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Individualized PEEP titration by lung compliance during one-lung ventilation: a meta-analysis

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Abstract

Background Despite the physiological advantages of positive end-expiratory pressure (PEEP), its optimal utilization during one-lung ventilation (OLV) remains uncertain. We aimed to investigate whether individualized PEEP titration by lung compliance is associated with a reduced risk of postoperative pulmonary complications during OLV.

Methods We searched PubMed, Embase, and the Cochrane Central Register of Controlled Trials until April 1, 2024, to identify published randomized controlled trials that compared individualized PEEP titration by lung compliance with fixed PEEP during OLV. The primary outcome was a composite of postoperative pulmonary complications. Secondary outcomes included clinical outcomes (pneumonia, atelectasis, ARDS, cardiovascular complications, mortality), respiratory mechanics, gas exchanges, and hemodynamic variables. Subgroup analyses were conducted for the primary outcome according to the PEEP titration method (dynamic compliance *vs.* driving pressure/static compliance, stepwise decremental *vs.* incremental strategy).

Results Ten trials involving 3426 patients were included. Compared with fixed PEEP, individualized PEEP titration by lung compliance was associated with reduced risk of a composite of postoperative pulmonary complications (eight trials, 3351 patients, risk ratio [RR] 0.55, 95% CI 0.38–0.78). Subgroup analyses suggested the association was evident in the subgroup with titration by dynamic compliance rather than driving pressure/static compliance and in the subgroup with PEEP titration by stepwise decremental but not stepwise incremental strategy. Individualized PEEP titration by lung compliance was also associated with a reduced risk of pneumonia (RR 0.71, 95% CI 0.52–0.96) and atelectasis (RR 0.63, 95% CI 0.45–0.88), higher dynamic compliance, PaO_2, PaO_2/FiO_2, and lower driving pressure. The individualized and fixed PEEP groups did not differ in ARDS, cardiovascular complications, mortality, peak pressure, plateau pressure, $PaCO_2$, heart rate, and mean arterial pressure.

Conclusions Compared with fixed PEEP, individualized PEEP titration by lung compliance is associated with a reduced risk of postoperative pulmonary complications during OLV, especially in PEEP titration by dynamic compliance or stepwise decremental strategy. It improves respiratory mechanics and oxygenation with no difference in hemodynamic variables.

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Keywords Positive end-expiratory pressure, Lung compliance, One-lung ventilation, Postoperative pulmonary complications, Respiratory mechanics

Background

One-lung ventilation (OLV) is crucial for optimal surgical exposure for thoracic surgery. Meanwhile, mechanical ventilation potentially causes lung injury, thereby elevating the risk of postoperative pulmonary complications [1, 2]. Ranging from mild hypoxemia to severe respiratory failure, these complications have undesirable effects on patient outcomes [3]. A lung-protective ventilation strategy, generally incorporating low tidal volume, positive end-expiratory pressure (PEEP), and with or without recruitment maneuver, has been advocated as a favorable intervention to mitigate the risk of postoperative pulmonary complications [4].

Despite the recognized benefits of PEEP in maintaining alveolar recruitment and gas exchange, its optimal application during OLV still needs to be determined [5]. Growing evidence advocates individualized PEEP titration based on respiratory mechanics, particularly lung compliance, instead of fixed PEEP during OLV [6–15]. While a prior meta-analysis suggested reduced postoperative pulmonary complications and improved oxygenation with individualized PEEP settings during OLV in thoracic surgery [16], its findings were limited by a modest sample size of 849 patients and did not include two recent large randomized controlled trials (RCTs) totaling approximately 2500 patients [12, 14]. Moreover, the previous meta-analysis did not evaluate some clinical outcomes, respiratory mechanics, and hemodynamic safety. Thus, we comprehensively conducted a meta-analysis incorporating the latest evidence to investigate the role of individualized PEEP titration by lung compliance during OLV in patients undergoing thoracic surgery. Our primary objective was to assess the association between individualized PEEP titration by lung compliance and the risk of a composite of postoperative pulmonary complications. The secondary aim was to evaluate its effects on other clinical outcomes, respiratory mechanics, gas exchange, and hemodynamic variables.

Methods

Registration and protocol

We report this study following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement [17]. The protocol was registered at the International Prospective Register of Systematic Reviews (CRD42024529980).

Eligibility criteria

Studies were considered eligible if they met the following criteria: (1) Population: adult patients undergoing thoracic surgery with OLV; (2) Intervention: individualized PEEP titration by lung compliance (the highest dynamic, the highest dynamic static compliance, or the lowest driving pressure), low tidal volume, and with or without recruitment maneuver; (3) Comparison: fixed PEEP, low tidal volume, and with or without recruitment maneuver; (4) Outcomes: available data on clinical outcomes, respiratory mechanics, gas exchanges, and hemodynamic variables; and (5) Design: RCT. Meeting abstracts were not considered, given the possibility of insufficient information. Studies on cardiac surgery or lung transplantation and studies not published in peer-reviewed journals were excluded.

Literature search

An experienced medical librarian (SC) searched PubMed, Embase, and the Cochrane Central Register of Controlled Trials through April 1, 2024. Search strategies were developed, combining keywords and medical subject heading terms related to positive end-expiratory pressure, one-lung ventilation, lung compliance, and thoracic surgery (Table S1). Additionally, the reference lists of previous reviews and included studies were manually reviewed.

