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Positive end-expiratory pressure and postoperative pulmonary complications in laparoscopic bariatric surgery: systematic review and meta-analysis

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Abstract

Background This study compares the effect of positive end-expiratory pressure (PEEP) on postoperative pulmonary complications (PPCs) in patients with obesity undergoing laparoscopic bariatric surgery (LBS) under general anesthesia with mechanical ventilation.

Methods A comprehensive search was conducted in PubMed, Embase, Web of Science, Cochrane Central Register of Controlled Trials, China National Knowledge Internet, Wanfang database, and Google Scholar for studies published up to July 29, 2023, without time or language restrictions. The search terms included "PEEP," "laparoscopic," and "bariatric surgery." Randomized controlled trials comparing different levels of PEEP or PEEP with zero-PEEP (ZEEP) in patients with obesity undergoing LBS were included. The primary outcome was a composite of PPCs, and the secondary outcomes were intraoperative oxygenation, respiratory compliance, and mean arterial pressure (MAP). A fixed-effect or random-effect model was selected for meta-analysis based on the heterogeneity of the included studies.

Results Thirteen randomized controlled trials with a total of 708 participants were included for analysis. No statistically significant difference in PPCs was found between the PEEP and ZEEP groups (risk ratio = 0.27, 95% CI: 0.05–1.60; $p = 0.15$). However, high PEEP ≥ 10 cm H_2O significantly decreased PPCs compared with low PEEP < 10 cm H_2O (risk ratio = 0.20, 95% CI: 0.05–0.89; $p = 0.03$). The included studies showed no significant heterogeneity ($I^2 = 20\%$ & 0%). Compared with ZEEP, PEEP significantly increased intraoperative oxygenation and respiratory compliance (WMD = 74.97 mm Hg, 95% CI: 41.74-108.21; $p < 0.001$ & WMD = 9.40 ml cm H_2O^{-1}, 95% CI: 0.65–18.16; $p = 0.04$). High PEEP significantly improved intraoperative oxygenation and respiratory compliance during pneumoperitoneum compared with low PEEP (WMD = 66.81 mm Hg, 95% CI: 25.85-107.78; $p = 0.001$ & WMD = 8.03 ml cm H_2O^{-1}, 95% CI: 4.70-11.36; $p < 0.001$). Importantly, PEEP did not impair hemodynamic status in LBS.

Conclusions In patients with obesity undergoing LBS, high PEEP ≥ 10 cm H_2O could decrease PPCs compared with low PEEP < 10 cm H_2O, while there was a similar incidence of PPCs between PEEP (8–10 cm H_2O) and the ZEEP group. The application of PEEP in ventilation strategies increased intraoperative oxygenation and respiratory compliance

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without affecting intraoperative MAP. A PEEP of at least 10 cm H_2O is recommended to reduce PPCs in patients with obesity undergoing LBS.

Registration number CRD42023391178 in PROSPERO.

Keywords Bariatric surgery, Laparoscopic, Obesity, Meta-analysis, Positive end-expiratory pressure; postoperative pulmonary complications

Introduction

Pulmonary atelectasis occurs more frequently in patients with obesity under general anesthesia [1–4]. Alveolar collapse and intrapulmonary shunt impair pulmonary gas exchange and respiratory compliance [5]. Bariatric surgery is an effective treatment for obesity, with an estimated 696,191 operations performed globally in 2018 [6]. LBS is the preferred approach for 99.7% of patients due to its lower morbidity and mortality rates [7]. However, intraabdominal insufflation of carbon dioxide during LBS can increase intraabdominal pressure, causing a cranial shift of the diaphragm and compression of basal lung regions. Patients with obesity undergoing LBS under general anesthesia rapidly develop reduced functional residual capacity and increased atelectasis, resulting in an elevated risk of PPCs [8].

Obesity, defined as a Body Mass Index (BMI) ≥ 30 kg/m^2, is associated with increased perioperative morbidity and mortality [9]. In anesthetized patients, BMI is inversely related to arterial oxygen partial pressure. Decreased intraoperative oxygenation may lead to perioperative respiratory and hemodynamic detriments [10, 11]. Studies have reported that obesity is a risk factor for postoperative non-invasive ventilation, tracheal reintubation, and other morbidity and mortality outcomes [12]. Researchers have explored optimal ventilation strategies for LBS patients to reduce PPCs and improve intraoperative oxygenation and respiratory compliance. The effect of PEEP on PPCs, intraoperative oxygenation, respiratory compliance, and hemodynamic status has been investigated, but no consensus has been reached on the optimal PEEP level for LBS patients.

We conducted a systematic review and meta-analysis to determine the effect of PEEP on PPCs and other perioperative complications in patients with obesity undergoing LBS. Our primary aim was to explore the optimal level of PEEP for these patients to help anesthesiologists administer lung-protective management strategies in patients with obesity during LBS.

Methods

Ethical approval

As a meta-analysis of previously published literature, ethics approval was not required by the Ethics Committee of the Third Affiliated Hospital of Soochow University.

Search strategy

This meta-analysis strictly adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and rigorously tracked inclusion and exclusion criteria by population, intervention, comparison, outcomes, and study standards [13]. The study is registered in PROSPERO under the number CRD42023391178. Two authors (Chen Chen and Pingping Shang) independently retrieved published randomized controlled trials (RCTs) from PubMed, Embase, Web of Science, Cochrane Central Register of Controlled Trials, China National Knowledge Internet, Wanfang database, and Google Scholar website until July 29, 2023, without time or language limits. The bibliography of relevant studies was also searched for further identification of pertinent RCTs. The study included RCTs comparing PEEP with ZEEP or high PEEP with low PEEP, reporting PPCs, perioperative respiratory mechanics, hemodynamic status changes, and other intra- and postoperative complications in patients with obesity undergoing LBS (Appendix).

Inclusion and exclusion criteria

Inclusion criteria: (1) Study population: obesity patients (BMI > 30 kg/m^2) [14] undergoing LBS; (2) Intervention and control: PEEP vs. ZEEP (zero PEEP) or high PEEP vs. low PEEP; (3) Outcomes: The primary outcome was PPCs, defined as pneumonia, atelectasis, acute respiratory distress syndrome (ARDS), acute postoperative respiratory failure, hemodynamic instability, or reintubation (defined as respiratory failure after initial tracheal extubation requiring reintubation). Secondary outcomes were intraoperative oxygenation (PaO_2/FiO_2 ratio assessed with arterial blood gas analysis), respiratory compliance, and MAP; and (4) Study design: RCTs.

Exclusion criteria: (1) Studies published as observational studies, reviews, case reports, protocols, abstracts, letters, or conference proceedings; (2) Animal or cell studies; (3) Studies not involving patients with obesity or LBS; (4) Studies without outcomes of interest; and (5) Non-randomized trials.

