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Comparisons of two ventilation modes with lung recruitment maneuver during one-lung ventilation in patients undergoing thoracoscopic lobectomy.

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Abstract

Objective: The purpose of this study was to investigate the effects of two different ventilation modes: Volume-Controlled Ventilation (VCV) with Lung Recruitment Maneuvers (LRM) *vs.* Pressure-Controlled Ventilation (PCV) with LRM during One-Lung Ventilation (OLV) in patients undergoing thoracoscopic lobectomy.

Methods: Position of Double-lumen endobronchial tube (DLT) was assessed by a fiberoptic bronchoscope. At 10 min before LRM (T1), Mean Blood Pressure (MBP), Heart Rate (HR), arterial blood gas, Peak inspiratory pressure (P_{peak}), mean inspiratory pressure (P_{mean}), dynamic compliance (C_{dyn}) were measured in each ventilation mode. At 20 min After LRM (T2), MBP, HR, arterial blood gas, P_{peak}, P_{mean} and C_{dyn} were measured in every mode.

Results: The rate of change of index for VCV and PCV was PaO_2+161.3% *vs.* +53.7%, SaO_2+1.73% *vs.* +0.5%, respectively. At the point of T1, by comparing PCV with VCV, PaO_2 was higher, which was statistically significant (P<0.05). By comparing T2 with T1, both VCV-LRM and PCV-LRM groups had a significant decrease in P_{peak} and P_{mean} (P<0.05) .While they significantly increased the value of C_{dyn} (P<0.05). The rate of change of index for VCV and PCV was P_{peak}-34.7% *vs.* -25.9%, P_{mean}-27.4% *vs.* -18.8%, C_{dyn}+73.2% *vs.* +35.4%, respectively. AT T1, compared with VCV-LRM group, P_{peak}, P_{mean} and C_{dyn} was lower, lower and higher (P<0.05) in PCV-LRM group, the difference was statistically significant.

Conclusions: The VCV with LRM mode and PCV with LRM mode not only improved oxygenation during OLV for patients undergoing thoracoscopic lobectomy, but also attenuated airway pressure and improved dynamic compliance. It should be emphasized that the former is more effective than the latter.

Keywords: Volume controlled ventilation, Pressure controlled ventilation, Lung recruitment maneuver, One-lung ventilation.

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Introduction

Lung Recruitment Maneuver (LRM) is related to give the positive pressure ventilation higher than the normal pressure in the process of mechanical ventilation for a certain time. Its essence is to re-open the collapsed alveoli as modestly as possible, in order to improve oxygenation, increase lung compliance and reduce ventilation-related lung injury [1,2]. Previous studies had shown that LRM plays an important role in the treatment of respiratory failure and Adult Respiratory Distress Syndrome (ARDS). What is more important is that LRM can not only improve oxygenation, but also affect the regulation of alveolar surfactant and cytokines, significantly reducing the patients' morbidity and mortality [3,4]. Usually, it needs One-Lung Ventilation (OLV) in the thoracic surgery. During OLV the pulmonary shunt, blood flow imbalance and atelectasis at the ventilation lung during OLV, surgical area, patient position and the drugs for general anesthesia are the main factors that affect oxygenation [5,6]. In order to improve oxygenation and verify whether leakage after the lobectomy, LRM is often used as an important method for the thoracic surgery by surgeons. Volume-Controlled Ventilation (VCV) and Pressure-Controlled Ventilation (PCV) are important mechanical ventilation modes. The VCV mode can ensure the stabilization of minute ventilation volume. However, the higher peak inspiratory pressure (P_{peak}) is harmful to lung. The PCV mode has been found some advantages in improving arterial oxygenation and changing the airflow pattern. In past, VCV had been considered as a useful mechanical ventilation mode during OLV for a long time. But in recent years, PCV had been proved to be much more useful than VCV due to its advantages in improving oxygenation and reducing airway pressure [7,8].

A large number of studies have confirmed that LRM is a safe and reliable complement in protective lung ventilation strategies, which can play an active role in curing atelectasis, hypoxemia and post-operative pulmonary complications [9-11]. Up to now, there are few studies about the effects on hemodynamics and respiratory function for patients undergoing thoracoscopic lobectomy during OLV, by means of the LRM based on different mechanical ventilation. In this study, we aim at investigating the difference between VCV with LRM mode and PCV with LRM mode on hemodynamics and respiratory mechanics of the patients undergoing thoracoscopic lobectomy during OLV, which is extremely useful to the clinical work.