Study selection

Two reviewers (WJG and FZZ) independently conducted the selection process by removing duplicates, screening titles and abstracts for relevance, and assessing full-text articles for eligibility according to pre-specified eligibility criteria. Discrepancies were discussed with a third reviewer (HYY).

Data collection

Two reviewers (WJG and FZZ) independently collected data using a data extraction sheet, with discrepancies discussed with a third reviewer (HYY). We extracted the following information from original trials and their supplements, including trial characteristics (the first author

name, publication year, country, and number of patients), population (age, body mass index, American Society of Anesthesiologist physical status, and type of surgical procedure), ventilation setting (PEEP, tidal volume, recruitment maneuver, respiratory rate, ventilation mode, inspired fraction of oxygen [FiO_2], inspiratory/expiratory ratio, inspiratory pause, and end-tidal carbon dioxide), and data on outcomes.

Outcomes

The primary outcome was a composite of postoperative pulmonary complications. Secondary outcomes included clinical outcomes (pneumonia, atelectasis, acute respiratory distress syndrome [ARDS], cardiovascular complications, mortality), respiratory mechanics (dynamic compliance, driving pressure, peak pressure, plateau pressure), gas exchanges (arterial partial pressure of oxygen [PaO_2], arterial partial pressure of carbon dioxide [$PaCO_2$], PaO_2/FiO_2), and hemodynamic variables (heart rate, mean arterial pressure). The definitions and assessment time points of these outcomes were according to the original studies (Table S2 and S3).

Risk of bias assessment

Two reviewers (WJG and FZZ) independently appraised the risk of bias using the Cochrane Collaboration's tool [18]. The overall risk of bias (high, unclear, or low) for each trial was determined by the highest risk of bias level in the following domains: random sequence generation (selection bias), allocation concealment (selection bias), blinding of participants and personnel (performance bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias), and other bias.

Certainty of evidence assessment

Two reviewers (WJG and FZZ) independently evaluated the certainty of the evidence for each outcome as very low, low, moderate, or high using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework [19]. This assessment considered the following domains: risk of bias, inconsistency, indirectness, imprecision, publication bias, large effect, plausible confounding, and dose–response gradient.

Statistical analysis

Risk ratios (RRs) for dichotomous data or mean differences (MDs) for continuous data with 95% confidence intervals (CIs) were pooled using a random-effects model given clinical and methodology heterogeneity. Data expressed as median and interquartile range for continuous outcomes were converted to mean and standard deviation [20]. For more than two intervention groups, we combined all intervention groups into a single intervention group and all comparator groups into a single comparator group, as recommended by the Cochrane Handbook for Systematic Reviews of Interventions [21].

$$N = N_1 + N_2$$

$$M = \frac{N_1 M_1 + N_2 M_2}{N_1 + N_2}$$

$$SD = \sqrt{\frac{(N_1 - 1)SD_1^2 + (N_2 - 1)SD_2^2 + \frac{N_1 N_2}{N_1 + N_2}\left(M_1^2 + M_2^2 - 2M_1 M_2\right)}{N_1 + N_2 - 1}}$$

We used Cochran's Q test to assess statistical heterogeneity across studies, and the I^2 statistic quantified the degree of heterogeneity. An I^2 value > 50% indicated significant statistical heterogeneity. Publication bias was assessed by visually inspecting funnel plots and the Egger test [22]. All statistical analyses were performed using RevMan 5.4 and R version 4.3.2. We considered two-tailed $P < 0.05$ as statistically significant in all tests.

Subgroup analyses

Subgroup analyses for the primary outcomes were performed according to the PEEP titration method (dynamic compliance *vs.* driving pressure or static compliance, stepwise decremental *vs.* incremental strategy).

Results

Trial selection

Figure S1 shows the trial selection process. The initial search identified 2133 records. After reviewing full-text articles by eligibility criteria, 10 RCTs were included for analysis [6–15].

Trial characteristics

The trial characteristics are shown in Table 1 and Table S4. These RCTs were published between 2003 and 2024 and conducted in seven different countries (five in China [9–11, 13, 15], two in Korea [8, 12], one each in Italy [6] and Spain [7], and one in Spain, Italy, Turkey, Egypt, and Ecuador [14]). The sample size of the individual trial ranged from 30 to 1308, totaling 3426 patients. Most trials underwent lung resection and settled a low tidal volume of 5–7 ml kg^{-1} with recruitment maneuver. Individualized PEEP titration was based on the highest dynamic compliance in five trials [7, 9, 10, 14, 15], the highest static compliance in two [6, 11], and the lowest driving pressure in three [8, 12, 13]. No trial included prolonged end-inspiratory pauses to estimate the plateau pressure for calculating driving pressure or static compliance. Therefore, trials using the volume-controlled ventilation estimated Pplat at the end of