Literature screening and data extraction

Two authors (C.C. and P.P.S.) independently and rigorously screened the literature and extracted data using Endnote X9 software, based on the predefined inclusion and exclusion criteria. The following data were extracted from the included studies: (1) author, publication year, and country; (2) the number of cases and patients in the intervention and control groups; (3) the type of ventilation strategy in each group; and (4) data related to outcomes of interest for both groups. Any disagreements were resolved through discussion or referral to the third author (Y.T.Y.) during the data abstraction process.

Evaluation of literature quality

Two authors (C.C. and P.P.S.) independently evaluated the potential for bias using the tool outlined in the Cochrane Handbook for Systematic Reviews of Interventions [15]. Graphical data were extracted using the Web Plot Digitizer tool [16]. Data presented as median (range) were converted to mean (standard deviation) [17]. Additionally, the same two authors independently used the 7-point modified Jadad score to assess the methodological quality of each included trial [18]. Trials scoring 1 to 3 points were rated as poor quality, while those scoring 4 to 7 points were considered high quality.

Statistical analysis

All data were analyzed using RevMan 5.4 (Cochrane Collaboration). The weighted mean difference (WMD) and 95% confidence interval (CI) were estimated for continuous data, while the pooled risk ratio (RR) and 95% CI were used for dichotomous data. Each outcome was tested for heterogeneity, and a fixed-effect or random-effect model was chosen based on the absence or presence of significant heterogeneity ($I^2 > 50\%$) [19]. Sensitivity analyses were conducted by examining the influence of the statistical model on the estimated treatment effect; analyses that adopted the fixed-effect model were repeated using a random-effect model, and vice versa. Furthermore, sensitivity analyses were performed to evaluate the influence of individual studies on the overall effects. Statistical significance was defined as $p < 0.05$, and all p-values were two-sided.

Results

Study selection

A total of 590 studies and reports were identified and screened for inclusion (Fig. 1). Of these, 577 were excluded for various reasons, and 66 were potentially relevant but did not meet the inclusion criteria after full-text evaluation. Twenty potentially relevant trials were evaluated for inclusion. Four studies were excluded because they did not involve LBS, one study did not report outcomes of interest, one study was not a randomized controlled trial (RCT), and another study was a protocol and was in the research stage after contacting the corresponding author. Finally, 13 randomized trials, including relevant data from 708 patients, fulfilled all inclusion criteria (Table 1) [20–32].

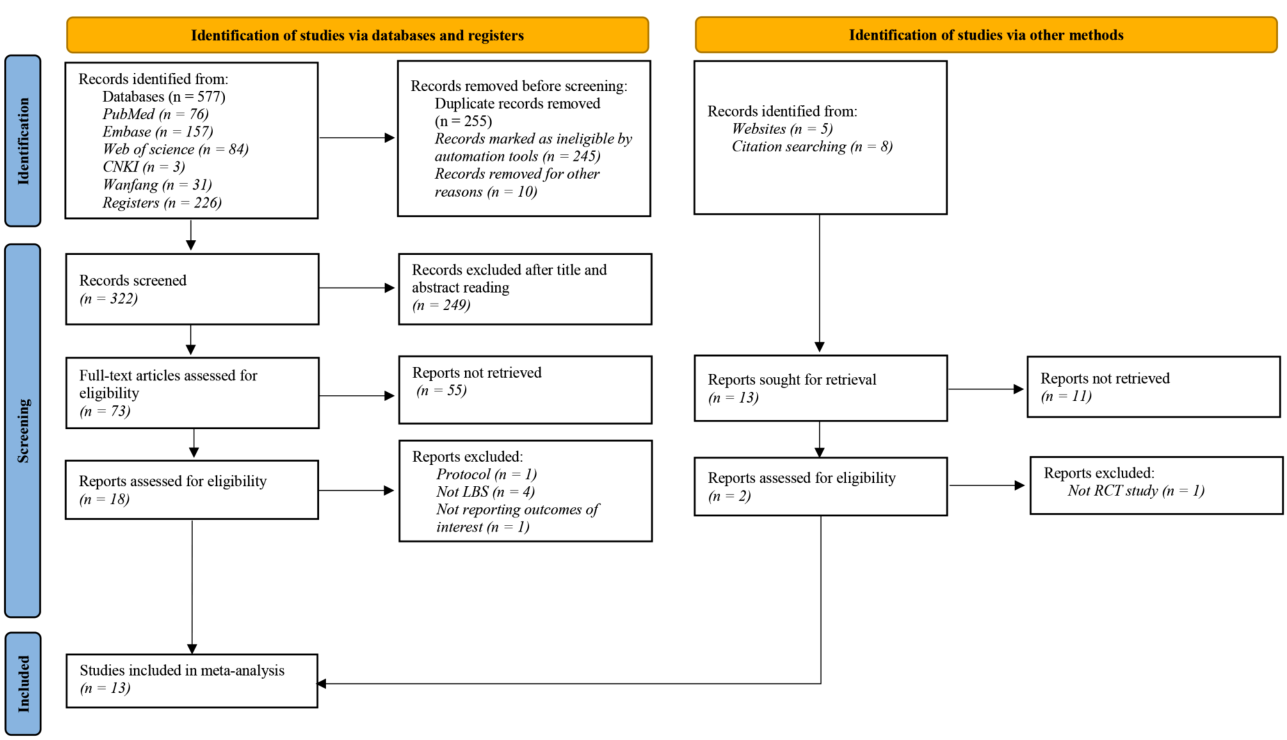


Fig. 1 Study selection process. CNKI, China National Knowledge Infrastructure; RCT, randomized controlled trial; LBS, laparoscopic bariatric study