Materials and Methods

This study was approved by the Ethics Committee and all patients or their nearest relatives signed anesthetic informed consent before anesthesia. Thirty patients undergoing thoracoscopic lobectomy, ASA I-II, aged between 20 and 50 years old, including 16 males and 14 females were enrolled into the study.

Exclusion criteria

History of lung surgery; poor lung function; coronary heart disease; arrhythmias with unstable hemodynamics; chronic obstructive pulmonary disease; history of tracheotomy; chest and abdomen deformities; Muscle joint disease; disagree with clinical test.

Patients were classified into VCV with LRM group (VCV-LRM group) and PCV with LRM (PCV-LRM group) according to a controlled, randomized design produced by computer-generated codes.

After the patients went into the operating room, Electrocardiogram (ECG), pulse oximetry and Bispectral Index (BIS) had been performed. The arterial cannula was inserted into the radial artery and a central venous catheter was inserted from the right internal jugular vein for arterial pressure and central venous pressure monitoring and collecting blood samples. General anesthesia was induced with midazolam (0.05 mg/kg), etomidate (0.3 mg/kg), sufentanyl (0.4 μg/kg), and atracurium (0.2 mg/kg). A left double lumen trachea (DLT, Mallinckrodt-Endobronchial Tube, Covidien, Made in Ireland) was intubated (no. 37 for male and no. 35 for female patients), and the DLT was positioned using a fiberoptic bronchoscope before and after changing the patient to a lateral decubitus position. All patients were intubated with left-side DLT if possible. Anesthesia was maintained with a continuous infusion of remifentanil (0.15 μg/kg/min), propofol (5 mg/kg/h), and atracurium was administered intermittently as needed. The depth of anesthesia was maintained similarly between BIS 40 and 55 in both groups. The inspiration-to-expiration ratio (I: E) was 1:1.5 and FIO_2 was 100% in two groups. End-tidal carbon dioxide ($ETCO_2$) was kept to be 35-40 mmHg during OLV by adjusting the respiratory rate. Two ventilation modes were used with a tidal volume of 8 ml/kg in terms of ideal body weight. LRM was done twice at five minutes after suctioning when lobe was cut off in two groups. LRM: kept the continuous positive inflation airway pressure of 30 cmH_2O for 30 s. LRM was performed manually by means of ventilator, with 10 ml/min gas flow of 100% oxygen [12]. After the end of LRM, the previous mechanical ventilation continued to be used. During operation, SpO_2 should be maintained above 95% at all times. If SpO_2 fell below 95%, the following treatments were taken: sucking sputum, checking and adjusting the catheter position by fiberoptic bronchoscopy, two lung ventilation. If SpO_2 cannot return to more than 90%, the patient would be removed from the study. 6% HES 130/0.4 (Voluven®; Fresenius Kabi, Germany) and Ringer fluid were used to hold the stable arterial pressure and heart rate. If Mean Blood Pressure (MBP) continued to fall below 60 mmHg for more than 5 min, intravenous administration of ephedrine 5 mg was taken. At the end of the operation, all patients were transferred into Intensive Care Unit (ICU). All patients were operated on by thoracic surgeons and were managed by the same team of anesthesiologists.

Measurements

At 10 min before LRM (T1), MBP, Heart Rate (HR), arterial blood gas, Peak inspiratory pressure (P_{peak}), mean inspiratory pressure (P_{mean}), dynamic compliance (C_{dyn}) were measured in each ventilation mode. At 20 minutes After LRM (T2), MBP, HR, arterial blood gas, P_{peak}, P_{mean}, C_{dyn} were measured in each ventilation mode.

Statistical analysis

SPSS 17.0 pack-age (SPSS Inc., Chicago, IL) statistical software was used for data analysis. All data were expressed as mean ± Standard Deviation (SD). Comparison between groups were performed by using independent samples T-test, intra-group comparison using ANOVA analysis, LSD test was used to compare the two groups. A P-value<0.05 was considered to be statistically significant.

