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Volume-controlled ventilation versus pressure-controlled ventilation and recruitment maneuvers in video-assisted thoracoscopic surgery

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ABSTRACT

Aims: Various ventilation strategies can be applied to prevent lung injury during one-lung ventilation (OLV). We compared intraoperative ventilation strategies in terms of haemodynamic and respiratory parameters in video-assisted thoracoscopic surgery (VATS).

Methods: Sixty VATS patients, with American Society of Anesthesiologists score of I-III, receiving volume-controlled ventilation (VCV) (Group V) (n=30) or pressure-controlled ventilation (PCV) and recruitment maneuver (RM) (Group P) (n=30) were included in this prospective study. Mean arterial pressure (MAP), peripheral oxygen saturation (SpO_2), tidal volume (TV), airway pressures, compliance, and arterial blood gas values were recorded. In Group P, RM was applied after the 15th minute of OLV. The clinical efficacy and safety of VCV and PCV during VATS were evaluated.

Results: The MAP and PaO_2 were similar between groups throughout the follow-up ($p>0.05$). The peak inspiratory pressure (PIP) and Pplateau in Group V were higher than those in Group P ($p<0.05$). In Group P, there was an increase in TV, airway pressures, and compliance values at the 1st, 2nd, and 3rd minutes of RM ($p<0.05$). No significant change was observed in SpO_2, PaO_2, airway pressures, and compliance in Group P at post-RM 15th min ($p>0.05$).

Conclusions: The ventilation modes did not have clinical superiority over each other. Nonetheless, lower PIP and Pplateau values found during PCV were considered advantage. In Group P, the RM applied during OLV increased compliance and TV. However, extensive research is needed to develop RM models that will ensure improvements in respiratory parameters will last longer.

Introduction

Video-assisted thoracoscopic surgery (VATS) is used widely in thoracic surgery. The advantages of VATS over open techniques include less postoperative pain, better respiratory functions, and shorter hospital stay (1,2). VATS is usually performed with the help of one-lung ventilation (OLV). OLV is a specific application performed to facilitate manipulations and protect other pulmonary structures. However, serious complications can develop, such as hypoxemia (PaO_2 <80 mmHg, SpO_2 <90%) and acute lung injury (ALI) (3,4).

Currently, various "lung-protective ventilation (LPV) strategies" are recommended to prevent ALI and hypoxemia due to OLV (5). Nonetheless, randomized controlled trials (RCTs) investigating both intraoperative ventilation strategies, and the selection of volume-controlled ventilation (VCV) or pressure-controlled ventilation (PCV) mode are not sufficient to provide evidence. Reviewing the literature, the use of intraoperative PCV can provide better oxygenation, lower airway pressures, and more effective CO_2 elimination. The PCV applied with recruitment maneuvers (RM) would improve oxygenation (6). However, it was found that PCV and VCV modes showed the same performance in terms of intraoperative oxygenation and postoperative complications during OLV in the other study (7).

Despite different strategies, the incidence of postoperative pulmonary complications may still be high (8). Since the optimum intraoperative ventilation strategy effective in preventing lung injury in thoracic surgery patients has not yet been clarified yet, studies on this subject are still ongoing.

We hypothesized that PCV, especially along with RM, could be a more effective ventilation strategy than VCV in patients undergoing VATS. We compared the effects of VCV and PCV applications on hemodynamics and oxygenation in patients who underwent VATS. We also evaluated the effects of the RM in the PCV mode.

