Int J Clin Exp Med 2014;7(4):1094-1098
www.ijcem.com /ISSN:1940-5901/IJCEM0000128

Original Article

Applications of pressure control ventilation volume guaranteed during one-lung ventilation in thoracic surgery

Jun Pu[1], Zhenxiu Liu[2], Liye Yang[1], Yanan Wang[1], Jingjing Jiang[1]

[1]*Department of Anesthesiology, Changzheng Hospital, Second Military Medical University, 415 Fengyang Road, Shanghai, People's Republic of China;* [2]*Jiangsu Province Key Laboratory of Anesthesiology, Xuzhou Medical College, Xuzhou 221002, China*

Received April 11, 2014; Accepted April 13, 2014; Epub April 15, 2014; Published April 30, 2014

Abstract: Objective: To explore the effects of ventilatory mode "pressure controlled ventilation-volume guaranteed" (PCV-VG) on the inspiratory pressures, oxygenation parameters and hemodynamics of patients during one lung ventilation (OLV) for thoracic surgery, compared with volume controlled ventilation (VCV). Methods: Twenty participants were recruited and equally assigned into two groups in a controlled, randomized, crossover design. Group A: VCV was performed initially and changed into PCV-VG after 30 min; Group B: In the reverse order. Blood gas analysis, peak inspiratory pressure (Ppeak), mean inspiratory pressure (Pmean), plateau inspiratory pressure (Plateau) were measured at four different time points: (1) 30 min after total lung ventilation (TLV); (2) 30 min after one lung ventilation (VCV or PCV-VG); (3) 30 min after shifting to the other ventilatory mode, and (4) 30 min after reconstruction of TLV. Results: The Ppeak, Plateau, and Pmean were significantly lower in PCV-VG compared with VCV. There was significant increase in arterial partial pressure of oxygen under PCV-VG. Conclusion: In patients undergoing thoracic surgery with OLV, pressure controlled volume guaranteed mode of ventilation may have better effects by decreasing inspiratory pressure parameters and improving arterial oxygenation than volume controlled ventilation.

Keywords: One lung ventilation, volume controlled ventilation, pressure controlled ventilation-volume guaranteed, inspiratory pressure parameters, arterial oxygenation

Introduction

Postoperative pulmonary complications, particularly acute lung injury (ALI), are a primary cause of death among thoracic surgery patients [1]. Risk factors for the occurrence of postoperative ALI include preoperative health status and the extent of injury incurred during surgical procedures; in addition, patients who receive one-lung ventilation (OLV) during surgery or who undergo cardiopulmonary bypass are at increased risk of ALI [2]. Volume-controlled ventilation (VCV) is a commonly used mode of ventilation during anesthesia. In particular, VCV approaches include normal tidal volume (VT) OLV and low-VT high-frequency OLV. The use of VCV can ensure the maintenance of minute ventilation; however, a constant flow rate may result in higher peak inspiratory pressures, increasing the incidence of barotrauma and causing the uneven distribution of pulmonary gas. Compared with VCV, pressure-controlled ventilation (PCV) can produce lower airway pressure, reduce the incidence of barotrauma, maintain the uniform distribution of pulmonary gas, and improve oxygenation [3]. However, a drawback of PCV is that VT can change as a patient's lung compliance changes; therefore, minute ventilation is not necessarily maintained.

Guaranteed-volume PCV (PCV-VG) is a novel mode of ventilation that has been utilized in recent years. This mode of ventilation involves a decelerating flow and constant pressure. Mechanical parameters are automatically adjusted with each patient breath to provide a predetermined VT with minimal positive pressure. PCV-VG combines the advantages of VCV and PCV to maintain ventilation volume while

producing a low incidence of barotrauma. Thus, PCV-VG may become a preferred approach for OLV during thoracic surgery.

At present, there are few clinical studies on the PCV-VG mode of ventilation. In this study, a crossover design was used to conduct a randomized controlled trial that compared the effects of PCV-VG and VCV with respect to pressure parameters and respiratory and circulatory indicators during OLV in thoracic surgery patients, thereby providing a basis for the clinical application of the PCV-VG mode of ventilation.