Table 1 Characteristics of included randomized controlled trials

Study	Country	Number of patients	Surgical procedure	Individualized PEEP group			Fixed PEEP group			Outcomes
				V_T (ml/kg)	PEEP (cmH_2O)	RM	V_T (ml/kg)	PEEP (cmH_2O)	RM	
Mascotto 2003 [6]	Italy	50	Lung resection	9	Stepwise incremental PEEP by 2 from 0 until the highest C_{stat}	No	9	0	No	Clinical outcomes: atelectasis
Ferrando 2014 [7]	Spain	30	Lung resection	5–7	Stepwise decremental PEEP by 2 from 20 until the highest C_{dyn}	Yes	5–7	5	Yes	Respiratory mechanics: Ppeak Gas exchanges: PaO_2, $PaCO_2$
Park 2019 [8]	Korea	292	Lung resection or esophagectomy	6	Stepwise incremental PEEP by 1 from 2 to 10 until the lowest DP	Yes	6	5	Yes	Clinical outcomes: composite PPCs, pneumonia, ARDS, cardiovascular complications, mortality Respiratory mechanics: DP, Ppeak, Pplat Gas exchanges: PaO_2, $PaCO_2$
Li 2020 [9]	China	176	Lung resection	5–6	Stepwise decremental PEEP by 2 from 20 to 6 until the highest C_{dyn}	Yes	5–6	5	Yes	Clinical outcomes: composite PPCs, pneumonia, atelectasis Respiratory mechanics: C_{dyn}, Ppeak, Pplat Gas exchanges: $PaCO_2$, PaO_2/FiO_2 Hemodynamic variables: heart rate, MAP
Xu 2021 [10]	China	45	Lung resection or esophagectomy	6	Stepwise incremental PEEP by 1 from 4 until the highest C_{stat} and C_{dyn}	Yes	6	0	Yes	Respiratory mechanics: C_{dyn}, DP, Ppeak, Pplat Gas exchanges: PaO_2/FiO_2 Hemodynamic variables: heart rate, MAP
Zhang 2021 [11]	China	58	Lung resection	5–7	Stepwise decremental PEEP by 2 from 15 until the highest C_{stat}	Yes	5–7	5	Yes	Clinical outcomes: composite PPCs, pneumonia, atelectasis Respiratory mechanics: DP, Ppeak, Pplat Gas exchanges: PaO_2, $PaCO_2$ Hemodynamic variables: heart rate, MAP
Park 2023 [12]	Korea	1170	Lung resection	5	Stepwise decremental PEEP by 1 from 10 to 0 until the lowest DP	Yes	5	5	Yes	Clinical outcomes: composite PPCs, pneumonia, atelectasis, ARDS, cardiovascular complications, mortality Respiratory mechanics: DP Gas exchanges: PaO_2, PaO_2/FiO_2

Table 1 (continued)

Study	Country	Number of patients	Surgical procedure	Individualized PEEP group			Fixed PEEP group			Outcomes
				V_T (ml/kg)	PEEP (cmH_2O)	RM	V_T (ml/kg)	PEEP (cmH_2O)	RM	
Yu 2023 [13]	China	207	Lung resection	6	Stepwise decremental PEEP by 1 from 12 to 4 until the lowest DP	Yes	6	4	Yes	Clinical outcomes: composite PPCs, pneumonia, atelectasis Respiratory mechanics: C_{dyn}, DP, Ppeak, Pplat Gas exchanges: PaO_2, $PaCO_2$ Hemodynamic variables: heart rate, MAP
Ferrando 2024 [14	Spain, Italy, Turkey, Egypt, and Ecuador	1308	Lung resection	5–6	Stepwise decremental PEEP by 2 from 20 until the highest C_{dyn}	Yes	5–6	4	Yes	Clinical outcomes: composite PPCs, pneumonia, atelectasis, ARDS, cardiovascular complications, mortality Respiratory mechanics: C_{dyn}, DP
Li 2024 [15]	China	90	Lung resection	5–6	Stepwise decremental PEEP by 2 from 16 until the highest C_{dyn}	Yes	5–6	6	Yes	Clinical outcomes: composite PPCs, pneumonia, atelectasis, ARDS Respiratory mechanics: C_{dyn}, Ppeak, Pplat Gas exchanges: PaO_2, $PaCO_2$, PaO_2/FiO_2 Hemodynamic variables: heart rate, MAP

ARDS, acute respiratory distress syndrome; Cdyn, dynamic compliance; Cstat, static compliance; DP, driving pressure; FiO_2, inspired oxygen concentration; MAP, mean arterial pressure; RM, recruitment maneuver; $PaCO_2$, arterial partial pressure of carbon dioxide; PaO_2, arterial partial pressure of oxygen; PEEP, positive end-expiration pressure; PPCs, postoperative pulmonary complications; Ppeak, peak pressure; Pplat, plateau pressure; V_T, tidal volume

the inspiratory pause. Those using pressure-controlled ventilation relied on the delivered pressure value to calculate dynamic compliance. Individualized PEEP titration was based on the stepwise decremental method in seven trials [7, 9, 11–15] and the stepwise incremental method in three [6, 8, 10]. Four trials [8, 12–14] were categorized as low risk of bias, five [6, 7, 10, 11, 15] as unclear, and one [9] as high (Figure S2). Adequate random sequence generation was reported in eight trials [6, 8, 9, 11–15], and appropriate allocation concealment was reported in five trials [8, 9, 12–14] (Figure S3).

