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Research Article

Efficiency of the newly introduced ventilatory mode "pressure controlled ventilation-volume guaranteed" in thoracic surgery with one lung ventilation

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KEYWORDS

Thoracic surgery;
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Volume controlled ventilation (VCV);
Pressure controlled ventilation-volume guaranteed (PCV-VG)

Abstract *Background:* Anesthesia for thoracic surgery routinely involves one lung ventilation (OLV). Volume controlled ventilation (VCV) was and still the most common method of performing OLV. We assumed that pressure controlled ventilation-volume guaranteed (PCV-VG) is a better ventilation strategy for OLV than VCV as regard the inspiratory pressures, oxygenation parameters and post-operative ventilatory outcome.

Methods: Forty patients undergoing elective thoracic surgery in the lateral position requiring at least 1 h of OLV were randomly assigned into two groups. Group VCV: VCV was performed throughout the operation. Group PCV-VG: PCV-VG was performed throughout the operation. Blood gas analysis, peak inspiratory pressure (P_{peak}), mean inspiratory pressure (P_{mean}), plateau inspiratory pressure (P_{plateau}) were measured: (1) During two lung ventilation (TLV1) 30 min after turning the patient to the lateral decubitus prior the beginning of OLV; (2) 30 min after initiation of OLV(OLV); (3) End of surgery: 30 min after reestablishing TLV (TLV2).

Results: The P_{peak} and the P_{plateau} were significantly lower in PCV-VG compared with VCV in all stages of the study (*P value* < 0.05). There was significant increase in all pressure values in OLV compared with TLV1 in the two groups (*P value* < 0.05). There were significant decrease in the mean Pao2 values during OLV and TLV2 compared with TLV1 in the two groups (*P value* < 0.05).

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Yet the Pao2 was significantly higher in the PCV-VG group at OLV and TLV2 compared to the OLV and TLV2 in VCV group. Also Pao2 was significantly lower in TLV2 compared with TLV1 in both groups (*P value* < 0.05).

Conclusion: In patients undergoing thoracic surgery with OLV, pressure controlled volume guaranteed mode of ventilation decreases inspiratory pressure parameters and improve arterial oxygenation better than volume controlled ventilation.

1. Introduction

Anesthesia for thoracic surgery routinely involves one lung ventilation (OLV) to facilitate surgical exposure, and to isolate and protect the lungs during the procedure. Unfortunately, this practice has been associated with hypoxemia. For many years, arterial hypoxemia during OLV was considered the most important problem for the anesthesiologist. At present, however, there is an increasing concern about the effects of ventilator settings on acute lung injury (ALI) as a consequence of OLV [1].

Volume controlled ventilation (VCV) was and still the most common method of performing one lung ventilation in patients undergoing thoracic surgery. Volume control involves a set tidal volume (VT). The ventilator calculates a flow based on the set tidal volume and the length of the inspiratory time to deliver that tidal volume. A typical volume-controlled pressure waveform increases throughout the entire inspiratory period, and rapidly decreases at the start of expiration, so an increase in the inspiratory pressure is usually observed, and with this excessive amount of inspiratory pressure, the vascular resistance of the dependant lung increases because of compression of intra alveolar vessels [2]. This will counteract hypoxic pulmonary vasoconstriction in the non dependant lung by diverting blood flow away from the ventilated lung, thereby increasing pulmonary shunt fraction [3].

Also the high inspiratory pressure may result in barotraumas of the dependant lung. In order to avoid high inspiratory pressures, lower tidal volumes and higher ventilator rates may be used, but lower tidal volumes have been demonstrated to predispose the dependant lung to atelectasis and worsen arterial oxygenation [4].

Pressure controlled ventilation-volume guaranteed (PCV-VG) is a new mode of ventilation in Datex–Omeda Ventilator, it considered a modification of pressure controlled ventilation in which a tidal volume is set and the ventilator delivers that volume using a decelerating flow and a constant pressure. The ventilator will adjust the inspiratory pressure needed to deliver the set tidal volume breath-by-breath so that the lowest pressure is used. The pressure range that the ventilator will use is between the PEEP + 2 cmH_2O level on the low end and 5 cmH_2O below the maximum pressure on the high end. The inspiratory pressure change between breaths is a maximum of ±3 cmH_2O [5].

This mode will deliver breaths with the efficiency of pressure controlled ventilation, yet still compensate for changes in the patient's lung characteristics. PCV-VG begins by first delivering a volume breath at the set tidal volume. The patient's compliance is determined from this volume breath and the inspiratory pressure level is then established for the next PCV-VG breath [5].

