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REVIEW

Intraoperative Ventilatory Strategies in Patients Undergoing Video-Assisted Thoracic Surgery: A Narrative Review

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ABSTRACT

Video-assisted thoracic surgery (VATS) and robotic-assisted thoracic surgery (RATS) are commonly used in thoracic surgery, yet postoperative complications still occur in up to 10% of the patients. The aim of our narrative review was to summarize the best available evidence on mechanical ventilation settings, particularly with regard positive end-expiratory pressure (PEEP) selection, tidal volume (VT) and ventilation mode, as well as the feasibility of two-lung ventilation in patients undergoing thoracic surgery using VATS or RATS techniques. We searched the MEDLINE/PubMed database using the terms "VATS" or "RATS" and "ventilation" between 1 January 2007 and 1 February 2025. Publications were screened by title or abstract. We discussed studies according to their methodological quality, ventilation mode, as well as the feasibility of two-lung ventilation in patients undergoing thoracic surgery using VATS or RATS techniques. In patients receiving one-lung ventilation (OLV), the application of a protective lung ventilation using an intermediate VT ranged between 5 and 8 ml (mL) of predicted body weight (PBW) and a PEEP of 5–8 cmH_2O was not found to be associated with a lower incidence of postoperative pulmonary complications and improved hospital outcomes. Titrating PEEP based on mechanical properties appears to enhance perioperative oxygenation and ventilatory mechanics and to reduce postoperative pneumonia. However, no conclusions can be drawn regarding ventilation modes, because only few studies have compared the same low VT using different pressure versus volume control modes. The feasibility of two-lung ventilation during specific thoracic surgery procedures has recently been positively evaluated, with

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no differences in postoperative complications found. The level of evidence for the ventilatory settings in patients undergoing VATS or RATS remains low. In conclusion, large randomized controlled trials (RCTs) are needed to determine whether certain intraoperative ventilatory strategies can reduce postoperative pulmonary complications (PPCs) in patients.

Keywords: One lung ventilation; Video-assisted thoracic surgery; Robotic-assisted thoracic surgery; Ventilation control modes; Protective ventilation

Key Summary Points

Protective ventilation strategy vs conventional ventilation during one lung ventilation (OLV): The effect of a protective lung strategy involving intermediate tidal volume (5–8 mL/kg PBW), PEEP of 5–8 cmH_2O, and recruitment maneuvers may improve perioperative oxygenation and mechanics, but the effects on postoperative pulmonary complications (PPCs) remain uncertain; large randomized controlled trials (RCTs) are required.
Positive end-expiratory pressure (PEEP) titration during OLV: A PEEP level around 8 cmH_2O is often optimal; titration based on driving pressure can improve oxygenation and mechanics and may reduce PPCs.
Ventilation mode: No mode is preferred; pressure controlled ventilation (PCV) may reduce the release of inflammatory mediators, suggesting a potential reduction in the risk of postoperative lung injury.
Oxygenation of the non-dependent lung: Recommended in principle, but the optimal technique remains undefined; possible methods include continuous positive airway pressure (CPAP), low respiratory rate, or high-frequency positive-pressure ventilation.
Role of total lung ventilation: It may be preferred for bleb resection, minimally invasive esophagectomy, or some cases of myasthenia gravis; its feasibility is supported, but there is no consistent benefit on clinical outcomes.

INTRODUCTION

A few decades ago, "open thoracotomy" was the preferred method of performing thoracic surgery, whereas nowadays video-assisted thoracic surgery (VATS) and robotic-assisted thoracic surgery (RATS) are used for the vast majority of procedures. Indeed, VATS and RATS are the most common surgical procedures for non-small cell lung cancer [1, 2]. Postoperative complications have been reported in up to 10% of the patients with a mortality rate of less than 1% [1]. To achieve ideal surgical exposure, it is necessary to ventilate the dependent lung avoiding ventilating the non-dependent lung (i.e., collapsing it). One-lung ventilation (OLV) remains the standard of care, but is still associated with well-known challenges, such as perioperative hypoxemia and ventilator-induced lung injury (VILI), as well as issues with airway management. These are all factors that are believed to contribute to postoperative pulmonary complications (PPCs). The incidence of PPCs in patients undergoing thoracic surgery is approximately 13–20% [3, 4].

This review aims to determine whether specific intraoperative ventilatory strategies, such as lung-protective ventilation (intervention) compared to conventional ventilation during OLV (comparison), or two-lung ventilation (intervention) compared with OLV (comparison), can improve intraoperative ventilatory parameters and reduce postoperative pulmonary complications (outcome) in patients undergoing VATS or RATS (population).

This article is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors.

SEARCH STRATEGY

We searched the MEDLINE/PubMed and Web of Science databases using the terms "VATS" or "RATS" alongside "ventilation" covering the period from 1 January 2007 to 1 February 2025. The initial search yielded 1442 publications. These publications were screened by title and by abstract, and 184 articles were identified as being potentially eligible by IF and BP. Exclusion criteria included publications in languages other than English, case reports, reviews, meta-analyses, non-human studies, studies on pediatric populations, and book chapters. All potentially eligible articles focusing on thoracic surgery and VATS or RATS procedures were retrieved in full and reviewed. The references of each article were reviewed to identify additional potentially eligible studies among randomized controlled trials (RCTs), prospective studies, and retrospective studies. We organized our review into thematic sections that were considered clinically relevant, using subheadings to divide content into more readable sections. Then, two authors selected the papers for each section on the basis of the methodological quality (RCTs first, then prospective comparative studies) and their own perspective. Discrepancies were resolved by consensus amongst the three reviewers (SC, IF, BP) with 34 articles being included in the final review. Furthermore, we evaluated each selected study using the GRADE approach [5] (Fig. 1).

PROTECTIVE VENTILATION STRATEGY

In the operating room, OLV is associated with a ventilation/perfusion mismatch and a reduction in end-expiratory lung gas volume. This can lead to hypoxemia and VILI [6]. Ideally, the ventilation strategy should maintain adequate gas exchange, minimize atelectasis, and prevent overdistention of the dependent lung. This can be achieved by setting adequate positive end-expiratory pressure (PEEP) levels and using a low tidal volume (VT). This is classically defined as a lung-protective ventilation strategy (PVS) [6, 7]. See Table 1.

The strongest evidence of the potential benefits of PVS comes from patients with acute respiratory distress syndrome (ARDS). However, little evidence supports the use of PVS in thoracic surgery [8, 9]. See Table 2.

Yang et al. [10] showed that in 100 patients undergoing elective lobectomy, PVS with low VT (pressure-controlled ventilation (PCV) adjusted to achieve a VT of 6 mLmL/kg, PEEP 5 cmH_2O, and fraction of inspired oxygen (FiO_2) 0.5) was associated with a lower incidence of PPCs (4% vs 22%) than the conventional strategy of high tidal volume (volume-controlled ventilation (VCV) with VT of 10 mL/kg, no PEEP, and FiO_2 of 1). However, Amar et al. found no difference in the incidence of postoperative complications in patients ventilated with high or low VT in a propensity score-matched analysis comparing two groups of 172 patients undergoing lung surgery [11].

