Original Article

Comparison between pressure-controlled ventilation with volume-guaranteed mode and volume-controlled mode in one-lung ventilation in infants undergoing video-assisted thoracoscopic surgery

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Background: The appropriate ventilation mode for one-lung ventilation (OLV) in infants undergoing video-assisted thoracoscopic surgery (VATS) remains controversial. Here we investigated the effect of ventilatory mode "pressure-controlled ventilation-volume guaranteed" (PCV-VG) on the airway pressures and oxygenation parameters by comparing it with volume-controlled ventilation (VCV).

Methods: We retrospectively analyzed the clinical data of infants aged 2 to 12 months who underwent extratracheal bronchial blockage for OLV in our center between January 2017 and August 2020. The infants were divided into two groups according to the OLV pattern: group G (n=30, receiving PCV-VG) and group V (n=28, receiving VCV). Mean arterial pressure (MAP), heart rate (HR), maximum inspiratory pressure (P_{peak}), mean airway pressure (P_{mean}), dynamic compliance (Cdyn), partial arterial pressure of oxygen (PaO_2) was measured and compared between these two groups 10 min before OLV (T1), 30 min after the onset of OLV (T2) and 15 min after OLV (T3). The possible occurrence of hypoxemia and hypotension during OLV was monitored.

Results: Compared to group V, group G had significantly higher $PaO_2$and C_{dyn} (both $P<0.05$) and significantly lower P_{peak} and P_{mean} (both $P<0.05$) in T2. However, all indicators did not show significant differences between these two groups at T1 and T3 (all $P>0.05$). The incidence of hypoxemia was significantly higher in group V than in group G ($P<0.05$), while the difference in the incidence of hypotension was not statistically significant ($P>0.05$).

Conclusions: Mechanical ventilation using the PCV-VG mode is possible in infants when performing OLV during VATS. Compared to VCV, PCV-VG can offer lower P_{peak} and P_{mean}, improve lung compliance, and achieve better oxygenation.

Keywords: One-lung ventilation (OLV); pressure-controlled ventilation with volume-guaranteed; infants; anesthesia

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Introduction

One-lung ventilation (OLV), or lung isolation, protects the healthy lung from contamination by blood or secretions at the surgical site (1). Additionally, it provides the operator with a clear surgical view to facilitate surgical operations. Thus, OLV has become a common mode of ventilation for video-assisted thoracoscopic surgery (VATS). However, OLV is not physiological and can cause adverse effects on the respiratory system (2), resulting in an imbalanced ventilation/blood flow ratio, increased intrapulmonary shunt (Qs/Qt), and decreased arterial partial pressure of oxygen (PaO_2) (3). Furthermore, pulmonary ischemia-reperfusion can induce the release of inflammatory factors, leading to acute lung injury and affecting the prognosis (4,5). It is necessary to choose the appropriate mode of mechanical ventilation to avoid lung injury related to respiration. Clinically, volume-controlled ventilation (VCV) is a common and classical mode of ventilation in OLV (6,7). Although VCV ensures a stable and accurate ventilation volume, a high peak inspiratory pressure P_{peak} during OLV may lead to pressure injury and other uneven air distribution in the lungs (8). The "pressure-controlled ventilation volume guaranteed" (PCV-VG) mode, also known as the "pressure-regulated volume control" (PRVC) mode, allows the anesthesia machine to reduce lung injury by minimizing intrathoracic and airway pressures in response to changes in lung compliance, while ensuring a predetermined minimum ventilation volume (9). The use of the PCV VG mode for mechanical ventilation after general anesthesia for pediatric cardiac surgery has been reported in the literature (10). The effects of VCV mode versus PCV-VG mode on oxygenation parameters and airway pressure during OLV for open heart surgery in adults have also been compared. (11) Previous studies mostly focused on the effects of different ventilation modes on respiratory mechanics or lung injury in adults during one-lung ventilation (2,11), while fewer studies have compared the PCV-VG mode with the VCV mode when performing OLV in infants undergoing video-assisted thoracoscopic surgery (VATS). Here we retrospectively analyzed the medical records of infants undergoing OLV during VATS in our center from January 2017 to August 2020 to compare the effects of PCV-VG versus VCV on respiratory mechanics and PaO_2. We present the following article in accordance with the STROBE reporting checklist (available at https://dx.doi.org/10.21037/tp-21-421).

Methods

All procedures performed in this study involving human participants were in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by institutional committee ethics board of Fujian Maternity and Child Health Hospital (No. 2020YJ192). Individual consent for this retrospective analysis was waived.

