Original Article

Pressure-controlled versus volume-controlled ventilation during one-lung ventilation for video-assisted thoracoscopic lobectomy

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Background: It is controversial as to which ventilation mode is better during one-lung ventilation (OLV). This study was designed to figure out whether there was any difference between volume controlled ventilation (VCV) and pressure controlled ventilation (PCV) on oxygenation and postoperative complications under the condition of protective ventilation (PV).

Methods: Sixty-five patients undergoing video-assisted thoracoscopic lobectomy were randomized into two groups. Patients in group V received VCV mode during OLV while patients in group P received PCV. The tidal volume (VT) in both groups was 6 mL per predicted body weight (PBW). Positive end-expiratory pressure (PEEP) was set at the level of 5 cmH_2O in both groups. Arterial gas analysis were performed preoperatively with room air (T_0), at 15 mins (T_1) and 1 h (T_2) after OLV, at the end of OLV (T_3), 30 min after PACU admission (T_4), 24 h after surgery (post-operative day 1, POD_1) and 48 h after surgery (post-operative day 2, POD_2). Peak inspiratory airway pressure (Ppeak) and plateau airway pressure (Pplat) were recorded at T_1, T_2 and T_3. The perioperative complications were also recorded.

Result: Sixty-four patients completed this study. Ppeak in group V was significantly higher than that in group P (T_1 22.3±2.9 *vs.* 18.7±2.1 cmH_2O; T_2 22.2±2.8 *vs.* 18.7±2.6 cmH_2O). There were no differences with Pplat and intraoperative oxygenation index (T_1 203.3±109.7 *vs.* 198.1±93.4; T_2 216.8±79.1 *vs.* 232.1±101.4). The postoperative oxygenation index (T_4 525.0±160.9 *vs.* 520.7±127.1, post-operative day 1 (POD_1) 452.1±161.3 *vs.* 446.1±109.1; post-operative day 2 (POD_2) 403.8±93.4 *vs.* 396.7±92.8) and postoperative complications were also comparable between these two groups.

Conclusions: When they were utilized during OLV, PCV and VCV had the same performance on the intraoperative oxygenation and postoperative complications under the condition of PV.

Keywords: Postoperative complications; lung injury; one-lung ventilation (OLV); ventilation mode

Submitted Jan 11, 2017. Accepted for publication Mar 30, 2017.
doi: 10.21037/jtd.2017.04.36
View this article at: http://dx.doi.org/10.21037/jtd.2017.04.36

Introduction

Respiratory complications especially postoperative acute lung injury (ALI) is the main cause of morbidity and mortality after thoracic surgery with one-lung ventilation (OLV) (1). In order to decrease the incidence of ALI after OLV and to prevent the respiratory complications after thoracic surgery, protective ventilation [PV; mainly including VTs of 6 mL/predicted body weight (PBW) and positive end-expiratory pressure (PEEP) of 5 cmH_2O] is recommended during OLV (2,3).

For a long time, small VT was believed to be more benefit than large one. The most convincing data was from Dr. Yang (4) which showed that pressure controlled ventilation (PCV) with low VT (6 mL/kg) was associated with lower incidence of postoperative lung dysfunction than volume controlled ventilation (VCV) with large VT (10 mL/kg). In 2007, Schultz *et al.* (5) published recommendations on intraoperative VT and suggested utilizing lower VT (≤6 mL/kg) in patients with abnormal lungs and/or risk factors for ALI.

With further studying of small VT ventilation, some new findings came out. Blum *et al.* (6) showed that the incidence of postoperative ARDS was 0.2% in a general surgical population and the intraoperative risk factor included driver pressure instead of low tide volume. In thoracic surgery, the expected incidence of postoperative ALI was as high as 4.2% (7) and the independent risk factors included intraoperative ventilatory pressure index instead of VT. Fernández-Pérez *et al.* (8) designed a study to prove their hypothesis that higher VT would be associated with higher risk of respiratory failure secondary to ALI, but the result showed that mean first hour peak airway pressure but not VT was associated with ALI. The clinical researches above made us reconsider to utilize the ventilation mode with lower airway pressure during high risk operations especially thoracic surgeries with obligated OLV.

Song *et al.* (9) compared volume-controlled versus pressure-controlled ventilation-volume guaranteed mode (PCV-VG) during OLV. The result showed that in patients with normal lung function the airway pressure was lower in PCV-VG than that in VCV while the arterial oxygen tension remained the same. Lin *et al.* (10) also compared three different ventilation modes (VCV, PCV and PCV-VG) during OLV in elderly patients. It showed that the airway pressure and PaO_2 were both improved in PCV and PCV-VG group compared to VCV.