Table 1 Basic characteristics of the included studies

Study	Country	Surgery	BMI (kg/m^2)	Comparisons (PEEP in cm H_2O)	RM		Time points of measurement
					Timing	Details (pressure in cm H_2O)	
Almarakbi [20]	Saudi Arabia	LGB	33 (2) 34 (1) 33 (2) 33 (1)	1.VCV + PEEP 10 + repeated RM [15] 2.VCV + PEEP 10 + single RM [15] 3.VCV + PEEP 10 [15] 4.VCV + single RM [15]	After induction	Pressure 40 for 15 s	Five minutes after intubation, 10 min after PP. and every 10 min thereafter for a total of 50 min
Chen [21]	China	LSG	37.81 (4.60) 40.58 (6.21) 39.15 (4.31)	1.VCV + PEEP 10 + single RM [30] 2.VCV + PEEP 5 + single RM [30] 3.VCV + single RM [30]	Stop anesthesia	Pressure 30 for 15 s	Before induction, 5 min after intubation, 30 min after PP., 5 min after deflation, 30 min after extubation
Eichler [22]	Germany	LBS	46.17 (1.84) 50.71 (2.19)	1.PCV + stepwise PEEP + single RM [20] 2.PCV + PEEP 10 + single RM [17]	After position	Pressure 50 for 10 s	During the described PEEP ramp
Elshazly [23]	Egypt	LBS	43 (2.83) 43.85 (3.76)	1.VCV + stepwise PEEP [20] 2.VCV + PEEP 4 [20]	No		Baseline, 10 min after initiation of ventilation, 5 min after PP., 5 min every PEEP increase, at the end of surgery and 10 min after extubation
Elokda [24]	USA	LGB	44.4 (2.5) 44.5 (2.7)	1.VCV + PEEP 15 + single RM [25] 2. VCV + PEEP 5 [25]	Before positioning	Pressure 40 for 45 s	Preoperatively, before and after induction of PP., 30 min and 60 after PP.and at the end of surgery
El-Sayed [25]	Egypt	LGB	54 (2) 54 (3) 53 (2)	1.VCV + PEEP15 + single RM [19] 2.VCV + PEEP 15 + single RM + BiPAP [18] 3.VCV + PEEP 10 + single RM [19]	After intubation	Pressure 40 for 15 s	Before and 5 min after induction, after PP., and recruitment, release of PP., and before extubation
Hecker [26]	Belgium	LBS	42(1) 42(1)	1.VCV + stepwise PEEP + repeated RMs [50] 2.VCV + PEEP 10 + repeated RMs [50]	SpO2 < 95%	Stepwise fashion from 10 (3 breaths) to 15 to 20 (10 breaths) for approximately 2 min	After induction of anesthesia, after PP. inflation, after PP. exsufflation
Li [27]	China	LBS	40.1(3.5) 41.9(5.6)	1. VCV + PEEP 8 + two RMs [20] 2. VCV + individualized PEEP + two RMs [20]	Before and after the dynamic compliance–guided PEEP titration	From 10 to 25, 5 step every 30 s	Preoxygenation, after intubation, after titration and randomization, 10 min and 1 h after PP., before and 30 min after extubation, postoperative day 0 , day 1 ,day 2, day 7
Reinius [28]	Italy	LGB	45 (5) 45 (5) 44 (3)	1.VCV + PEEP 10 + single RM [10] 2.VCV + single RM [10] 3.VCV + PEEP 10 [10]	After intubation	Pressure 55 for 10 s	Before and 5 min after induction, 5 min, 20 min and 40 min after intervention
Saxena [29]	India	LBS	46.9 46.48	1.VCV + PEEP 10 [30] 2.VCV [30]	No		Preoperatively, after induction, 5 min and 10 min after intubatiion
Talab [30]	Saudi Arabia	LBS	38.30 (6.85) 44.53 (6.99) 41.8 (7.9)	1.VCV + PEEP 10 + single RM [22] 2.VCV + PEEP 5 + single RM [22] 3.VCV + single RM [22]	After intubation	VCM maintained for 7–8 s	Before and after induction, after VCM and inflation, 30 and 60 min after position, EOS, admission and discharge from PACU

Table 1 (continued)

Study	Country	Surgery	BMI (kg/m^2)	Comparisons (PEEP in cm H_2O)	RM Timing	RM Details (pressure in cm H_2O)	Time points of measurement
Wei [31]	China	LSG	43 (6) 48 (8) 45 (6)	1.VCV + PEEP 8 + single RM [11] 2.VCV + repeated RMs [11] 3.VCV [12]	After inflation and repeated every 30 min	Pressure 40 for 10 breaths	Five minutes after intubation, 5, 30 and 60 min after inflation, EOS
Yang [32]	China	LSG	38.2(5.5) 38.3(5.8)	1. VCV + PEEP 5 [22] 2. VCV + stepwise PEEP [23]	No		10 min after induction, 10 mim after PP, 30 and 90 min after PP, and 10 min after PP. closed

Abbreviations BMI, body mass index; LBS, laparoscopic bariatric surgery; LSG, laparoscopic sleeve gastrectomy; LGB, laparoscopic gastric banding/bypass; VCM, vital capacity maneuver; RM, recruitment maneuver; ARM, alveolar recruitment maneuver; VCV, volume control ventilation; PSV, pressure support ventilation; PEEP, positive end-expiratory pressure; PP, Pneumoperitoneum; EOS, end of surgery

Study characteristics and reported outcomes

The studies, published between 2009 and 2023, originated from 11 countries: Belgium (one), China (four), Egypt (two), Germany (one), India (one), Italy (one), Saudi Arabia (two), and the USA (one). The meta-analysis included a total of 708 patients who underwent LBS under general anesthesia with endotracheal intubation, comparing PEEP with zero end-expiratory pressure (ZEEP) or high PEEP with low PEEP [20–32]. The average modified Jadad score was 5 (range, 4–7), and the average group size was 54 patients (range, 30–100). The mean BMI was 42 kg/m^2 (range, 33–54), and the average capnoperitoneum pressure was 14 cm H_2O (range, 8–18) (Table 1).

Results of individual studies and synthesis of results

Sufficient data warranted a meta-analysis of PPCs for the following comparisons: PEEP vs. ZEEP and high PEEP ($\geq$10 cm H_2O) vs. low PEEP (<10 cm H_2O). Only three studies compared PEEP>10 cm H_2O and PEEP=10 cm H_2O, providing insufficient data to draw conclusions on PPCs and other meaningful outcomes (Table 2).

Study quality and risk of bias

Figure 2 illustrates the risk of bias. Four studies employed double-blind designs, while the others used single-blind designs. Four trials had unclear random sequence generation, and eight had unclear allocation concealment. The modified Jadad score of the 13 included RCTs ranged from 4 to 7, with no RCTs scoring "low quality" (3 points) and all included RCTs rated as "high quality" (4 points and above) (Table 3).

Table 2 Reported outcomes of included studies

Study	Reported outcomes: Intraop. Oxy.	Intraop. RC	Intra-op. MAP	PPCs
Almarakbi 2009 [20]	√	√		√
Chen 2022 [21]	√	√	√	√
Eichler 2017 [22]	√	√		
Elshazly 2020 [23]	√	√	√	√
Elokda 2019 [24]	√		√	√
El-Sayed 2012 [25]	√	√	√	√
Hecke 2019 [26]	√	√		√
Li 2023 [27]	√	√	√	√
Reinius 2009 [28]	√	√	√	
Saxena 2017 [29]	√		√	
Talab 2009 [30]			√	√
Wei 2018 [31]	√		√	√
Yang 2023 [32]		√	√	√

Intraop. = intraoperative; Oxy. = oxygenation; RC. = respiratory compliance; MAP, mean arterial pressure; PPCs, postoperative pulmonary complications