Methods

This single-center study with prospective enrollment was conducted on patients in the American Society of Anesthesiologists I-III risk class and administered OLV for elective VATS admitted to a tertiary care center between June 2015 and August 2015. Wedge resection or biopsy with VATS was planned. The study protocol agreed with the ethics committee approval, and informed consent was obtained for all participants. All procedureswere in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Patients with a diagnosis of chronic obstructive pulmonary disease, bronchiectasis, asthma, central airway obstruction, tuberculosis, bullous lungs, and those who had FEV_1 values of <80% and FEV_1/FVC <70% were excluded. Intracranial pathologies or cardiovascular diseases (advanced heart failure or coronary heart disease) were also among the exclusion criteria. The flowchart of study recruitment is shown in Figure 1. A total of 60 patients with a body-mass index between 18 and 30 kg/m^2 were divided into two groups. Thirty patients underwent VCV and were classified as Group V. Another 30 patients underwent PCV and RM and were classified as Group P. All patients who underwent PCV received RM as one of the LPV strategies. After sedative premedication with 2 mg of iv midazolam andpreoxygenation, general anesthesia was performed. Anesthesia was induced with 2.5 mg/kg of propofol, 1.5 µg/kg of fentanyl, and 0.7 mg/kg of rocuronium. Radial arterial catheterization was performed in all the patients. Endobronchial intubation was carried out with a left-sided double-lumen tube (DLT), without fiberoptic bronchoscopy (FOB). The DLT placement was confirmed conventionally by the inspection, auscultation, and peak inspiratory pressure (PIP) monitoring. After the patient waspositioned in the lateral decubitus position (LDP), a clinical re-evaluation was performed to check whether there was any displacement in the DLT. In case of unexpected hypoxemia, an increase in PIP value, or a decrease in tidal volume (TV), it was planned to check and correct the position of the DLT via FOB. However, none of the patients required a FOB throughout the operation. The maintenance of anesthesia was provided with sevoflurane at 1 minimum alveolar concentration, remifentanil (0.01-0.20 µg/kg/min), and rocuronium. A mixture of 80% O_2 and 20% air was used for ventilation. The inspiratory fresh gas flow rate was 4 L/min. The fluid administration was managed with balanced crystalloids at a dose of 4-6 mL/kg/hr, considering the fasting period of the patient and the risk group of the operation.

The respiratory rate was adjusted to keep the end-tidal CO_2 ($EtCO_2$) value in the range of 35 - 45 mmHg. In LDP, at the end of 15 min of TLV, arterial blood gas (ABG) sample was taken, OLV was initiated and positive end-expiratory pressure (PEEP) was adjusted to 5 cmH_2O. In Group V, TV was determined according to the ideal body weight, as 8 $mg.kg^{-1}$ during TLV and 6 $mL.kg^{-1}$ during OLV. In Group P, ventilation was performed to provide the same TV as VCV and with a maximum PIP of 35 mmHg during TLV and OLV. In this group, ABG analysis was performed after the 15^{th} minute of OLV, and RM was applied subsequently. The RM protocol was as follows: PIP/PEEP values were gradually increased and applied for 1 min each with 3 minutes as 30/10, 35/15, 40/20 cmH_2O. After 10 breaths, PIP and PEEP were reduced to baseline values (9).

In the perioperative period, electrocardiography, systolic blood pressure, diastolic blood pressure, mean arterial pressure (MAP), peripheral oxygen saturation (SpO_2), heart rate (HR), respiratory rate, invasive arterial pressures, and ABG were monitored. During the intraoperative period TV, $EtCO_2$, PIP, plateau pressure (Pplateau), and compliance measurements were also monitored. Measurement times were identified as pre-induction (T1), induction 3^{rd} min (T2), intubation 1^{st} min (T3), TLV 5^{th} min (T4), TLV 10^{th} min (T5), TLV 15^{th} min (T6), OLV 5^{th} min (T7), OLV 10^{th} minute (T8), OLV 15^{th} minute (T9), OLV 30^{th} min (T10), extubation 1^{st} minute (TE), recovery (TR). ABG analyses were performed on T1, T6, T9, and T10. At the end of the operation, ABG and vital signs were recorded during the TE and TR periods. After extubation, all the patients with Modified Aldrete Score ≥9, were transferred to the surgical intensive care unit for follow-up as a routine procedure of the clinic.

Statistical Analysis

To test the statistical significance of a difference of at least 10 (kPa) in terms of arterial oxygen saturation at a 90% power and 5% error level, between at least two of the groups in the sample width calculations, it was anticipated to include at least 26 cases in each group (10). Descriptive analyses of the study were expressed as the mean and standard deviation for numerical data, and frequency and percentages for categorical data. In comparisons between Group P and Group V, which are independent groups of the study, the chi-square test was completed for categorical data and the Mann-Whitney U test was completed for numerical data. To determine the temporal changes in each group, the Friedman non-parametric variance analysis was performed in general group comparisons. In cases where a difference was found in general group comparisons, the Wilcoxon signed-ranks test was used in post-hoc evaluations to determine from which measurement time this difference originated. All the statistical analyses of the study were interpreted by performing them in a two-way hypothesis structure and at the 5% type-1 error level. Statistical analyses of the study were done using Statistical Package for the Social Sciences (SPSS) 21 (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0., Armonk, NY: IBM Corp.) software.

