Systematic Review and/or Meta-analysis

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Effects of individualized positive end-expiratory pressure on intraoperative oxygenation and postoperative pulmonary complications in patients requiring pneumoperitoneum with Trendelenburg position: a systematic review and meta-analysis

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Background: Whether individualized positive end-expiratory pressure (PEEP) improves intraoperative oxygenation and reduces postoperative pulmonary complications (PPCs) remains unclear. This systematic review and meta-analysis examined whether individualized PEEP is associated with improved intraoperative oxygenation and reduced PPCs for patients needing pneumoperitoneum with the Trendelenburg position during surgery.

Methods: Medline, Embase, the Cochrane Library, and www.clinicaltrials.gov were searched for randomized controlled trials evaluating the effects of individualized PEEP on intraoperative oxygenation and PPCs in patients who required Trendelenburg positioning with pneumoperitoneum. The primary outcome was the oxygenation (PaO_2/FiO_2) during the procedure. Secondary outcomes included PPCs, intraoperative respiratory mechanics (driving pressure, compliance), and vasopressor consumption. DerSimonian–Laird random effects models were used to calculate mean differences (MDs) and log risk ratios (log RRs) with 95% confidence intervals (CIs). The Cochrane Risk-of-Bias tool 2.0 was applied to assess the risk of bias in included studies. The protocol of this meta-analysis has been registered in PROSPERO.

Results: We included 14 studies (1121 patients) that employed different individualized PEEP strategies. Compared with control groups, individualized PEEP groups exhibited a significantly improved intraoperative PaO_2/FiO_2 (MD = 56.52 mmHg, 95% CI: [33.98–79.06], $P < 0.001$) and reduced incidence of PPCs (log RR = −0.50, 95% CI: [−0.84 to −0.16], $P = 0.004$). Individualized PEEP reduced driving pressure while improving respiratory compliance. Intraoperative vasopressor consumption was similar between both groups. The weighted mean PEEP in the individual PEEP groups was 13.2 cmH_2O [95% CI, 11.7–14.6]. No evidence indicated that one individualized PEEP strategy is superior to others.

Conclusions: Individualized PEEP seems to work positively for lung protection in the Trendelenburg position and pneumoperitoneum in patients undergoing general anesthesia.

Keywords: artificial pneumoperitoneum, general anesthesia, laparoscopy, meta-analysis, positive end-expiratory pressure, Trendelenburg position

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Introduction

Laparoscopy is a well-established procedure for lower abdominal and pelvic surgery, which requires induction of pneumoperitoneum and Trendelenburg position (head-down tilt) to facilitate surgical manipulation[1,2]. Pneumoperitoneum combined with the Trendelenburg position causes cranial displacement of the diaphragm, leading to increased airway pressure and decreased lung compliance[3,4]. Moreover, elevated airway pressure may harm alveolar epithelial cells during mechanical ventilation, contributing to the collapse of alveoli and postoperative pulmonary complications (PPCs)[5]. Therefore, it is necessary to develop optimal ventilation strategies to minimize PPCs for patients undergoing laparoscopic surgery in the Trendelenburg position.

Positive end-expiratory pressure (PEEP) is an important protective strategy that maintains alveolar recruitment and reduces the occurrence of atelectasis[6]. However, optimal PEEP has not yet been established. A recent trial showed that applying a PEEP of 15 cmH_2O resulted in more homogeneous ventilation and favorable physiologic effects than a PEEP of 5 cmH_2O during robot-assisted laparoscopic prostatectomy[7]. This finding indicates that the conventional level of PEEP is unlikely to fit all patients, especially for those requiring special positioning and pneumoperitoneum during surgery. An increasing number of researchers recognized that the optimal PEEP should be based on the individual's constitution, body mass index, position, and intra-abdominal pressure[8,9]. However, in daily clinical practice, many anesthesiologists still set PEEP according to personal work experience at a fixed high or low level. A low level of PEEP is insufficient to prevent atelectasis, whereas excessive PEEP may cause lung overinflation and hemodynamic compromise during surgery[10,11].

There are already several methods for determining the optimal PEEP in clinical practice. Respiratory mechanics (driving pressure or respiratory compliance)-guided PEEP titration was mainly used[12], with esophageal manometry and electrical impedance tomography (EIT) on the rise[13,14]. However, the effects of individualized PEEP on respiratory outcomes during the perioperative period in patients in the Trendelenburg position with pneumoperitoneum have not yet been established. We conducted this systematic review and meta-analysis to examine whether individualized PEEP is required to improve intraoperative oxygenation and reduce PPCs for patients combining pneumoperitoneum with the Trendelenburg position during surgery. We hypothesized that individualized PEEP improves intraoperative oxygenation and reduces PPCs compared to fixed PEEP.

HIGHLIGHTS

- We evaluated patients needing pneumoperitoneum with Trendelenburg position in surgery.
- Individualized PEEP reduced driving pressure while improving respiratory compliance.
- Individualized PEEP is associated with improved intraoperative oxygenation.
- Individualized PEEP seems to work positively for lung protection.