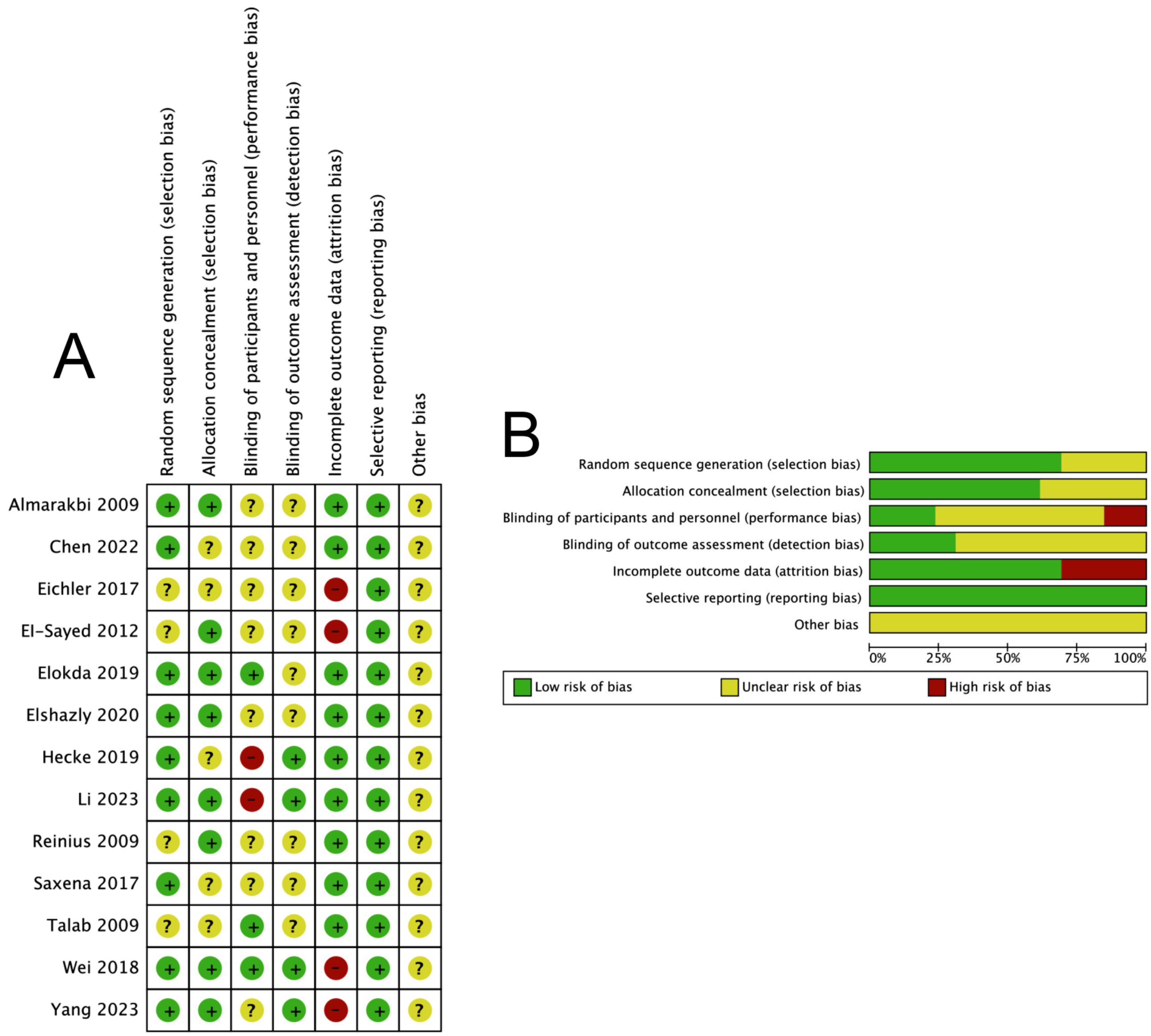


Fig. 2 Risk of bias. (**A**) Risk of bias summary: review authors' judgements about each risk of bias item for each included study; (**B**) Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies

PEEP vs. ZEEP

Six randomized trials, with 340 patients, compared PEEP with ZEEP [20, 21, 28–31]. PEEP levels were similar across the analyzed studies: 10 cm H_2O in five studies [20, 21, 28–30] and 8 cm H_2O in one study [31]. Most studies maintained PEEP until the end of the procedure, except for two [29, 30]. One study maintained PEEP for 10 min after intubation [29], while another discontinued PEEP due to a MAP decrease > 25% from baseline [30].

The incidence of PPCs was similar (risk ratio = 0.27, 95% CI: 0.05–1.60; $p = 0.15$) in the PEEP and ZEEP groups, with no significant heterogeneity found within the included studies ($I^2 = 20\%$). Adding PEEP to the ventilation strategy for LBS improved the intraoperative PaO_2/FiO_2 ratio (WMD = 74.97 mm Hg, 95% CI: 41.74-108.21; $p < 0.001$) and increased respiratory system compliance (WMD = 9.40 ml cm H_2O^{-1}, 95% CI: 0.65–18.16; $p = 0.04$). However, intraoperative MAP did not differ significantly between groups (WMD = 2.06 mm Hg, 95% CI -1.68-5.80; $p = 0.28$). Insufficient data precluded drawing other meaningful conclusions on outcomes (Fig. 3).

High PEEP vs. Low PEEP

Six studies, with 331 participants, compared high PEEP with low PEEP [21, 23, 24, 27, 30, 32]. Low PEEP varied from 4 to 8 cm H_2O, while high PEEP ranged from 10 to 25 cm H_2O. All studies conducted PEEP with recruitment maneuvers. The PEEP level in the high PEEP cohort was fixed in three studies [21, 24, 30] and individualized in the other three trials [23, 27, 32].

Table 3 Quality assessment of included studies

Study	Sample size	Modified Jadad Score				
		Randomization	Allocation	Blindness	Withdraws	Total
Almarakbi [20]	60	2	2	1	1	6
Chen [21]	90	2	1	1	1	5
Eichler [22]	37	1	1	1	1	4
Elshazly [23]	40	2	2	1	1	6
El-Sayed [24]	56	1	2	1	1	4
Elokda [25]	50	2	2	2	1	7
Hecke [26]	100	2	1	2	1	7
Li 2023 [27]	40	2	2	1	1	6
Reinius [28]	30	1	2	1	1	5
Saxena [29]	60	2	1	1	1	5
Talab [30]	66	1	1	2	1	5
Wei [31]	34	2	2	2	1	6
Yang [32]	45	2	2	1	1	7

High PEEP (≥10 cm H_2O) significantly decreased PPCs compared with low PEEP (<10 cm H_2O) (risk ratio=0.20, 95% CI: 0.05–0.89; p=0.03), with no significant heterogeneity found within the included studies (I^2=0%). Moreover, high PEEP significantly increased intraoperative oxygenation (WMD=66.81 mm Hg, 95% CI: 25.85-107.78; p=0.001) and improved respiratory compliance (WMD=8.03 ml cm H_2O^{-1}, 95% CI: 4.70-11.36; p<0.001) during pneumoperitoneum compared with low PEEP (Fig. 4). And high PEEP didn't impair MAP (WMD=3.69 mm Hg, 95% CI 1.59-5.78; p<0.001). Insufficient data precluded drawing other meaningful conclusions on outcomes (Fig. 4).

Sensitivity analysis and publication Bias

Sensitivity analyses, performed for each intervention and outcome by excluding individual studies and changing the statistical effect model, revealed no statistical change in the effect with the removal of any single article for the comparisons. The results proved stable and reliable, with no contradictory findings. A funnel plot was not conducted due to the limited number of included studies, which did not meet the criteria for testing true bias.