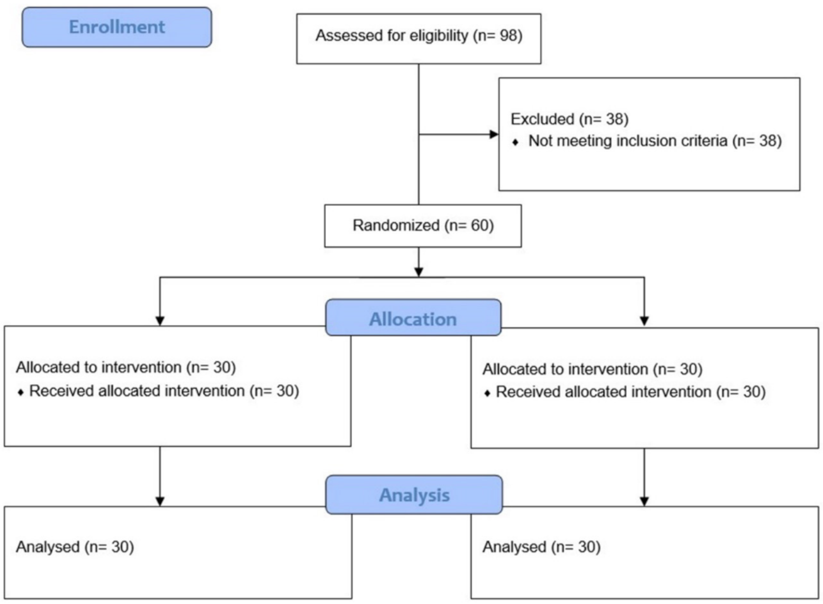

Figure 1. Flowchart of study recruitment

Table 1. Demographic and clinical characteristics of the patients

	Group P (n=30)	Group V (n=30)	p
Age (year), mean±SD	46.1±15.1	41.9±15	0.267
Body mass index (kg.m^{-2}), mean±SD	24.9±4.2	25.4±4.6	0.437
Ideal body weight (kg), mean±SD	64.3±12.4	67.5±12.3	0.180
Gender, n (%)			
Male	20 (66.7)	23 (76.7)	0.390
Female	10 (33.3)	7 (23.3)	
Pulmonary function tests, mean±SD			
FEV_1 (%)	90.6±11.6	88.3±9.4	0.291
FVC (%)	79.6±16.2	76.3±18.5	0.586
FEV_1/FVC (%)	76.7±10.1	75.6±10.7	0.552
Operation side, n (%)			
Right	19 (63.3)	13 (43.3)	0.121
Left	11 (36.7)	17 (56.7)	

SD: Standard deviation, FEV_1: Forced expiratory volume in 1 second, FVC: Forced vital capacity

Results

The study included 60 patients (17 female and 43 male) aged between 18 and 65 years (Table 1). There was no statistically significant difference in demographic parameters, operation side, and basal pulmonary functions (FEV_1, FVC, and FEV_1/FVC) between the groups (Table 1).

No statistically significant difference was found in the MAP values measured from the T1 to TR period between groups. A significant decrease in MAP was observed during the operation and TR period compared to T1 within both groups. MAP changes in T2, T3, T4, T7, T8, TE, and TR were statistically significant compared to the previous measurement time in both groups. Additionally, a statistically significant increase was observed in the transition from TLV to OLV. The changes in MAP values are shown in Figure 2A.

HR changes over time are shown in Table 2. Patients in Group P had a significantly lower HR at T4 than Group V. HR reduced significantly in Group P at T4 and beyond, compared with T1. In Group P, HR was significantly lower at T4 and T6 compared to the preceding measurement. In Group V, HR was significantly higher in T3 and lower in TR than in T1.While there was no difference in HR in the transition from TLV to OLV in Group P, HR decreased in Group V. In both groups, HR was significantly higher in TE and lower in TR than the preceding measurement.

