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REVIEW

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Effect of pressure-controlled ventilation and volume-controlled ventilation for laparoscopic surgery in the Trendelenburg position: a systematic review and meta-analysis

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Abstract

Background Volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) are commonly used in laparoscopic surgery in the Trendelenburg position, and pressure-controlled ventilation volume guaranteed (PCV-VG) has been increasingly used recently. However, there is still no consensus on the optimal ventilation mode. Therefore, a systematic review and meta-analysis were conducted to compare the effects of different ventilation modes for laparoscopic surgery in the Trendelenburg position.

Methods Multiple databases were searched for randomized controlled trials published before December 2024 to compare the effects of PCV, PCV-VG, and VCV in patients in the Trendelenburg position who underwent laparoscopic surgery. The primary outcomes included peak airway pressure (Ppeak), plateau airway pressure (Pplat), dynamic compliance (Cdyn), and blood gas analysis.

Results Sixteen studies were included in this meta-analysis. PCV [Ppeak, 15–40-min post-pneumoperitoneum and Trendelenburg position (T2): mean difference (*MD*) − 4.28, 95% confidence interval (*CI*) − 5.91 to − 2.64, $P < 0.01$; 60-min post-pneumoperitoneum and Trendelenburg position (T3): *MD* − 4.51, 95% *CI* − 5.41 to − 3.6, $P < 0.01$; 120-min post-pneumoperitoneum and Trendelenburg position (T4): *MD* − 5.63, 95% *CI* − 7.35 to − 3.91, $P < 0.01$; Cydn, T2: *MD* 3.15, 1.53 to 4.77, $P = 0.0001$; T3: *MD* 2.78, 95% *CI* 1.43 to 4.14, $P < 0.01$] and PCV-VG (Ppeak, T2: *MD* − 3.99, 95% *CI* − 7.2 to − 0.78, $P = 0.01$; T3: *MD* − 3.46, 95% *CI* − 6.5 to − 0.42, $P = 0.03$; Cydn, T3: *MD* 4.44, 95% *CI* 2.23 to 6.66, $P < 0.01$; T4: *MD* 3.61, 95% *CI* 1.31 to 5.91, $P = 0.002$) significantly reduced Ppeak and improved Cydn compared with VCV after pneumoperitoneum and Trendelenburg position. PaO_2, pH, and PaO_2/FiO_2 did not differ between PCV and VCV or between PCV-VG and VCV during intraoperative surgery.

Conclusions Our meta-analysis suggests that in laparoscopic surgery in the Trendelenburg position, PCV or PCV-VG can provide a lower Ppeak and higher Cdyn throughout surgery but cannot offer better oxygenation than VCV. PCV or PCV-VG might be optimal for laparoscopic surgery in the Trendelenburg position.

Keywords Ventilation mode, Ventilation mode, Laparoscopic surgery, Meta-analysis

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Introduction

The laparoscopic approach with pneumoperitoneum and Trendelenburg positioning is widely used for abdominal or pelvic surgeries, with faster convalescence, shorter hospital stays, and higher survival rates (Kennedy et al. 2014). Pneumoperitoneum with carbon dioxide (CO_2) might result in adverse cardiopulmonary effects, including tachycardia, hypertension, and impaired pulmonary dynamic compliance, which are aggravated by the Trendelenburg position.

Volume-controlled ventilation (VCV) provides fixed minute ventilation but leads to high airway pressure during the Trendelenburg position and pneumoperitoneum. Pressure-controlled ventilation (PCV) provides constant inspiratory airway pressure by decelerating flow, but hypoventilation can occur when pulmonary compliance is impaired. Pressure-controlled ventilation volume-guaranteed (PCV-VG) is an alternative to pressure-controlled ventilation; unlike PCV, PCV-VG automatically calculates the pressure limit by comparing the Cdyn at each breath and provides a preset tidal volume with the minimum required airway pressure(Ball et al. 2015). To date, there is no consensus on the optimal mechanical ventilation mode for laparoscopic surgery in the Trendelenburg position. Thus, in this systematic review and meta-analysis, we compared the effects of PCV and PCV-VG with those of VCV on respiratory mechanics and oxygenation in laparoscopic surgery in the Trendelenburg position and attempted to determine the optimal ventilation mode.

Materials and methods

The protocol of this systematic review and meta-analysis was registered in PROSPERO (CRD42023464470). This meta-analysis was performed according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines.

Information sources and search strategy

We conducted a comprehensive search of the PubMed, Embase, Cochrane Library, and Web of Science databases for articles published in English up to December 2024. Appendix 1 provides a detailed overview of the search strategy. We also searched the Clinical Trials Registry for unpublished studies. In addition, we reviewed the references cited in the retrieved literature to identify potentially eligible trials.

Eligibility and exclusion criteria

The inclusion criteria were as follows: (1) adult patients aged 18 years or older who underwent elective laparoscopic surgery in the Trendelenburg position, (2) RCTs, and (3) PCV or PCV-VG versus VCV. The exclusion criteria were as follows: (1) body mass index (BMI) ≥ 30 kg/m^2, (2) nonelective surgery, (3) studies not published in English, (4) RCTs with missing data or from which data could not be effectively extracted, and (5) articles without full text.

Study selection and data extraction

Two researchers (C. W. and Y. Q.) independently searched and assessed titles, abstracts, and full-text articles to obtain potentially relevant articles. Disagreements were resolved through consensus, or if a consensus could not be reached, a third researcher (Y. Y. X.) provided an opinion. Two researchers (C. W. and Y. Q.) independently extracted the data via a preassigned standardized data summary sheet. Discrepancies were resolved by examination and discussion with a third reviewer (Y. Y. X.). Incomplete or missing data were requested via e-mail from the original author. We extracted the following variables: trial characteristics, demographic data, intervention and control procedures, and the primary outcomes. The outcomes were compared five times: T1 (time after anesthesia induction), T2 (15–40 min after pneumoperitoneum and the Trendelenburg position), T3 (approximately 60 min after pneumoperitoneum and the Trendelenburg position), T4 (approximately 120 min after pneumoperitoneum and the Trendelenburg position), and T5 (after CO_2 desufflation and the patient resumed the supine position). The primary outcomes were peak airway pressure (Ppeak), plateau airway pressure (Pplat), and dynamic compliance (Cdyn). The secondary outcome was blood gas analysis.