Methods

This study was conducted in accordance with the guidelines recommended by the Cochrane Collaboration, and the systematic review was written in line with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses, Supplemental Digital Content 1, http://links.lww.com/JS9/D339, Supplemental Digital Content 2, http://links.lww.com/JS9/D340) and AMSTAR (Assessing the methodological quality of systematic reviews, Supplemental Digital Content 3, http://links.lww.com/JS9/D341) Guidelines[15,16]. The protocol of this meta-analysis was registered in the International Prospective Register of Systematic Reviews (CRD42023494353; date of registration: 28 December 2023) database before data extraction. Medline, Embase, the Cochrane Library, and www.clinicaltrials.gov were searched. We used the search terms "positive end-expiratory pressure," "PEEP," "artificial pneumoperitoneum," "pneumoperitoneum," "head-down tilt," and "Trendelenburg position" to identify related randomized controlled trials (RCTs) exploring the effects of individual PEEP during laparoscopic surgery in Trendelenburg position under general anesthesia published in English from 2000 to 2024 (Supplementary Data 4, Supplemental Digital Content 4, http://links.lww.com/JS9/D342). The date of the last computer search was 28 February 2024. The reference lists of the identified papers were manually explored to identify further relevant studies. Additional studies were identified by screening the bibliographies of the retrieved reports. The authors of the original studies were contacted and asked to provide additional information if necessary.

Inclusion and exclusion criteria

We included all RCTs that studied individualized PEEP during surgery in the Trendelenburg position with pneumoperitoneum, regardless of participants' age or sex. Studies were excluded for the following reasons: (1) retrospective studies, (2) non-RCTs, and (3) animal studies. Reviews, abstracts, protocols, and letters were also excluded. Two independent reviewers performed the searches and study selection. Any conflicts over inclusion or exclusion were discussed between the two reviewers and then with senior authors until a consensus was reached.

Assessing the risk of bias and evaluating the quality of studies

Two reviewers independently assessed the risk of bias for the included trials using the Cochrane Risk-of-Bias tool 2.0[17]. The trials were evaluated according to the guidelines summarized in the Cochrane Handbook for Systematic Reviews of Interventions in the following domains: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. The quality of included trials was assessed by two independent reviewers using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE)[18] and graded as 'high,' 'moderate,' 'low,' or 'very low,' based on the risk of bias, inconsistency, indirectness, and imprecision of our results (Supplementary Data 3, Supplemental Digital Content 4, http://links.lww.com/JS9/D342). Any disagreements were resolved through discussions with a third author.

Data extraction

The included trials reported various parameters at various time points in the Trendelenburg position. We collected the data 60 min after the CO_2 pneumoperitoneum and Trendelenburg positioning. If these data were absent in an article, we selected those closest to this time point. Data were obtained from numerical data in the text or tables. Otherwise, relevant information was extracted from graphs if it could be precisely estimated or by e-mailing the original authors. The following variables were extracted from included studies: oxygenation, driving pressure, pulmonary dynamic compliance (Cdyn), and vasopressor consumption during the procedure. Oxygenation data at the end of surgery was also collected if the mean operation time was > 3 h. PPCs defined by authors in the original studies were collected. If there were more than one intervention group in the article, they were combined following the method provided in the Cochrane Handbook.

Statistical analysis

STATA 18 (StataCorp) was applied to compare the individualized PEEP and control groups. Log risk ratios (Log RRs) were used to express the effect size for dichotomous outcomes, while mean differences (MDs) were used to express the effect size for quantitative variables. All estimates were provided with their corresponding 95% confidence intervals (CIs). The statistical heterogeneity was assessed using the I^2 value and $P < 0.01$. Values of I^2 <25%, 25–50%, and ≥ 50% were considered low, modest, and large heterogeneity, respectively. We calculated log RRs and MDs with their 95% CIs using DerSimonian–Laird random-effects models. A P-value <0.05 was considered statistically significant. When the heterogeneity was large, we performed subgroup and prespecified combinatorial exclusion sensitivity analyses to determine individual studies or clusters of studies that strongly contributed to the heterogeneity. Funnel plots were used to determine publication bias by visually assessing the asymmetry and using Egger's test.

Results

Study section

Using the above search strategy, we identified 67 papers by searching the Medline ($n = 44$), Embase ($n = 11$), Cochrane Library ($n = 8$), and www.clinicaltrials.gov databases ($n = 4$). Considering the six relevant papers from manual retrieval and five duplicates. Sixty-eight potentially relevant papers were screened. Forty-seven papers were excluded after screening titles and abstracts. Then 4 papers were excluded due to experimental design ($n = 3$) unavailable full-text ($n = 1$). In total, 17 full-text papers were further analyzed in-depth, of which three were excluded because of retrospective study ($n = 1$)[19] and non-Trendelenburg positioning ($n = 2$)[20,21]. Ultimately, 14 RCTs were included in the meta-analysis[14,22–34]. Almost all (13/14) included RCTs were published within the last three years (2020–2023). A detailed flowchart of the study is shown in Figure 1. Assessments of the risk of bias from individual studies are shown in Figure 2. The major characteristics of these studies are listed in Table 1. The population sizes for the individualized PEEP groups ranged from 28 to 363, and the total population was 1121 patients, with 564 in the individualized PEEP group and 557 in the control group.