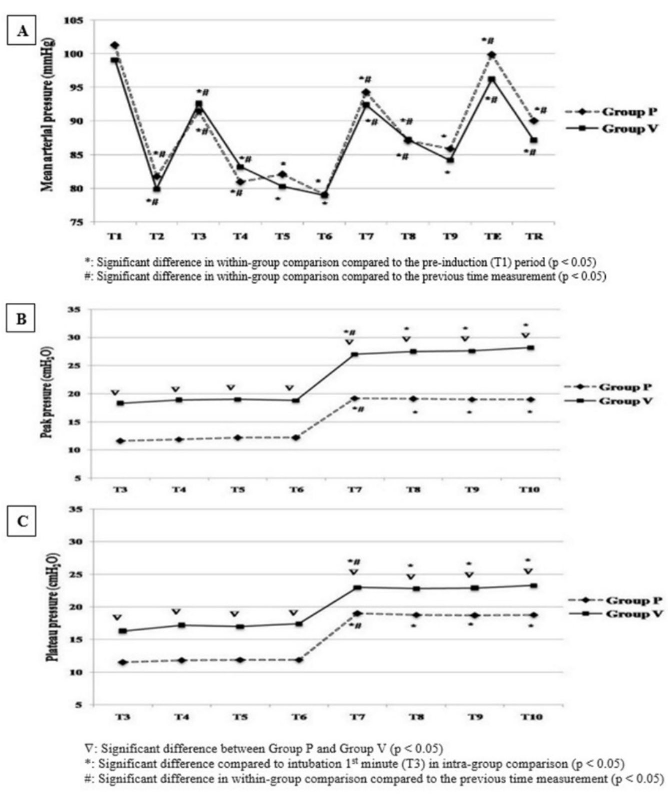

Figure 2. A) Mean arterial pressure. B) Peak inspiratory pressure. C) Plateau pressure

Measurement times: pre-induction (T1), induction 3rd min (T2), intubation 1st min (T3), TLV 5th min (T4), TLV 10th min (T5), TLV 15th min (T6), OLV 5th min (T7), OLV 10th minute (T8), OLV 15th minute (T9), OLV 30th min (T10), extubation 1st minute (TE), recovery (TR)

The changes in SpO_2 are shown in Table 2. T5 and T6 SpO_2 values were lower in Group V. In both groups, compared with the T1, SpO_2 increased during the operation. SpO_2 decreased in TE compared to T10 in Group P. The decrease in SpO_2 in TR compared with the TE was also significant. The decrease in SpO_2 during the transition from TLV to OLV in both groups was not significant. No significant change was observed in SpO_2 in Group P 15 min after RM (OLV 30th min; T10) than before RM (OLV 15th min; T9).

The differences in PaO_2 are shown in Table 2. No statistically significant difference was detected in the PaO_2 from the T1 period to the TR period between groups. A significant increase was observed in PaO_2 at all measurements compared with T1. In both groups, a statistically significant decrease was observed in PaO_2 with the transition from TLV to OLV, and the decrease in PaO_2 in the TR period was significant compared with the TE. In Group P, no significant change was observed in PaO_2 at 15 min (T10) after RM than before RM (T9).

The PIP and Pplateau in Group V were significantly higher at all periods compared to Group P ($p<0.05$). There was an increase in PIP and Pplateau during OLV compared to T3 and in the transition from TLV to OLV in groups ($p<0.05$). At the 15th min (T10) after RM, no significant change was observed in PIP and Pplateau compared to pre-RM in Group P (T9) ($p>0.05$). Changes in PIP and the Pplateau are shown in Figures 2B, 2C.

There was no difference in compliance at any measurement time in Groups P and V. Compliance decreased following the transition from TLV (Group P: 47.2±13.9; Group V: 41.2±14.1 $mL.cmH_2O^{-1}$) to OLV (Group P: 31.3±13.6; Group V: 27.7±8.2 $mL.cmH_2O^{-1}$) in both groups ($p<0.05$). There was no significant change in compliance at 15 min (T10) after RM (30.1±7.3 $mL.cmH_2O^{-1}$) than before RM (T9) (29.1±9.7 $ml.cmH_2O^{-1}$) in Group P.

The results of RM in Group P are summarized in Table 3. When the effects of RM at in the 1st, 2nd, and 3rd minutes were compared with T9 (pre-RM), there was no difference in MAP, SpO_2, and HR values, while TV, PIP, Pplateau, and compliance values increased. The changes in all parameters measured at the 1st, 2nd, and 3rd minutes of RM were similar. No hemodynamic complications, intraoperative hypoxemia, or post-operative ALI findings were observed during the study. We did not observe a barotrauma, such as pneumothorax, related to RM or OLV.