Assessment of quality

The quality of the included RCTs was assessed using the revised Cochrane risk-of -bias 2.0 tool (Sterne et al. 2019). The revised Cochrane risk-of-bias 2.0 tool includes a randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Each domain was rated as "low," "some concerns," or "high." We contacted the corresponding author of the RCT in case of uncertainty regarding these items. We used the Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) framework to assess the strength of evidence.

Statistical analysis

Statistical analysis was performed using Review Manager version 5.3 software (the Cochrane Collaboration, London, UK) and Stata 17.0 (StataCorp). The calculation of the size effect was the mean difference (MD) with a 95% confidence interval (CI) for these variables. All analyses were conducted using a random effects model due to

wide clinical and methodological variability across the trials. Meta-regression was used to investigate the potential relationships among the three ventilation modes. Subgroup analysis was performed to investigate the possible heterogeneity. The sensitivity analysis was performed when considering the presence of heterogeneity. For graphic values, WebPlotDigitizer was used to extract numerical data (Drevon et al. 2016). Medians were reported with interquartile ranges (IQRs), and values were converted to mean values and standard deviations (SDs) via the methods of Luo et al. and Wan et al. (Luo et al. 2016; Wan et al. 2014). We did not assess publication bias because fewer than 10 studies were included for each outcome.

Results

Study selection

We identified 251 articles from the database and other sources, and the full versions of 49 were retrieved after screening and detailed selection. Finally, 16 studies were included in this meta-analysis. The flow diagram of the clinical trial retrieval procedure is shown in Fig. 1.

Study characteristics

The details of the study characteristics are presented in Table 1. Among the 16 included studies, 9 (Lee et al. 2020; Assad and El sayed AA, Khalil MA. 2016; Kim et al. 2018; Li et al. 2021; Dusitkasem et al. 2016; Hirabayashi et al. 2020; Park et al. 2019; Lian et al. 2016; Oğurlu et al. 2010) compared VCV with PCV, and 8 (Deng et al. 2023; Lee et al. 2020; Assad and El sayed AA, Khalil MA. 2016; Kim et al. 2018; Li et al. 2021; Dusitkasem et al. 2016; Hirabayashi et al. 2020; Park et al. 2019) compared VCV with PCV-VG. Laparoscopic gynecologic surgery was studied in six trials (Deng et al. 2023; Dusitkasem et al. 2016; Lian et al. 2016; Oğurlu et al. 2010; Liao et al. 2016; Jeon et al. 2011), robot-assisted laparoscopic radical prostatectomy in five trials (Lee et al. 2020; Kim et al. 2018; Hirabayashi et al. 2020; Park et al. 2019; Choi et al. 2011), and other surgery procedures in five trials (Assad and El sayed AA, Khalil MA. 2016; Li et al. 2021; Choi et al. 2019; Jaju et al. 2017; Veerasamy et al. 2022), including one trial of laparoscopic colectomy, two trials of robotic pelvic surgery, and two trials of laparoscopic abdominal surgery. Characteristics of included studies were shown in Table 1.