Kim et al. [12] randomized 60 patients undergoing wedge resection by VATS to conventional ventilation (VT 10 mL/kg), PVS (VT 6 mL/kg with PEEP 5 cmH_2O) and PVS associated with recruitment maneuvers (RM) 10 min after the onset of OLV. They found that in the bronchoalveolar lavage (BAL) fluid from the dependent lung, TNFα concentrations (i.e., a proinflammatory cytokine) were lower in the PVS with RM group, while interleukin (IL)–10 concentrations (an anti-inflammatory cytokine) were significantly higher in the conventional ventilation group. Conversely, Ahn et al. [13] found no difference in the inflammatory response between groups when comparing a conventional strategy (VT 10 mL/kg, FiO_2 1.0, and no PEEP) with a PVS (VT 6 mL/kg, FiO_2 0.5, and PEEP 5 cmH_2O) during OLV [13]. However, in a subgroup of patients with coronary heart disease, PVS significantly reduced the inflammatory response in the lungs [14].

Further reduction of VT to 4 mL/kg compared to 6 and 8 mL/kg with 5 cmH_2O of PEEP during OLV resulted in a significantly lower extravascular lung water content [15], with a similar incidence of PPCs and hospital outcomes among the groups. Within the PVS

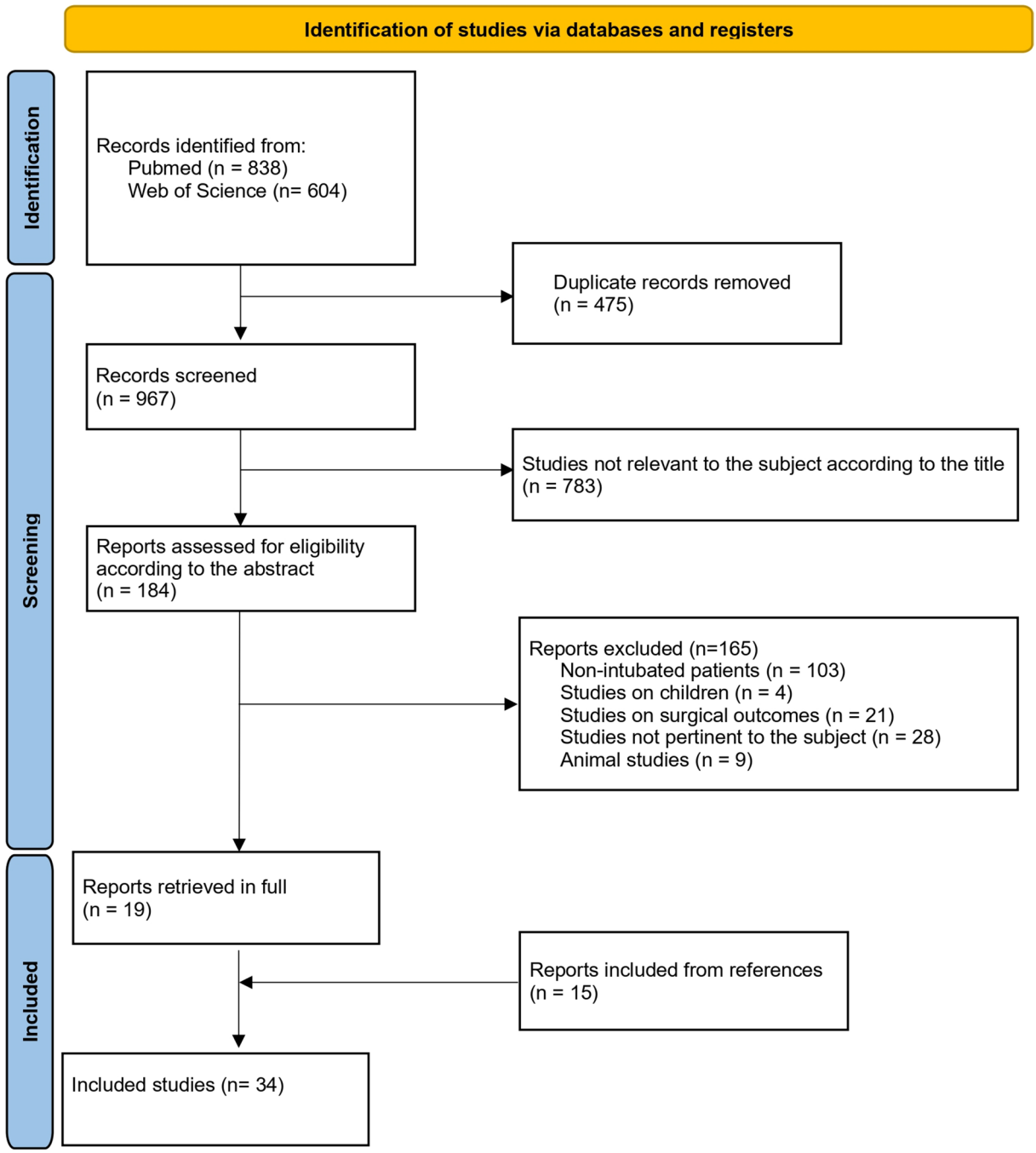


Fig. 1 Overview of the search strategy and screening process for study inclusion

strategy, the effect of a RM prior to OLV in the supine position was investigated by comparing three ventilation strategies: VT at 8 mL/kg; VT at 8 mL/kg with PEEP at 8 cmH_2O; and RM applied immediately before OLV followed by a PEEP at 8 cmH_2O [16]. The PVS, including RM application, was associated with a significantly higher arterial oxygenation and dynamic compliance as well as a lower dead space fraction at the end of the surgery. In

Table 1 Summary of the definition of protective vs conventional ventilation from the cited studies

Protective ventilation strategy	Conventional ventilation
Tidal volume 5–8 mL/kg predicted body weight and PEEP at least of 5 cmH_2O with or without recruitment maneuver FiO_2 titrated from 100% to minimum 50% to obtain saturation of peripheral oxygen > 95%	Tidal volume 10 mL/kg, zero end-expiratory pressure, FiO_2 100%

Amar et al. [11] define a protective lung strategy as the application of VT 8 mL/kg and a non-protective lung strategy as ≥ 8 mL/kg. There were no differences in PEEP selection between groups because this was an observational study so the ventilator parameters were chosen at the discretion of clinicians

FiO_2 inspired fraction of oxygen, *PEEP* positive end-expiratory pressure, *VT* tidal volume

contrast, a recent multicenter RCT, comparing two strategies (lower VT 4 mL/kg PBW, with PEEP at 5 cmH_2O and RMs vs higher VT 6 mL/kg PBW with no PEEP and no RM) in patients undergoing elective thoracoscopic or open lung major resection, did not find any differences in terms of postoperative complications (28.5% vs 30.8%), hospital length of stay, or mortality [17]. A larger retrospective study found no correlation between a PVS with VT at 5 mL/kg and at least PEEP at 5 cmH_2O during OLV and the incidence of PPCs (11–15%) [18].