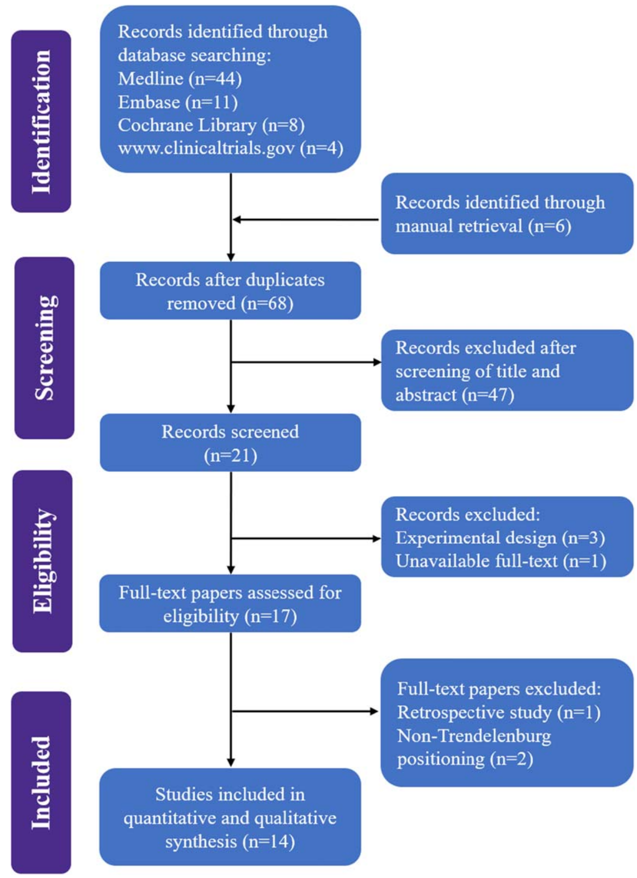

Figure 1. PRISMA flow diagram.

Primary outcomes

Oxygenation

The primary outcome was oxygenation during the CO_2 pneumoperitoneum and Trendelenburg position, calculated from the pressure of arterial oxygen (PaO_2) and FiO_2 as PaO_2/FiO_2. The PaO_2/FiO_2 could be directly extracted from 12 studies and calculated in two. The DerSimonian–Laird random effects model analysis showed that PaO_2/FiO_2 was significantly higher in the individualized PEEP group than in the control group, which indicated that PEEP was still an effective regulator of oxygenation during pneumoperitoneum combined with Trendelenburg positioning. The MD of PaO_2/FiO_2 between the individualized and control groups was 56.52 mmHg (95% CI: [33.98–79.06], $P < 0.001$, Fig. 3). However, the I^2 value was 85%, suggesting substantial heterogeneity among the 14 studies. To reduce the possible effects of heterogeneity, we performed a subgroup analysis by pooling the 14 studies into four subgroups based on the PEEP titration strategy (Fig. 3): driving pressure-guided PEEP, pulmonary compliance-guided PEEP, esophageal pressure-guided PEEP, and others. Most subgroups had lower heterogeneity except the others subgroup ($I^2 = 87\%$; P for heterogeneity <0.01). In the driving pressure-guided PEEP subgroup, the MD

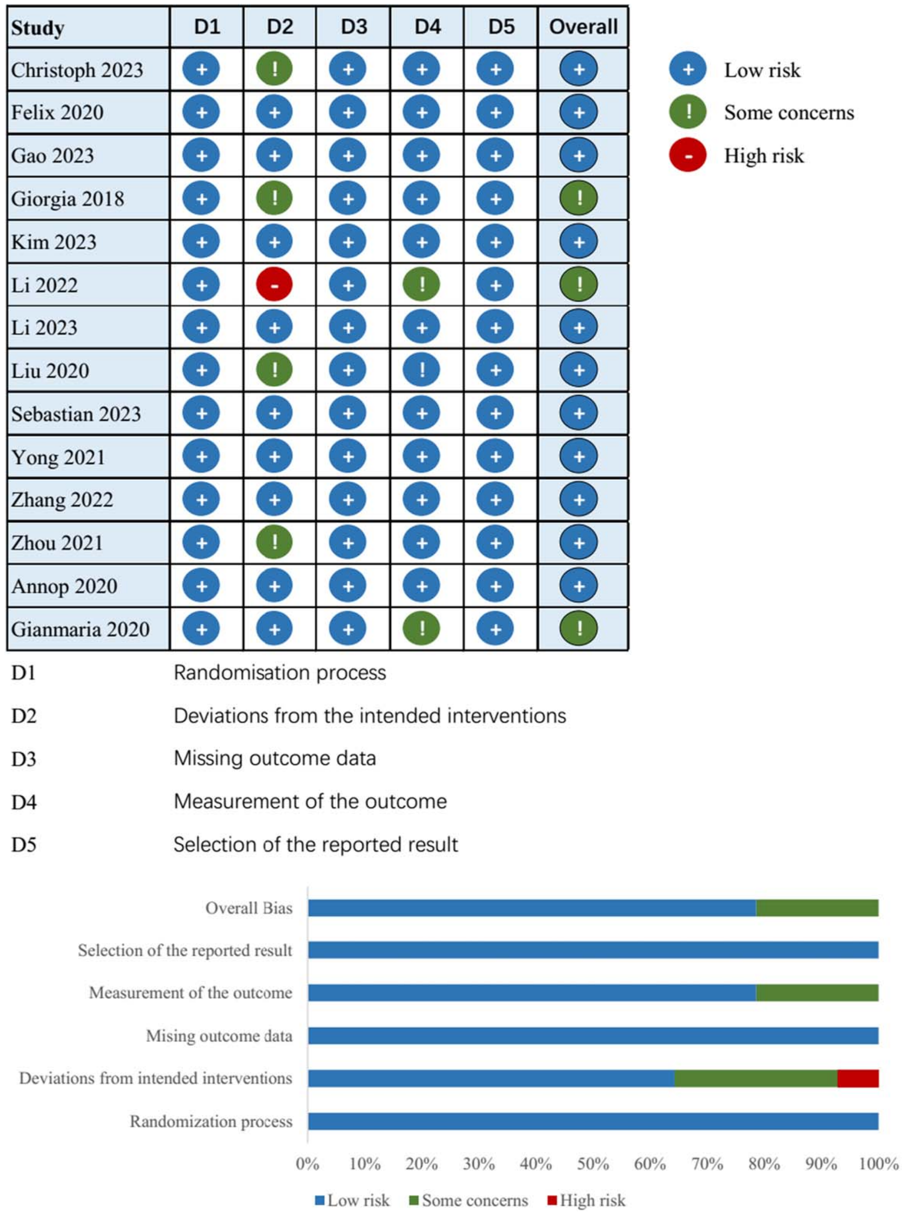

Figure 2. Assessment for risk of bias.