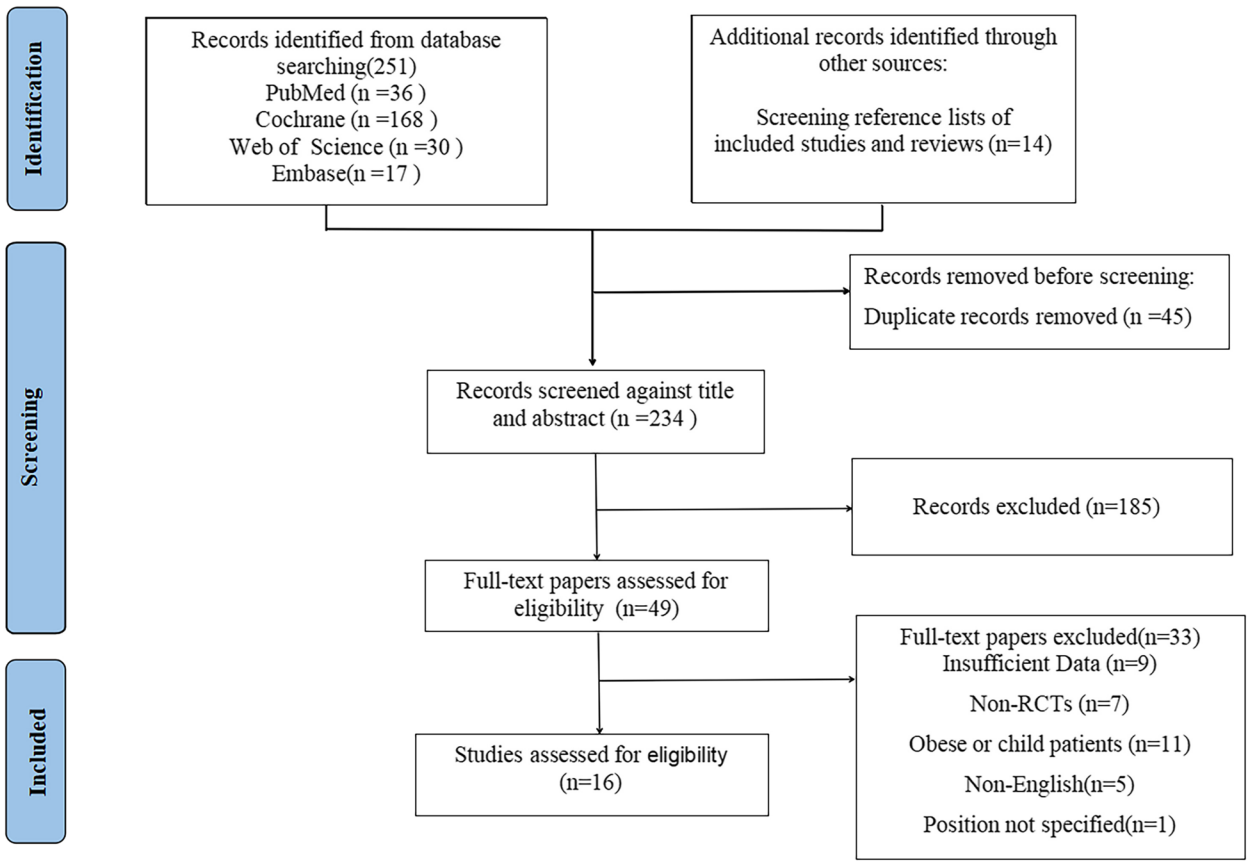

Fig. 1 The flow chart of study selection

Table 1 Characteristics of included studies

Study, year	Age	No. total		Type of surgery	Mechanical ventilation			Position	Main outcomes	Main conclusions
		PCV/PCV-VG	VCV		PCV/PCV-VG(V_T)		VCV(V_T)			
Deng et al., 2023	45–75	32	32	Gynecologic	PCV-VG	8 mL/kg	8 mL/kg	30°	①	PCV-VG offered greater Cdyn, and it can protect mucociliary clearance function
Choi et al., 2019	20–65	23	23	LSC/colectomy	PCV	8 mL/kg (IBW)	8 mL/kg (IBW)	30°	①③	PCV offered lower Ppeak than VCV
Choi et al., 2011	NA	17	17	RALP	PCV	8 mL/kg	8 mL/kg	30°	①②③	PCV offered greater Cdyn and lower Ppeak
Jaju et al., 2017	20–70	30	30	Robotic pelvic	PCV	8 mL/kg	8 mL/kg	40°	①②③	PCV offered lower Ppeak and greater Cdyn for the same levels of MV than VCV
Lee et al., 2020	20–65	20	20	RALP	PCV/PCV-VG	8 mL/kg (IBW)	8 mL/kg (IBW)	45°	①②③	PCV and PCV-VG provided lower Ppeak and improved Cdyn, without differences in arterial blood gas compared with VCV
Lian et al., 2017	20–65	13	13	LSC/HE	PCV	NA	NA	30°	②③	PCV offered a lower Ppeak compared with VCV
Oğurlu et al., 2010	20–50	30	30	LSC/gynecologic	PCV	10 mL/kg	10 mL/kg	30°	①②	PCV offered lower Ppeak, Pplat, and higher Cydn than VCV
Veerasamy et al., 2022	18–75	26	25	Robotic pelvic	PCV	7 mL/kg (PBW)	7 mL/kg (PBW)	30°	①②③	PCV reduces P_{aw} and improves Cdyn compared with VCV
Liao et al., 2016	20–70	25	27	LSC/gynecologic	PCV	8 mL/kg	8 mL/kg	15–20°	①③	PCV offered lower Ppeak and higher Cydn but no advantages in oxidative stress or quality of recovery over VCV
Jeon et al., 2011	NA	30	30	LSC/gynecologic	PCV	10 mL/kg (IBW)	10 mL/kg (IBW)	15°	①③	PCV ensures oxygenation while minimizing the increases of the Ppeak
Assad et al., 2016	18–70	20	20	LSC	PCV-VG	8 mL/kg	8 mL/kg	30°	①②③	PCV-VG was superior to VCV in its ability to provide ventilation with lower Ppeak and greater Cydn
Kim et al., 2018	20–80	39	39	RALP	PCV-VG	8 mL/kg (IBW)	8 mL/kg (IBW)	30°	①②③	PCV-VG offered lower Pmean and was an acceptable alternative to VCV
Li et al., 2022	20–70	30	30	LSC	PCV-VG	7 mL/kg (PBW)	7 mL/kg (PBW)	30°	①③	PCV-VG produced favorable lung mechanics and oxygenation compared with VCV
Dusitkasem et al., 2016	20–60	16	16	LSC/gynecologic	PCV-VG	8 mL/kg (IBW)	8 mL/kg (IBW)	NA	①②	PCV-VG provided lower Ppeak might lower the risk of lung injury compared with VCV
Hirabayashi et al., 2020	18–85	14	14	RALP	PCV-VG	8–10 mL/kg (IBW)	8–10 mL/kg (IBW)	25–30°	①②	PCV-VG reduced physiological dead space rate
Park et al., 2019	NA	38	38	RALP	PCV-VG	Vt: 8 mL/kg (IBW)	8 mL/kg (IBW)	30°	①②③	PCV-VG decreased Ppeak without hemodynamic instability, but it did not improve oxygenation

LSC Laparoscopic, *HE* Hysterectomy, *RALP* Robot-assisted laparoscopic radical prostatectomy, *NA* Not available, *IBM* Ideal body weight, *PBM* Predicted body weight, V_T, tidal volume; *Ppeak*, peak airway pressure, *Pplat* Plateau airway pressure, *Cdyn* Dynamic compliance. ①Respiratory variables. ②Hemodynamic variables. ③Arterial blood gas analysis

Risk-of-bias summary

The risk of bias in the included studies is shown in Fig. 2. From the Cochrane risk-of-bias assessment, 5 RCTs (Deng et al. 2023; Park et al. 2019; Jeon et al. 2011; Choi et al. 2019; Veerasamy et al. 2022) were classified as having a low risk, 10 RCTs (Lee et al. 2020; Assad et al. 2016; Kim et al. 2018; Li et al. 2021; Dusitkasem et al. 2016; Lian et al. 2016; Oğurlu et al. 2010; Liao et al. 2016; Choi et al. 2011; Jaju et al. 2017) were classified as having some concerns, and 1 study(Hirabayashi et al. 2020) was classified as having a high risk. Figure 3 summarizes the risk-of-bias assessment in the five domains of each study.

Intraoperative Ppeak

Thirteen trials (Lee et al. 2020; Assad et al. 2016; Kim et al. 2018; Li et al. 2021; Dusitkasem et al. 2016; Park et al. 2019; Lian et al. 2016; Oğurlu et al. 2010; Liao et al. 2016; Jeon et al. 2011; Choi et al. 2011, 2019; Veerasamy et al. 2022) reported the intraoperative Ppeak. Compared with the VCV group, the PCV group (*MD*: −0.71, 95% *CI*, −1.47 to 0.04, $P = 0.06$, $I^2 = 65\%$) or PCV-VG group (*MD*: −0.37, 95% *CI*, −0.97 to 0.23, $P = 0.23$, $I^2 = 52\%$) revealed no significant difference in the intraoperative Ppeak at T1. Compared with the VCV group, the PCV group (T2: *MD* − 4.28, 95% *CI*, −5.91 to −2.64, $P < 0.01$, $I^2 = 75\%$; T3: *MD* − 4.51, 95% *CI* − 5.41 to −3.6, $P < 0.01$, $I^2 = 0\%$; T4: *MD* − 5.63, 95% *CI* − 7.35 to −3.39, $P < 0.01$, $I^2 = 28\%$; T5: *MD* − 1.44, 95% *CI* − 2.52 to −0.36, $P = 0.009$, $I^2 = 73\%$) and PCV-VG group (T2: *MD* − 3.99, 95% *CI* − 7.2 to −0.78, $P = 0.01$, $I^2 = 91\%$; T3: *MD* − 3.46, 95% *CI* − 6.5 to −0.42, $P = 0.03$, $I^2 = 94\%$) presented significantly lower intraoperative Ppeak values. Furthermore, the PCV-VG group revealed no significant difference in the intraoperative Ppeak compared with the VCV group at T5 (*MD* − 0.57, 95% *CI* − 1.89 to 0.75, $P = 0.4$, $I^2 = 82\%$). The results were shown in Tables 2 and 3. Subgroup analysis showed no effect of the type of surgery on meta-analysis results. The results of the subgroup analysis were shown in Appendix 3. The meta-regression results did not differ significantly. The meta-regression was shown in Appendix 4. The sensitivity analysis confirmed that the results remained unchanged when any study was omitted at each time point. The sensitivity analysis was shown in Appendix 5.