Primary outcome

Eight RCTs [6, 8, 9, 11–15] involving 3351 patients reported the data on a composite of postoperative pulmonary complications. Compared with fixed PEEP, individualized PEEP titration by lung compliance was associated with reduced risk of a composite of postoperative pulmonary complications (RR 0.55, 95% CI 0.38–0.78, $P=0.0009$; Fig. 1).

Subgroup analyses

The association between individualized PEEP titration and reduced risk of a composite of postoperative pulmonary complications was evident in the subgroup with PEEP titration by dynamic compliance (RR 0.49, 95% CI 0.36–0.66, $P<0.00001$) rather than driving pressure/static compliance (RR 0.65, 95% CI 0.40–1.04, $P=0.07$; Figure S4), and in the subgroup with PEEP titration by stepwise decremental (RR 0.53, 95% CI 0.36–0.80, $P=0.002$) but not stepwise incremental strategy (RR 0.58, 95% CI 0.28–1.21, $P=0.15$; Figure S5).

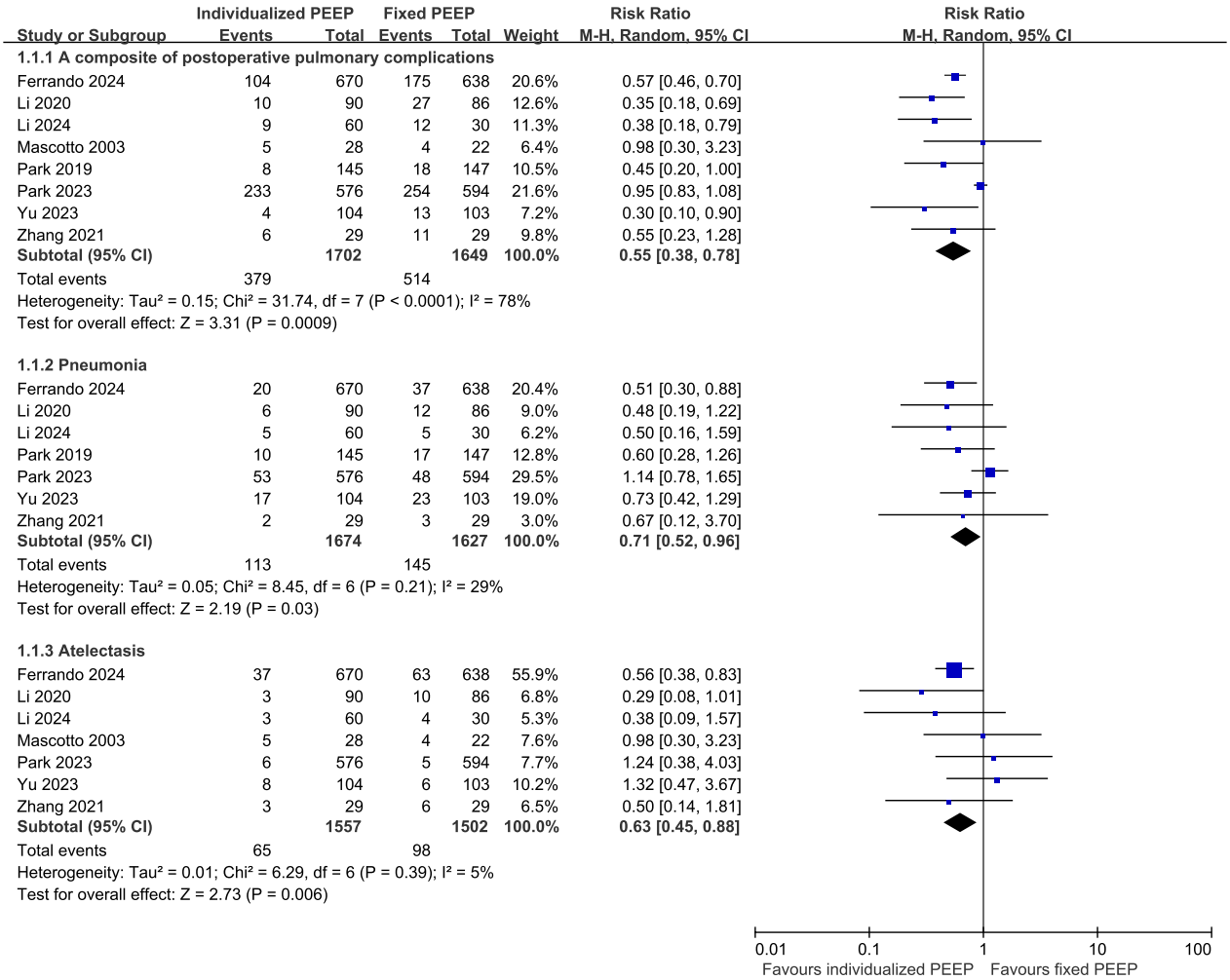

Fig. 1 Forest plot for a composite of postoperative pulmonary complications, pneumonia, and atelectasis. CI, confidence interval; PEEP, positive end-expiration pressure