Materials and methods

Clinical data

A total of 20 patients who underwent elective thoracic surgery at Shanghai Changzheng Hospital between October 2013 and December 2013 were selected for participation in this study. These patients received at least one hour of OLV during surgery. The study subjects included 11 males and 9 females and ranged from 39 to 80 years of age. The average age and weight of the study subjects were 59.8 years and 60.1 ± 9.7 kg, respectively. Study participants were in American Society of Anesthesiologists (ASA) class II and ASA class III and exhibited essentially normal preoperative heart, lung, liver, and kidney function. After providing informed consent, the subjects were randomly divided into experimental groups A and B, with 10 patients in each group.

Anesthesia method

All patients received an intramuscular injection of 0.5 mg atropine and 0.1 g phenobarbital 30 minutes prior to anesthesia. Blood pressure, heart rate (HR), electrocardiogram (ECG) readings, pulse oxygen saturation (SpO_2), and end-tidal carbon dioxide ($P_{ET}CO_2$) were continuously and noninvasively monitored after patients entered the operating room. To establish a fluid path, radial artery cannulation was performed under local anesthesia, allowing for the invasive monitoring of arterial blood pressure and the analysis of blood gases. Anesthesia was induced with 0.05 mg/kg midazolam, 2 mg/kg propofol, 2 μg/kg fentanyl, and 0.6 mg/kg cisatracurium besilate. A double-lumen endotracheal tube (Smith, Australia) was inserted; after a fiberoptic bronchoscopy was performed to confirm that the tube was correctly positioned, the tube was connected to a Datex-Ohmeda (Advance-Aisys) anesthesia machine. During surgery, target-controlled infusions of propofol (AstraZeneca, Italy) and remifentanil (Yichang Humanwell Pharmaceutical, Hubei, China) were used to maintain target plasma concentrations of 3-3.5 μg/mL and 4-6 μg/mL, respectively, and additional fentanyl and cisatracurium besilate were intermittently administered as needed. No vasodilators or inhaled anesthetics were used during the operation.

Ventilation method

The overall ventilation procedure during anesthesia was divided into the following three stages: the first stage (two-lung ventilation with VCV (TLV-VCV)): The parameters utilized during this stage included a VT of 8-10 ml/kg, an inspiratory-to-expiratory ratio of 1:2, an inspiratory pause of 0.9 s, and a respiratory rate of 12 breaths/minute. $P_{et}CO_2$ was maintained at 30-35 mmHg. The T1 time point was set to 30 minutes after the start of ventilation.

The second stage (OLV): In Group A, VCV was first used for OLV. For this VCV treatment, the VT was 8-10 ml/kg, the respiratory rate was 12 breaths/minute, and a $P_{et}CO_2$ of 30-35 mmHg was maintained. The T2 time point was set to 30 minutes after beginning OLV; at this time, the mode of ventilation was changed to PCV-VG, with the same ventilation parameters. The T3 time point was set to 30 minutes after this change in ventilation mode. In Group B, PCV-VG was first used for OLV. For this PCV-VG treatment, VT was 8-10 ml/kg; the respiratory rate was 12 breaths/minute, and a $P_{et}CO_2$ of 30-35 mmHg was maintained. The T2 time point was set to 30 minutes after beginning OLV; at this time, the mode of ventilation was changed to VCV, with the same ventilation parameters. The T3 time point was set to 30 minutes after this change in ventilation mode.

The third stage (post-reconstruction two-lung ventilation with volume-controlled ventilation (TLVpostR-VCV)): The TLVpostR-VCV mode of ventilation was performed after OLV was completed. This stage used the same ventilation parameters that were utilized during the first stage. The T4 time point was set to 30 minutes after the start of TLVpostR-VCV.

Outcome measures

Values for the following indicators were obtained at time points T1-T4:

Table 1. Respiratory parameters between two groups

	Group A				Group B			
	T1	T2	T3	T4	T1	T2	T3	T4
Ppeak (cmH_2O)*	18.1 ± 1.9	28.7 ± 3.8	24.1 ± 3.8	20.1 ± 3.4	20.0 ± 3.1	24.4 ± 2.2	28.7 ± 3.6	22.2 ± 3.2
Plateau (cmH_2O)*	15.8 ± 2.1	25.6 ± 3.9	23.0 ± 4.1	17.4 ± 3.5	17.2 ± 2.7	23.1 ± 2.1	25.3 ± 3.0	19.2 ± 3.0
Pmean (cmH_2O)*	6.5 ± 0.5	9.8 ± 0.9	9.3 ± 0.9	6.9 ± 0.7	7.0 ± 1.2	9.7 ± 3.5	10.2 ± 3.3	7.7 ± 1.3

*Statistically significant differences between the two groups.