The application of PVS compared to a conventional ventilation during OLV seems to be non-beneficial in terms of:

- Reducing the incidence of PPCs with low-moderate certainty of evidence from randomized and observational studies
- Reducing the inflammatory response after OLV in terms of reduced alveolar levels of TNFα and serum levels of IL-10 and C-reactive protein with moderate certainty of evidence from randomized studies
- Improving oxygenation and compliance during and after OLV albeit with moderate certainty of evidence from a single-center small randomized study

We suggest applying a PVS versus a conventional ventilation strategy during OLV despite the beneficial effect on clinical outcome having not been demonstrated.

PEEP Selection

The optimal level of PEEP during OLV remains controversial (Table 3). Excessive PEEP levels increase pulmonary vascular resistance, decrease venous blood return, lead to a disproportionate alveolar expansion, and increase shunt, thereby decreasing oxygenation. They also increase the driving pressure (i.e., plateau pressure minus PEEP) resulting in mechanical and biological lung injury, which can increase PPCs. Conversely, low PEEP levels can have detrimental effects, including decreased oxygenation, and increased shunting, as well as reduced opening and closing effects [19].

Yao et al. randomized 50 patients undergoing VATS lobectomy into two groups [20]: the "optimal oxygenation titration group" in which PEEP was increased by 1 cmH_2O from 3 cmH_2O every 4 min during OLV until maximal arterial oxygenation was achieved; and the "optimal compliance titration group" in which PEEP was increased by 1 cmH_2O every 4 min during OLV until the best lung compliance was achieved. Four minutes after the onset of OLV, the patients in the "optimal compliance titration group" had significantly lower PEEP levels than those in the "optimal oxygenation titration group" (7.68 ± 1.28 cmH_2O vs 11.24 ± 1.71 cmH_2O). Additionally, driving pressure and peak values were lower in the optimal compliance titration group, while dynamic lung compliance was higher with no adverse effects on hemodynamics. The authors

Table 2 Summary of clinical studies assessing the effects of protective lung ventilation strategies in thoracic surgery, including study design, patient population, primary outcomes, main results, and certainty of evidence according to GRADE 3.0

Author and study design	Patients (*n*)	Aim	Main results	GRADE 3.0 certainty of evidence
Protective lung strategy				
Yang et al. [10] Single-center prospective randomized controlled study	100	To compare conventional VCV strategy (VT 10 mL/kg, ZEEP, FiO_2 100%) vs PVS (VT 6 mL/kg, PEEP 5 cmH_2O, FiO_2 50%) in terms on oxygenation 72 h after surgery and on SpO_2, $PaCO_2$, and peak inspiratory pressure during OLV for elective lobectomy	PVS group needed elevated FiO_2 to maintain a $SpO_2 > 95\%$ with lower peak pressure during OLV and showed lower incidence of pulmonary dysfunction in terms of hypoxemia and lung infiltrations after surgery In the PVS group, the incidence PPCs was significantly lower than in the VCV group (incidence of PaO_2/FiO_2 ratio < 300 mmHg, lung infiltration, or atelectasis: 4% vs 22%)	Moderate
Amar et al. [11] Single center, prospective, observational study	1080	To evaluate the effect of protective lung ventilation (VT < 8 mL/kg of PBW) during OLV compared to non-protective ventilation (VT ≥ 8 mL/kg) in terms of PPCs (pneumonia and/or ARDS) in patients undergoing pulmonary resection	No significant reduction in pneumonia or ARDS, with PLV (VT < 8 mL/kg) during OLV in thoracic surgery. Under conditions of fluid restriction and controlled peak airway pressures, the additional benefit of PLV appears small in this setting	Low
Kim et al. [12] Single-center prospective randomized controlled study	60	To evaluate the effect of RM 10 min after the start of OLV in a PVS (6 mL/kg in OLV with PEEP 5 cmH_2O) compared to traditional ventilation (VT 10 mL/kg) and protective ventilation alone (6 mL/kg in OLV with PEEP 5 cmH_2O) in terms of BAL's cytokines concentration	After OLV in the dependent lung TNFα in the BAL was lower in protective ventilation with RM group. IL-10 serum levels were significantly higher in the traditional ventilation compared to protective ventilation with RM group	Moderate

Table 2 continued

Author and study design	Patients (*n*)	Aim	Main results	GRADE 3.0 certainty of evidence
Ahn et al. [13] Single-center prospective comparative study	62	To compare conventional OLV (VT 10 mL/kg, FiO_2 1.0, ZEEP) to protective OLV (VT 6 mL/kg, FiO_2 0.5, PEEP 5 cmH_2O) in terms of oxygenation, respiratory mechanics, plasma IL-6 and malondialdehyde levels before during and after OLV in patients undergoing VATs	IL-6 and malondialdehyde increased over time in both groups without statistical differences between groups. Oxygenation and respiratory mechanics did not show differences. The protective OLV did not provide advantages over conventional OLV	Low
Liu et al. [14] Single-center prospective randomized controlled study	60	To compare conventional ventilation group (VT 10 mL/kg and ZEEP) vs protective ventilation group (VT 6 mL/kg and 6 cmH_2O PEEP) during and after OLV in coronary heart disease patients undergoing VATs for lung resection on plasma cytokines concentration, respiratory mechanics and oxygenation	Protective ventilation group showed a reduction in airway pressure, an improvement in dynamic compliance and oxygenation, and reduced concentrations of and C-reactive protein during lung resection	Moderate
Qutub et al. [15] Single-center prospective randomized double-blinded controlled study	39	To investigate the effect of different VT on the dependent lung (4 mL/kg vs 6 mL/kg vs 8 mL/kg) on EVLWI during OLV for VATs. Secondary outcomes included hemodynamics, oxygenation indices, incidences of postoperative acute lung injury, atelectasis, pneumonia, morbidity and 30-day mortality	Use of VT 4 mL/kg during OLV resulted in lower EVLW, although no patient developed acute lung injury. No difference was found among the three groups in terms of need for intraoperative CPAP, hypoxemia during OLV, postoperative atelectasis, length of hospital stays, postoperative pneumonia, morbidity, and 30-day mortality	Moderate