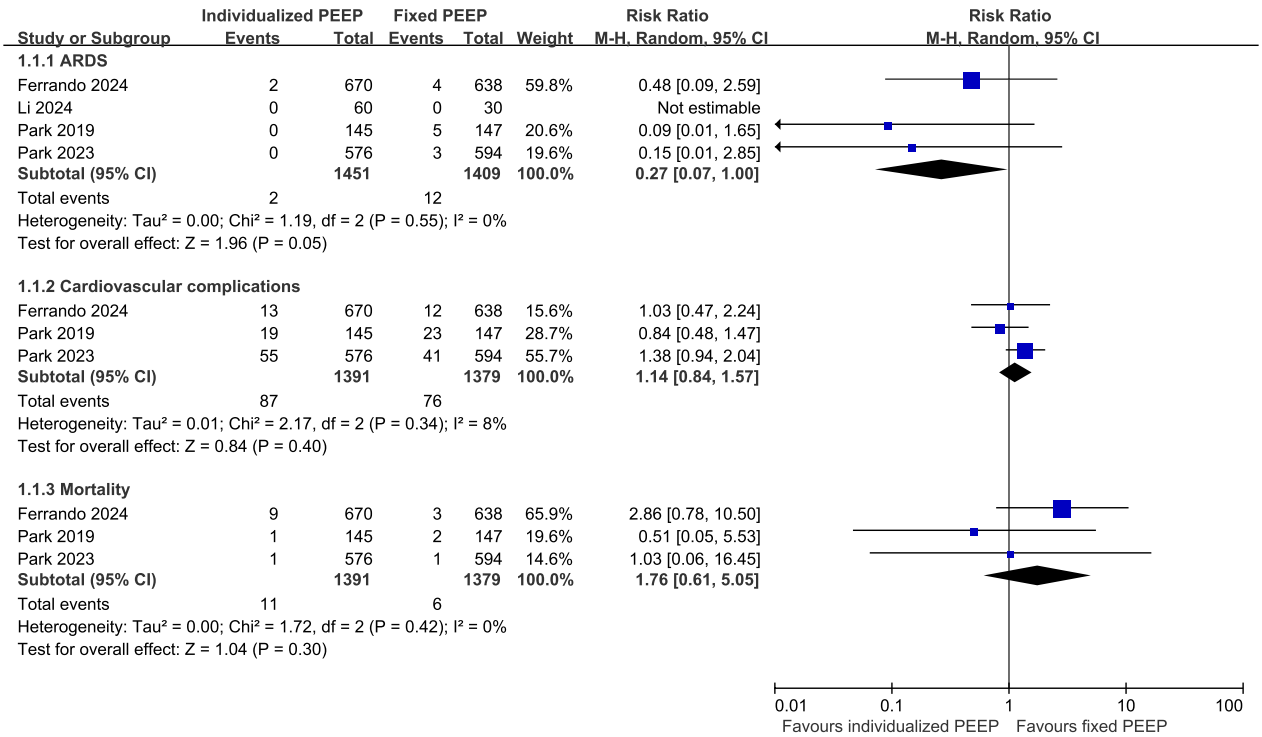

Fig. 2 Forest plot for ARDS, cardiovascular complications, and mortality. ARDS, acute respiratory distress syndrome; CI, confidence interval; PEEP, positive end-expiration pressure

Secondary outcomes

Clinical outcomes

Compared with fixed PEEP, individualized PEEP titration was associated with reduced risk of pneumonia (RR 0.71, 95% CI 0.52–0.96, $P=0.03$; Fig. 1) and atelectasis (RR 0.63, 95% CI 0.45–0.88, $P=0.006$; Fig. 1). There was no difference in ARDS (RR 0.27, 95% CI 0.07–1.00, $P=0.05$; Fig. 2), cardiovascular complications (RR 1.14, 95% CI 0.84–1.57, $P=0.40$; Fig. 2), and mortality (RR 1.76, 95% CI 0.61–5.05, $P=0.30$; Fig. 2) between the individualized and fixed PEEP groups.

Respiratory mechanics

Figure 3 shows the results for respiratory mechanics. Compared with fixed PEEP, individualized PEEP titration was associated with higher dynamic compliance (MD 8.43 ml/cmH_2O, 95% CI 6.11 to 10.74, $P<0.00001$) and lower driving pressure (MD − 2.13 cmH_2O, 95% CI − 3.06 to − 1.19, $P<0.00001$). There was no difference in peak pressure (MD − 0.56 cmH_2O, 95% CI − 1.69 to 0.57, $P=0.33$) and plateau pressure (MD 0.43 cmH_2O, 95% CI − 1.59 to 2.46, $P=0.68$) between the individualized and fixed PEEP groups.

Gas exchanges

Figure 4 shows the results for gas exchanges. Compared with fixed PEEP, individualized PEEP titration was associated with higher PaO_2 (MD 14.84 mmHg, 95% CI 8.14 to 21.54, $P<0.00001$) and PaO_2/FiO_2 (MD 23.87 mmHg, 95% CI 13.65 to 34.08, $P<0.00001$). There was no difference in $PaCO_2$ (MD − 0.21 mmHg, 95% CI − 1.32 to 0.90, $P=0.71$) between the individualized and fixed PEEP groups.

Hemodynamic variables

Figure S6 shows the results for hemodynamic variables. There was no difference in heart rate (MD 0.87 beats/min, 95% CI − 0.55 to 2.30, $P=0.23$) and mean arterial pressure (MD -1.64 mmHg, 95% CI − 5.65 to 2.36, $P=0.41$) between the individualized and fixed PEEP groups.