Results

There were no significant difference between the two groups in the demographic characteristics (P>0.05) and the data on the operative procedure as indicated in Tables 1 and 2. There were no significant changes (P>0.05) in MBP, HR during this study illustrated in Table 3. By comparing T2 with T1, the PaO_2 for VCV-LRM and PCV-LRM increases and the SaO_2 for VCV increases as well, this was statistically significant. The rate of change of index for VCV and PCV was PaO_2+161.3% *vs.* +53.7%, SaO_2+1.73% *vs.* +0.5%, respectively. At the point of T1, by comparing PCV with VCV, PaO_2 was higher, which was statistically significant shown in Table 4. By comaparing T2 with T1, both VCV-LRM and PCV-LRM groups had a significant decrease in P_{peak} and P_{mean} (P<0.05) .While they significantly increased the value of C_{dyn} (P<0.05), the difference was statistically significant. The rate of change of index for VCV-LRM and PCV-LRM was P_{peak}-34.7% *vs.*

-25.9%, P_{mean}-27.4% *vs.* -18.8%, C_{dyn}+73.2% *vs.* +35.4%, respectively. AT T1, compared with VCV-LRM group, P_{peak}, P_{mean} and C_{dyn} were lower, lower and higher (P<0.05) in PCV-LRM group, the difference was statistically significant, which can be found in Table 5.

Table 1. *Baseline characteristics of the patients at study inclusion (n=30).*

Characteristics	VCV-LRM	PCV-LRM	P value
Age (year)	54 ± 13	52 ± 12	P>0.05
Sex (male/female)	7/8	8/7	P>0.05
Body mass index (kg/m^2)	22.5 ± 2.6	21.9 ± 2.3	P>0.05
Preoperative PaO_2 (mmHg)	74.8 ± 9.6	72.9 ± 9.1	P>0.05
Preoperative $PaCO_2$ (mmHg)	43.6 ± 5.2	41.8 ± 5.8	P>0.05
Side (right/left)	9/6	10/5	P>0.05
ASA physical status, n (%) II	9 (60%)	8 (53%)	P>0.05
ASA physical status, n (%) I	6 (40%)	7 (47%)	P>0.05

Data are shown as mean ± SD. PaO_2: Arterial blood oxygen tension; $PaCO_2$: Arterial blood carbon dioxide tension; ASA: American Society of Anesthesiologists; SD: Standard Deviation.

Table 2. *Intraoperative data of the patients (n=30).*

Intraoperative parameters	VCV-LRM	PCV -LRM	P value
Duration of surgery (min)	169 ± 20	163 ± 22	P>0.05
Duration of OLV (min)	111 ± 45	112 ± 38	P>0.05
Perioperative blood loss (ml)	409 ± 92	426 ± 110	P>0.05
Perioperative urine output (ml)	436 ± 172	458 ± 175	P>0.05
Perioperative fluid administration (l)	2.3 ± 0.5	2.4 ± 0.6	P>0.05

Table 3. *Hemodynamic variables in two ventilation modes during one-lung ventilation.*

Variable	T1		T2	
	VCV-LRM	PCV-LRM	VCV-LRM	PCV-LRM
MAP (mmHg)	94.2 ± 12.5	95 ± 11.9	96.9 ± 9.2	96.0 ± 12.6
HR (beats/min)	65.1 ± 10	66.9 ± 11.5	65.3 ± 10.4	71.9 ± 10.8

Data are presented as means ± SD. No significant differences were noted between the groups, p>0.05.

Table 4. *Arterial blood gas values in two ventilation modes during one-lung ventilation.*

Variable	T1		T2	
	VCV-LRM	PCV-LRM	VCV-LRM	PCV-LRM
PaO_2 (mmHg)	111.5 ± 18.1*	176.8 ± 39.4	291.3 ± 111.7	271.7 ± 100.3
$PaCO_2$ (mmHg)	39.2 ± 3.4	40.7 ± 4.1	39.5 ± 4.8	41.5 ± 4.3
SaO_2 (%)	97.9 ± 1.9*	99.1 ± 0.9	99.6 ± 0.7	99.6 ± 0.8