Table 2 continued

Author and study design	Patients (*n*)	Aim	Main results	GRADE 3.0 certainty of evidence
Choi et al. [16] Single-center prospective randomized controlled study	99	To investigate the effects of three strategies: VT at 8 mL/kg, vs VT at 8 mL/kg with PEEP at 8 cmH_2O vs RM applied immediately before OLV followed by a PEEP at 8 cmH_2O before, during and after OLV	RM group showed better oxygenation and dead space after OLV, compliance was better in PEEP and RM groups compared with control group during and after OLV without differences in hemodynamic variables	Moderate
Piccioni et al. [17] Multicenter, randomized, single-blind, controlled trial	880	To compare two OLV strategies: low VT 4 mL/kg with PEEP 5 cmH_2O and alveolar RVs, vs high VT 6 mL/kg with ZEEP on PPCs in patients undergoing lobectomy or pneumonectomy	Both OLV strategies—one with lower tidal volume, PEEP 5 cmH_2O, and ARMs and the other with higher tidal volume—led to similar incidence in PPCs, hospital stay, or mortality (28.5% lower vs 30.8% higher)	Moderate
Colquhoun et al. [18] Multicenter, retrospective, observational study	3232	To investigate the correlation between a protective ventilation VT 5 mL/kg with at least PEEP 5 cmH_2O and PPCs	There is no independent link between a low VT lung-protective ventilation strategy and the overall incidence of PPCs (11–15%)	Moderate

ARDS acute respiratory distress syndrome, *ARM* alveolar recruitment maneuver, *BAL* bronchoalveolar lavage, *CPAP* continuous positive airway pressure, *EVLWI* extravascular lung water content index, FiO_2 inspired fraction of oxygen, *IL* interleukin, *OLV* one lung ventilation, $PaCO_2$ partial pressure of carbon dioxide in arterial blood, *PBW* predicted body weight, *PEEP* positive end-expiratory pressure, *PPC* postoperative pulmonary complication, *PLV* protective lung ventilation, *PVS* protective ventilation strategy, *RM* recruitment maneuver, SpO_2 peripheral oxygen saturation, *TNFα* tumor necrosis factor alpha, *VATs* video-assisted thoracic surgeries, *VCV* volume controlled ventilation, *VT* tidal volume, *ZEEP* zero end-expiratory pressure

Table 3 Summary of clinical studies assessing the PEEP selection during video-assisted thoracic, including study design, patient population, primary outcomes, main results, and certainty of evidence according to GRADE 3.0

Author and study design	Patients (*n*)	Aim	Main results	GRADE 3.0 certainty of evidence
PEEP selection				
Yao et al. [20] Single-center prospective RCT	50	To compare two PEEP titration strategies according to the best oxygenation vs the best compliance in an elderly population undergoing lobectomy	Best compliance-guided PEEP titration strategy resulted in lower PEEP level than that identified by the best oxygenation titration strategy. This resulted in enhanced lung function, lower peak pressures, and higher lung compliance without affecting MAP or HR	Low for clinical outcomes Moderate for physiological outcomes
Zhang et al. [21] Single-center prospective RCT	58	To investigate the optimal PEEP titration strategy (decremental PEEP trial by starting PEEP 15 cmH_2O until the maximum compliance vs standard PEEP 5 cmH_2O) during OLV in terms of oxygenation and respiratory mechanics in patients undergoing VATS lobectomy	Optimal PEEP obtained by PEEP decremental titration based on lung compliance resulted in increased compliance, reduced driving pressure, and higher oxygenation with little effect on hemodynamics	Low for clinical outcomes Moderate for physiological outcomes
Spadaro et al. [22] Single-center prospective RCT	60	To compare the effects of two PEEP titration strategies (stepwise increase or decrease in a range of 0–16 cmH_2O) in terms of respiratory mechanics, ventilation/perfusion mismatch, and gas exchange	Both strategies were equally able to reduce intraoperative shunt but the decremental strategy significantly decreased intraoperative driving pressure and PaO_2/FiO_2 ratio after surgery compared to the incremental strategy	Low for clinical outcomes Moderate for physiological outcomes

Table 3 continued

Author and study design	Patients (*n*)	Aim	Main results	GRADE 3.0 certainty of evidence
Kim et al. [23] Single-center prospective RCT	52	To investigate the effect of two levels of PEEP (zero and 6 cmH_2O) on intraocular pressure in patients undergoing OLV for VATS	Application of 6 cmH_2O of PEEP during OLV did not increase intraocular pressure nor decrease ocular perfusion pressure significantly, but enhanced oxygenation and dynamic compliance	Low for clinical outcomes Moderate for physiological outcomes
Park et al. [24] Single-center prospective RCT	292	To compare two protective ventilation strategies: protective ventilation group VT at 6 mL/kg of ideal body weight, PEEP at 5 cmH_2O and RM vs driving pressure group VT at 6 mL/kg of ideal body weight, RM, and individually titrated PEEP to achieve the lowest driving pressure during OLV in terms of reducing PPCs	Driving pressure-guided ventilation during OLV was associated to a reduced incidence of PPCs (6.9% vs 15%)	High

FiO_2 inspired fraction of oxygen, *HR* heart rate, *MAP* mean arterial pressure *OLV* one lung ventilation, *$PaCO_2$* partial pressure of carbon dioxide in arterial blood, *PBW* predicted body weight, *PEEP* positive end-expiratory pressure, *PPC* postoperative pulmonary complication, *RCT* randomized controlled study, *RM* recruitment maneuver, *VATs* video-assisted thoracic surgeries, *VT* tidal volume

concluded that PEEP titration guided by lung compliance improves lung function in patients undergoing pulmonary lobe resection.

Similarly, Zhang et al. [21] compared two PEEP strategies in a RCT involving 58 patients undergoing elective VATS lobectomy. In the first group, PEEP was decreased by 2 cmH_2O every 2 min from 15 cmH_2O until maximum pulmonary compliance was achieved vs a standard PEEP of 5 cmH_2O. The optimal PEEP obtained using the decremental trial based on lung compliance was 8.8 ± 2.4 cmH_2O, which was significantly higher than that in the standard group. This resulted in higher oxygenation and lower driving pressure 20 min after the application of the optimal PEEP, with no differences in airway plateau or peak pressure. There were no differences in clinical outcomes such as hemodynamics, PPCs, and length of hospital between groups.

Assuming that a PEEP strategy based on mechanical properties may be more beneficial than a PEEP strategy based on oxygenation or an unchanged PEEP strategy, Spadaro et al. compared an incremental PEEP trial with a decremental PEEP trial to determine the lowest driving pressure during OLV [22]. Sixty patients undergoing VATS were randomly assigned to each group. In the "incremental PEEP group", PEEP was gradually increased by 2 cmH_2O from ZEEP to 16 cmH_2O. In the "decremental PEEP group", a RM was applied before and after the trial, then PEEP was gradually decreased by 4 cmH_2O from 16 cmH_2O. In both groups, each step was maintained for 1 min while VT and respiratory rate remained unchanged. The two procedures resulted in similar levels of PEEP (8 [6–12] cmH_2O) vs 8 [8–10] cmH_2O) and similar mechanical power values in OLV after titration. The shunt volume decreased by a similar amount in both groups. However, in the "decremental PEEP" group, driving pressure decreased (8 [7–11] cmH_2O vs 10 [9–11] cmH_2O) and oxygenation improved.