Intraoperative Pplat

Six trials (Kim et al. 2018; Hirabayashi et al. 2020; Park et al. 2019; Lian et al. 2016; Oğurlu et al. 2010; Choi et al. 2019) were reported on Pplat. There were no between-group differences in Pplat between the PCV group and the VCV group at T1 (*MD* − 0.16, 95% *CI* − 0.69 to 0.38, $P = 0.57$, $I^2 = 0\%$), T2 (*MD* − 3.05, 95% *CI* − 6.4 to 0.3, $P = 0.07$, $I^2 = 89\%$), or T5 (*MD* − 1.31, 95% *CI* − 2.99 to 0.37, $P = 0.13$, $I^2 = 76\%$) or between the PCV-VG group and the VCV group (T1: *MD* 0.28, 95% *CI* − 0.29 to 0.86, $P = 0.34$, $I^2 = 0\%$; T2: *MD* − 0.85, 95% *CI* − 4.48 to 2.77, $P = 0.64$, $I^2 = 89\%$; T3: *MD* − 0.63, 95% *CI* − 2.25 to 0.98, $P = 0.44$, $I^2 = 20\%$; T4: *MD* − 0.36, 95%

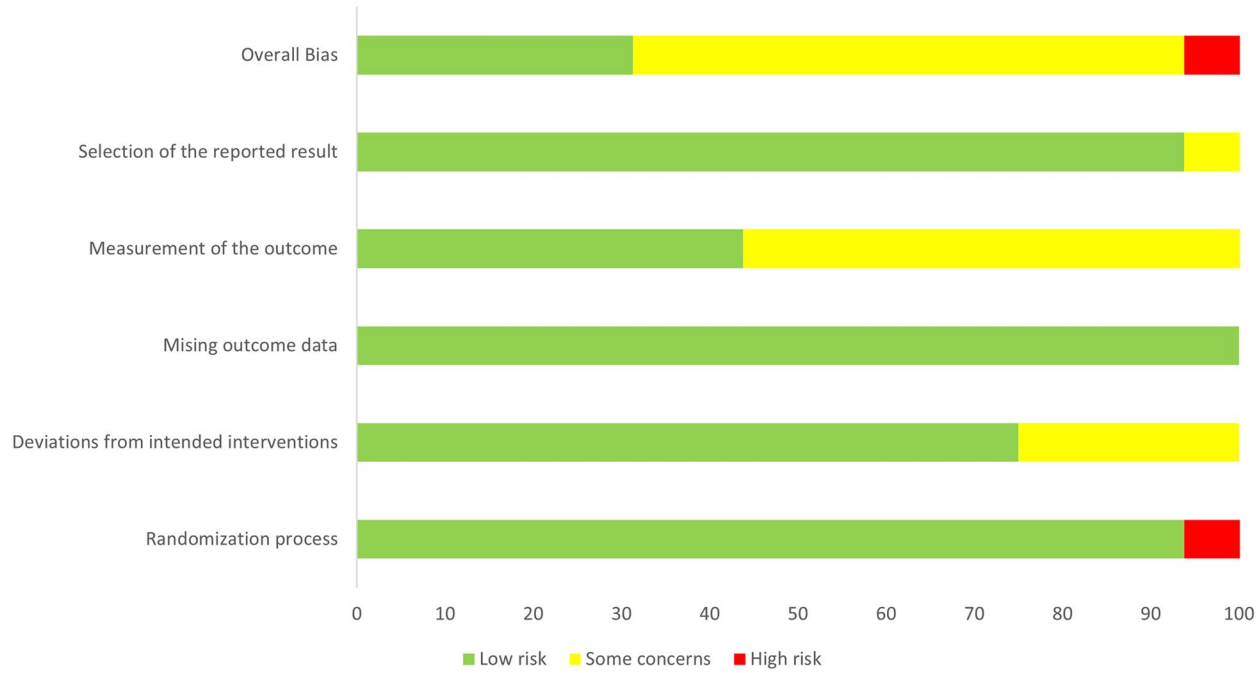

Fig. 2 Risk-of-bias assessment using the Cochrane risk-of-bias 2.0 tool

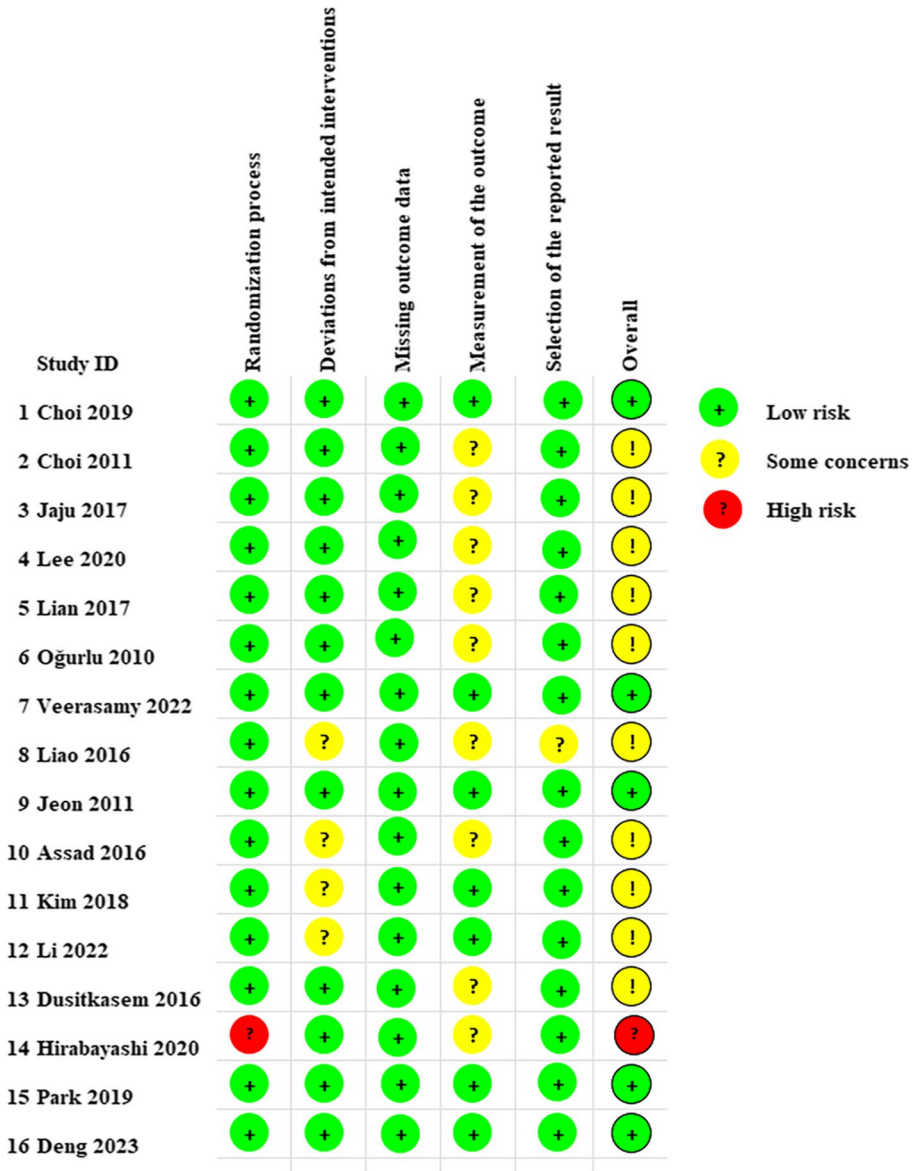

Fig. 3 Risk-of-bias assessments in the five domains of each study

CI − 1.71 to 1, *P* = 0.6, I^2 = 0%; T5: *MD* 0.16, 95% *CI* − 0.65 to 0.97, *P* = 0.7, I^2 = 0%). The results were shown in Tables 2 and 3. Subgroup analysis showed no effect of the type of surgery on meta-analysis results. The results of the subgroup analysis were shown in Appendix 3. The results of the meta-regression between PCV and VCV and between PCV-VG and VCV were not significant. The meta-regression was shown in Appendix 4. The results of the sensitivity analysis revealed that the Pplat values of the two ventilation modes were robust. The sensitivity analysis was shown in Appendix 5.

Intraoperative Cdyn

Fourteen trials (Deng et al. 2023; Lee et al. 2020; Assad et al. 2016; Li et al. 2021; Dusitkasem et al. 2016; Hirabayashi et al. 2020; Lian et al. 2016; Oğurlu et al. 2010; Liao et al. 2016; Jeon et al. 2011; Choi et al. 2011, 2019; Jaju et al. 2017; Veerasamy et al. 2022) reported Cdyn. Compared with the VCV group, the PCV group (*MD* 1.03, 95% *CI* − 0.85 to 2.92, *P* = 0.28, I^2 = 54%) or PCV-VG group (*MD* 1.12, 95% *CI* − 0.97 to 3.2, *P* = 0.29, I^2 = 60%) revealed no significant difference in intraoperative Cdyn at T1. Greater Cdyn values were detected in the PCV group (T2: *MD* 3.15, 95% *CI* 1.53 to 4.77, *P* =