Unfortunately neither studied presented the postoperative data and furthermore the VTs were set to 8 mL/kg which was not fulfilled the criteria of PV during OLV nowadays. No data of oxygenation index which is an important index of ALI was given in these studies. So we designed this study to investigate the difference of PCV and VCV mode on the peak inspiratory airway pressure (Ppeak), Pplat during OLV and oxygenation index intra- and post-operative.

Methods

General design

This is a single center, single blinded prospective study on two different ventilation modes during one lung ventilation for patients undergoing video-assisted thoracoscopic lobectomy. The study was approved by institutional ethics committee of Zhongshan Hospital, Fudan University (No. B2012-064) and was registered in ClinicalTrails.gov under the number NCT03061617. After written informed consents were obtained, 70 patients with primary lung cancer undergo video-assisted thoracoscopic lobectomy in Zhongshan Hospital were enrolled and randomized into two groups: VCV group (group V) or PCV group (group P).

Inclusion criteria were age between 18–75 years, ASA I–II, lateral decubitus position with at least 1 h OLV and preoperative FEV_1 >50% predicted. Preoperative exclusion criteria were previous lobectomy, COPD, asthma, uncompensated cardiac disease or contraindications for epidural catheter. Intraoperative exclusion criteria were SpO_2 under 90% after intratracheal suction, reconfirmation the position of double lumen tracheal tube (DLT) and recruitment maneuver of dependant lungs.

Protocol

Epidural catheters were placed at $T_{6–7}$ intervertebral spaces before induction and analgesia effect was confirmed using 5 mL 1% lidocaine. Patients were induced by propofol (target-controlled infusion, Ce =2.5 μg/mL), fentanyl (2 μg/kg), remifentanil (0.2 μg/kg/min) and rocuronium (0.6 mg/kg). DLT was intubated and fiberoptic bronchoscopy was used to confirm its position. Anesthesia was maintained with propofol (Ce =3–4 μg/mL), fentanyl and rocuronium. In each patient, 10 mL 0.15% ropivacaine was used epidurally as loading dose and 5 mL was added every 1 h after induction.

The ventilation setting during two-lung ventilation is as follows: VT 8 mL/kg, f 10 breaths/min, PEEP 0 cmH_2O. And the goals of hemodynamic management during our study were the same as other surgeries in our center which was within ±20% of the baseline.

In Group V, OLV was performed using VCV mode with Vt =6 mL/kg, PEEP 5 cmH_2O. In Group P, OLV was performed using PCV mode with PEEP 5 cmH_2O, Ppeak/Pplat adjusted to achieve Vt =6 mL/kg. In each case, respiratory rate was adjusted to maintain $EtCO_2$ 35–45 mmHg and FiO_2 was increased from 50% to achieve SpO_2 over 90%. Patients were extubated and transferred to PACU after surgery.

Ppeak, Pplat, respiratory rate and VT were recorded at 15 min (T_1), 1 h (T_2) after the beginning of OLV and at