was 73.55 mmHg (95% CI: [57.67–89.43], $P < 0.001$, $I^2 = 31\%$; P for heterogeneity = 0.23). In the pulmonary compliance-guided PEEP subgroup, the MD was 24.22 mmHg (95% CI: [14.25–34.18], $P < 0.001$, $I^2 = 69\%$; P for heterogeneity = 0.01). In the esophageal pressure-guided PEEP subgroup, the MD was 59.53 mm Hg (95% CI: [26.06–93.01], $P < 0.001$, $I^2 = 0\%$; P for heterogeneity = 0.77).

Although driving pressure-guided PEEP trials had a higher MD of PaO_2/FiO_2 than esophageal pressure-guided and pulmonary compliance-guided PEEP trials, there seems to be no difference among subgroups, as the P for subgroup interaction was 0.32. Sensitivity analysis showed that Sebastian and colleagues' study[30] greatly impacted heterogeneity among the pulmonary compliance-guided PEEP subgroup. After removing this study, the I^2 value was reduced from 69% to 31%. However, the MD only reduced from 24.22 (95% CI: [14.25–34.18], $P < 0.01$) to 20.22 (95% CI: [9.9–30.55], $P < 0.001$).

The mean operative time was > 3 h in four studies[25,28,33,34]. We performed subgroup analysis in these four studies, which showed that individualized PEEP could also improve intraoperative PaO_2/FiO_2 at the end of the operation for lengthy surgeries. The MD was 38.20 mm Hg (95% CI: [4.21–72.20], $P = 0.03$, $I^2 = 52.7\%$; P for heterogeneity = 0.1) (Supplementary Fig. S2, Supplemental Digital Content 4, http://links.lww.com/JS9/D342).

Secondary outcomes

PPCs

A composite of PPCs included atelectasis, hypoxemia, acute respiratory distress syndrome, pneumonia, pleural effusion,

Table 1

Characteristics of the included randomized controlled trials.

Study ID	Study population	Type of surgery	Pneumoperitoneum pressure (mmHg)	Bed angle (°)	Sample size		Optimal PEEP identify	PEEP value (cmH_2O)		Recruitment maneuver	
					Intervention	Control		Intervention	Control	Intervention	Control
Piriyapatsom and Phetkampang (2020)[22]	> 18 years, female ASA I–II	Gynecological surgery	12–15	45	22	22	PEEP guided by esophageal pressure	12.4 ± 1.9	5	NA	NA
Gao *et al.* (2023)[24]	> 18 years, male ASA I–III	RALP	15	30	23	23	PEEP decremental guided by SpO_2	16 [12–18]	5	Yes	Yes
Cammarota *et al.* (2020)[34]	> 18 years, ASA I–II	RALP, Hysterectomy	NM	NM	14	14	PEEP guided by esophageal pressure	11.6 ± 4.7	5.1 ± 2	Yes	Yes
Girrbach *et al.* (2020)[14]	49–76 years, male ASA I–III	RALP	NM	30	20	20	PEEP decremental guided by EIT	14 [8–20]	5	Yes	NA
Blecha *et al.* (2023)[30]	< 80 years, male ASA I–III	RALP	15	35–45	48	50	PEEP decremental guided by lung compliance	15.5 ± 1.71	5	Yes	NA
Boesing *et al.* (2023)[23]	> 18 years, male ASA I–III	RALP	15	25	24	12	PEEP decremental guided by driving pressure or esophageal pressure	18 [16–18]	5	Yes	Yes
Kim *et al.* (2023)[26]	> 18 years, with a moderate or high risk of PPCs	Gynecological surgery, RALP, Cystectomy, Colorectal surgery	NM	NM	178	185	PEEP decremental guided by driving pressure	13.6 ± 2.1	5	Yes	If SpO_2 <95%
Li *et al.* (2023)[28]	ASA I–III	RALP	12	NM	23	24	PEEP decremental guided by driving pressure	14 [10–14]	5	Yes	Yes
Yong *et al.* (2021)[31]	> 20 years, male ASA I–II	RALP	NM	NM	30	30	PEEP decremental guided by lung compliance	14 [12–18]	7	Yes	Yes
Zhang *et al.* (2022)[32]	18–80 years	Gynecological laparoscopy	14	30	24	24	PEEP incremental guided by driving pressure	11 [8–12]	5	NA	NA
Spinazzola *et al.* (2018)[25]	> 18 years, female ASA I–II	Gynecological robotic surgery	NM	> 30	20	20	Associated with recruitment maneuver	8–10	5	Yes	Yes
Li *et al.* (2022)[27]	ASA I–III	Gastrointestinal surgery, Gynecology	12 ± 2	30	60	60	PEEP incremental guided lung compliance	8 [6–10]	5	NA	NA
Liu *et al.* (2020)[29]	≥ 18 years, female ASA I–III	Laparoscopic total hysterectomy surgery	13–15	NM	44	43	PEEP decremental guided by lung compliance	6–14	0	Yes	NA
Zhou *et al.* (2023)[33]	> 65 years, male ASA I–III	RARP	12	20–25	32	32	PEEP decremental guided by lung compliance	11	0	Yes	NA

Data are presented as mean ± SD or median [interquartile range].
EIT, electrical impedance tomography; NM, not mentioned; RALP, robot-assisted laparoscopic prostatectomy.