Table 2 The comparison outcomes and quality of the evidence of PCV and VCV

Variable	No. total	Mean difference [95% *CI*] PCV versus VCV	I^2 (%)	*P*	Quality of the evidence
Ppeak					
T_1	369	− 0.71 [− 1.47, 0.04]	65	0.06	⊕◯◯◯Very low[a,b,c]
T_2	232	− 4.28 [− 5.91, − 2.64]	75	< 0.01	⊕◯◯◯Very low[a,b,d]
T_3	152	− 4.51 [− 5.41, − 3.6]	0	< 0.01	⊕⊕◯◯Low[a,c]
T_4	111	− 5.63 [− 7.35, − 3.91]	28	< 0.01	⊕⊕⊕◯Moderate[c]
T_5	257	− 1.44 [− 2.52, − 0.36]	73	0.009	⊕⊕◯◯Low[a,c]
Pplat					
T_1	132	− 0.16 [− 0.69, 0.38]	0	0.57	⊕⊕◯◯Low[a,c]
T_2	132	− 3.05 [− 6.4, 0.3]	89	0.07	⊕◯◯◯Very low[a,b,c]
T_5	132	− 1.31 [− 2.99, 0.37]	76	0.13	⊕◯◯◯Very low[a,b,c]
Cydn					
T_1	429	1.03 [− 0.85, 2.92]	54	0.28	⊕⊕◯◯Low[a,c]
T_2	232	3.15 [1.53, 4.77]	55	0.0001	⊕⊕◯◯Low[a,c]
T_3	212	2.78 [1.43, 4.14]	60	< 0.01	⊕◯◯◯Very low[a,b,c]
T_4	171	1.32 [− 1.13, 3.77]	79	0.29	⊕◯◯◯Very low[b,c]
T_5	317	2.89 [0.85, 4.93]	64	0.006	⊕⊕◯◯Low[b,c]
PaO_2					
T_1	272	− 5.66 [− 16.9, 5.58]	0	0.32	⊕◯◯◯Very low[a,c]
T_2	100	− 6.39 [− 28.54, 15.76]	26	0.57	⊕◯◯◯Very low[a,c]
T_3	152	− 4.33 [− 17.19, 8.52]	0	0.51	⊕◯◯◯Very low[a,c]
T_4	60	12.76 [− 10.42, 35.94]	0	0.28	⊕⊕◯◯Low[c]
T_5	160	1.87 [− 12.54, 16.28]	2	0.8	⊕◯◯◯Very low[a,c]
$PaCO_2$					
T_1	289	− 0.57 [− 1.27, 0.12]	25	0.11	⊕◯◯◯Low[a,c]
T_2	100	− 0.68 [− 1.42, 0.05]	0	0.07	⊕◯◯◯Very low[a,c]
T_3	118	0.43 [− 0.41, 1.27]	0	0.32	⊕◯◯◯Very low[a,c]
T_4	77	− 2.39 [− 4.28, − 0.5]	45	0.01	⊕⊕⊕◯Moderate[c]
T_5	177	− 0.16 [− 2.92, 2.61]	86	0.91	⊕◯◯◯Very low[a,b,c]
PaO_2/FiO_2					
T_1	369	− 8.37 [− 23.35, 6.6]	0	0.27	⊕⊕◯◯Low[c]
T_2	146	12.55 [− 48.1, 73.2]	66	0.69	⊕⊕◯◯Low[c]
T_3	152	− 4.29 [− 26.2, 17.63]	0	0.7	⊕⊕◯◯Low[c]
T_4	111	0.51 [− 27.19, 28.21]	38	0.97	⊕⊕◯◯Low[c]
T_5	257	0.17 [− 18.1, 18.43]	4	0.99	⊕⊕◯◯Low[c]