Discussion

Ventilation strategies in LBS are varied, and limited convincing evidence is available for patients with obesity under general anesthesia. Randomized trials comparing PEEP with ZEEP and high PEEP with low PEEP were consequently pooled for meta-analysis to find evidence supporting the use of PEEP and determine the optimal PEEP level for clinical practice. Despite the variability among the included trials, some consensus can be drawn from the analysis.

First, PEEP, compared with ZEEP, significantly improves intraoperative oxygenation and respiratory compliance statistically, although it does not decrease PPCs. Reinius et al. reported that after induction of anesthesia, patients with obesity rapidly developed paralysis, reducing end-expiratory lung volume and contributing to atelectasis and oxygenation decline [28]. They found through computerized tomography that in patients with obesity, anesthesia and paralysis decreased the fractional amount of normally aerated tissue from 71 to 50%, increased the fractional amount of poorly aerated tissue from 28 to 39%, and increased nonaerated tissue from 1 to 11%. Additionally, Wei et al. found that the improvement of oxygenation in the PEEP group was reduced after the conclusion of surgery and exsufflation of CO_2 pneumoperitoneum [31]. The PEEP effect had no significant hemodynamic consequences. Sexna et al. confirmed that although PEEP had the potential to decrease venous return and cardiac output, no hemodynamic consequences were observed in their study, which was consistent with our analysis [29]. Talab et al. also confirmed that their application of PEEP was not accompanied by a significant reduction in MAP, even after pneumoperitoneum and positioning (modified lithotomy position and anti-Trendelenburg) [30]. This can be explained by sufficient preoperative preload with crystalloid solution (20 mL/kg/h), suspension of high pressure, and the use of vasopressors as necessary during surgery. As a result, in patients with obesity, PEEP can be safely applied without adverse effects on hemodynamic stability.

Second, high PEEP ≥ 10 cm H_2O decreases PPCs compared with low PEEP < 10 cm H_2O and increases intraoperative oxygenation and respiratory function while not significantly affecting MAP during pneumoperitoneum. According to research on patients in the intensive care unit (ICU) concluded that for patients in the ICU without ARDS, a lower PEEP strategy was non-inferior to a higher PEEP strategy [33]. They excluded all patients with morbid obesity (body mass index [BMI] > 40), which might explain the difference in conclusion compared

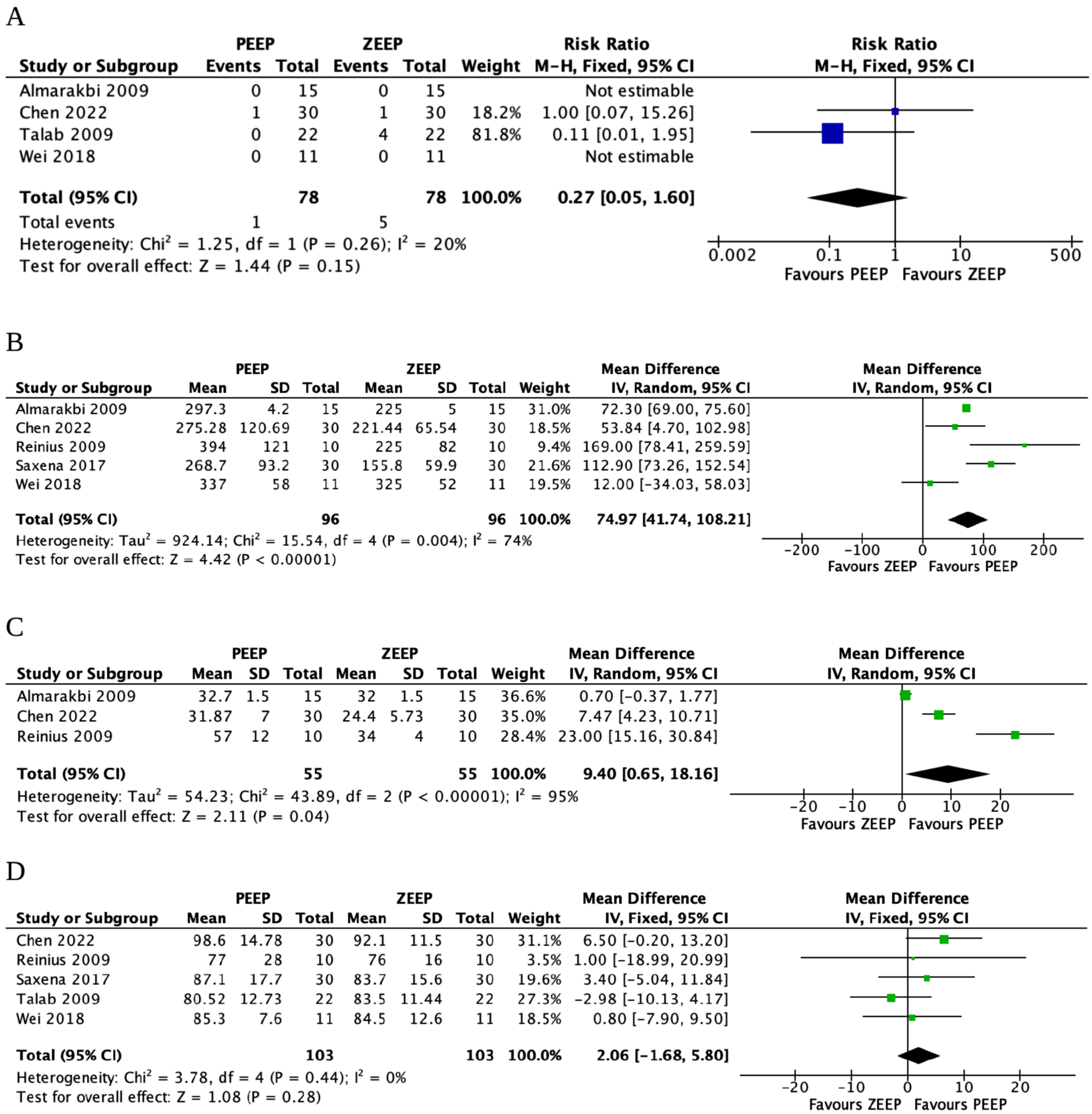
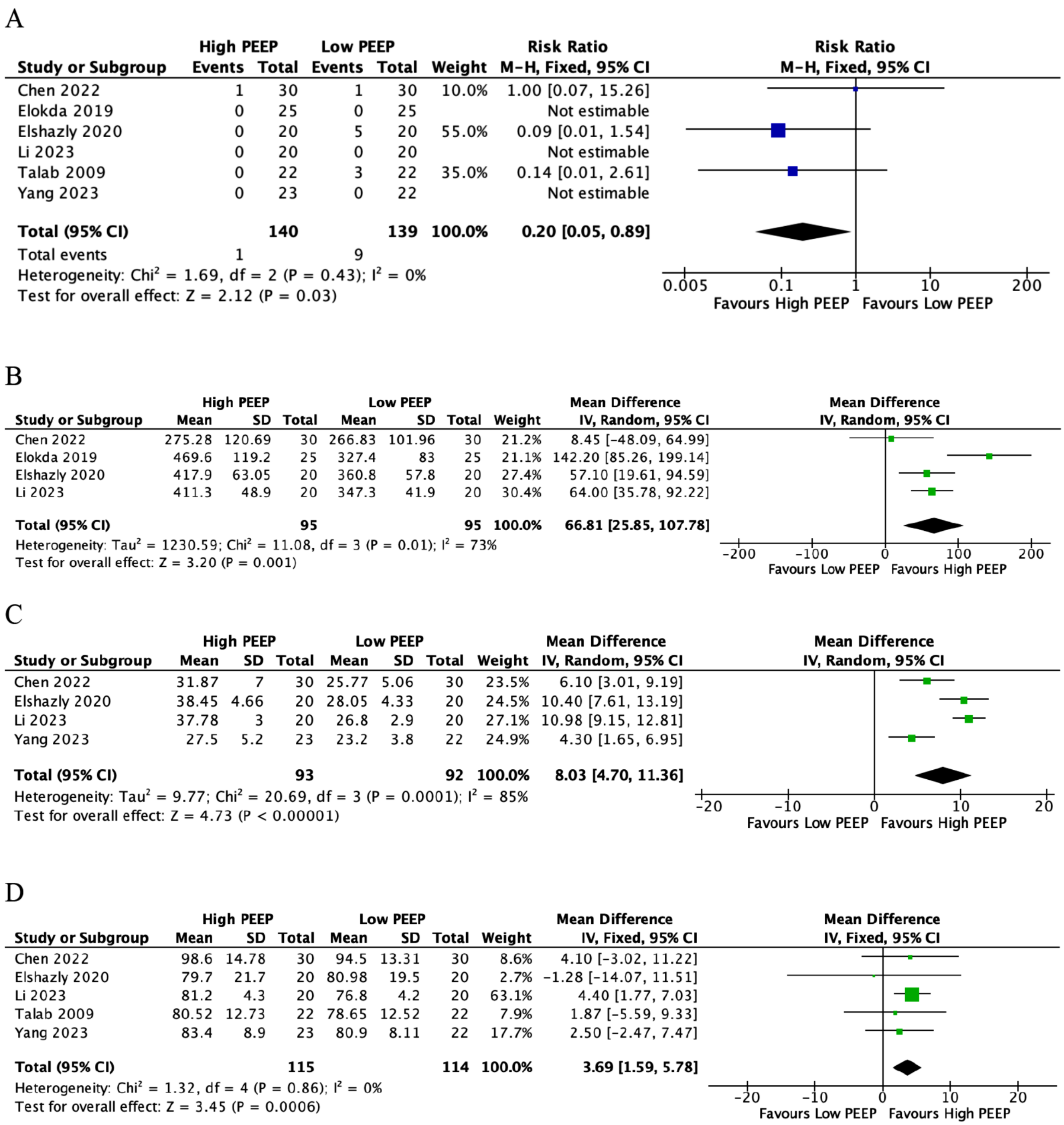