In a RCT, Kim et al. demonstrated that, regardless of the PEEP titration strategy employed, applying a moderate fixed PEEP level of 6 cmH_2O during OLV improved oxygenation and dynamic compliance without adverse effects, compared to ZEEP [23]. However, previous RCTs have demonstrated that the PEEP titration based on mechanical properties achieves better physiological outcomes in terms of oxygenation, driving pressure, and dynamic compliance. Nevertheless, the impact on postoperative clinical outcomes has been poorly investigated.

Recently, the hypothesis that PEEP titration based on mechanical properties could be beneficial during both the intraoperative period and postoperative periods was confirmed. In a double-blind RCT, the "driving pressure group" ($n = 145$) received VT at 6 mL/kg of ideal body weight, RM, and individually titrated PEEP to achieve the lowest driving pressure during OLV. The "other group" received a protective ventilation VT at 6 mL/kg of ideal body weight, PEEP at 5 cmH_2O, and RM. Driving pressure-guided ventilation was associated with fewer cases of postoperative pneumonia or ARDS (6.9% vs 15%) [24].

Most studies have found that a PEEP level around 8 cmH_2O is optimal in terms of oxygenation and lung mechanics. PEEP selection during OLV based on optimizing respiratory system compliance rather than on strategies based on achieving the best oxygenation or on fixed PEEP levels has been associated with:

- An improvement in respiratory mechanics and oxygenation with moderate certainty of evidence from small randomized studies
- A reduction in the incidence of PPCs, with high certainty of evidence from a single-center randomized study

In brief, we suggest titrating PEEP during OLV according to driving pressure to achieve the best possible physiological and clinical outcomes.

Volume vs Pressure-Controlled Ventilation Mode

A key question in the management of mechanical ventilation during thoracic surgery is which ventilation mode is more effective in reducing the incidence of acute lung injury after OLV and preventing PPCs. The selected studies on this topic are summarized in Table 4.

Table 4 Summary of clinical studies comparing volume vs pressure control mode during video-assisted thoracic surgery, including study design, patient population, primary outcomes, main results, and certainty of evidence according to GRADE 3.0

Author and study design	Patients (*n*)	Aim	Main results	GRADE 3.0 certainly of evidence
Volume vs pressure control mode				
Song et al. [29] Single-center prospective RCT	27	To investigate the effects of VCV vs PCV-VG with VT 8 mL/kg of actual body weight on airway pressure and oxygenation applied in a random fashion during OLV for VATS and open lung surgery	During PCV-VG peak airways pressure was lower and exhaled VT was higher without any differences in oxygenation compared with VCV during OLV	Low
Unzueta et al. [30] Single-center prospective RCT	58	To investigate the effect of VCV vs PCV on oxygenation during OLV for VATS	PCV during OLV reduced peak airway pressures but did not improve oxygenation compared to VCV	Low
Lin et al. [31] Single-center prospective RCT	66	To evaluate differences in terms of airway pressure and oxygenation in elderly patients randomized to VCV, PCV, and PCV-VG modes to obtain VT 8 mL/kg during OLV for VATs	Peak pressure was significantly lower in PCV and PCV-VG modes compared with VCV, without differences between the PCV and PCV-VG group. Oxygenation was higher in PCV-VG group	Low
Zhu et al. [32] Single-center prospective RCT	65	To investigate the difference between PCV and VCV modes on peak airway pressure, Plateau pressure during OLV and intra- and postoperative oxygenation index in patients undergoing VATS for lobectomy	Peak airway pressure was higher in VCV group without any differences in plateau airway pressure and intraoperative oxygenation index. Postoperative oxygenation index and PPCs were similar	High
Tan et al. [33] Single-center prospective RCT	60	To evaluate differences in terms of respiratory mechanics, hemodynamics variables, and gas exchange in patients ventilated in VCV vs PCV during OLV for VATS	Airways resistances, peak and plateau pressures were lower in PCV group. TNFα and IL-6 levels were lower in PCV, while the anti-inflammatory IL-10 was higher. Hemodynamic and gas exchange were similar	Moderate

Table 4 continued

Author and study design	Patients (*n*)	Aim	Main results	GRADE 3.0 certainly of evidence
Breunig et al. [34] Single-center prospective observational study	15	To evaluate the inflammatory response in terms of cytokine and chemokine concentrations in BAL fluid from both lungs, pleural fluid, and serum in patients undergoing OLV during thoracic surgery	OLV significantly increased IL-6 and IL-1RA concentrations in BAL fluid from both the ventilated and the non-ventilated lung, as well as in pleural fluid and serum, indicating a systemic and local inflammatory response	Low

BAL bronchoalveolar lavage, *IL* interleukin, *OLV* one lung ventilation, *PPC* postoperative pulmonary complication, *PCV* pressure-controlled ventilation, *PCV-VG* pressure-controlled ventilation volume guaranteed, *TNFα* tumor necrosis factor alpha, *VATs* video-assisted thoracic surgeries, *VCV* volume-controlled ventilation, *VT* tidal volume

Pressure-controlled ventilation (PCV) provides a decelerating inspiratory flow pattern which improves ventilation distribution, recruits poorly ventilated lung regions, thereby improving oxygenation when compared to the square waveform of volume-controlled ventilation (VCV) [25–28]. PCV with volume guarantee (PCV-VG) requires manual pressure adjustment and delivers the preset VT at the lowest possible pressure.

Song et al. [29] compared VCV and PCV-VG during OLV in 27 patients undergoing VATS and open lung surgery. They found that the airway pressure was lower in the PCV-VG group than in the VCV group with similar arterial oxygen tension levels. Similar results were found by Unzueta et al. [30]. Lin et al. [31] compared three different ventilation modes (VCV, PCV, and PCV-VG) during OLV in elderly patients. Airway pressure and arterial pressure oxygen (PaO_2) were both improved in the PCV and PCV-VG groups. However, all three studies used a VT of 8–9 mL/kg, which is higher than the recommended value of 6 mL/kg. Furthermore, they did not provide any data on PPCs.