Discussion

We aimed in this study to compare the effects of VCV and PCV on hemodynamics and oxygenation in patients undergoing VATS. Briefly, VCV and PCV modes showed no

Table 2. **Heart rate, SpO_2, and PaO_2 values**

	Periods	Group P (n=30)	Group V (n=30)	p
	T1	87.1±15	85.3±12.6	0.807
	T2	85.0±15.2	87.8±13.4	0.248
	T3	87.1±14.8	90.4±11.5*	0.240
	T4	81.2±13.4*†	88.5±12.9	**0.016‡**
Heart rate, mean±SD	T5	80.3±12.5*	86.1±12.3	0.053
($beats.min^{-1}$)	T6	78.5±11.6*†	82.8±16.3	0.086
	T7	77.3±17.1*	80.7±10.2†	0.604
	T8	76.3±12.5*	80.5±12.6	0.231
	T9	77.2±11.8*	81.1±12.3	0.173
	TE	85.4±14†	87.7±12.4†	0.158
	TR	75.0±13.8*†	80.8±14.7*†	0.190
	T1	96.5±2.0	96.3±2.6	0.875
	T2	99.5±0.9*†	99.1±2.1*†	0.173
	T3	99.5±0.6*	99.1±1.2*	0.246
	T4	99.4±0.7*	99.1±0.9*	0.130
	T5	99.5±0.8*	99.1±1.9*	**0.042‡**
SpO_2 (%), mean±SD	T6	99.4±0.9*	98.6±1.9*	**0.023‡**
	T7	98.0±2.8*	97.4±2.8*	0.129
	T8	97.8±2.3*	97.7±2.4*	0.670
	T9	98.1±2.3*	97.7±2.3*	0.400
	T10	97.1±1.2*	97.2±1.5*	0.521
	TE	95.7±1.3†	98.8±2.0*	0.745
	TR	95.1±6.4*	94.8±2.8*†	0.125
	T1	89.3±21.2	87.8±15.9	0.859
	T6	292.7±68.0*†	263.7±83.3*†	0.198
PaO_2 (mmHg), mean±SD	T9	144.4±64.8*†	143.3±53.8*†	0.842
	T10	143.8±63.7*	142.2±55.1*	0.576
	TE	155.9±80.1*	153.3±67.2*	0.906
	TR	107.5±29.3*†	103.4±28.1*†	0.663

*: Significant difference in within-group comparison compared to the pre-induction (T1) period ($p<0.05$).
†: Significant difference in within-group comparison compared to the previous time measurement ($p<0.05$).
‡: Significant difference between Group P and Group V ($p<0.05$).
Measurement times: pre-induction (T1), induction 3rd min (T2), intubation 1st min (T3), TLV 5th min (T4), TLV 10th min (T5), TLV 15th min (T6), OLV 5th min (T7), OLV 10th minute (T8), OLV 15th minute (T9), OLV 30th min (T10), extubation 1st minute (TE), recovery (TR).
SD: Standard deviation, SpO_2: Peripheral oxygen saturation, PaO_2: Partial pressure of arterial oxygen

Table 3. **Measurements in Group P before and after the recruitment maneuvers (mean±SD)**

	T9	RM (1st min)	RM (2nd min)	RM (3rd min)	p
MAP (mmHg)	85.9±1.6	84.0±10.7	85.8±11.4	83.6±10.2	0.129
SpO_2 (%)	98.1±2.3	98.0±2.3	97.8±2.5	97.8±2.6	0.073
HR ($beat.min^{-1}$)	77.2±11.8	76.8±11.2	79.2±12.7	78.4±11.8	0.169
TV (mL)	422±66.8	471.7±7.6*	495.7±88.9*	476.3±101.1*	**<0.001**
PIP (cmH_2O)	19.0±3.5	26.7±4.3*	31.7±3.8*	36.6±3.6*	**<0.001**
Pplateau (cmH_2O)	18.7±3.5	26.4±4.3*	31.1±4.0*	36.4±3.6*	**<0.001**
Compliance ($mL.cmH_2O^{-1}$)	29.1±9.7	31.1±10.2*	31.5±9.3*	29.9±9.3*	**0.005**