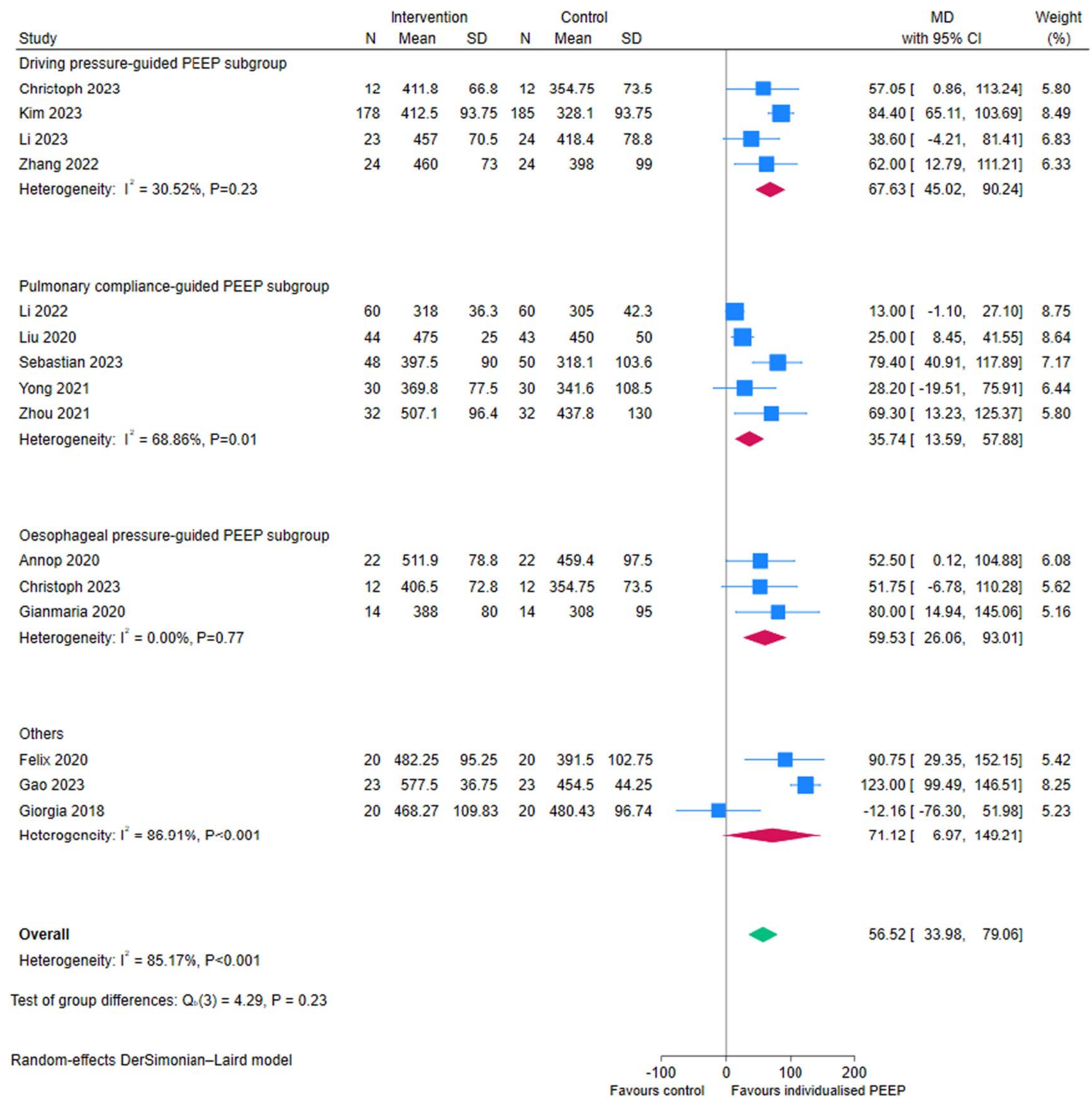

Figure 3. Forest plot for intraoperative oxygenation: individualized PEEP group versus control group. PEEP, positive end-expiratory pressure.

bronchospasm, pneumothorax, aspiration pneumonia, early extubation failure, and the requirement for reintubation. However, the definition of PPCs was described individually in each trial, and the follow-up time ranged from 0 to 7 days (Supplementary Data 1, Supplemental Digital Content 4, http://links.lww.com/JS9/D342). A total of eight trials were conducted to record the events of PPCs, and six provided clear descriptions and diagnostic criteria for PPCs[22,26,29,31–33]. One trial only counted the number of hypoxemia cases in the post-anesthesia care unit[24]. Therefore, we arbitrarily analyzed the incidence of any PPCs in these seven clinical trials, with 353 patients in the individualized PEEP groups and 359 in the control groups[22,24,26,29,31–33]. Individualized PEEP significantly reduced PPCs using the Der Simonian–Laird random effects model (log RR = – 0.50, 95% CI: [– 0.84 to – 0.16], $P = 0.004$, $I^2 = 0\%$; P for heterogeneity = 0.627; Fig. 4).