PCV Pressure-controlled ventilation, *VCV* Volume-controlled ventilation, *T1* After anesthesia induction under the supine position; *T2*, 15–40-min post-pneumoperitoneum and Trendelenburg position; *T3*, 60-min post-pneumoperitoneum and Trendelenburg position; *T4*, 120-min post-pneumoperitoneum and Trendelenburg position; *T5*, after CO_2 desufflation and resuming the supine position. [a]Failure to conceal allocation or failure to blind. [b]Rated down because of high heterogeneity. [c]Rated down because of imprecision. [d]Rated down because of publication bias

0.0001, $I^2 = 55\%$; T3: *MD* 2.78, 95% *CI* 1.43 to 4.14, $P < 0.01$, $I^2 = 60\%$; T5: *MD* 2.89, 95% *CI* 0.85 to 4.93, $P = 0.006$, $I^2 = 64\%$) and PCV-VG group (T3: *MD* 4.44, 95% *CI* 2.23 to 6.66, $P < 0.01$, $I^2 = 90\%$; T4: *MD* 3.61, 95% *CI* 1.31 to 5.91, $P = 0.002$, $I^2 = 63\%$; T5: *MD* 6.6, 95% *CI* 3.81 to 9.38, $P < 0.01$, $I^2 = 33\%$) than in the VCV group. Cydn levels did not differ between the PCV group (*MD* 1.32, 95% *CI* − 1.13 to 3.77, $P = 0.29$, $I^2 = 79\%$) at T4 and the PCV-VG group (*MD* 4.12, 95% *CI* − 0.56 to 8.79, $P = 0.08$, $I^2 = 90\%$) at T2 compared with the VCV group. The results were shown in Tables 2 and 3. Subgroup analysis showed no effect of the type of surgery on meta-analysis results. The results of the subgroup analysis were shown in Appendix 3. The results of the meta-regression analysis were not significant. The meta-regression analysis was shown in Appendix 4. The effects of the two ventilation modes on Cdyn were robust, according to the results of the sensitivity analysis. The sensitivity analysis was shown in Appendix 5.

Table 3 The comparison outcomes and quality of the evidence of PCV-VG and VCV

Variable	No. total	Mean difference 95% *CI* PCV-VG versus VCV	I^2 (%)	*P*	Quality of the evidence
Ppeak					
T_1	294	− 0.37 [− 0.97, 0.23]	52	0.23	⊕⊕◯◯Low[a]
T_2	266	− 3.99 [− 7.2, − 0.78]	91	0.01	⊕◯◯◯Very low[a,b]
T_3	292	− 3.46 [− 6.5, − 0.42]	94	0.03	⊕◯◯◯Very low[a,b]
T_5	254	− 0.57 [− 1.89, 0.75]	82	0.4	⊕◯◯◯Very low[a,b]
Pplat					
T_1	182	0.28 [− 0.29, 0.86]	0	0.34	⊕⊕◯◯Low[a]
T_2	154	− 0.85 [− 4.48, 2.77]	89	0.64	⊕◯◯◯Very low[a,b]
T_3	120	− 0.63 [− 2.25, 0.98]	20	0.44	⊕⊕◯◯Low[a]
T_4	106	− 0.36 [− 1.71, 1]	0	0.6	⊕⊕◯◯Low[a]
T_5	154	0.16 [− 0.65, 0.97]	0	0.7	⊕⊕◯◯Low[a]
Cydn					
T_1	264	1.12 [− 0.97, 3.2]	60	0.29	⊕⊕◯◯Low[a]
T_2	112	4.12 [− 0.56, 8.79]	90	0.08	⊕◯◯◯Very low[a,b,c]
T_3	236	4.44 [2.23, 6.66]	90	< 0.01	⊕◯◯◯Very low[a,b,c]
T_4	124	3.61 [1.31, 5.91]	63	0.002	⊕⊕⊕◯Moderate[a]
T_5	100	6.6 [3.81, 9.38]	33	< 0.01	⊕⊕⊕◯Moderate[a]
PaO_2					
T_1	294	0.98 [− 5.08, 7.04]	0	0.75	⊕⊕◯◯Low[a]
T_2	234	− 0.04 [− 9.11, 9.04]	34	0.99	⊕⊕◯◯Low[a]
T_3	294	11.9 [− 6.65, 30.45]	88	0.21	⊕⊕◯◯Low[a]
T_5	254	7.63 [− 13.31, 28.57]	88	0.48	⊕⊕◯◯Low[a]
$PaCO_2$					
T_1	322	0.08 [− 0.44, 0.61]	0	0.76	⊕⊕◯◯Low[a]
T_2	234	0.14 [− 0.52, 0.79]	0	0.68	⊕⊕◯◯Low[a]
T_3	260	− 0.44 [− 1.41, 0.53]	24	0.37	⊕⊕◯◯Low[a]
T_5	254	− 0.83 [− 1.74, 0.08]	0	0.07	⊕⊕◯◯Low[a]
pH					
T_1	253	0.01 [− 0.00, 0.01]	14	0.07	⊕⊕◯◯Low[a]
T_2	194	0.00 [− 0.01, 0.02]	62	0.88	⊕⊕◯◯Low[a]
T_3	219	0.01 [− 0.00, 0.01]	0	0.08	⊕⊕⊕◯Moderate[a]
T_5	214	0.01 [− 0.00, 0.02]	0	0.09	⊕⊕◯◯Low[a]
PaO_2/FiO_2					
T_1	216	1.58 [− 8.42, 11.57]	0	0.76	⊕⊕◯◯Low[a]
T_2	156	5.06 [− 14.24, 24.37]	30	0.61	⊕◯◯◯Very low[a,c]
T_3	182	18.56 [− 18.05, 55.16]	88	0.32	⊕⊕◯◯Low[a]
T_5	176	19.74 [− 11.71, 51.20]	75	0.22	⊕⊕◯◯Low[a]

