric impedance tomography belt cephalad in the chest. Wang *et al.*,[20] in their study on the effects of individualized PEEP with RM, concluded that PEEPIND with RM was more effective in improving oxygenation and respiratory compliance. Since PEEP to be used differs in patients with obesity according to BMI, PEEPIND seems to be more beneficial in patients with obesity undergoing laparoscopic patients.

Postoperative effects of ARM

Whalen *et al.*[4] reported similar PaO_2/FiO_2, hospitalization duration, and incidence of pulmonary complications in the RM + PEEP and PEEP-only groups. Similarly, Ahmed *et al.*[11] reported no difference in oxygenation in the RM and non-RM groups. Nestler *et al.*[15] demonstrated that

RM + PEEPIND leads to improved oxygenation, ventilation distribution, EELV, and lung mechanics in the intraoperative period, but the effect lasts 2–6 h. Similarly, Wang *et al*.[20] also demonstrated that the impact of RM + PEEP vanished when patients were shifted from PACU. Contrary to the above findings, Talab *et al*.[6] reported earlier discharge from PACU and lower atelectasis score on CT in the RM + PEEP 10 group in the postoperative period. El Sayed[10], in his study, concluded that RM with PEEP 15 combined with bilevel positive airway pressure (BiPAP) in the postoperative period led to significant improvement in the respiratory rate and PaO_2/FiO_2 in the 24 h of postoperative period and lesser intensive care unit stay compared to the other groups, which received nasal oxygen. They concluded that intraoperative RM with PEEP combined with postoperative BiPAP efficiently prevents alveolar derecruitment.[10] Almarakbi *et al*.[7] reported higher oxygen saturation in the repeated RM + PEEP group and earlier discharge from the hospital in the repeated RM group. Also, Severac *et al*.[19] demonstrated a significantly lower incidence of pulmonary dysfunction in PACU and on the first postoperative day in the RM + PEEP group. Whether using RM + PEEP leads to improved oxygenation and decreased PPC in the postoperative period remains debatable. Further investigations are required to study the effect of repeated RM and the use of BiPAP in extending the beneficial impact of RM in obese patients undergoing laparoscopic surgery in the postoperative period.

Hemodynamic instability with ARM

El Sayed *et al*.[10] reported that total vasopressors used in RM and non-RM groups were comparable, and no persistent hypotension was reported.[10] Whalen *et al*.[4] reported increased use of vasopressors in the RM group compared to the non-RM group. Tafer *et al*.[5] reported good hemodynamic tolerance of RM with no change of more than 20% in the vitals and no increase in the need for vasopressors. Similarly, Elokda *et al*.[13] reported no difference in hemodynamic parameters between the two groups. Nestler *et al*.[15] reported a higher incidence of hypotension and vasopressor requirement in the RM + PEEP group. However, no difference in lactates, base excess, or any signs of shock or cardiovascular insufficiency was observed. In addition, high levels of individualized PEEP were used (an average of 18.5 cm H_2O). Wang *et al*.[20] also demonstrated a higher need for vasopressors in the PEEPIND plus RM group, but the hemodynamic parameters remain comparable between the two groups at all time points. Though studies have reported increased use of vasopressors with the use of RM, hemodynamic parameters remained comparable, and none of the studies reported the need to terminate RM. In addition, most of the authors used adequate fluid preloading before RM. Enough evidence suggests that RM is safe and tolerable with adequate fluid preloading in patients with obesity undergoing laparoscopic surgery.[22-27]

Conclusions

RM, followed by a higher PEEP and individualized PEEP, effectively improves intraoperative oxygenation and respiratory mechanics in obese patients undergoing laparoscopic surgery. RM is safe and does not cause adverse hemodynamic effects. The type of RM to be used, the number and timing of RM, the postoperative beneficial effects, and the need for supplemental oxygen remain questionable. Further studies are needed to provide guidelines for using RM effectively in patients with obesity undergoing laparoscopic surgery.

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Conflicts of interest

There are no conflicts of interest.

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Appendix 1

SEARCH

The below mentioned search terms were used to search PubMed and Google Scholar and were adjusted for the other databases:

1. (Obese) OR (Obesity)) OR (Overweight))
2. (laparoscopic) OR (laparoscopy) OR (laparoscopic surgery)
3. (((Recruitment Maneuver) OR (Recruitment))
4. (lung) OR (pulmonary)
5. #1 AND #2 AND #3 AND #4