*: Significant difference when compared to OLV 15th min (T9) ($p<0.05$).
SD: Standard deviation, T9: OLV 15th minute, HR: Heart rate, MAP: Mean arterial pressure, PIP: Peak inspiratory pressure, Pplateau: Plateau pressure, RM: Recruitment maneuver, SpO_2: Peripheral oxygen saturation, TV: Tidal volume, OLV: One-lung ventilation

significant clinical differences. There was also no significant difference in oxygenation during and after RM. Hypoxemia, the first of the undesirable effects in the OLV process, is mainly due to intrapulmonary shunt (4). In our study, conducted by providing proper monitoring for gas exchange, it was observed that oxygenation decreased slightly in both groups during the transition from TLV to OLV.

It is safe to set FiO_2 at the lowest possible level to provide $SpO_2 \geq 92\text{-}94\%$ during OLV (11). The use of inhalation anesthetics should be preferred in thoracic surgery (12). Sevoflurane was shown to provide better oxygenation, lower driving pressure, and less pro-inflammatory response compared to propofol, especially during lung resections (13). In our study, we used sevoflurane, adjusted FiO_2 to 0.8, and observed no critical decrease or increase in oxygenation.

The choice of the ideal TV and PEEP in OLV is still controversial. Many researchers chose to use low TV and moderate PEEP, as we did in the current study. A low TV (5-6 $mL.kg^{-1}$) and 5 cmH_2O PEEP combination provided sufficient oxygenation while decreasing the incidence of ALI perioperatively in a previous study (14). In the study by Ferrando et al. (15), during OLV in thoracic surgery, the effects of “individualized” PEEP and “standard” PEEP (5 cmH_2O) were compared. Arterial oxygenation was found superior with individualized PEEP, and the effects of alveolar RM on lung function were better preserved (15). Although moderate PEEP is conventionally and widely used for OLV, the future trend seems to be to routinely implement individualized PEEP.

As soon as OLV begins, PIP and the Pplateau may increase by about 50% (16). Airway pressures should be controlled during OLV, and Pplateau <25 mmHg, and PIP <35 mmHg should be targeted (17). We observed an optimal increase in airway pressures and a decrease in compliance, as expected, with the transition from TLV to OLV in both groups. We also observed lower PIP and Pplateau in the PCV group than in the VCV group during OLV. The lower airway pressures found in PCV mode may have been due to the decreasing flow pattern.

Intraoperative PCV can provide better oxygenation, lower airway pressures, and more effective CO_2 elimination. A lower TV target, long inspiration time, appropriate PEEP, and PCV applied with RM would improve oxygenation (6). According to a guideline on the management of mechanical ventilation in lobectomy patients, PCV should be preferred (18).

Another study found that PCV and VCV modes had the same performance in terms of intraoperative oxygenation and postoperative complications during OLV (7). VCV or PCV mode is recommended for lung-protective OLV. However, it is emphasized that PCV can be chosen in cases where the risk of ALI increases, such as after bullous lung, pneumonectomy, and lung transplantation (17). Consistent with our findings, Pardos et al. (19) compared VCV and PCV modes in OLV and found no difference in oxygenation but lower airway pressures in PCV mode.

Concerning the effects of VCV and PCV on hemodynamics in VATS patients, no statistically significant difference was observed in HR and MAP values (20). We detected an increase in blood pressure with the transition from TLV to OLV in both groups. A decrease in HR was observed with the transition to OLV in the VCV group. When a 5-minute HR of TLV was compared, was lower in the PCV group. However, PCV or VCV did not make a significant clinical difference in hemodynamics.

RMs are breathing maneuvers that are performed with hyperinflation in different durations and pressures to reopen atelectatic areas. While opening closed alveoli with RM, they should also be kept open. Currently, there is no consensus on the routine use and benefits of RM in anesthetized patients with healthy lungs. Miura et al. (21) reported that only the patients with lower compliance responded to alveolar RM.

The dead space volume decreases with RM, oxygenation improves, and a balanced ventilation/perfusion is achieved (14,22). Tusman et al. (22) found that arterial oxygenation increased after RM in OLV, and that application of 40 cmH_2O of inflation pressure for 40 seconds was effective. In our study, there was no significant difference between the SpO_2 at the 1st, 2nd, and 3rd min during RM in the PCV group. This finding can be explained by the sufficient but relatively high FiO_2 we used. When the 15th minute after RM was compared with pre-RM, similar SpO_2 and PaO_2 values suggested that RM did not affect oxygenation. During the RM, due to high PIP and PEEP application, an effective increase was observed in airway pressures, TV, and compliance.