Zhu et al. [32] compared PVC to VCV in 65 patients during VATS lobectomy while applying PVS (VT at 6 mL/kg and PEEP at 5 cmH_2O). Peak pressure was higher in the VCV group, but there were no differences in plateau pressure and oxygenation at different intraoperative time points. During the postoperative period, oxygenation was similar over the first 2 days and no difference in the rate of complications was found between groups after 30 days. In a similarly designed RCT, Tan et al. [33] found similar results: intraoperative blood gas analysis, hemodynamics, and length of hospital stay did not differ between groups, although peak and plateau pressures were lower in the PCV group. However, the VCV group had higher intraoperative pro-inflammatory cytokine concentrations, while the PCV group had higher anti-inflammatory cytokine concentrations. As TNFα and IL-6 concentrations have been correlated with the degree of lung injury during OLV [34, 35], PCV seems to be associated with reduced intraoperative pressure and pro-inflammatory factors as well as a reduced risk of VILI. However, it should

be noted that only a few studies have compared the same low VT using VCV versus PCV.

We do not recommend a preferred ventilatory mode at the bedside even if the use of PCV seems to be associated with fewer inflammatory mediators, suggesting a lower risk of postoperative lung injury.

GAS EXCHANGE

The performance of gas exchange during OLV in VATS has been extensively assessed. Several studies have compared gas exchange (PaO_2, $PaCO_2$, and/or PaO_2/FiO_2 ratio) in OLV with that in two-lung ventilation (TLV) [9–13, 17, 20, 30, 31, 34–39]. However, no mechanical ventilation setting allows the same quality of gas exchange to be maintained in OLV as in TLV.

Interestingly, the LAS VEGAS study which assessed current mechanical ventilation practices during general anesthesia for thoracic surgery ($n=302$) found that the recommended intraoperative mechanical ventilation settings involving low VT, low driving pressure, and low-to-moderate PEEP were not applied to the vast majority of patients [40]. Compared with TLV, patients receiving OLV had a lower VT as well as higher peak and plateau pressure, driving pressures, and PEEP levels and a higher respiratory rate, while receiving more RMs. The incidence of PPCs was higher in patients with a higher ARISCAT score than in those with a lower score (48% vs 28.9%) but there was no difference between OLV and TLV (48.8 vs 41.8%) or between endoscopic and open procedures (34.8% vs 47.7%) [41].

Some studies have examined the feasibility of TLV during thoracic surgery. These studies focused on specific types of surgery, such as bleb resection, minimally invasive esophagectomy (MIEs), and thymectomy. The aforementioned studies are summarized in Table 5.

Two RCTs tested the effects of different maneuvers on isolated lungs during OLV. Kremer et al. [36] found that higher PaO_2 levels were achieved using differential lung ventilation techniques during OLV, by alternately ventilating the non-dependent lung with continuous positive airway pressure (CPAP) and a portable ventilator at low rate and pressure. Similarly, in another RCT, applying either high-frequency positive-pressure ventilation (HPPV) to the non-dependent lung with a VT of 2 mL/kg, an inspiratory-to-expiratory ratio of less than 0.3 and a respiratory rate of 60 cycles/min or CPAP resulted in higher PaO_2 levels than during OLV. HPPV further improved gas exchange in the isolated lung than CPAP application, although CPAP provided a much better operative field [39].

The effect of hypercarbia on lung oxygenation during thoracic surgery remains unclear.

Hypercapnia has been demonstrated to improve tissue oxygenation and reduce lung edema in animal models and human studies [42, 43]. However, the relationship between hypercapnia induced by protective lung ventilation during OLV and oxygenation has not been extensively investigated.

Interestingly, a recent study enrolled 262 patients who were randomized into three groups. The respiratory rate was adjusted to obtain a partial pressure of arterial carbon dioxide of 40 ± 5 mmHg in group 40, 50 ± 5 mmHg in group 50, and 60 ± 5 mmHg in group 60 during OLV. Permissive hypercapnia improved lung oxygenation without increasing the risk of PPCs to less than 6% or the length of hospital stay [44]. It is probable that hypercapnia increases pulmonary vascular resistance in the non-dependent lung or decreases pulmonary vascular resistance in the dependent ventilated lung, thereby promoting hypoxic vasoconstriction [43–45].

On the basis of the weak evidence, we recommend a strategy for oxygenating the non-dependent lung; the modalities remain to be determined.

Specific Surgical Thoracic Procedures

Bleb Resection

The smaller size of the resection makes TLV a viable option for bleb resection. Cerfolio et al. [46] reported that VATS with TLV was feasible and provided excellent visualization of the

Table 5 Summary of clinical studies comparing gas exchange during video-assisted thoracic surgery and with a particular overview in specifical thoracic procedure such as bleb resection, minimally invasive esophagectomy, and thymectomy

Author and study design	Patients (*n*)	Aim	Main results	GRADE 3.0 certainty of evidence
Gas exchange				
Kremer et al. [36] Single-center prospective RCT	30	To compare the efficacy on oxygenation of the application on the non-dependent lung in random order of CPAP and DLV with low tidal volume of 50 mL and 8 cycles for minutes during OLV	Oxygenation was significantly higher with OLV + DLV compared to OLV + CPAP, while $PaCO_2$ remained unchanged. Surgical field exposure was not significantly affected	Moderate
Lee et al. [37] Single-center prospective RCT	80	To investigate the effect of TLV during thoracoscopic bleb resection using CO_2 insufflation on intraoperative surgical field visibility, $PaCO_2$, airway pressures, and postoperative clinical outcomes including complications and hospital stay	TLV with CO_2 insufflation improved the surgical field only in the initial phase of the procedure. It led to higher $PaCO_2$ and airway pressures, but no clinical benefit in terms of oxygenation or postoperative outcomes	Moderate
Kim et al. [38] Single-center prospective RCT	60	To compare three strategies: a conventional ventilation strategy (VT 10 mL/kg, ZEEP, FiO_2 100%) versus a PVS (VT 6 mL/kg) vs PVS (VT 6 mL/kg with PEEP 5 cmH_2O, FiO_2 50%) in terms of PaO_2/FiO_2 ratio, hypoxemia incidence, peak and plateau airway pressures, and lung compliance during OLV in patients undergoing elective VATS wedge resection	OLV with high VT (10 mL/kg) showed higher PaO_2/FiO_2 ratio than did OLV with low VT. Adding 5 cmH_2O PEEP to low VT did not improve oxygenation. No significant differences in airway pressures or lung compliance were found	Low