Infants who underwent OLV during VATS in our center from January 2017 to August 2020 were selected. The inclusion criteria were as follows: (I) American Society of Anesthesiologists (ASA) physical status II or III; (II) aged 2–12 months; (III) undergoing VATS and receiving extratracheal bronchial blockage occlusion for OLV; and (IV) PCV-VG or VCV for OLV.

Exclusion criteria included: (I) accompanied by disease(s) in another system(s); (II) conversion to open chest operation during surgery; and (III) with incomplete medical data.

According to the inclusion and exclusion criteria, 58 infants undergoing VATS were included and divided into two groups: group V (n=28, receiving PCV-VG) and group G (n=30, receiving VCV). The two groups did not show significant differences in terms of sex ratio, age, body weight, surgical time, and duration of OLV (all P>0.05) (*Table 1*).

All infants were tracheally intubated for general

Table 1 Demographic and clinical characteristics of the two groups ($\bar{x}\pm s$)

Parameter	Group V (n=28)	Group G (n=30)	P value
Male/female ratio	15/13	16/14	–
Age (months)	8.29±2.55	8.40±1.99	0.855
Body weight (kg)	7.35±2.38	7.05±2.62	0.651
Operative time (min)	76.12±10.72	77.03±8.08	0.715
OLV duration (min)	55.11±7.97	53.13±5.43	0.271

OLV, one-lung ventilation.

Table 2 Comparison of the perioperative hemodynamics of the two groups ($\bar{x}$±s)

Parameter	Group V (n=28)	Group G (n=30)	P value
T1			
MAP (mmHg)	52.50±6.93	50.47±5.39	0.212
HR (bpm)	115.53±12.07	117.87±10.25	0.428
T2			
MAP (mmHg)	48.89±7.91	50.47±5.40	0.375
HR (bpm)	116.84±12.38	117.87±10.25	0.731
T3			
MAP (mmHg)	52.28±5.57	50.40±6.12	0.227
HR (bpm)	118.33±8.97	116.63±10.09	0.502

MAP, the mean arterial pressure; HR, heart rate.

anesthesia. Anesthesia was induced with intravenous atropine 0.01 mg/kg, propofol 2–3 mg/kg, sufentanil 0.3–0.5 μg/kg, and rocuronium 0.6 mg/kg. After denitrogenation for 2 minutes, the glottis was exposed under video laryngoscopy. A blocking bronchial catheter (Tappa, Zhejiang, China) was placed, followed by the insertion of an endotracheal tube. The location of the blocking bronchial catheter was adjusted by a fiberoptic bronchoscope (FOB), and then the anesthesia machine was connected for mechanical ventilation of the double lung. Anesthesia was maintained with remifentanil 0.2–0.5 μg/kg/min, sevoflurane 1–3%, and rocuronium 5–6 μg/kg/min. VCV was applied in group V, and PCV-VG was applied in group G. Ventilator settings during two-lung ventilation were as follows: FiO_2 0.4–0.6, PEEP 3–5 mmHg, I/E ratio 1:1.5, VT 8–10 mL/kg, R 30–35 times/min, and oxygen flow 2–3 L/min. However, the ventilator settings during OLV were as follows: FiO_2 0.8–1.0, PEEP 3–5 mmHg, I/E ratio 1:1.5, VT 4–6 mL/kg, R 30–35 times/min, and oxygen flow 2–3 L/min; the $PETCO_2$ was maintained at 40–55 mmHg. A chest drainage bottle was connected at the end of the thoracic operation, and a recruitment maneuver was performed (12), during which the airway pressure was maintained at 30 mmHg for 10 s by hand-controlled squeezing of the balloon, repeated 3 to 5 times. After surgery, the patient was transferred to the pediatric intensive care unit (PICU) for postoperative observation.

General data, including sex ratio, age (in months), body weight, operative time, and duration of OLV, were collected from medical records. Data related to anesthesia management were also collected, including mean arterial pressure (MAP), heart rate (HR), peak inspiratory pressure (P_{peak}), mean airway pressure (P_{mean}), dynamic compliance (C_{dyn}). The number of patients who experienced hypoxemia (defined as oxygen saturation S_PO_2 <90%) and/or hypotension (defined as MAP below 20% of the baseline value) during OLV was recorded. Arterial blood was drawn for blood gas analysis and determination of PaO_2 in a lateral recumbent position 10 minutes before OLV (T1), 30 minutes after the onset of OLV (T2), and 10 minutes after OLV (T3).

Statistical analysis

Statistical analysis was performed using SPSS software (23.0 version, IBM Corp., Armonk, NY). The measurement data for the normal distribution were presented as a mean ± SD used by the *t*-test. Categorical variables were shown as frequency (percentage) and evaluated with the χ^2 test. A P value less than 0.05 was defined as statistically significant.