PCV-VG Pressure-controlled ventilation volume guaranteed, *VCV* Volume-controlled ventilation, *T1* After anesthesia induction under the supine position, *T2* 15–40 min post pneumoperitoneum and Trendelenburg position, *T3*, 60 min post pneumoperitoneum and Trendelenburg position; *T4*, 120 min post pneumoperitoneum and Trendelenburg position; *T5*, after CO_2 desufflation and resuming the supine position. [a]Failure to conceal allocation or failure to blind. [b]Rated down because of high heterogeneity. [c]Rated down because of imprecision. [d]Rated down because of publication bias

Blood gas analysis

The arterial oxygen pressure (PaO_2) and arterial carbon dioxide pressure ($PaCO_2$) and pH were analyzed at five time points. Statistical analysis was not performed due to the limited availability of data of pH between PCV and VCV groups. The outcomes at each time point are shown in Tables 2 and 3. Among the 16 included articles, 10 (Lee et al. 2020; Park et al. 2019; Lian et al. 2016; Liao et al. 2016; Jeon et al. 2011; Choi et al. 2011; Jaju et al. 2017) reported the PaO2 concentration. Eleven trials (Lee et al. 2020; Assad et al. 2016; Li et al. 2021; Park et al. 2019; Lian et al. 2016; Liao et al. 2016; Jeon et al. 2011; Choi et al. 2011, 2019; Jaju et al. 2017; Veerasamy et al. 2022) reported the PaO_2/FiO_2 ratio. Eleven trials

(Lee et al. 2020; Assad et al. 2016; Kim et al. 2018; Li et al. 2021; Hirabayashi et al. 2020; Park et al. 2019; Lian et al. 2016; Liao et al. 2016; Jeon et al. 2011; Jaju et al. 2017; Veerasamy et al. 2022) reported the $PaCO_2$ concentration, and 4 trials (Assad et al. 2016; Kim et al. 2018; Li et al. 2021; Park et al. 2019) reported pH values. There were no significant differences between the PVC group and the VCV group or the PCV-VG group and the VCV group in terms of PaO_2, $PaCO_2$, pH values, and PaO_2/FiO_2 at these five time points, except for a lower $PaCO_2$ with an MD of −2.39 in the PCV group (95% *CI* − 4.28 to −0.5, $P = 0.01$, $I^2 = 45\%$) than in the VCV group at T4. The results were shown in Tables 2 and 3. The results of the meta-regression analysis were not significant. The meta-regression analysis was shown in Appendix 4. The results of the sensitivity analysis revealed that our findings are robust. The sensitivity analysis was shown in Appendix 5.

Discussion

This meta-analysis is the first to compare PCV or PCV-VG with VCV in terms of respiratory mechanics and blood gas analysis in laparoscopic surgery in the Trendelenburg position. Our meta-analysis suggests that PCV or PCV-VG can offer a lower Ppeak and better Cydn in laparoscopic surgery in the Trendelenburg position.

The VCV provides a fixed flow to guarantee the preset tidal volume. During laparoscopic surgery in the Trendelenburg position, high airway pressure might occur and increase the risk of ventilator-induced lung injury (VILI). Theoretically, the inspiratory flow waveform of the PCV shows a decelerating pattern, which can limit peak airway pressure and potentially improve arterial oxygenation with a better distribution of inspired gas (Prella and Domenighetti 2002). PCV has been reported to reduce the risk of ventilator-induced lung injury (Suh et al. 2010). Gupta et al. reported that PCV provided better oxygenation and lower peak airway pressure than VCV in laparoscopic cholecystectomy (Gupta et al. 2012). Choi reported that the PCV had no advantages over the VCV in terms of respiratory mechanics in the Trendelenburg position (Choi et al. 2011). Our meta-analysis revealed that the PCV could offer a significantly lower Ppeak during laparoscopic surgery in the Trendelenburg position than the VCV, even after CO_2 desufflation. This finding is consistent with the meta-analysis by Wang, in which PCV reduced Ppeak compared with VCV in laparoscopic surgery but not in the Trendelenburg position (Wang et al. 2015).

According to a study by Hirvonen et al., the Trendelenburg position leads to a 20% decrease in lung compliance, and pneumoperitoneum leads to an additional 30% decrease during laparoscopic hysterectomy (Hirvonen et al. 1995). Our meta-analysis revealed that the PCV group had better dynamic compliance than the VCV group not only during pneumoperitoneum in the Trendelenburg position but also after CO_2 desufflation. These findings indicate that PCV might reduce the risk of pulmonary barotrauma by reducing Ppeak and improving Cydn.

PCV-VG is an innovative ventilation mode that has been increasingly used recently. PCV-VG provides a preset VT with digital feedback mechanisms and automatically calculates the pressure limits. It combines the advantages of deceleration and constant pressure to ensure the target VT without increasing airway pressure. Lee and colleagues reported that the use of PCV-VG did not result in better oxygenation but did lead to a higher Cdyn than VCV during laparoscopic surgery in the Trendelenburg position (Lee et al. 2020). Given the findings of our study, we found that PCV-VG offered a significantly lower Ppeak and better Cydn than did VCV, and we believe that PCV-VG ventilation is significantly superior in reducing respiratory load during laparoscopic surgery in the Trendelenburg position. However, we did not find any evidence of PCV and PCV-VG in patients undergoing laparoscopic Trendelenburg positioning. Bao C et al. reported that PCV-VG could improve lung compliance and may be the optimal ventilation mode for infants and young children undergoing spinal cord untethering surgery (Bao et al. 2024). PCV-VG can provide adequate tidal volume and may offer advantages over the PCV mode; however, further research is needed to confirm these findings.