Fig. 3 PEEP vs. ZEEP. (**A**) Impact of PEEP on PPCs; (**B**) Impact of PEEP on intraoperative oxygenation (PaO_2/FiO_2 ratio) (mm Hg); (**C**) Impact of PEEP on intraoperative respiratory compliance (ml cm H_2O^{-1}); (**D**) Impact of PEEP on intraoperative MAP (mm Hg). PEEP, positive end-expiratory pressure; ZEEP, zero PEEP; PPCs, postoperative pulmonary complications; MAP, mean arterial pressure

to our study. Chen et al. concluded from their research results that both 5 cm H_2O PEEP and 10 cm H_2O PEEP can equally improve oxygenation during the operation [21]. However, they found that oxygenation in the PEEP 10 cm H_2O group decreased more slightly than in the PEEP 5 cm H_2O group and with less dead space after pneumoperitoneum, indicating that a high PEEP level could alleviate the effect of pneumoperitoneum on oxygenation for a longer duration. Hecke et al. used individual PEEP manipulation to optimize dynamic compliance, resulting in a mean PEEP level of 10 cm H_2O [26], which was consistent with the conclusions of Talab and Coussa that 10 cm H_2O was the optimal PEEP level to reduce atelectasis and maintain oxygenation in patients with obesity during surgery [30]. It was also found that the application of PEEP was not accompanied by a significant reduction in MAP (decrease in MAP > 25% of baseline), even after pneumoperitoneum and positioning. Bohm et al. demonstrated that high positive airway pressures were hemodynamically well tolerated in patients with obesity



A

Study or Subgroup	High PEEP Events	High PEEP Total	Low PEEP Events	Low PEEP Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Chen 2022	1	30	1	30	10.0%	1.00 [0.07, 15.26]
Elokda 2019	0	25	0	25		Not estimable
Elshazly 2020	0	20	5	20	55.0%	0.09 [0.01, 1.54]
Li 2023	0	20	0	20		Not estimable
Talab 2009	0	22	3	22	35.0%	0.14 [0.01, 2.61]
Yang 2023	0	23	0	22		Not estimable
Total (95% CI)		**140**		**139**	**100.0%**	**0.20 [0.05, 0.89]**
Total events	1		9			

Heterogeneity: $Chi^2 = 1.69$, df = 2 (P = 0.43); $I^2 = 0\%$
Test for overall effect: Z = 2.12 (P = 0.03)

B

Study or Subgroup	High PEEP Mean	High PEEP SD	High PEEP Total	Low PEEP Mean	Low PEEP SD	Low PEEP Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2022	275.28	120.69	30	266.83	101.96	30	21.2%	8.45 [−48.09, 64.99]
Elokda 2019	469.6	119.2	25	327.4	83	25	21.1%	142.20 [85.26, 199.14]
Elshazly 2020	417.9	63.05	20	360.8	57.8	20	27.4%	57.10 [19.61, 94.59]
Li 2023	411.3	48.9	20	347.3	41.9	20	30.4%	64.00 [35.78, 92.22]
Total (95% CI)			**95**			**95**	**100.0%**	**66.81 [25.85, 107.78]**

Heterogeneity: $Tau^2 = 1230.59$; $Chi^2 = 11.08$, df = 3 (P = 0.01); $I^2 = 73\%$
Test for overall effect: Z = 3.20 (P = 0.001)

C

Study or Subgroup	High PEEP Mean	High PEEP SD	High PEEP Total	Low PEEP Mean	Low PEEP SD	Low PEEP Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2022	31.87	7	30	25.77	5.06	30	23.5%	6.10 [3.01, 9.19]
Elshazly 2020	38.45	4.66	20	28.05	4.33	20	24.5%	10.40 [7.61, 13.19]
Li 2023	37.78	3	20	26.8	2.9	20	27.1%	10.98 [9.15, 12.81]
Yang 2023	27.5	5.2	23	23.2	3.8	22	24.9%	4.30 [1.65, 6.95]
Total (95% CI)			**93**			**92**	**100.0%**	**8.03 [4.70, 11.36]**