Results

Hemodynamic indicators

The hemodynamic indicators did not show significant differences between group V and group G at T1, T2, and T3 (*Table 2*).

P_{peak}, P_{mean}, and C_{dny}

P_{peak} and P_{mean} were significantly lower, and C_{dyn} was significantly higher in group G than in group V in T2 (all

Table 3 Comparison of respiratory mechanics of the two groups ($\bar{x}\pm s$)

Parameter	Group V (n=28)	Group G (n=30)	P value
T1			
P_{peak} (cmH_2O)	17.06±2.05	16.07±2.83	0.139
P_{mean} (cmH_2O)	7.85±2.21	7.22±2.87	0.355
C_{ydn} (mL/cmH_2O)	23.02±1.58	22.67±2.82	0.566
PaO_2 (mmHg)	228.03±47.01	217.73±50.37	0.425
$PaCO_2$ (mmHg)	39.0±3.12	38.5±4.89	0.522
T2			
P_{peak} (cmH_2O)	22.59±2.67[ab]	19.23±3.71[c]	<0.001
P_{mean} (cmH_2O)	10.39±1.63[ab]	9.17±2.42[c]	0.029<0.05
C_{ydn} (mL/cmH_2O)	13.15±2.36[ab]	14.33±1.30[c]	0.021<0.05
PaO_2 (mmHg)	123.70±32.58[ab]	142.30±29.40[c]	0.026<0.05
$PaCO_2$ (mmHg)	46.50±4.44[b]	46.23±6.16[c]	0.852
T3			
P_{peak} (cmH_2O)	17.36±2.09	16.67±2.58	0.270
P_{mean} (cmH_2O)	7.21±2.84	6.90±2.34	0.651
C_{ydn} (mL/cmH_2O)	21.90±4.55	22.97±3.57	0.322
PaO_2 (mmHg)	225.97±43.05	218.77±39.53	0.509
$PaCO_2$ (mmHg)	38.79±3.24	38.37±3.24	0.668

[a], P<0.05, compared to group G; [b], P<0.05, compared to T1 in group V; [c], P<0.05, compared to T1 in group G. P_{peak}, the peak airway pressure; P_{mean}, the mean airway pressure; C_{dyn}, pulmonary compliance; PaO_2, arterial partial pressure of oxygen.

Table 4 Comparison of intraoperative complications between two groups

Parameter	Group V	Group G	P value
Number of patients	28	30	–
Intraoperative hypotension, n (%)	3 (10.7)	5 (16.7)	0.567
Intraoperative hypoxemia, n (%)	8 (28.6)[a]	2 (6.7)	0.027

[a], P<0.05, compared to group G.

P<0.05) (*Table 3*).

Compared to T1, T2 had significantly elevated P_{peak} and P_{mean} and significantly decreased C_{dny} in groups V and G.

More specifically, compared to the values at T1, Ppeak at T2 increased significantly by 5.04 (95% CI: 3.30–6.77) and 3.17 (95% CI: 1.56–4.77) in group V and group G, respectively (both P<0.001) and P_{mean} at T2 increased significantly by 2.46 (95% CI: 1.32–3.61) and 2.40 (95% CI: 1.05–3.75) (both P<0.001); however, Cdyn decreased significantly by 10.04 (95% CI: 8.99–11.08) and 8.33 (95% CI: 7.24–9.43) (both P<0.001).

PaO_2 and $PaCO_2$

PaO_2 was significantly higher in group G than in group V in T2 (P<0.05); however, PaO_2 did not show significant differences in T1 and T3 (both P>0.05).

PaO_2 decreased significantly in T2 than in T1 in both group V [by 104.64 (95% CI: 81.68–127.61)] and group G [by 75.43 (95% CI: 50.66–100.20)] (both P<0.05) (*Table 4*).

$PaCO_2$ did not show significant differences between two groups in T1, T2, and T3 (all P>0.05).

$PaCO_2$ increased significantly in T2 than in T1 in both group V [by 7.500 (95% CI: 5.35–9.65)] and group G [by 7.933 (95% CI: 4.93–10.94)] (both P<0.05) (*Table 4*).

Incidences of hypotension and hypoxia

Hypoxemia and hypotension were observed in both groups. The incidence of hypoxemia was significantly higher in group V than in group G (P<0.05), whereas the incidence of hypotension was not significantly different (P>0.05).

Discussion

This retrospective study found that the PCV-VG mode provided lower P_{peak} and P_{mean}, higher lung compliance, and better oxygenation during OLV in infants undergoing VATS.