Table 5 continued

Author and study design	Patients (*n*)	Aim	Main results	GRADE 3.0 certainty of evidence
El-Tahan et al. [39] Single-center prospective RCT	30	To compare the effects on oxygenation and surgical field quality of the application in random order of CPAP and HFPPV on non-dependent lung	Both CPAP and HFPPV improved PaO_2 compared with OLV. HFPPV was associated with higher PaO_2 compared to CPAP. CPAP provided a significantly better operative field compared with HFPPV	Moderate
Uhlig et al. [41] Post hoc analysis of the prospective multi-center cross-sectional LAS VEGAS	1460	To compare TLV versus OLV in patients undergoing thoracic surgery and to assess their association with the incidence of PPCs	Under OLV VT was lower, while plateau, driving pressures, PEEP levels, and RR were higher as well as FiO_2 compared with TLV. The incidence of PPCs was higher in patients with higher ARISCAT score than in those with a lower score (48% vs 28.9%) but there was no difference between OLV and TLV (48.8 vs 41.8%)	Moderate
Joe et al. [44] Single-center prospective RCT	262	To compare the impact of three levels of hypercapnia by adjusting RR to obtain $PaCO_2$ of 40 ± 5 mmHg vs 50 ± 5 mmHg vs 60 ± 5 mmHg during OLV on lung oxygenation and on the occurrence of PPCs	Permissive hypercarbia ($PaCO_2$ 50 ± 5 and 60 ± 5 mmHg) during OLV improved oxygenation during OLV without increasing the risk of PPCs that is less than 6%	High
Specifical thoracic procedures: bleb resection, MIE, thymectomy				
Kim et al. [12] Single-center prospective comparative study	102	To evaluate the safety and feasibility of TLV (VT 4 mL/kg, RR 23 cycles/min) vs OLV (VT 8 mL/kg, RR 12 cycles/min) during needlescopic bleb resection	Airway pressure was significantly lower in the TLV group; the time from endotracheal intubation to the incision and the total anesthesia time were shorter in the TLV group	Moderate

Table 5 continued

Author and study design	Patients (*n*)	Aim	Main results	GRADE 3.0 certainty of evidence
Lee et al. [48] Prospective RCT	48	To compare the effect of different RR (15 vs 18 vs 22 cycles/min) during TLV with VT 5 mL/kg for bleb resection in terms of gas exchange, pH, and optimal surgical field	RR of 15 cycles/min with VT 5 mL/kg resulted in physiologic arterial pH, paO_2, $paCO_2$ and guaranteed an optimal surgical field	Moderate
Souche et al. [49] Multicenter retrospective case–control study	150	To compare the efficacy of thoracoscopic MIE in the prone position using TLV with artificial pneumothorax versus OLV during thoracotomic Ivor Lewis esophagectomy, in terms of surgical outcomes, oxygenation, and PPCs after 30 days	PPCs (re-intubation rate, mechanical ventilation length) were lower in MIE group with TLV compared to conventional thoracotomy with OLV (24 vs 44%). Surgical outcomes and intraoperative hypercapnia were similar	Moderate
Tanigawa et al. [50] Single-center retrospective study	67	To study the changes in terms of respiratory mechanics during artificial pneumothorax TLV in VATS esophagectomy in prone position at different timepoints: after intubation, in prone position, after artificial pneumothorax TLV and in supine position	Among the timepoints driving pressure was similar without differences in the treatment of hypoxemia. Compliance was reduced during artificial pneumothorax TLV. BMI and preoperative FEV_1 significantly influenced compliance reduction	Low
Cai et al. [51] Single-center retrospective study	147	To compare TLV with artificial pneumothorax vs OLV in patients undergoing VATS esophagectomy in semi-prone position in terms of surgical outcomes, respiratory function, and PPCs	TLV resulted in better intraoperative respiratory function $PaCO_2$, PaO_2, SaO_2, shorter preparation time for anesthesia induction, less blood loss, shorter surgical time, and less postoperative hospital stay. The incidence of PPCs was similar	Low

Table 5 continued

Author and study design	Patients (*n*)	Aim	Main results	GRADE 3.0 certainty of evidence
Nomura et al. [52] Single-center retrospective study	119	To examine the efficacy of TLV with artificial pneumothorax in prone position vs OLV in patients undergoing VATS esophagectomy in terms of surgical outcomes, oxygenation, and inflammatory responses	TLV group showed shorter thoracic operation time than the OLV group (without conversion to thoracotomy), higher PaO_2/FiO_2 on postoperative day 5 and 7, lower C-reactive protein levels compared to OLV group. PPCs were similar between groups (16.7% in the TLV group vs 23.9% OLV group)	Low
Baloch et al. [53] Single-center prospective comparative study	87	To compare TLV on prone position vs OLV in semi-decubitus position during VATs esophagectomy	TLV (with VT 350 mL PEEP 5 cmH_2O, RR 16 cycles/min) resulted in lower blood loss, surgical length, ICU stay vs OLV (with VT of 400 mL)	Low
Zhao et al. [54] Single-center retrospective study	315	To evaluate the safety and feasibility of TLV with artificial pneumothorax in VATs thymectomy compared to OLV in terms of surgical variables, intraoperative oxygenation, hemodynamics, postoperative complications, and hospital stay	No significant differences were found in terms of operative time, postoperative hospital stay, complications, hemodynamic parameters, and oxygenation between TLV and OLV group. End-tidal CO_2 was higher in TLV group at 15 min and 30 min after initiation of the surgery	Low

The table include study design, patient population, primary outcomes, main results, and certainty of evidence according to GRADE 3.0

BMI body mass index, *CPAP* continuous positive airway pressure, *DLV* differential lung ventilation, FEV_1 forced expiratory volume in 1 s, FiO_2 inspired fraction of oxygen, *HFPPV* high-frequency positive-pressure ventilation, *ICU* intensive care unit, *MIE* minimally invasive esophagectomy, *OLV* one lung ventilation, $PaCO_2$ partial pressure of carbon dioxide in arterial blood, PaO_2 partial pressure of oxygen in arterial blood, *PEEP* positive end-expiratory pressure, *PPC* postoperative pulmonary complication, *PVS* protective ventilation strategy, *RR* respiratory rate, SaO_2 arterial oxygen saturation, *TLV* two lung ventilation, *VATs* video-assisted thoracic surgeries, *VT* tidal volume, *ZEEP* zero end-expiratory pressure

pleural space, enabling pleural biopsies and talc insufflation in patients with malignant pleural effusion or effusion of unknown origin.

One study compared OLV with a VT of 8 mL/kg and a respiratory rate of 12 cycles/min with TLV during bleb resection in patients with spontaneous pneumothorax. The TLV strategy with a low VT of 4 mL/kg and a respiratory rate of 23 cycles/min to maintain adequate gas exchange was found to be safe and effective. This approach was also associated with a significant reduction in the time from endotracheal intubation to incision and in the total duration of anesthesia, making it a viable alternative for a relatively short and simple procedures [47].

There are several methods that can be used to improve the quality of the surgical view. The simplest method is probably to decrease the VT, which is then compensated for by increasing the respiratory rate. Lee et al. [48] randomized 48 patients undergoing to bleb resection to receive three different respiratory rates (15 vs 18 vs 22 cycles/min) during TLV with a VT of 5 mL/kg. They found that a rate of 15 cycles/min did not result in any abnormal physiological changes in terms of PaO_2 or $PaCO_2$ while ensuring an optimal surgical field. Interestingly, this study also found no significant difference in $PaCO_2$ and end-tidal carbon dioxide ($ETCO_2$) values among different respiratory rates, despite significantly different minute ventilations.