Table 2. Blood gas analysis between two groups

	Group A				Group B			
	T1	T2	T3	T4	T1	T2	T3	T4
PaO_2 (mmHg)*	466.0 ± 55.7	170.6 ± 20.8	215.8 ± 25.7	393.5 ± 68.6	444.9 ± 67.8	223.9 ± 23.7	160.4 ± 19.2	393.3 ± 58.0
$PaCO_2$ (mmHg)	33.4 ± 2.4	34.3 ± 3.1	34.1 ± 2.5	33.6 ± 2.5	35.3 ± 3.0	35.8 ± 3.2	36.6 ± 3.3	35.8 ± 3.7
pH	7.43 ± 0.04	7.40 ± 0.04	7.41 ± 0.03	7.4 ± 0.06	7.40 ± 0.04	7.39 ± 0.04	7.38 ± 0.03	7.40 ± 0.04
SaO_2 (%)	100 ± 0	99.3 ± 1.3	99.5 ± 1.0	100 ± 0	100 ± 0	98.2 ± 3.0	98.4 ± 3.1	99.8 ± 0.4

*Statistically significant differences between the two groups.

(1) Respiratory mechanics parameters: VT, peak airway pressure (Ppeak), plateau airway pressure (Plateau), and mean airway pressure (Pmean).

(2) Arterial blood gas analysis: arterial partial pressure of oxygen (PaO_2), arterial partial pressure of carbon dioxide ($PaCO_2$), pH, and oxygen saturation (SaO_2).

(3) Hemodynamics: HR, systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and central venous pressure (CVP).

Statistical analysis

All data are expressed as $\bar{x} \pm s$. Cross-stage comparisons between the two examined ventilation modes were conducted as follows: T-tests were performed after testing for carryover effects [4], and repeated-measures analysis of variance was used for pairwise comparisons of data from different time points. The SPSS 17.0 statistical software package was used for data analysis, and $P < 0.05$ was regarded as statistically significant.

Results

Respiratory parameters

The respiratory parameter data obtained at each time point are presented in **Table 1**. There were no significant differences in VT between the two examined ventilation modes at T2 and T3. No carryover effects in Ppeak from stage 2 to stage 3 were detected ($P = 0.916$), and comparisons of the two examined ventilation modes revealed significant differences in Ppeak ($P < 0.001$). Similarly, there were no carryover effects on Plateau or Pmean ($P = 0.945$ and $P = 0.72$, respectively), and comparisons of the two examined ventilation modes revealed significant differences for both parameters ($P < 0.001$ and $P = 0.002$, respectively). Compared with VCV, PCV-VG produced lower peak airway pressures, plateau pressures, and mean airway pressures.

Blood gas analysis

The blood gas data obtained at each time point are presented in **Table 2**. In both groups, PaO_2 was significantly lower at T2, T3, and T4 than at T1 ($P < 0.05$). No carryover effects on PaO_2 from stage 2 to stage 3 were detected ($P = 0.892$), and comparisons of the two examined ventilation modes revealed significant differences in PaO_2 ($P < 0.001$). There were also no carryover effects on $PaCO_2$ ($P = 0.145$), but comparisons of the two examined ventilation modes revealed no significant differences in $PaCO_2$ ($P = 0.113$). No carryover effects on pH were observed ($P = 0.294$), and comparisons of the two examined ventilation modes revealed significant differences in pH ($P = 0.02$). Finally, there were no carryover effects on SaO_2 ($P = 0.297$), but comparisons of the two examined ventilation modes revealed no significant differences in SaO_2 ($P = 1.00$). Thus, relative to VCV, PCV-VG produces improved arterial PaO_2 and higher pH values;