Heterogeneity: $Tau^2 = 9.77$; $Chi^2 = 20.69$, df = 3 (P = 0.0001); $I^2 = 85\%$
Test for overall effect: Z = 4.73 (P < 0.00001)

D

Study or Subgroup	High PEEP Mean	High PEEP SD	High PEEP Total	Low PEEP Mean	Low PEEP SD	Low PEEP Total	Weight	Mean Difference IV, Fixed, 95% CI
Chen 2022	98.6	14.78	30	94.5	13.31	30	8.6%	4.10 [−3.02, 11.22]
Elshazly 2020	79.7	21.7	20	80.98	19.5	20	2.7%	−1.28 [−14.07, 11.51]
Li 2023	81.2	4.3	20	76.8	4.2	20	63.1%	4.40 [1.77, 7.03]
Talab 2009	80.52	12.73	22	78.65	12.52	22	7.9%	1.87 [−5.59, 9.33]
Yang 2023	83.4	8.9	23	80.9	8.11	22	17.7%	2.50 [−2.47, 7.47]
Total (95% CI)			**115**			**114**	**100.0%**	**3.69 [1.59, 5.78]**

Heterogeneity: $Chi^2 = 1.32$, df = 4 (P = 0.86); $I^2 = 0\%$
Test for overall effect: Z = 3.45 (P = 0.0006)

Fig. 4 High PEEP vs. low PEEP. (**A**) Impact of high PEEP on PPCs; (**B**) Impact of high PEEP on intraoperative oxygenation (PaO_2/FiO_2 ratio) (mm Hg); (**C**) Impact of high PEEP on intraoperative respiratory compliance (ml cm H_2O^{-1}); (**D**) Impact of high PEEP on intraoperative MAP (mm Hg). PEEP, positive end-expiratory pressure; PPCs, postoperative pulmonary complications; MAP, mean arterial pressure

with or without capnoperitoneum after preload optimization [34]. Jellinek et al. demonstrated the absence of any hemodynamic compromise at high levels of PEEP if central venous pressures were kept higher than 10 mm Hg [38].

Several studies explored the optimal PEEP levels for patients with obesity undergoing LBS. Almarakbi et al. concluded that lung recruitment combined with PEEP 10 cm H_2O was associated with the best respiratory system compliance and the best PaO_2/FiO_2 ratio in patients with obesity undergoing LBS [20]. Wang et al. used electrical impedance tomography (EIT) to individualize PEEP levels and showed that a PEEP level of 14.3 (2.3) cm H_2O could improve intraoperative oxygenation and respiratory compliance [35]. Nestler et al. also studied patients undergoing laparoscopic sleeve gastrectomy using EIT and found that a mean PEEP of 18.5 cm H_2O could restore end-expiratory lung volume, regional ventilation distribution, and oxygenation during anesthesia [36]. Furthermore, Eichler et al. used EIT aiming for a positive transpulmonary pressure (P_L) and confirmed that optimal PEEP levels between 10 and 15 cm H_2O before and 20 and 25 cm H_2O during capnoperitoneum, respectively, were necessary for LBS [22]. Moreover, the improvement in oxygenation persisted during the post-anesthesia care unit (PACU) period. High PEEP ≥ 10 cm H_2O raises concerns about barotrauma (pneumothorax, air in the mediastinum, or subcutaneous emphysema). However, no barotrauma was found in the included studies.

Limitations

This meta-analysis has several limitations. First, despite conducting an extensive literature search, the number of retrieved RCTs fulfilling the inclusion criteria was limited, and the included studies had relatively small sample sizes. Second, the included trials employed different RM strategies, with peak pressures varying from 30 to 50 cm H_2O and durations ranging from several seconds to minutes. Third, due to limited data, conclusions could not be drawn regarding certain perioperative complications, such as intraoperative bleeding, PACU stay, hospital length of stay, and ICU admission rate.

Conclusions

In patients with obesity undergoing LBS, high PEEP ≥ 10 cm H_2O could decrease the incidence of PPCs compared to low PEEP < 10 cm H_2O. However, the incidence of PPCs was similar between the PEEP (8–10 cm H_2O) and ZEEP groups. The addition of PEEP to ventilation strategies improved intraoperative oxygenation and respiratory compliance without affecting intraoperative MAP. Based on these findings, we recommend using a PEEP of at least 10 cm H_2O to reduce the risk of PPCs in patients with obesity undergoing LBS.

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Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Author contributions

Yuntai Yao designed the study, wrote the protocol, and was responsible for registration of the protocol at International Prospective Register of Systematic Reviews (PROSPERO). Chen Chen and Pingping Shang contributed to screening and selecting articles for inclusion. All authors contributed to extracting and analyzing data. All authors were involved in writing the paper and had final approval of the submitted and published versions.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

As a meta-analysis of previously published literature, ethics approval was not required by the Ethics Committee of the Third Affiliated Hospital of Soochow University.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Min WK, Jin S, Choi YJ, Won YJ, Lee K, Lim CH. Lung ultrasound score-based assessment of postoperative atelectasis in obese patients according to inspired oxygen concentration: a prospective, randomized-controlled study. Med (Baltim). 2023;102(7):e32990. https://doi.org/10.1097/MD.0000000000032990.
2. Li X, Liu H, Wang J, et al. Individualized positive end-expiratory pressure on postoperative atelectasis in patients with obesity: a Randomized Controlled Clinical Trial. Anesthesiology. 2023;139(3):262–73. https://doi.org/10.1097/ALN.0000000000004603.
3. Lagier D, Zeng C, Fernandez-Bustamante A, Vidal Melo MF. Perioperative Pulmonary Atelectasis: part II. Clin Implications Anesthesiology. 2022;136(1):206–36. https://doi.org/10.1097/ALN.0000000000004009.
4. Pelosi P, Croci M, Ravagnan I, et al. The effects of body mass on lung volumes, respiratory mechanics, and gas exchange during general anesthesia. Anesth Analg. 1998;87:654–60.
5. Hedenstierna G. Gas exchange during anesthesia. Br J Anaesth. 1990;64(4):507–14. https://doi.org/10.1093/bja/64.4.507.
6. Angrisani L, Santonicola A, Iovino P, Ramos A, Shikora S, Kow L. Bariatric surgery Survey 2018: similarities and disparities among the 5 IFSO chapters. Obes Surg. 2021;31(5):1937–48. https://doi.org/10.1007/s11695-020-05207-7.
7. Alalwan AA, Friedman J, Park H, et al. US national trends in bariatric surgery: a decade of study. Surgery. 2021;170:13.
8. Littleton SW, Tulaimat A. The effects of obesity on lung volumes and oxygenation. Respir Med. 2017;124:15–20. https://doi.org/10.1016/j.rmed.2017.01.004.