In our study we assume that PCV-VG is a better ventilation strategy for OLA than VCV as it lead to a decrease in the inspiratory pressure parameters and better arterial oxygenation during OLA and may improve post-operative ventilatory outcome.

Table 1 Patient characteristics and operative data.

Variable	VCV group $n = 19$	PCV-VG group $n = 18$	*P* value
Age (year)	34.7 ± 7.6	33.4 ± 6.4	0.562
Wt (kg)	75.6 ± 14.5	71.8 ± 19.7	0.507
Sex (M/F)	12/7	10/8	
ASA (I/II/III)	10/6/3	8/6/4	
Duration of OLV (min)	75.6 ± 34.7	88.7 ± 42.1	0.308
Duration of surgery (min)	278 ± 65	295 ± 83	0.745
Preoperative FVC (% of predicted)	76.4 ± 11.3	74.1 ± 14.4	0.547
Preoperative FEV1 (% of predicted)	74.3 ± 12.5	73.4 ± 11.7	0.823
Surgical procedure			
Metastatectomy	7	5	
Lobectomy	5	6	
Cr oesophagus	3	4	
Mediastinal mass	4	2	
Chest wall mass	0	1	

Data are mean ± SD.
OLV = one-lung ventilation, VCV = volume control ventilation, PCV-VG = pressure control ventilation-volume guaranteed.

Table 2 Respiratory variables at different stages of the study.

Variable	VCV group ($n = 19$)			PCV-VG group ($n = 18$)		
Set time points	TLV1	OLV	TLV2	TLV1	OLV	TLV2
Inspiratory pressures (cm H_2O)						
P_{peak}	18.75 ± 2.61	22.40 ± 2.48 $(P < 0.001)^{*}$	19.75 ± 2.73	14.10 ± 1.89 $(P < 0.001)^{\dagger}$	17.65 ± 1.98 $(P < 0.001)^{*}$ $(P < 0.001)^{\dagger}$	15.30 ± 1.31 $(P < 0.001)^{\dagger}$
P_{plateau}	14.24 ± 1.27	17.24 ± 3.61 $(P < 0.001)^{*}$	15.41 ± 1.36	10.34 ± 2.26 $(P < 0.001)^{\dagger}$	14.12 ± 2.41 $(P < 0.001)^{*}$ $(P < 0.001)^{\dagger}$	11.14 ± 3.28 $(P < 0.001)^{\dagger}$
P_{mean}	4.65 ± 1.39	7.20 ± 1.77 $(P < 0.001)^{*}$	5.65 ± 1.39	3.80 ± 1.06 $(P = 0.043)^{\dagger}$	6.10 ± 1.29 $(P < 0.001)^{*}$ $(P = 0.037)^{\dagger}$	4.70 ± 1.39 $(P = 0.045)^{\dagger}$

Data are presented as mean ± SD.

TLV1 = two lung ventilation, 30 min after turning the patient to the lateral decubitus position.

OLV = one-lung ventilation, 30 min after initiation of OLV.

TLV2 = two-lung ventilation, 30 min after reestablishing TLV.

P_{peak} = peak inspiratory pressure, P_{plateau} = plateau inspiratory pressure, P_{mean} = mean inspiratory pressure.

VCV = volume control ventilation, PCV-VG = pressure control ventilation-volume guaranteed.

[*] P value < 0.05 compared with two-lung ventilation in the same group TLV1 (within group comparison).

[†] P value < 0.05 compared with VCV group at the same time point.

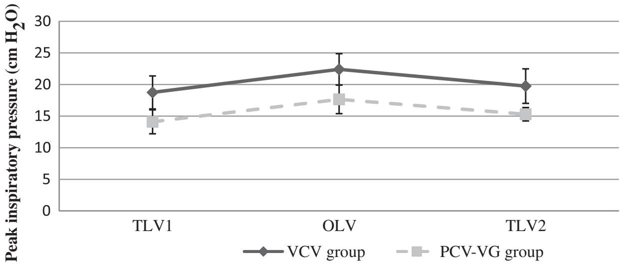
2. Patients and methods

After approval by the local ethics committee and after obtaining written informed consent from each individual, 40 patients aged 18–45 undergoing elective open thoracic surgery in the lateral position requiring at least 1 h of OLV were enrolled. All patients were ASA physical status I, II and III with normal pulmonary function preoperatively. Patients had a history of obstructive airways disease, bronchial asthma, uncompensated cardiac disease or hemodynamically significant arrhythmias were excluded from the study. Patients with any chest infection (clinically or radiologically) were also excluded.