Individualized PEEP also reduced postoperative hypoxemia (log RR = – 0.77; 95% CI: [– 1.41 to – 0.12], $P = 0.020$; $I^2 = 0\%$, P for heterogeneity = 0.590). There was no difference in the incidence of postoperative atelectasis in the individualized PEEP group compared with the control group (log RR = – 0.52; 95% CI: [– 1.25 to – 0.21], $P = 0.165$; $I^2 = 25\%$; P for heterogeneity = 0.258) (Fig. 4).

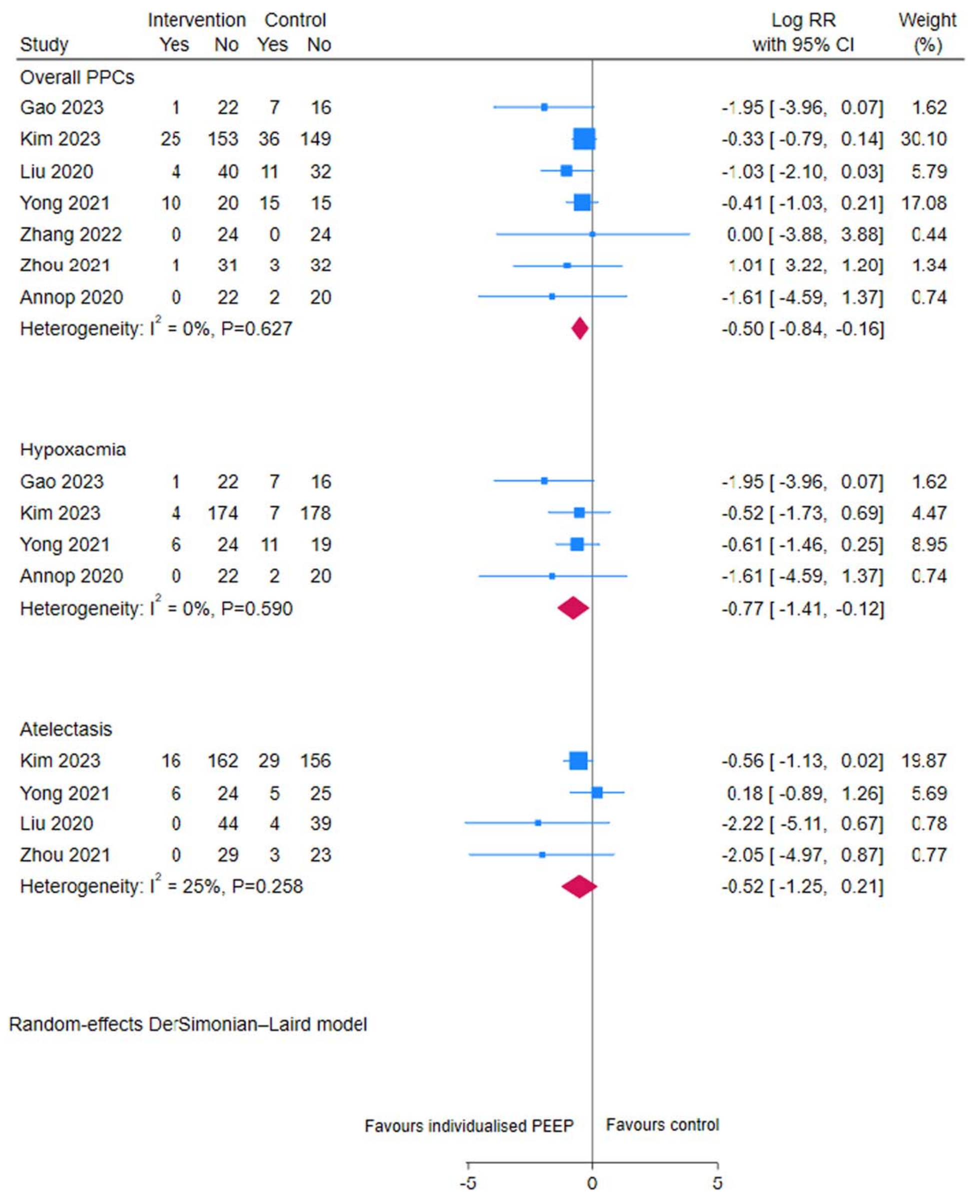

Figure 4. Forest plot for PPCs: individualized PEEP group versus control group. PEEP, positive end-expiratory pressure; PPC, postoperative pulmonary complication.

Respiratory mechanics

Cdyn was analyzed in 11 RCTs[22–25,27–33] involving 690 patients. Results showed that individualized PEEP optimized Cdyn compared with control groups (MD = 6.63 ml/cmH$_2$O, 95% CI: [4.47–8.79], $P < 0.001$, Fig. 5A). However, the heterogeneity was 87% ($P < 0.001$ for heterogeneity) and did not decrease with the removal of any study, indicating a large heterogeneity among the 11 studies.

Driving pressure was reported in nine RCTs [14,22,23,26,28,30–32,34] with 764 patients. Mantel–Haenszel random effects model analysis showed that the driving pressure was significantly lower in the individualized PEEP group than in the control group. The MD was – 4.26 cmH$_2$O (95% CI: [– 5.14 to – 3.38], $P < 0.001$; $I^2 = 69\%$; P for heterogeneity = 0.001; Fig. 5B). Sebastian and colleagues' trial[29] significantly impacted the heterogeneity of the six trials. Excluding it reduced the I^2 value from 69% to 0%, and the MD of driving pressure was – 3.76 cmH$_2$O (95% CI: [– 4.20 to – 3.32], $P < 0.001$; $I^2 = 0\%$; P for heterogeneity = 0.7). This strongly suggests that individualized PEEP reduces driving pressure.