Data are shown as mean ± SD; SaO_2: Arterial Oxygen Saturation; *P<0.05 (VCV-LRM *vs.* PCV-LRM)

Table 5. *Respiratory mechanics in two ventilation modes during one-lung ventilation.*

Variable	T1		T2	
	VCV-LRM	PCV-LRM	VCV-LRM	PCV-LRM
P_{peak} (cmH_2O)	24.2 ± 3.9*	20.8 ± 3.6#	15.8 ± 2.8	15.4 ± 2.4
P_{mean} (cmH_2O)	9.4 ± 1.3 #	8.5 ± 1.2	6.8 ± 0.9	6.9 ± 1.1
C_{dyn} (ml/ cmH_2O)	23.9 ± 4.4*	32.2 ± 9.9#	41.1 ± 8.4	43.6 ± 8.8

Data are shown as mean ± SD. *P<0.05 (compared with others periods); #P<0.05 (VCV-LRM *vs.* PCV-LRM).

Discussion

LRM refers to the expansion of intrapulmonary pressure by opening the collapsed alveoli through a sufficiently high pressure or capacity within a limited time. Its main purpose is to recovery function residual capacity. In recent years, a large number of studies have shown that LRM can improve oxygenation and reduce atelectasis and lung injury [1,2,7,11,13]. This study compared the differences in arterial oxygenation, airway pressure of VCV with LRM and PCV with LRM to observe the differences in the hemodynamics, oxygenation and respiratory mechanics based on the different ventilation modes during OLV for thoracoscopic lobectomy.

Studies have confirmed that LRM as a simple and effective reexpansion alveolar approach, which can not only improve intraoperative oxygenation, but also reduce postoperative pulmonary complications [14,15]. In Tusman's [7] previous research for non-thoracic surgery, it can be found that LRM can improve oxygenation and reduce pulmonary complications. In recent years, Tusman [11] has reported that giving LRM in the OLV significantly increased arterial oxygenantion during lung ventilation. However, inadequate LRM led to ischemia-reperfusion injury and aggravate inflammatory response induced by ventilation.

Lobectomy patients had reduced lung capacity, while the clinical LRM requires higher pressure, which can more likely cause mechanical lung injury to the bilateral lung [12,13]. In our study, the experimental data obtained by LRM showed that the mechanical ventilation airway pressure is not high in clinical practice. It is lower than the airway pressure before LRM, avoiding the occurrence of mechanical lung injury [14].

Pulmonary artery pressure increases after pneumonectomy, which may be due to the decrease of pulmonary vascular bed and the increase of pulmonary blood flow, circulation pressure and vascular resistance [16]. The decrease of lung respiratory area can result in hypoxia, which lead to pulmonary vasoconstriction and the increase of vascular resistance. The end-diastolic volume of right ventricular will increase significantly after pneumonectomy. In addition, the heart will work more and be with hypoxia, resulting in the decrease of Right Ventricular Ejection Fraction (RVEF) [17]. In our research, we found that LRM had no significant effect on circulation. That is probably because cardiopulmonary function of the patient was in good condition and LRM had little effect on cardiac contractility. However, there may be another explanation for the above results. After LMR, the increase of arterial oxygenation will alleviate hypoxia-induced pulmonary vasoconstriction, thereby reducing pulmonary vascular resistance and pulmonary artery pressure. And then the patient's right ventricular end-diastolic volume would recovery, maintaining the right heart function well. In addition, that's because the decrease of pulmonary vascular resistance reduces artery pressure and has little effect on left heart return blood volume, ensuring the stroke volume of the heart. LMR has attraction on the lungs, which will stimulate the vagus nerve, reduce heart rate, reduce oxygen consumption and ensure supply and demand balance for the myocardial oxygen. And heart function was not impaired quite a lot. Furthermore, we maintained adequate blood volume during the procedure and did not cause a reduction in the volume of the right ventricle due to LRM. Thus, it was clinically safe, perhaps it is because we did not monitor this phenomenon. In the future study we will further monitor cardiac function by transesophageal or other advanced instruments through other useful methods.