Thus, for bleb resection, we recommend a protective ventilation strategy using TLV instead of OLV.

Minimally Invasive Esophagectomy (MIE)

In addition to the general disadvantages of OLV, at least two further potential issues have been reported in connection with OLV during MIE. Firstly, it can be difficult to excise the left recurrent laryngeal nerve lymph node because of the presence of a double-lumen endotracheal tube [49]; secondly, some MIEs are performed in the prone position. In this position, the improvement in ventilatory-to-blood flow ratio expected during OLV as a result of hypoxic pulmonary vasoconstriction may be less effective than in the left lateral decubitus position. Furthermore pneumothorax can reduce the compliance of the collapsed lung [50].

While few studies have compared OLV with TLV, all of these studies report the advantages of TLV.

In a retrospective study by Cai et al. [51], TLV with artificial pneumothorax was compared with OLV in the semi-prone position. The study found that TLV with artificial pneumothorax provided better intraoperative respiratory function ($PaCO_2$, PaO_2, SaO_2), a shorter preparation time for anesthesia induction, less blood loss, a shorter thoracoscopic operating time, and a shorter postoperative hospital stay with a similar number of the resected thoracic lymph nodes. PPCs did not differ significantly between the two groups. Similarly, a subsequent study reported better oxygenation on postoperative day 5 and reduced inflammation during the postoperative period, as well as a shorter operative time and similar PPCs (16.7% vs 23.9%) in the TLV group with carbon dioxide insufflation compared with the OLV group [52].

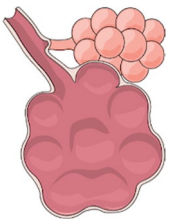
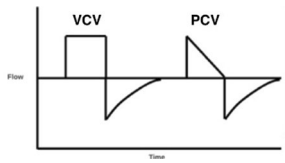
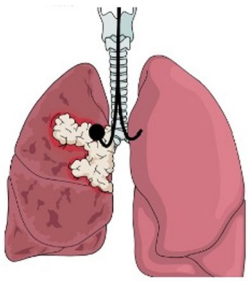
Baloch et al. [53] reported similar benefits with TLV, including lower blood loss, a shorter surgical procedure, and ICU stay and similar PPCs. Notably, the ventilation strategy was detailed: VT was set at 350 mL for TLV and 400 mL for OLV varying according to airway pressures fluctuations, PEEP was set at 5 cmH_2O with a FiO_2 of 1 and a respiratory rate of 16 cycles/min. Surprisingly, a VT of 350 mL during TLV did not compromise surgical comfort.

Similarly, we propose a TLV-based protective ventilation strategy for MIEs instead of OLV.

VATS Thymectomy

Given the need to reduce muscle relaxant doses in patients with myasthenia gravis, the use of TLV with a single-lumen endotracheal tube and

Table 6 Summary of the main topics addressed in this review

Best practice suggestions on mechanical ventilation during OLV for VATS	Grade 3.0 Certainty of evidence
	
PVS	
We suggest to apply a PVS during OLV VT 5–8 mL/kg of PBW and PEEP at least of 5 cmH_2O with or without recruitment maneuver	
It reduces the inflammatory response after OLV in terms of reduced levels of alveolar and serum cytokines and C-reactive protein	Moderate
It improves oxygenation and compliance during and after OLV	Moderate
No benefits in terms of reduction in the incidence of PPCs have been demonstrated	Moderate
	
PEEP selection	
We suggest to titrate PEEP during OLV according to best driving pressure or best respiratory system compliance	
To obtain best respiratory mechanics and oxygenation	Moderate
To reduce the incidence of PPCs	High
	
PCV or PCV-VG vs VCV mode	
We cannott recommend a preferred ventilatory mode	
The use of PCV or PVC-VG vs VCV seems to be associated with	
Lower peak airways pressures and similar oxygenation during OLV	Low
Lower inflammatory markers	Moderate
Similar PPCs	High
	
Gas exchange	Low
We recommend a strategy for oxygenating the non-dependent lung, the modalities remain to be determined	
Specific surgical thoracic procedures	
Bleb resection: we suggest a TLV-based PVS instead of OLV	Moderate
MIE: we suggest a TLV-based PVS instead of OLV	Low–moderate
Thymectomy: no specific ventilation strategy can be suggested	Low

OLV one lung ventilation, *MIE* minimally invasive esophagectomy, *PBW* predicted body weight, *PCV* pressure-controlled ventilation, *PCV-VG* pressure-controlled ventilation volume guaranteed, *PEEP* positive end-expiratory pressure, *PPCs* postoperative pulmonary complications, *PVS* protective ventilation strategy, *TLV* two lung ventilation, *TV* tidal volume, *VATs* video-assisted thoracic surgeries, *VCV* volume-control ventilation

artificial pneumothorax with CO_2 insufflation has recently been investigated. A retrospective study comparing TLV with CO_2 insufflation and OLV during VATS thymectomy found no significant differences in operative time, postoperative hospital stay, complications, hemodynamic parameters, and oxygenation between the TLV group and OLV groups [54].

As a result of the weak evidence on this topic, no specific ventilation strategy can be recommended.

CONCLUSION

This literature review highlights the many uncertainties regarding the setting of mechanical ventilation during OLV in patients undergoing thoracic surgery (Table 6). The use of OLV raises a considerable number of issues, including operator experience, inflammation associated with the method itself, complications arising from the devices used to exclude a lung, and the associated costs. Intermediate VT ranging between 5 and 8 mL/PBW, PEEP set at 5–8 cmH_2O, and RMs appear to be associated with improved perioperative oxygenation and ventilatory mechanics. However, the effect of ventilatory settings on outcomes, including postoperative pulmonary complications, remains unclear. To date, PVS does not appear to be associated with improved outcomes in patients receiving OLV; however, this does not support the use of a non-protective strategy.

The only strategies that have been demonstrated to improve oxygenation during OLV are the alternative applications of CPAP or a low respiratory rate and pressure in the non-dependent lung or high-frequency positive-pressure ventilation.

The use of TLV is based on a very limited level of evidence, but seems feasible for a few procedures. However, no differences in terms of PPCs have been found.

Large RCTs are needed to determine whether some ventilatory strategies can reduce PPCs in patients undergoing VATS.

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Declarations

Conflicts of Interest. Authors Silvia Coppola, Bruno Pastene, Isabella Fratti, Mert Sentürk, Ebru Emre Demirel, and Davide Alberto Chiumello have no conflicts of interest to declare. Author Marc Leone is a member of the Editorial Board of *Advances in Therapy*. He was not involved in the selection of peer reviewers for the manuscript nor in any of the subsequent editorial decisions.

Ethical Approval. This article is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors.

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