Compared with thoracotomy, thoracoscopic surgery has the advantages of small incision, less postoperative pain, faster recovery and shorter hospital stay (13). One lung ventilation is an essential anesthesia technique in thoracoscopic surgery. OLV provides a good environment for VATS by allowing ventilation through the healthy lung, while allowing the intentional collapse of the lung on the operative side, keeping the operative field relatively still (14). OLV can also prevent blood or secretions from the diseased side from entering the healthy side during surgery, preventing cross-infection in both lungs. However, based on characteristics of infant respiratory physiology, it is prone tendency toward shunt and hypoxemia when implementing OLV through thoracoscopy (15). As a non-physiological ventilation mode, OLV, when performed inappropriately, can lead to ventilator-induced lung injury (VILI). Excessively high P_{peak}, prolonged inspiratory time, and partial alveolar hyperinflation due to the uneven distribution of gas in the lungs are the main causes of VILI (16). Due to their small airway lumen, infants and children have high airway resistance and poor lung compliance; compared to adults, they are more prone to high airway pressure and ventilation/blood flow disproportion and are more likely to develop lung dysfunction. It is necessary to choose the appropriate mode of mechanical ventilation to avoid lung injury related to respiration.

VCV is currently a common ventilation mode during anesthesia. In the VCV mode, the flow rate gradually increases during the ventilator inspiratory phase. Therefore, the pressure of the airways gradually increases, with small airways and alveoli expanding until the set tidal volume is converted to the expiratory phase in a set time.

In our current study, we found in both groups that C_{dyn} was significantly lower in T2 compared to T1 and returned to the baseline level in T3. During OLV, the elasticity of lung tissue, thoracic compliance, and resistance to airways changes dramatically due to the specific body position, affecting lung compliance. In our current study, C_{dyn} was significantly higher in group G than in group V at T2, i.e., during OLV, and P_{peak} and P_{mean} were significantly lower in group G than in group V. Lung compliance decreases during OLV. To ensure the delivery of a preset tidal volume to the lungs of a pediatric patient, the PCV-VG mode automatically adjusts the air delivery rate and the airway pressure level according to reduced lung compliance, resulting in a prolonged inspiratory phase and the lowest P_{peak}; it is adjusted to the expiratory mode after the target tidal volume is reached. A meta-analysis found significantly lower P_{peak} (P<0.00001) in the PCV-VG group than in the VCV group in adults undergoing OLV (17).

During mechanical ventilation, a change in intrathoracic pressure can affect the venous return and thus circulatory function. In our current study, there was no significant difference in the incidences of MAP and hypotension during OLV between the two groups.

We also found no statistical differences in PaO_2 and $PaCO_2$ between the PCV-VG mode and the VCV mode in T1 and T3 during double lung ventilation. In T2, however, although the PO_2 value was above 100 mmHg in both groups, it was significantly higher in group G than in group V. Similarly, the incidence of hypoxemia was significantly higher in group V than in group G. Possible explanations may include the following: First, VCV is associated with high P_{peak} during OLV, which aggravates the mechanical strain on the lung tissue (18). In addition, it will worsen the uneven distribution of gas in the lungs, resulting in alveolar hyperinflation. Therefore, more blood flows to the nonventilated lung, weakening hypoxic pulmonary vasoconstriction and increasing the incidence of hypoxemia (19). Second, the decrease in airflow during the air delivery pattern of the PCV-VG mode makes the airway pressure reach its maximum at the beginning of inspiration, which will be maintained throughout the inspiratory phase. Small airways and alveolar tissues open in the shortest time, so even tissues with low compliance can receive a certain amount of air, and the constant plateau pressure is more conducive to oxygen diffusion. Therefore, it possibly reduces the injury caused by high airway pressure, improving intrapulmonary shunting to some extent, and lung compliance, which facilitates alveolar ventilation and oxygenation. Ghabach *et al.* (20) and Mahmoud *et al.* (11) also found that PCVVG significantly reduced airway pressure and improved oxygenation (compared to VCV).

There are still some limitations to this study. This study is a retrospective single-center study involving a small sample size, and there may have been some selective deviation. Besides, this study was a retrospective study, not a prospective case-control study, which also limited its statistical potency, but we still believed that such a study had certain clinical significance. Future research needed to consider variations of factors and complete a larger sample to confirm our conclusions.

Conclusions

Mechanical ventilation using the PCV-VG mode is feasible in infants when performing OLV during VATS. Compared to VCV, PCV-VG can offer lower P_{peak} and P_{mean}, improve lung compliance, and achieve better oxygenation.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All procedures performed in this study involving human participants were in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by institutional committee ethics board of Fujian Maternity and Child Health Hospital (No. 2020YJ192). Individual consent for this retrospective analysis was waived.

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