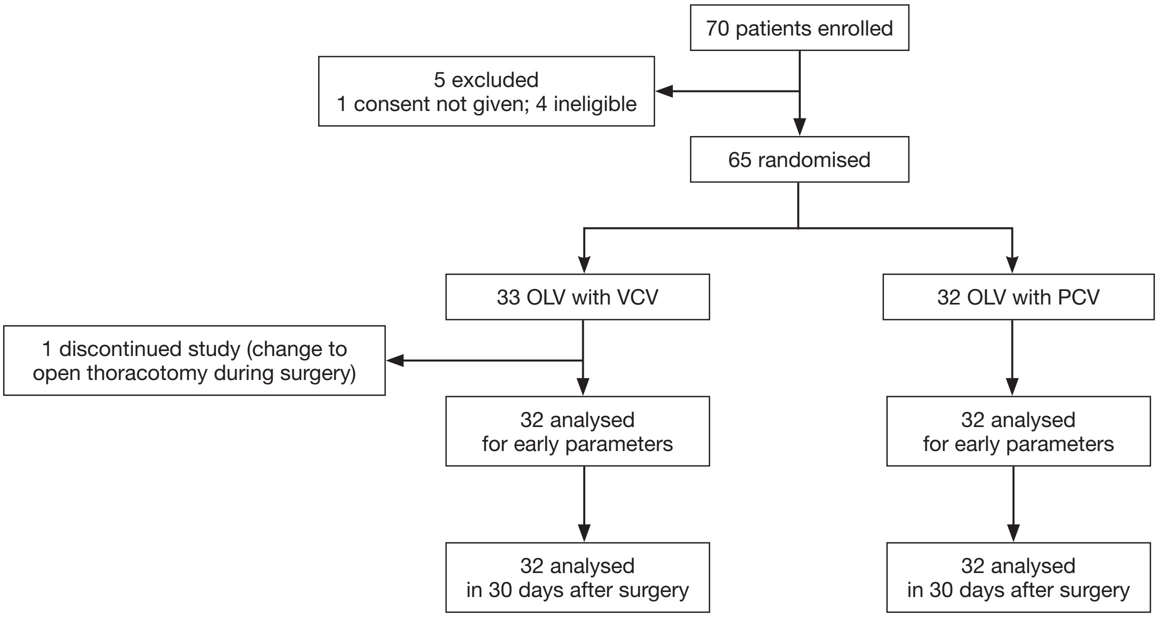

Figure 1 Diagram showing the flow of the patients enrolled in the study. Seventy patients were enrolled before surgery and 64 ones analyzed for early parameters. OLV, one-lung ventilation; VCV, volume controlled ventilation; PCV, pressure controlled ventilation.

the end of OLV (T_3). Arterial gas analysis were performed preoperatively with room air (T_0) and at T_1, T_2, T_3, 30 min after PACU admission (T_4), post-operative day 1 (POD_1) and day 2 (POD_2).

Duration of surgery, intraoperative blood loss, intraoperative urine output, intraoperative fluid infusion were recorded as well as pulmonary complication, cardiovascular complication and others.

Statistical analysis

The quantitative data were expressed as mean and standard deviation. The categorical data were expressed as number of cases and percentage of the total. Student's *t*-test or the Mann-Whitney test was used for quantitative data. Fischer exact test was used to compare qualitative data. A value of $P<0.05$ was considered significant. According to the results of Pu's study (11), 35 subjects per group allowed detection of a 50 mmHg reduction in PaO_2 (FiO_2 100) during OLV with $\alpha=0.05$ and a 90% power.

Results

Seventy patients were enrolled in this study and sixty-four completed it (see flow chart in *Figure 1*). All the demographic data are shown in *Table 1*. All the surgery related data are presented in *Table 2*. There were no difference with demographic features and surgery related factors between these two groups.

Intraoperative variables are shown in *Table 3*. Gas analysis results of arterial blood sample at T_0, T_1, T_2 and T_3 were presented as well as the ventilation parameters. There were no differences with arterial blood gas analysis results (i.e., pH, PaO_2, $PaCO_2$) between these two groups. Ppeak in group P was lower than that in group V at any time point during OLV. As to oxygenation index, we did not find any difference between these two groups not only during operation but also in postoperative period. We followed up arterial blood gas for two days after operations and no difference was showed up (*Table 4*).

After 30 days' follow-up, no difference was found in pulmonary, cardiovascular and other complications between them. The numbers of postoperative pneumonia cases were 2 and 1 in group V and group P respectively. There was one case of respiratory failure in group V due to surgery related problem and reintubation was happened to this case (*Table 5*).

Discussion

Our results showed that during OLV in patients under video-assisted thoracoscopic lobectomy, the performance of PCV mode was superior to VCV in Ppeak during OLV

Table 1 Preoperative demographic characteristics of the patients

Characteristics	Group V (n=32)	Group P (n=32)	P value
Age (yr)	57.1±9.5	56.2±11.0	0.726
Sex ratio (M/F)	14/18 (43.7/56.3)	18/14 (56.3/43.7)	0.454
Height (cm)	165.7±7.7	164.4±6.5	0.476
Body weight (kg)	63.1±10.5	65.1±10.3	0.448
BMI (kg/m^2)	22.8±2.4	24.0±2.8	0.086

Numerical data are expressed as means ± SD. Categorical data are expressed as number of patients and %. BMI, Body mass index.

Table 2 Intraoperative data of the patients

Intraoperative factors	Group V (n=32)	Group P (n=32)	P value
Operation site (left/right)	14/18 (43.7/56.3)	19/13 (59.4/40.6)	0.317
Duration of surgery (min)	122.8±40.6	122.8±34.7	1.000
Urine output (mL)	193±106	226±237	0.486
Blood loss (mL)	55±41	78±66	0.110
Fluid administration (L)	0.9±0.3	0.8±0.2	0.592

Numerical data are expressed as means ± SD. Categorical data are expressed as number of patients and %. VATS, video-assisted thoracoscopic surgery.