9. Bray GA. The battle of the Bulge. Dorrance: A History of Obesity Research; 2007.
10. Shah U, Wong J, Wong DT, Chung F. Preoxygenation and intraoperative ventilation strategies in obese patients: a comprehensive review. Curr Opin Anaesthesiol. 2016;29(1):109–18. https://doi.org/10.1097/ACO.0000000000000267.
11. Boesing C, Schaefer L, Hammel M, et al. Individualized positive end-expiratory pressure titration strategies in Superobese patients undergoing laparoscopic surgery: prospective and nonrandomized crossover study. Anesthesiology. 2023;139(3):249–61. https://doi.org/10.1097/ALN.0000000000004631.
12. O'Gara B, Talmor D. Perioperative lung protective ventilation. BMJ. 2018;362. https://doi.org/10.1136/bmj.k3030.
13. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372. https://doi.org/10.1136/bmj.n71.
14. American Society for Matabolic and Bariatric Surgery (https://asmbs.org). Bariatric Surgery in ClassI Obesity (accessed 21. March 2020). Avaliable from http://asmbs.org/resources/bariatric-surgery-in-class-i-obesity
15. Higgins JPT, Thomas J, Chandler J et al. Cochrane Handbook for Systematic Reviews of Interventions version 6.3 (updated February 2022). Cochrane, 2022. www.training.cochrane.org/handbook
16. Drevon D, Fursa SR, Malcolm AL. Intercoder reliability and validity of WebPlotDigitizer in extracting graphed data. Behav Modif. 2017;41:323–39.
17. Hozo SP, Djulbegovic B, Hozo I. Estimating the mean and variance from the median, range, and the size of a sample. BMC Med Res Methodol. 2005;5:13.
18. Mohsina S, Gurushankari B, Niranjan R, Sureshkumar S, Sreenath GS, Kate V. Assessment of the quality of randomized controlled trials in surgery using Jadad score: where do we stand? J Postgrad Med. 2022;68(4):207–12. https://doi.org/10.4103/jpgm.JPGM_104_21.
19. Borenstein M, Hedges LV, Higgins JPT, Rothstein HR. A basic introduction to fixed-effect and random-effects models for meta-analysis. Res Synth Method. 2010;1:97–111.
20. Almarakbi WA, Fawzi HM, Alhashemi JA. Effects of four intraoperative ventilatory strategies on respiratory compliance and gas exchange during laparoscopic gastric banding in obese patients. Br J Anaesth. 2009;102(6):862–8. https://doi.org/10.1093/bja/aep084.
21. Chen M, Niu X, Wang H, et al. Effect of positive end-expiratory pressure ventilation on pulmonary function in obese patients undergoing laparoscopic sleeve gastroectomy. J Tongji Univ. 2022;43(1):44–9. https://doi.org/10.12289/j.issn.1008-0392.21117.
22. Eichler L, Truskowska K, Dupree A, Busch P, Goetz AE, Zöllner C. Intraoperative Ventilation of morbidly obese patients guided by Transpulmonary pressure. Obes Surg. 2018;28(1):122–9. https://doi.org/10.1007/s11695-017-2794-3.
23. Elshazly M, Khair T, Bassem M, Mansour M. The use of intraoperative bedside lung ultrasound in optimizing positive end expiratory pressure in obese patients undergoing laparoscopic bariatric surgeries. Surg Obes Relat Dis. 2021;17(2):372–8. https://doi.org/10.1016/j.soard.2020.09.023.
24. Elokda SA, Farag HM. Preemptive alveolar recruitment Maneuver followed by PEEP in obese patients undergoing laparoscopic gastric banding. Does it make a difference? A Randomized Controlled Clinical Study. 2019. https://doi.org/10.2174/2589645801913010031
25. Khaled M, El-Sayed MM. Tawfeek.Perioperative ventilatory strategies for improving arterial oxygenation and respiratory mechanics in morbidly obese patients undergoing laparoscopic bariatric surgery. Egypt J Anaesth. 2012;28:9–15.
26. Van Hecke D, Bidgoli JS, Van der Linden P. Does lung compliance optimization through PEEP manipulations reduce the incidence of postoperative hypoxemia in laparoscopic bariatric surgery? A Randomized Trial. Obes Surg. 2019;29(4):1268–75. https://doi.org/10.1007/s11695-018-03662-x.
27. Li X, Liu H, Wang J, et al. Individualized positive end-expiratory pressure on postoperative atelectasis in patients with obesity: a randomized controlled. Clin Trial Anesthesiology. 2023;139:262–73.
28. Reinius H, Jonsson L, Gustafsson S, et al. Prevention of atelectasis in morbidly obese patients during general anesthesia and paralysis: a computerized tomography study. Anesthesiology. 2009;111(5):979–87. https://doi.org/10.1097/ALN.0b013e3181b87edb.
29. Saxena D, Singh P, Dixit A, Arya B, Bhandari M, Sanwatsarkar S. Single minute of positive end-expiratory pressure at the time of induction: effect on arterial blood gases and Hemodynamics in morbidly obese patients undergoing laparoscopic bariatric surgery. Anesth Essays Res. 2017;11(3):758–61. https://doi.org/10.4103/aer.AER_17_17.
30. Talab HF, Zabani IA, Abdelrahman HS, et al. Intraoperative ventilatory strategies for prevention of pulmonary atelectasis in obese patients undergoing laparoscopic bariatric surgery. Anesth Analg. 2009;109(5):1511–6. https://doi.org/10.1213/ANE.0b013e3181ba7945.
31. Wei K, Min S, Cao J, Hao X, Deng J. Repeated alveolar recruitment maneuvers with and without positive end-expiratory pressure during bariatric surgery: a randomized trial. Minerva Anestesiol. 2018;84(4):463–72. https://doi.org/10.23736/S0375-9393.17.11897-3.
32. Yang G, Zhang P, Li L, Wang J, Jiao P, Wang J, Chu Q. Driving pressure-guided ventilation in obese patients undergoing laparoscopic sleeve gastrectomy: a Randomized Controlled Trial. Diabetes Metab Syndr Obes. 2023;16:1515–23. https://doi.org/10.2147/DMSO.S405804.
33. Writing Committee and Steering Committee for the RELAx Collaborative Group, Algera AG, Pisani L, Serpa Neto A, et al. Effect of a lower vs higher positive end-expiratory pressure strategy on ventilator-free days in ICU patients without ARDS: a Randomized Clinical Trial. JAMA. 2020;324(24):2509–20. https://doi.org/10.1001/jama.2020.23517.
34. Bohm SH, Thamm OC, von Sandersleben A, et al. Alveolar recruitment strategy and high positive end-expiratory pressure levels do not affect hemodynamics in morbidly obese intravascular volume-loaded patients. Anesth Analg. 2009;109:160–3.
35. Wang ZY, Ye SS, Fan Y, et al. Individualized positive end-expiratory pressure with and without recruitment maneuvers in obese patients during bariatric surgery. Kaohsiung J Med Sci. 2022;38(9):858–68. https://doi.org/10.1002/kjm2.12576.
36. Nestler C, Simon P, Petroff D, et al. Individualized positive end-expiratory pressure in obese patients during general anaesthesia: a randomized controlled clinical trial using electrical impedance tomography. Br J Anaesth. 2017;119(6):1194–205. https://doi.org/10.1093/bja/aex192.

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