Table 3. Hemodynamics between two groups

	Group A				Group B			
	T1	T2	T3	T4	T1	T2	T3	T4
HR (b/min)	76.8 ± 12.3	79.3 ± 7.6	76.7 ± 6.6	73.7 ± 13.2	72.9 ± 7.9	75.5 ± 10.8	73.8 ± 9.2	71.2 ± 8.4
SBP (mmHg)	135.3 ± 16.4	123.1 ± 18.3	122.2 ± 11.5	120.9 ± 9.9	139.6 ± 20.7	129.1 ± 10.5	120.6 ± 13.3	124.5 ± 9.7
DBP (mmHg)	73.6 ± 10.9	72.1 ± 10.1	73.4 ± 8.2	69.3 ± 6.5	75.1 ± 10.3	70.4 ± 6.3	68.7 ± 7.3	71.6 ± 7.6
MAP (mmHg)	96.3 ± 12.1	92.1 ± 18.7	93.3 ± 12.0	87.2 ± 7.1	96.2 ± 13.1	90.3 ± 6.5	86.1 ± 8.3	88.3 ± 8.9
CVP (cmH_2O)	6.4 ± 1.6	7.2 ± 0.8	7.6 ± 1.0	7.9 ± 1.3	7.3 ± 0.9	7.7 ± 1.7	7.9 ± 1.8	7.8 ± 1.3

however, VCV and PCV-VG did not significantly differ with respect to $PaCO_2$ and SaO_2.

Hemodynamics

The hemodynamic data obtained at each time point are presented in **Table 3**. There were no carryover effects on HR, SBP, DBP, MAP, or CVP ($P = 0.352$, $P = 0.706$, $P = 0.365$, $P = 0.400$, and $P = 0.490$, respectively), and comparisons of the two examined ventilation modes revealed no significant differences in any of these parameters ($P = 0.791$, $P = 0.097$, $P = 0.207$, $P = 0.141$, and $P = 0.691$, respectively). Thus, there were no significant differences in hemodynamic indicators between VCV and PCV-VG.

Discussion

In this study, we found that in a comparison of the PCV-VG and VCV modes of ventilation for OLV during thoracic surgery, PCV-VG produced better patient oxygenation, significantly lower peak airway pressure and plateau pressure, and slightly lower mean airway pressure. These results indicated that PCV-VG, which provides decelerating flow, may be superior to VCV with respect to alveolar ventilation and gas distribution [5]. An examination of PaO_2 values at the T1, T2, T3, and T4 time points revealed that varying degrees of decrease in PaO_2 occurred after resuming two-lung ventilation relative to the period prior to OLV; these findings suggest that in either examined mode of OLV, there exist factors such as pulmonary atelectasis that influence oxygenation. PCV-VG produces higher pH values in patients than VCV, which could indicate that of the two examined ventilation modes; PCV-VG may be associated with better oxygenation. VT was nearly identical for these two ventilation modes, suggesting that PCV-VG is indeed able to deliver a predetermined ventilation volume to patients. There were no significant differences in hemodynamic parameters between the two ventilation modes, indicating that these ventilation modes produced similar effects on patient circulatory systems.

High airway pressure during OLV can cause barotrauma, which is a major cause of postoperative ALI in thoracic surgery patients [6]. Ppeak is generally considered to be associated with dynamic lung compliance, whereas Plateau is associated with static lung compliance, and Pmean is associated with alveolar ventilation and oxygenation [7]. However, it remains unclear which airway pressure indicators are significantly correlated with the incidence of postoperative ALI. The results of this study suggest that relative to VCV, the PCV-VG mode of ventilation is capable not only of producing more optimal respiratory mechanics parameters but also enhancing patient oxygenation; thus, the use of PCV-VG instead of VCV could potentially reduce the incidence of postoperative ALI. This possibility merits additional investigation. However, the improvements in PaO_2 produced by PCV-VG relative to VCV may be associated with a decrease in pulmonary shunt. High airway pressure during OLV may cause blood to enter the non-ventilated lung, exacerbating ventilation/perfusion imbalances. Compared with VCV, PCV-VG can generate lower airway pressures, reducing the shunting of blood between lungs.

The PCV-VG ventilation mode combines the advantages of VCV and PCV, delivering a predetermined VT while maintaining minimal airway pressure. To date, many studies have compared PCV and VCV [8-12]; however, few investigations have compared PCV-VG and VCV [13]. Moreover, the results from comparisons of PCV and VCV remain controversial. Studies by Li and Li et al. [8, 9] found that PCV was superior to VCV for OLV because PCV produced lower airway pressures, reduced pulmonary shunt, and improved oxygenation. However, investigations by Patricia and Unzueta et al. failed to corroborate these benefits of PCV [11, 12]. The fact

that minute ventilation is not necessarily maintained in PCV may be relevant to the aforementioned findings, although further studies comparing VCV and PCV may be required. Boules et al. [13] first evaluated the effects of PCV-VG and VCV on various parameters, including indicators of respiratory mechanics and hemodynamics, during OLV. Similarly to our results, the findings of Boules et al. indicated that PCV-VG provided improved oxygenation and lower airway pressures relative to VCV. So far, no relevant studies have compared PCV-VG and PCV; thus, this topic requires additional investigation. In addition, further research is needed to investigate whether the use of PCV-VG instead of other ventilation modes can reduce postoperative complications and improve patient prognoses.