When OLV 15th and 30th min values were compared, we did not find any between-group and within-group differences in hemodynamics, oxygenation, and respiratory parameters. It showed that the effects in the first 3 min did not persist. RM can lead to some complications, such as barotrauma, hypoxemia, and hypotension (23). However, we did not record any RM-related complications. There was no significant hemodynamic difference between the RM and pre-RM period. The values of MAP and HR at 1, 2, and 3 min of RM were not different compared with pre-RM. RM did not also cause hypotension or any deterioration in hemodynamics.

Recently, the “open-lung approach (OLA)” ventilator strategy (low TV, RM, and reductive PEEP titration) has been put on the agenda. A study on the effects of OLA during OLV recommended individualized PEEP adjustment (24). Besides, Slinger (25) reported that the benefit of the OLA is low in VATS patients compared to routine OLV applications. As the research for LPV in thoracic surgery is still in progress, current studies support the combined use of low TV, RM, and PEEP as the three main components of LPV (26).

Study Limitations

Our study has several limitations. Firstly, routine bronchoscopic control of the DLT placement was not available. In general left-sided DLT, which can be easily used without the need for routine FOB, is preferred. We also used the left-sided DLT uneventfully, without the need for a FOB. Secondly, we used widely accepted, fixed (5 cmH_2O) PEEP intraoperatively. Thirdly, we did not perform a follow-up for long-term postoperative pulmonary complications.

Conclusion

In conclusion, this study showed that the VCV and PCV modes did not have clinical superiority over each other regarding hemodynamics and oxygenation in VATS patients. This finding suggests that both modes are effective and can be used safely in patients who are respiratory and hemodynamically stable preoperatively. However, the lower peak and plateau pressure in the PCV group may be an advantage in preventing ALI. In the PCV group, RM applied in the OLV period effectively provided higher compliance and TV. Nevertheless, future RCTs should be conducted to improve these parameters to have a stable effect on oxygenation and to optimize RMs.

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Ethics

Ethics Committee Approval: Ethics approval for the study was obtained from Kecioren Training and Research Hospital Clinical Research Ethics Committee (date: 27.05.2015, reference number: 859/2015).

Informed Consent: Consent form was filled out by all participants.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Surgical and Medical Practices - Analysis or Interpretation - Writing: E.S., H.S., M.T., F.U., A.A., Concept - Design: E.S., H.S., F.U., Data Collection and Processing: E.S., Literature Search: E.S., H.S.