Vasopressor consumption during surgery

Of the 14 studies, five reported the total dosage of vasoactive drugs[24,26,28,31,33]. Further, four studies used ephedrine and phenylephrine to treat hypotension, and one study used norepinephrine only (Supplementary Data 2, Supplemental Digital Content 4, http://links.lww.com/JS9/D342). For a unified comparison, we converted phenylephrine to ephedrine and norepinephrine equivalents at the ratio of phenylephrine 5 μg = ephedrine 1 mg = norepinephrine 1 μg. The overall analysis

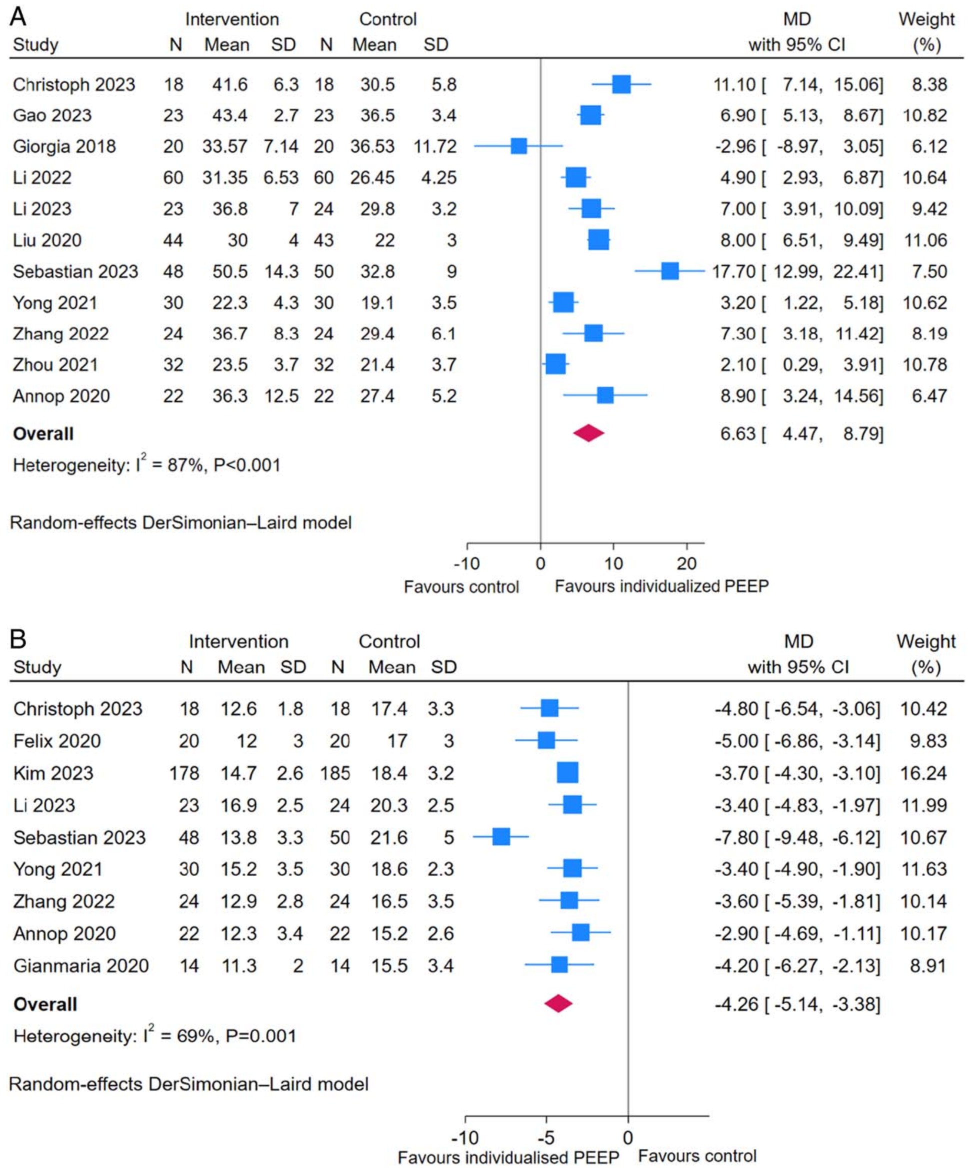

Figure 5. Forest plot for respiratory mechanics: individualized PEEP group versus control group. A, Cdyn, B, Driving pressure. Cdyn, pulmonary dynamic compliance; PEEP, positive end-expiratory pressure.

showed no differences in intraoperative vasopressor doses between groups (MD = 11.46 mg, 95% CI: [– 13.19 to 36.11], $P = 0.36$) with large heterogeneity ($I^2 = 61\%$, $P = 0.04$; Fig. 6).

The PEEP level in the individual PEEP groups

Among the 14 included studies, 11 reported the mean/median levels of PEEP in the individual PEEP groups[14,22–24,26–28,30–32,34]. The mean PEEP ranged between 8.0 and 17.3 cm H_2O. We used the generic inverse variance method in the DerSimonian–Laird random effects model to calculate the mean level of PEEP from the 11 studies. The result showed that the weighted mean PEEP in the individual PEEP groups was 13.2 cmH_2O [95% CI, 11.7–14.6] (Supplementary Fig. S3, Supplemental Digital Content 4, http://links.lww.com/JS9/D342).

Assessment of publication bias

Funnel plots showed that the included studies were symmetrically distributed, indicating that publication bias may be small (Supplementary Fig. S1, Supplemental Digital Content 4, http://links.lww.com/JS9/D342). The Egger regression test further suggested a low publication bias for PaO_2/FiO_2 ($P = 0.99$) and PPCs ($P = 0.15$).