Similar to most previous studies (Toker et al. 2020; Nguyen and Wolfe 2005), our meta-analysis revealed no statistically significant differences in the arterial oxygen pressure or oxygenation index. We believe that the heterogeneity might result from differences in the inspired oxygen concentration, the flow rate of insufflation, and the absorption of carbon dioxide. Hence, the age of the participants ranged from 18 to 85 years, and oxygenation in those participants was unclear, which might also have affected the results. For PCV-VG and VCV, most included studies set an inspiratory: expiratory ratio of 1:2, and two studies set a 1:1 ratio, which could reduce the development of atelectasis and improve oxygenation by increasing the inspiratory time and might affect the results.

Our meta-analysis had several limitations. First, we excluded patients with respiratory disease and obesity owing to their potential effects on oxygenation and respiratory mechanics. Second, the included studies had small sample sizes, and there was high heterogeneity among the included studies. Further studies with larger sample sizes are needed to test which ventilation mode is

optimal for such surgeries. Fourth, Ppeak and lung compliance have been robustly associated with postoperative pulmonary complications. Although our meta-analysis confirmed that PCV and PCV-VG reduce Ppeak and enhance lung compliance, only a small number of studies have specifically examined postoperative pulmonary complications in laparoscopic surgeries conducted under the Trendelenburg position. Given the paucity of data, we were unable to perform a comprehensive statistical analysis in this context. Consequently, well-designed, high-quality randomized controlled trials are essential to elucidate the impact of various ventilation strategies on postoperative pulmonary complications in patients undergoing Trendelenburg laparoscopy.

Conclusion

Our meta-analysis revealed that in laparoscopic surgery in the Trendelenburg position, PCV and PCV-VG can provide lower Ppeak values and higher Cdyn values throughout surgery and cannot offer better oxygenation than can VCV. PCV-VG may be the optimal ventilation mode; however, the current level of evidence is limited, and further research is needed to confirm its advantages.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13741-025-00540-w.

Supplementary Material 1: Appendix 1. Search strategy. Appendix 2. The Forest plots: Figure 1. The Forest plots of Ppeak between PCV and VCV. Figure 2. The Forest plots of Ppeak between PCV-VG and VCV. Figure 3. The Forest plots of Cydn between PCV and VCV. Figure 4. The Forest plots of Cydn between PCV-VG and VCV. Figure 5. The Forest plots of Pplat between PCV and VCV. Figure 6. The Forest plots of Pplat between PCV-VG and VCV. Figure 7. The Forest plots of PaO_2 between PCV and VCV. Figure 8. The Forest plots of PaO_2 between PCV-VG and VCV. Figure 9. The Forest plots of $PaCO_2$ between PCV and VCV. Figure 10. The Forest plots of $PaCO_2$between PCV-VG and VCV. Figure 11. The Forest plots of pH between PCV-VG and VCV. Figure 12. The Forest plots of Oxygenation index between PCV and VCV. Figure 13. The Forest plots of Oxygenation index between PCV-VG and VCV. Appendix 3. Subgroup analysis: Figure 1. The subgroup analysis of Ppeak between PCV and VCV at T1. Figure 2. The subgroup analysis of Ppeak between PCV-VG and VCV at T1. Figure 3. The subgroup analysis of Ppeak between PCV and VCV at T2. Figure 4. The subgroup analysis of Ppeak between PCV-VG and VCV at T2. Figure 5. The subgroup analysis of Ppeak between PCV and VCV at T3. Figure 6. The subgroup analysis of Ppeak between PCV-VG and VCV at T3. Figure 7. The subgroup analysis of Ppeak between PCV and VCV at T5. Figure 8. The subgroup analysis of Ppeak between PCV-VG and VCV at T5. Figure 9. The subgroup analysis of Pplat between PCV and VCV at T1. Figure 10. The subgroup analysis of Pplat between PCV and VCV at T2. Figure 11. The subgroup analysis of Pplat between PCV and VCV at T5. Figure 12. The subgroup analysis of Cydn between PCV and VCV at T1. Figure 13. The subgroup analysis of Cydn between PCV-VG and VCV at T1. Figure 14. The Subgroup analysis of Cydn between PCV and VCV at T2. Figure 15. The subgroup analysis of Cydn between PCV and VCV at T3. Figure 16. The subgroup analysis of Cydn between PCV-VG and VCV at T3. Figure 17. The subgroup analysis of Cydn between PCV and VCV at T4. Figure 18. The subgroup analysis of Cydn between PCV-VG and VCV at T4. Figure 19. The subgroup analysis of Cydn between PCV and VCV at T1. Appendix 4. Meta-regression. Tabel 1. Meta-regression of respiratory variables and blood gas analysis between PCV vs VCV and PCV-VG vs VCV. Appendix 5. Sensitivity analysis: Figure 1. The sensitivity analysis of Ppeak at T1-2 and T5 of Pressure-controlled ventilation and Volume-controlled ventilation. Figure 2. The sensitivity analysis of Ppeak at T2-3 and T5 of Pressure-controlled ventilation volume guaranteed and Volume-controlled ventilation. Figure 3. The sensitivity analysis of Pplat at T2 and T5 of Pressure-controlled ventilation and Volume-controlled ventilation. Figure 4. The sensitivity analysis of Pplat at T2 of Pressure-controlled ventilation volume guaranteed and Volume-controlled ventilation. Figure 5. The sensitivity analysis of Cydn at T4 and T5 of Pressure-controlled ventilation and Volume-controlled ventilation. Figure 6. The sensitivity analysis of Cydn at T1-3 and T4 of Pressure-controlled ventilation volume guaranteed and Volume-controlled ventilation. Figure 7. The sensitivity analysis of PaO_2 at T3 and T5 of Pressure-controlled ventilation volume guaranteed and Volume-controlled ventilation. Figure 8. The sensitivity analysis of PCO_2 at T5 of Pressure-controlled ventilation and Volume-controlled ventilation. Figure 9. The sensitivity analysis of Oxygenation index at T2 of Pressure-controlled ventilation and Volume-controlled ventilation. Figure 10. The sensitivity analysis of Oxygenation index at T3 and T5 of Pressure-controlled ventilation volume guaranteed and Volume-controlled ventilation. Figure 11. The sensitivity analysis of pH at T2 of Pressure-controlled ventilation volume guaranteed and Volume-controlled ventilation

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Authors'contributions
Cui Wen and Yi Qi participated in selecting the study and extracting data; Yingying Xiang and Qianyun Pang performed the statistical analysis and drafting of the manuscript; Ran An and Jingyu Xiao participated in conceptualization, formal analysis, and drafting of the manuscript. All authors read and approved the final manuscript.

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