Certainty of evidence

Table S5 shows detailed GRADE profiles. The certainty of the evidence was moderate for a composite of postoperative pulmonary complications. The certainty of evidence for secondary outcomes ranged from moderate to high.

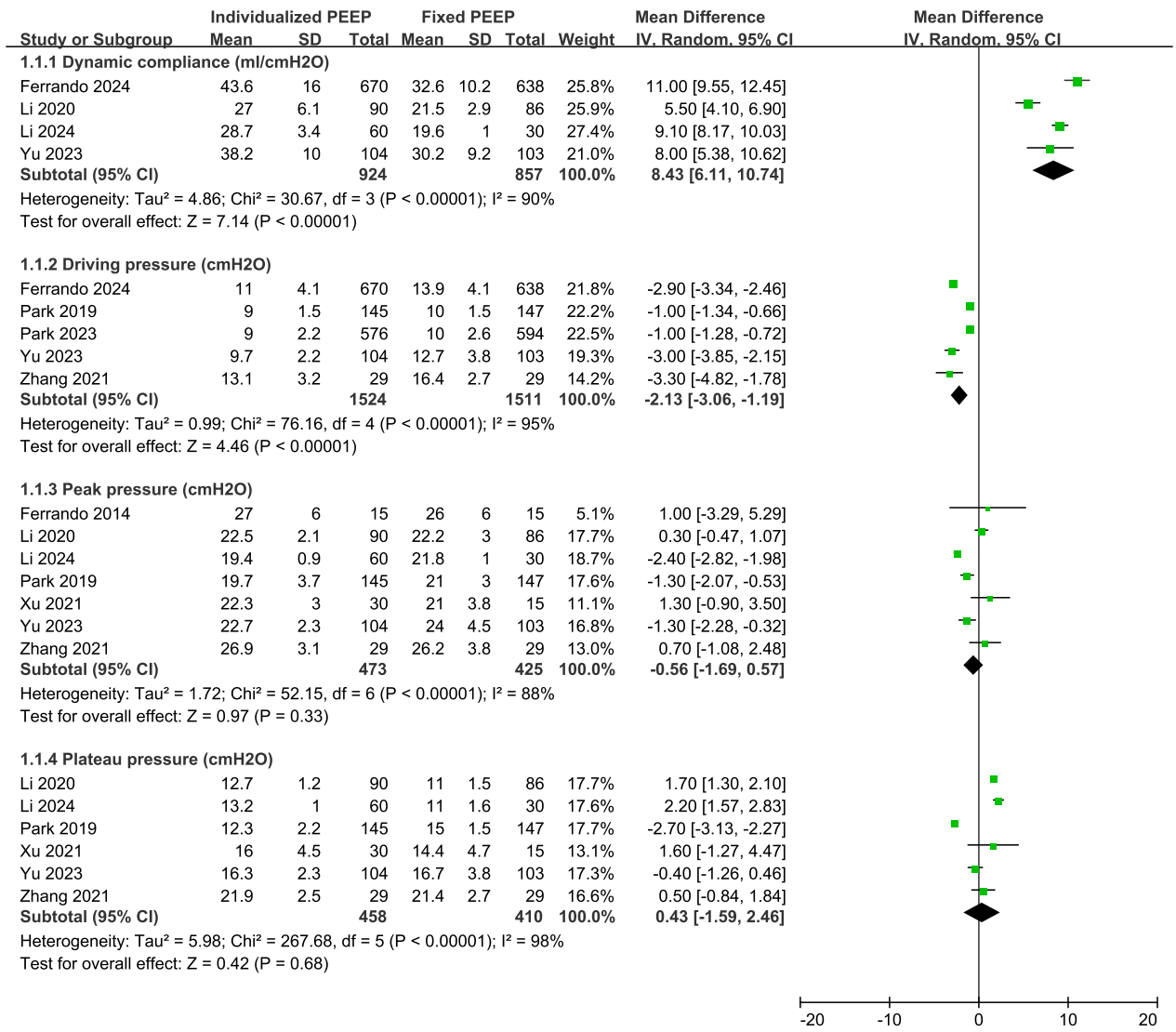

Fig. 3 Forest plot for respiratory mechanics. CI, confidence interval; PEEP, positive end-expiration pressure; SD, standard deviation

Publication bias

There was no evidence of publication bias for all outcomes by visually inspecting funnel plots (Figures S7 and S8) and the Egger test ($P > 0.05$).

Discussion

Main findings

This meta-analysis included the latest evidence and found that individualized PEEP titration by lung compliance was associated with a reduced risk of a composite of postoperative pulmonary complications compared with fixed PEEP. Subgroup analyses suggested that the association was evident in the subgroup with PEEP titration by dynamic compliance or stepwise decremental strategy. Furthermore, individualized PEEP titration by lung compliance was associated with a reduced risk of pneumonia and atelectasis. It also improved respiratory mechanics (higher dynamic compliance and lower driving pressure) and oxygenation (higher PaO_2 and PaO_2/FiO_2) with no difference in hemodynamic variables.