Discussion

Over the past decades, PEEP has been proposed as an effective approach for preventing intraoperative lung collapse and PPCs in patients undergoing general anesthesia. However, there is still a lack of consensus and systematic verification of the level of PEEP

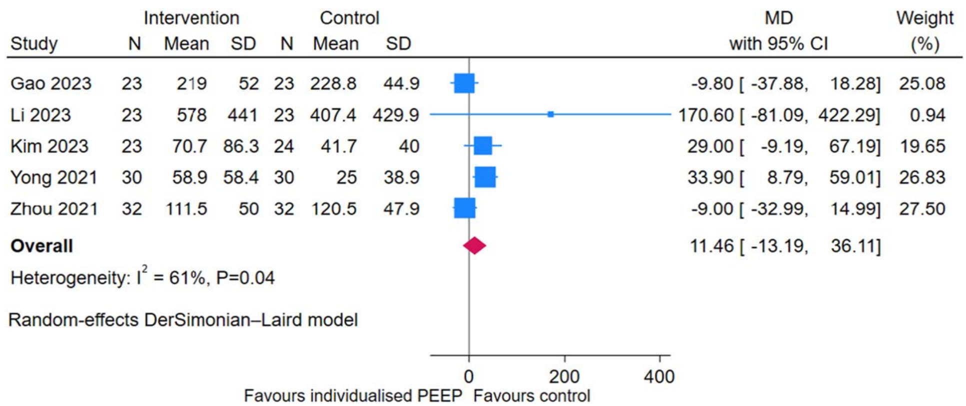

Figure 6. Forest plot for vasopressor consumption during surgery: individualized PEEP group versus control group. PEEP, positive end-expiratory pressure.

in patients with pneumoperitoneum in the Trendelenburg position undergoing general anesthesia. Our results showed that individualized PEEP could improve oxygenation in the Trendelenburg position and pneumoperitoneum during surgery. Individualized PEEP also reduced the incidence of PPCs, possibly due to reduced driving pressure and improvement in Cdyn. Furthermore, individualized PEEP did not increase the consumption of vasoactive drugs during the procedure.

Pneumoperitoneum increases airway pressure and reduces functional residual capacity during general anesthesia[35]. These side effects are accentuated by the steep Trendelenburg position[36,37]. Additionally, expiratory flow limitation is common during lower abdominal and pelvic laparoscopic surgery and is associated with worsening gas exchange, increased V/Q mismatch, and altered lung mechanics[38]. Thus, optimal PEEP should be sufficient to prevent intraoperative lung collapse without causing alveolar hyperinflation and hemodynamic instability.

Several approaches have been used to determine the optimal PEEP, in addition to common methods based on interindividual variability of respiratory system compliance and changes in driving pressure. EIT, SpO_2, and esophageal manometry were also used in the studies we included. EIT-guided PEEP has been shown to improve oxygenation for both obese and non-obese patients in previous studies, but there is still little evidence on PPCs[22,39]. Esophageal manometry has also been verified to significantly benefit oxygenation and respiratory compliance, especially in critically ill patients[40]. Our study has no evidence to show which approach was superior. Further studies are needed to compare the clinical outcomes of different approaches to determining the optimal PEEP.

Bolther *et al.*[41] found that a higher level of PEEP increased intra-alveolar and intrathoracic pressure and may lead to hypotension (reduced venous return). However, in our study, the dose of vasopressors required to maintain blood pressure within the desired range did not differ between the two groups. This indicated that individualized PEEP did not influence hemodynamics. Future studies should carefully standardize the criteria for using vasopressors when evaluating the hemodynamic impact of individualized PEEP.

A recent retrospective cohort analysis showed that driving pressure was significantly associated with PPCs and intraoperative adverse events during open and closed abdominal surgeries[42]. In our study, the individualized PEEP groups had lower driving pressure than the control groups. This result is also in accordance with the Assessment Respiratory Risk in Surgical Patients in Catalonia (ARISCAT) score, in which airway plateau pressure and driving pressure are higher in patients at increased risk than in those at low risk[43].

Our study had some limitations. Only RCTs published in English were included. Additionally, we arbitrarily used the definitions for PPCs provided by individual studies to study the incidence of PPCs. We did not perform subgroup analysis on other factors, such as obesity, surgery type, fluid type, and volume. Although visual assessment of funnel plots and Egger regression suggested the likelihood of publication bias, only 14 studies were included in our analysis, and the funnel plot is inconclusive as a tool for detecting publication bias for 14 studies or fewer. Further studies are required to clarify these issues.

In conclusion, our study demonstrates that individualized PEEP during surgery could improve arterial oxygenation and reduce PPCs without increasing hemodynamic unitability. However, further research is needed to determine which method is superior for research. We suggest that stricter and larger RCTs are required.

Ethical approval

All analyses were based on previously published studies; thus, no ethical approval is required.

Consent

All analyses were based on previously published studies; thus, no patient consent is required.

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Author contribution

Y.W.: conceptualization; L.G., B.Z., M.L., and Q.Y.: study design; L.G., B.Z., and J.Q.: literature search; L.G., B.Z., X.Y., B.L., and J.S.: data extraction. All authors were involved in the interpretation of findings, drafting of the article, and approval of the article.

Conflicts of interest disclosure

The authors declare conflicts of interest.

Research registration unique identifying number (UIN)

CRD42023494353. https://www.crd.york.ac.uk/prospero/ – for systematic reviews.

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Lingqi Gao and Yingwei Wang.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Provenance and peer review

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