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References

1. Kaseda S, Aoki T, Hangai N, Shimizu K. Better pulmonary function and prognosis with video-assisted thoracic surgery than with thoracotomy. Ann Thorac Surg. 2000;70:1644-1646.
2. Nagahiro I, Andou A, Aoe M, Sano Y, Date H, Shimizu N. Pulmonary function, postoperative pain, and serum cytokine level after lobectomy: a comparison of VATS and conventional procedure. Ann Thorac Surg. 2001;72:362-365.
3. Sentürk M. New concepts of the management of one-lung ventilation. Curr Opin Anaesthesiol. 2006;19:1-4.
4. Lohser J. Evidence-based management of one-lung ventilation. Anesthesiol Clin. 2008;26:241-272.
5. Licker M, Diaper J, Villiger Y, et al. Impact of intraoperative lung-protective interventions in patients undergoing lung cancer surgery. Crit Care. 2009;13:R41.
6. Jiang J, Li B, Kang N, Wu A, Yue Y. Pressure-Controlled Versus Volume-Controlled Ventilation for Surgical Patients: A Systematic Review and Meta-analysis. J Cardiothorac Vasc Anesth. 2016;30:501-514.
7. Zhu YQ, Fang F, Ling XM, Huang J, Cang J. Pressure-controlled versus volume-controlled ventilation during one-lung ventilation for video-assisted thoracoscopic lobectomy. J Thorac Dis. 2017;9:1303-1309.
8. Park M, Ahn HJ, Kim JA, et al. Driving Pressure during Thoracic Surgery: A Randomized Clinical Trial. Anesthesiology. 2019;130:385-393.
9. Tusman G, Böhm SH, Sipmann FS, Maisch S. Lung recruitment improves the efficiency of ventilation and gas exchange during one-lung ventilation anesthesia. Anesth Analg. 2004;98:1604-1609.
10. Weingarten TN, Whalen FX, Warner DO, et al. Comparison of two ventilatory strategies in elderly patients undergoing major abdominal surgery. Br J Anaesth. 2010;104:16-22.
11. Okahara S, Shimizu K, Suzuki S, Ishii K, Morimatsu H. Associations between intraoperative ventilator settings during one-lung ventilation and postoperative pulmonary complications: a prospective observational study. BMC Anesthesiol. 2018;18:13.
12. Sun B, Wang J, Bo L, et al. Effects of volatile vs. propofol-based intravenous anesthetics on the alveolar inflammatory responses to one-lung ventilation: a meta-analysis of randomized controlled trials. J Anesth. 2015;29:570-579.
13. de la Gala F, Piñeiro P, Reyes A, et al. Postoperative pulmonary complications, pulmonary and systemic inflammatory responses after lung resection surgery with prolonged one-lung ventilation. Randomized controlled trial comparing intravenous and inhalational anaesthesia. Br J Anaesth. 2017;119:655-663.
14. Meleiro H, Correia I, Charco Mora P. New evidence in one-lung ventilation. Rev Esp Anestesiol Reanim (Engl Ed). 2018;65:149-153.
15. Ferrando C, Mugarra A, Gutierrez A, et al. Setting individualized positive end-expiratory pressure level with a positive end-expiratory pressure decrement trial after a recruitment maneuver improves oxygenation and lung mechanics during one-lung ventilation. Anesth Analg. 2014;118:657-665.
16. Grichnik KP, Clark JA. Pathophysiology and management of one-lung ventilation. Thorac Surg Clin. 2005;15:85-103.
17. Slinger PD, Campos JH. Anesthesia for thoracic surgery. In: Miller RD (editor). Miller's Anesthesia. 8th ed. Philadelphia, Elsevier Saunders; 2015:1942-2006.

18. Gao S, Zhang Z, Brunelli A, et al. The Society for Translational Medicine: clinical practice guidelines for mechanical ventilation management for patients undergoing lobectomy. J Thorac Dis. 2017;9:3246-3254.

19. Pardos PC, Garutti I, Piñeiro P, Olmedilla L, de la Gala F. Effects of ventilatory mode during one-lung ventilation on intraoperative and postoperative arterial oxygenation in thoracic surgery. J Cardiothorac Vasc Anesth. 2009;23:770-774.

20. Tan J, Song Z, Bian Q, Li P, Gu L. Effects of volume-controlled ventilation vs. pressure-controlled ventilation on respiratory function and inflammatory factors in patients undergoing video-assisted thoracoscopic radical resection of pulmonary carcinoma. J Thorac Dis. 2018;10:1483-1489.

21. Miura Y, Ishikawa S, Nakazawa K, Okubo K, Makita K. Effects of alveolar recruitment maneuver on end-expiratory lung volume during one-lung ventilation. J Anesth. 2020;34:224-231.

22. Tusman G, Böhm SH, Suarez-Sipmann F, Turchetto E. Alveolar recruitment improves ventilatory efficiency of the lungs during anesthesia. Can J Anaesth. 2004;51:723-727.

23. Eren Öngür F, Erolçay H, Yüceyar L, Sayılgan C, Öngür M, Demirkaya A. The comparison of the effects of volume vs pressure controlled ventilation on recruitment maneuver during one lung ventilation. GKDA Derg. 2010;16:16-22.

24. iPROVE Network investigators, Belda J, Ferrando C, Garutti I. The Effects of an Open-Lung Approach During One-Lung Ventilation on Postoperative Pulmonary Complications and Driving Pressure: A Descriptive, Multicenter National Study. J Cardiothorac Vasc Anesth. 2018;32:2665-2672.

25. Slinger PD. Optimizing One-Lung Ventilation: Moving Beyond Tidal Volume. J Cardiothorac Vasc Anesth. 2018;32:2673-2675.

26. Şentürk M, Slinger P, Cohen E. Intraoperative mechanical ventilation strategies for one-lung ventilation. Best Pract Res Clin Anaesthesiol. 2015;29:357-369.