Comparison with previous evidence

The rationale for using PEEP is to maintain a lung volume above the closing capacity. This prevents alveolar collapse and intrapulmonary shunting that can cause hypoxemia during OLV. Furthermore, an adequate PEEP level avoids the cyclic recruitment/decruitment of lung units that promote endothelial and epithelial damage and subsequent lung inflammation [23]. Conversely, excessively high PEEP values can cause overdistension with a subsequent increase in alveolar dead space and diversion

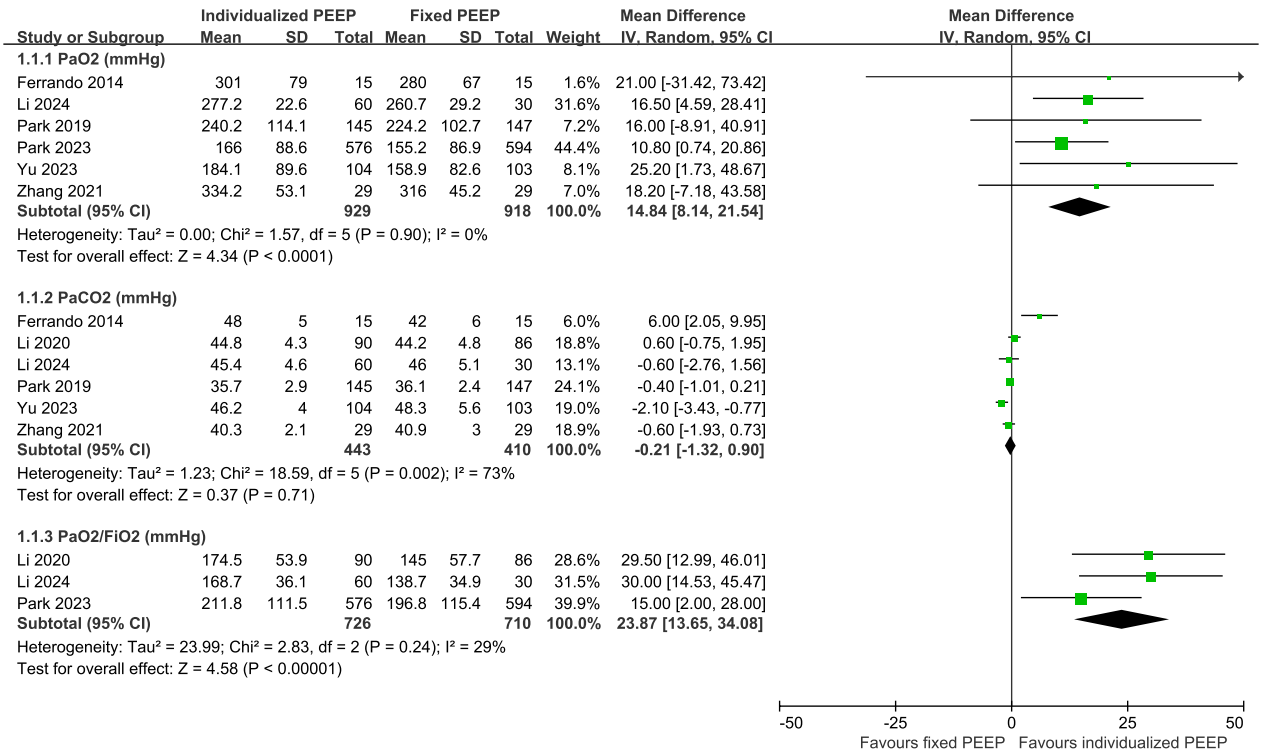

Fig. 4 Forest plot for gas exchanges. CI, confidence interval; FiO_2, inspired oxygen concentration; $PaCO_2$, arterial partial pressure of carbon dioxide; PaO_2, arterial partial pressure of oxygen; PEEP, positive end-expiration pressure; SD, standard deviation

of blood flow [24]. Recently, in a meta-analysis, Peel et al. confirmed that PEEP, compared with no PEEP, offers physiologic advantages during OLV [5]; however, the optimal PEEP titration strategy is yet to be determined. The authors pointed out that most studies report surrogate outcomes (e.g., physiological measures) rather than clinical outcomes. Therefore, Peel et al. invoked the need to design studies to evaluate the impact of recruitment maneuvers and PEEP on clinical outcomes. Subsequently, another meta-analysis by Li et al. demonstrated that an individualized PEEP setting during OLV was associated with fewer postoperative pulmonary complications and better oxygenation [16]. However, these findings were primarily derived from dissertations from China with a limited sample size of 849 patients, potentially limiting their generalizability. Moreover, Li et al. primarily focused on a composite of postoperative pulmonary complications, neglecting other critical patient-centered outcomes, such as pneumonia, atelectasis, ARDS, cardiovascular complications, and mortality. Additionally, data on respiratory mechanics and hemodynamic variables were lacking.

Notably, our meta-analysis is the largest to date, incorporating seven additional RCTs totaling over 3000 patients compared to previous analyses. We also conducted subgroup analyses based on the PEEP titration method. Moreover, we expanded outcome reporting to include pneumonia, atelectasis, ARDS, cardiovascular complications, and mortality. Additionally, we provided data on respiratory mechanics and hemodynamic variables.