Table 3 Intraoperative variables of the patients

Variable	Baseline		OLV 15 min		OLV 60 min		TLV, after lung resection	
	Group V	Group P	Group V	Group P	Group V	Group P	Group V	Group P
Ppeak (cmH_2O)	–	–	22.3±2.9	18.7±2.1*	22.2±2.8	18.7±2.6*	21.8±3.4	18.7±2.7*
Pplateau (cmH_2O)	–	–	17.4±2.4	18.7±2.1	17.6±2.8	18.7±2.6	17.2±2.8	18.7±2.7
pH	7.44±0.03	7.43±0.02	7.37±0.03	7.36±0.04	7.35±0.04	7.34±0.05	7.33±0.05	7.33±0.05
PaO_2 (mmHg)	87.0±11.7	84.2±9.3	123.6±72.8	104.3±48.0	127.3±48.5	121.3±52.2	211.7±83.8	178.6±82.4
$PaCO_2$ (mmHg)	37.5±3.9	37.4±3.8	42.9±6.9	44.7±6.2	45.5±5.5	44.9±6.6	47.4±6.9	45.7±7.3
Oxygenation index	414.3±55.8	400.9±44.3	203.3±109.7	198.1±93.4	216.8±79.1	232.1±101.4	365.2±145.1	329.4±161.7

Numerical data are expressed as means ± SD. *, compared to group V, P<0.05. OLV, one-lung ventilation; TLV, two-lung ventilation.

Table 4 Postoperative arterial blood gas results of the patients

ABG result	PACU		Postoperative day 1		Postoperative day 2	
	Group V	Group P	Group V	Group P	Group V	Group P
pH	7.36±0.04	7.35±0.04	7.41±0.03	7.41±0.05	7.42±0.05	7.41±0.05
PaO_2 (mmHg)	215.3±66.0	213.5±52.1	137.3±47.5	139.3±33.5	124.0±33.9	115.3±34.3
$PaCO_2$ (mmHg)	43.0±4.4	43.8±5.5	37.8±5.2	38.0±6.8	37.8±6.2	38.4±6.2
Oxygenation index	525.0±160.9	520.7±127.1	452.1±161.3	446.1±109.1	403.8±93.4	396.7±92.8

Numerical data are expressed as means ± SD. ABG, arterial blood gas.

Table 5 Frequency of perioperative complications

Types of complications	Group V (n=32) (%)	Group P (n=32) (%)	P value
Pulmonary complications			
Air leak >5 days	6 (18.8)	4 (12.5)	0.732
Pneumonia	2 (6.3)	1 (3.1)	1.000
Bronchopleural fistula	0	0	
Respiratory failure	1 (3.1)	0	1.000
ARDS	0	0	
Reintubation	1 (3.1)	0	1.000
Tracheostomy	0	0	
Pulmonary embolism	0	0	
Cardiovascular complications			
Arrhythmia requiring treatment	1 (3.1)	3 (9.4)	0.613
Myocardial infarction	0	0	
Others			
Renal dysfunction	2 (6.3)	2 (6.3)	1.000
Central neurologic event	0	0	
Sepsis	0	0	
Unexpected return to operating room	1 (3.1)	0	1.000
Unexpected ICU admission	1 (3.1)	0	1.000
Mortality within 30 days	0	0	

but not the intra- nor post-operative oxygenation index. There was no difference with pulmonary or cardiovascular complications between these two modes.

The strategy of OLV went from large volume ventilation (same VT as two lung ventilation) to small volume ventilation with appropriate PEEP (5 cmH_2O). Low VT ventilation is widely known as PV especially in ARDS (12).

High airway pressure associated with mechanical ventilation is thought to be the main risk of ventilator related lung injury (13). According to the result from Licker *et al.* (7), there were four independent factors for primary ALI: high intraoperative ventilatory pressure, excessive fluid infusion, pneumonectomy and preoperative alcohol abuse. Among these four factors what we anesthesiologist can intervene was to optimize the intraoperative ventilatory pressure and limit intraoperative fluid infusion. In this study we focused on the intraoperative ventilatory pressure and we wanted to figure out the difference of patients' outcome between two commonly used ventilator modes during OLV.