The effective gas exchange of the lung depends on the matching of the ventilation/perfusion ratio (V/Q). Due to the operation of disconnecting ventilator tubing, general anesthesia drugs, patient position, pure oxygen inhalation and repeated suction, ventilation lung is not in good condition after anesthesia. However, the relative increase in blood perfusion results in the decreased V/Q and intrapulmonary shunt. In addition, intrapulmonary shunt reduces the oxygenation, decreases cardiac output and lung collapse induced by the application of OLV, leading to the mismatch of V/Q and the occurrence of hypoxia [18-20].

Before LRM, we have observed that PCV was superior to VCV on improving oxygenation and dynamic compliance, decreasing airway pressures, which was consistent with other studies [21,22]. The possible reason is that improvement in homogeneous distribution of inspired gas, the slow-down airflows reducing the peak airway pressure, decreasing alveolar peak pressure and alveolar tension, making pulmonary blood flow increase, ultimately improve the VA/Q in the PCV [23,24]. Tugrul et al. [25] showed that PCV had advantages in improving arterial oxygenation during OLV. This improvement could be explained by the above characteristics. On the contrary, some studies had found that there was no difference between VCV and PCV for improving oxygenation during OLV for patients with good preoperative pulmonary function. The reason may be that preoperative respiratory function was worse in present study compared with the Unzueta [26] study.

This study was mainly to apply LRM to reduce the dead space and increase the functional residual capacity and effective gas exchange area, finally increasing the PaO_2. LRM makes the collapse of the lung segment expansion, increases lung compliance and improves pulmonary respiratory mechanics [27]. After LRM, the differences between two groups of peak airway pressure, compliance and plateau pressure were not statistically significant, while the respiratory mechanics have been improved obviously, especially in group VCV-LRM. We found that LRM was more effective for VCV to improve PaO_2, increase lung compliance and reduce airway pressure. The possible reason is as following: 1. LRM has been shown to reexpand the collapsed dependent lung areas that develop in almost all anesthetized patients. The higher the pressure for VCV mode, the bigger difference between peak airway pressure and plateau pressure, the poorer gas diffusion, and the more lung segment collapse. After LRM, Lung segment reexpansion is obvious, especially in group VCV-LRM. The pulmonary ventilation/blood flow had been improved, increasing the oxygenation and dynamic compliance to a higher level. 2. Lung segment collapse in group PCV-LRM was less than that in group VCV-LRM. In addition, better gas dispersion in group PCV-LRM led to better oxygenation. Although LRM operation can improve oxygenation, the increasing level was limited. 3. After lung resection, remaining lung blood flow significantly increases, the same to pulmonary vascular resistance. However, LRM can increase intra-alveolar pressure and drive the lungs residual blood out, favoring reducing pulmonary artery pressure. Furthermore, LRM can increase oxygenation, helping to alleviate hypoxic pulmonary contraction. There was no significant difference in oxygenation before and after LRM between the two groups. Thus, the difference between the two groups was not statistically significant. At last, we found that LRM in group VCV-LRM is more conducive to improve oxygenation and ameliorate respiratory mechanics.

There was no statistically significant difference in carbon dioxide between the two groups. That is probably because the cardiopulmonary function of the patients was good, the diffusion function of carbon dioxide is 20 times of oxygen and minute ventilation was determined according to the ideal body weight in our study. They kept the gas exchange normal, so no hypercapnia or hypocapnia occurred in either group.

In a word, VCV with LRM can reduce pulmonary vascular resistance and reduce pulmonary shunt and enhance gas dispersion to a higher extent during OLV. It should be stressed that further research is necessary to determine the exact causes and correlation factors. The oxygenation and respiratory mechanics improvement in VCV with LRM is better than PCV with LRM.

However, there is still limitation in the present study. Surgical manipulation potentially affected the arterial oxygenation and cardiac function. As we know, pulmonary artery occlusion might have affected the shunt fraction and decreased arterial oxygenation. In addition, the generalizability of the conclusions was limited because a small group of patients was selected in a single-center. Surgical manipulation made by the different type and scope of surgical resection may potentially produce some effects on the results of our study [28,29].

Conclusion

The VCV-LRM and PCV-LRM mode not only improved oxygenation during OLV for patients undergoing thoracoscopic lobectomy, but also attenuated airway pressure and improved dynamic compliance. It should be emphasized that the former is more effective than the latter.

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