Potential implications for clinical practice

The findings of our study have some implications for clinical practice. Although the results of our study are encouraging, a large RCT may help to further clarify our findings, given that this is a meta-analysis of heterogeneous studies. Subgroup analyses suggested that the association was evident when individualized PEEP was titrated by dynamic compliance rather than driving pressure or static compliance. The fact that using dynamic compliance to set PEEP is superior to using driving pressure or static compliance may seem surprising from a physiological point of view. In fact, dynamic compliance is calculated considering the peak airway pressure, which is partly influenced by flow resistance rather than lung and chest characteristics. In our opinion, this result may depend on several factors. First, the measurement of plateau pressure, useful for estimating driving pressure and static compliance, was performed in most studies in suboptimal conditions, i.e., with respiratory rates of 12 breaths per minute or more. The

estimation of plateau pressure instead requires a quasi-static condition (ideally no flow), which is achieved with an inspiratory pause of about 5–10 s or by setting the respiratory rate to low values (< 10/min) with a ratio between inspiratory and expiratory time preferably 1:1. Second, the study by Ferrando et al. [14], which has a significant weight in the analysis, used dynamic compliance for PEEP titration, which was found by our analysis to be superior to driving pressure or static compliance. It is, therefore, possible that the factor negatively affected the results. Third, the protocols adopted in the studies are heterogeneous, especially regarding the strategy for lung alveolar recruitment and PEEP trials based on driving pressure or static compliance. Subgroup analyses also suggested that the association was evident when individualized PEEP is titrated by stepwise decremental but not stepwise incremental strategy. Spadaro et al. compared the physiological effects of two strategies for PEEP titration during OLV on respiratory mechanics, ventilation/perfusion mismatch, and gas exchange: by stepwise increase starting from zero PEEP ($PEEP_{INCREMENTAL}$) or by stepwise decrease after a lung recruitment maneuver ($PEEP_{DECREMENTAL}$) [25]. In this randomized trial, they found that both the $PEEP_{INCREMENTAL}$ and the $PEEP_{DECREMENTAL}$ strategies could decrease intraoperative shunt, but only $PEEP_{DECREMENTAL}$ improved oxygenation and lowered intraoperative driving pressure. These results may partially explain the observed subgroup difference in postoperative pulmonary complications in our meta-analysis, favoring the stepwise decremental PEEP titration strategy.

Our findings highlight clinicians may need to tailor ventilation strategies when using individualized PEEP titration for OLV in clinical practice. However, while international expert panel-based consensus recommended individualized PEEP titration for lung-protective ventilation in surgical patients, the optimal method for individualized PEEP titration remains to be determined [26]. Future updated recommendations can integrate our findings to aid clinical decision-making, with suggestions on individualized PEEP titration by dynamic compliance or stepwise decremental strategy until more robust data are available. We found that individualized PEEP titration improved respiratory mechanics (higher dynamic compliance and lower driving pressure) and oxygenation (higher PaO_2 and PaO_2/FiO_2) with no difference in hemodynamic variables. This is important because it helps clinicians to better manage OLV by counteracting possible hypoxemia with a more standardized approach than in the past and respecting the principles of protective ventilation. In summary, compared with fixed PEEP, individualized PEEP titrated by lung compliance is associated with reduced risk of postoperative pulmonary complications during OLV, especially in PEEP titration by dynamic compliance or stepwise decremental strategy. Incorporating these findings into clinical practice may improve patient outcomes.

Study limitations

Our study has certain limitations. Firstly, the included studies used different definitions for outcomes, particularly postoperative pulmonary complications, which could introduce heterogeneity affecting the findings. Secondly, the differences in the methods for selecting individualized PEEP titration across the included studies, such as a recruitment maneuver before PEEP titration and the varying levels of inspiratory pressures applied, could contribute to the heterogeneity and affect the results of the meta-analysis. Thirdly, there were differences in the assessment time points for respiratory mechanics, gas exchanges, and hemodynamic variables across the included studies, ranging from 10 to 45 min after starting OLV. Fourthly, despite the benefit of individualized PEEP titrated by lung compliance, the evidence of its use in specific populations, such as obesity, is limited. A recent RCT found that dynamic compliance-guided PEEP was associated with a lower risk of postoperative atelectasis than fixed PEEP in patients undergoing laparoscopic bariatric surgery [27]. Lastly, the possibility of small study bias cannot be entirely ruled out. It may impact the validity of our findings, particularly given the relatively small number of studies included for analyses.

Conclusions

Compared with fixed PEEP, individualized PEEP titrated by lung compliance is associated with a reduced risk of a composite of postoperative pulmonary complications during OLV, especially in PEEP titration by dynamic compliance or stepwise decremental strategy. Individualized PEEP titration improves respiratory mechanics and oxygenation with no difference in hemodynamic variables.

Abbreviations

ARDS	Acute respiratory distress syndrome
CI	Confidence interval
FiO_2	Inspired fraction of oxygen
MD	Mean difference
OLV	One-lung ventilation
PaO_2	Arterial partial pressure of oxygen
$PaCO_2$	Arterial partial pressure of carbon dioxide
PEEP	Positive end-expiratory pressure
RCT	Randomized controlled trial
RR	Risk ratio

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13054-024-05237-y.

Additional file 1.

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Not applicable.

Author contributions
Study conception and design: WJG and HYY. Acquisition, analysis, and interpretation of data: all authors. Manuscript drafting: WJG. Critical revision for important intellectual content: all authors. Final approval of the manuscript: all authors. All authors agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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