PCV was always used to avoid higher airway pressure and provide better oxygenation (14). From previous studies we found that the controversy on better performance of PCV over VCV really existed. So we designed this study to figure out whether PCV had better performance on intra- and post-operative oxygenation and postoperative pulmonary complications in low risk patient during OLV.

Because the VTs in PCV are highly variable (15), we adjusted ventilation pressure to maintain the same volume during OLV so that we can balanced the volume related lung injury (volutrauma). The modified PCV ventilation we adopted here was similar with PCV-VG which was utilized in some recent papers (9,10). PCV-VG is the newest ventilation mode in anesthesia machine (16). It delivers the preset VT with the lowest possible pressure. Unfortunately in our center we did not have such new mode in our anesthesia machine, so we adjusted the pressure manually to obtain the same volume as PCV-VG did.

PCV generates a square pressure waveform with a decelerating inspiratory flow pattern which leads to a more even distribution of VT, recruitment of insufficiently ventilated lung units and oxygenation improvement (14,17,18). Additionally, the rapid alveolar inflation caused by the high initial flow rate in PCV can avoid regional overdistension and lead to better ventilation perfusion matching (19). Though there were a few studies compared PCV and VCV mode during OLV, but very few had evaluated the oxygenation index and postoperative lung complications between these two ventilation modes especially under PV strategy which is highly recommended during OLV.

It was Pplat not Ppeak which was strongly correlated with barotrauma (20). From our study there was no difference with Pplat and also no difference in pulmonary complications though the Ppeak was higher in group V. All the airway pressure were under the recommended range with Ppeak under 35 cmH_2O and Pplat under 25 cmH_2O (21,22).

The first study of PCV-VG (11) and following studies on OLV in thoracic surgery (9) showed that PCV-VG provided better oxygenation and lower airway pressure, but unfortunately they did not compare the postoperative complications and prognosis. Our study not only focused on the intraoperative performance of these two ventilation modes but also during postoperative period. Our result showed that PCV really had lower Ppeak as previous studies suggested but the oxygenation index of two groups were similar intraoperatively and post-operatively.

And also there were no difference with any postoperative complications between these two groups in present study. The result of our study was consistence with the recent meta-analysis on intraoperative mechanical ventilation strategies in patients undergoing one lung ventilation (23). In this meta-analysis, they suggested that PV but not pressure-controlled ventilation can decrease the incidence of PPCs (postoperative pulmonary complications). PCV and VCV had similar effect on PPCs. Our randomized controlled perspective study suggested that under the condition of low VT and proper PEEP, PVC mode did not show better performance either intraoperatively or postoperatively. Previous study showed that low VT along with low PEEP could increase the atelectasis (24) so we set the PEEP at the level of 5 cmH_2O which seemed to be necessary for PV (23). Under these settings we did not find any increased incidence of atelectasis in group V compared with group P. Another recent meta-analysis (25) on comparison of pressure-controlled ventilation with volume-controlled ventilation during OLV got the conclusion that PCV had better performance on oxygenation and Ppeak. Our result showed a lower Ppeak in group P but not better oxygenation. Although previous study implied PCV was in association with better oxygenation during OLV (26), PCV per se did not show any effect on gas exchange (27,28). We set the same PEEP value in both groups and this maybe the main reason why there was no significant difference with oxygenation between two groups.

As to the patients with high risks of PPCs, elderly patients seemed to get more intraoperative benefits from both PCV and PCV-VG ventilation modes during OLV (10). But there was still no data for postoperative complications and prognosis. At the mean time their VT (8 mL/kg) was higher than we used (6 mL/kg) in this study.

The limitation of our study was that the patients enrolled were at low risk of PPCs and it was important to find out if the risk patients can benefit from suitable ventilation mode during OLV. Furthermore we did not test the inflammatory cytokines from the reactions of our body to different ventilation mode during OVL.

In conclusion, our present study showed that VCV and PCV had the same performance of PPCs under the condition of PV.

Acknowledgements

This work was supported by the research foundation from The 2nd Oriental Congress of Anesthesiology and Perioperative Medicine for the research on optimizing the intraoperative ventilation strategy in minimal invasive thoracic surgery.

Footnote

Conflicts of Interest: The authors have no conflicts of interests to declare.

Ethical Statement: The study was approved by institutional ethics committee of Zhongshan Hospital, Fudan University (No. B2012-064) and written informed consent was obtained from all patients.

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Cite this article as: 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(5):1303-1309. doi: 10.21037/jtd.2017.04.36