This study utilized randomized, controlled trials in a crossover design. Relative to a parallel group design, this crossover design enabled the same rates of type I and type II errors to be achieved with a smaller sample size. However, a key issue with crossover designs is that interventions during the first stage may produce significant carryover effects during the second stage. In this study, no significant "washout" period was established because the relevant intraoperative indicators, such as airway pressures, rapidly changed as ventilation modes and parameter settings were altered; thus, carryover effects were unlikely to occur. The actual results of statistical analysis demonstrated that there were no significant carryover effects in an examined indicator between the two stages of interest.

In summary, the results of this study indicated that during OLV in thoracic surgery, the use of PCV-VG instead of VCV can not only produce more optimal respiratory mechanics and improve patient oxygenation but may also reduce the incidence of postoperative pulmonary complications. Additional research is required to address the effects of ventilation modes on patient prognoses.

Disclosure of conflict of interest

None.

Address correspondence to: Dr. Jingjing Jiang, Department of Anesthesiology, Changzheng Hospital, Second Military Medical University, 415 Fengyang Road, Shanghai 200003, China. E-mail: czjingjingjiang@163.com

References

[1] Licker M, Fauconnet P, Villiger Y and Tschopp JM. Acute lung injury and outcomes after thoracic surgery. Curr Opin Anesthesiol 2009; 22: 61-7.

[2] Kilpatrick B and Slinger P. Lung protective strategies in anaesthesia. Brit J Anaesth 2010; 105: i108-i16.

[3] Nichols D and Haranath S. Pressure Control Ventilation. Crit Care Clin 2007; 23: 183-99.

[4] Wellek S and Blettner M. On the proper use of the crossover design in clinical trials: part 18 of a series on evaluation of scientific publications. Dtsch Arztebl Int 2012; 109: 276-81.

[5] Cadi P, Guenoun T, Journois D, Chevallier JM, Diehl JL and Safran D. Pressure-controlled ventilation improves oxygenation during laparoscopic obesity surgery compared with volume-controlled ventilation. Brit J Anaesth 2008; 100: 709-16.

[6] Alam N, Park BJ, Wilton A, Seshan VE, Bains MS, Downey RJ, Flores RM, Rizk N, Rusch VW and Amar D. Incidence and risk factors for lung injury after lung cancer resection. Ann Thoracic Surg 2007; 84: 1085-91.

[7] Marini JJ and Ravenscraft SA. Mean airway pressure: physiologic determinants and clinical importance--Part 2: Clinical implications. Crit Care Med 1992; 20: 1604-16.

[8] Li J, Xu XH, Zou XH and Chang YT. Pressure-controlled versus volume-controlled ventilation during one-lung ventilation for thoracic surgery. J Pract Med 2009; 25: 1771-1.

[9] Li FR, Ding J, Gao J, Geng EJ and Shen LN. Comparison of pressure controlled with volume controlled ventilation in lung protective strategy during aged patient's one—lung anesthesia. Shandong Medical Journal 2009; 49: 11-3.

[10] Tuğrul M, Camci E, Karadeniz H, Sentürk M, Pembeci K and Akpir K. Comparison of volume controlled with pressure controlled ventilation during one-lung anaesthesia. Brit J Anaesth 1997; 79: 306-10.

[11] Cruz Pardos P, Garutti I, Piñeiro P, Olmedilla L and de la Gala F. Effects of ventilatory mode during one-lung ventilation on intraoperative and postoperative arterial oxygenation in thoracic surgery. J Cardiothor Vasc Anesth 2009; 23: 770-4.

[12] Unzueta MC, Casas JI and Moral MV. Pressure-controlled versus volume-controlled ventilation during one-lung ventilation for thoracic surgery. Anesth Analg 2007; 104: 1029-33.

[13] Boules NS and Ghobrial HZ. Efficiency of the newly introduced ventilatory mode "pressure controlled ventilation-volume guaranteed" in thoracic surgery with one lung ventilation. Egypt J Anaesth 2011; 27: 113-9.