All patients underwent arterial blood gases; lung spirometry (forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV1)) and chest x-ray prior to surgery. Upon arrival to the operating room, patients were monitored with electrocardiogram and pulse oximetry and noninvasive blood pressure. A 16-gauge IV catheter was inserted in an upper extremity vein and 3 mg midazolam were given, also a 20-gauge catheter was inserted in a radial artery under local anesthesia for invasive arterial pressure monitoring and blood gas analysis. A right internal jugular central venous catheter was inserted under local anesthesia for central venous pressure monitoring. After preoxygenation, anesthesia was induced with fentanyl 2 μg/kg, propofol 2 mg/kg, and atracurium 0.5 mg/kg. isoflurane (0.8–1.5% expiratory concentration).

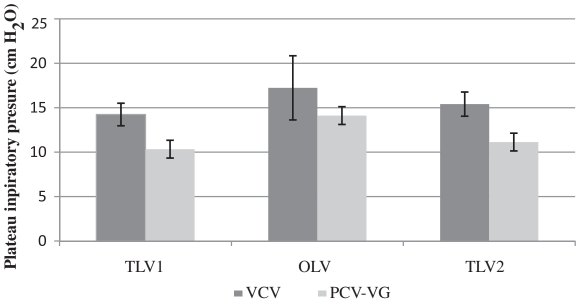
The trachea was intubated with a double lumen tube (Portex Blue Line Endobronchial Tube, Smiths Medical, Mexico) no. 37 for male and no. 35 for female patients. Left double-lumen tubes were chosen as long as there was no contraindication. The position of the tube was confirmed by auscultation before and after turning the patient to the lateral decubitus position. During OLV, the lumen of the nonventilated side was left open to the air. All patients' lungs were ventilated with a Datex-Omeda Ventilator (S/5 Avance-Aisys). Patients were randomly assigned, according to a computer-generated random number table, to one of two groups. Group VCV: VCV was performed throughout the operation as follows: Initially, two lung ventilation (TLV) using a FIO_2 of 1.0, VT of 8–10 mL/kg with inspiratory pause 5% of inspiratory time and a ventilator rate of 12/min, then the rate was adjusted to maintain end-tidal carbon dioxide tension ($ETCO_2$) of 30–35 mmHg. An inspiration to expiration ratio of 1:2 was used, and it was unchanged during all the study. No external positive end expiratory pressure (PEEP) was applied. Upon initiation of OLV, (OLV-VCV) we use a VT of 6 mL/kg, and the ventilator rate adjusted to maintain $ETCO_2$ of 30 to 35 mmHg. Group PCV-VG: PCV-VG was performed throughout the operation as follows: Initially, two lung ventilation (TLV) using a FIO_2 of 1.0, VT of 8–10 mL/kg with inspiratory pause 5% of inspiratory time and a ventilator rate of 12 min^{-1}, then the rate was adjusted to maintain end-tidal carbon dioxide tension ($ETCO_2$) of 30–35 mmHg. An inspiration to expiration ratio of 1:2 was used. No external positive end expiratory pressure (PEEP) was applied; inspiratory pressure was adjusted (not exceeding 35 cmH_2O). Upon initiation of OLV, (OLV-PCV-VG) we use a VT of 6 mL/kg, and the ventilator rate adjusted to maintain $ETCO_2$ of 30–35 mmHg.

Blood gas analysis, peak inspiratory pressure (P_{peak}), mean inpiratory pressure (P_{mean}), plateau inspiratory pressure (P_{plateau}) were measured and recorded at three stages: (1)



TLV1= Two lung ventilation, 30 min after turning the patient to the lateral decubitus
OLV = One-lung ventilation, 30 min after initiation of OLV
TLV2= Two-lung ventilation, 30 min after reestablishing TLV
VCV= volume control ventilation, PCV-VG= pressure control ventilation - volume guaranteed

Figure 1 Peak inspiration pressure in the two groups at different stages of the study.



TLV1= Two lung ventilation, 30 min after turning the patient to the lateral decubitus
OLV = One-lung ventilation, 30 min after initiation of OLV
TLV2= Two-lung ventilation, 30 min after reestablishing TLV
VCV= volume control ventilation, PCV-VG= pressure control ventilation- volume guaranteed

Figure 2 Pla#132;teau inspiratory pressure in the two groups at different stages of the study.

During TLV 30 min after turning the patient to the lateral decubitus position prior the beginning of OLV (TLV1); (2) 30 min after initiation of OLV (OLV); (3) End of surgery: 30 min after reestablishing TLV (TLV2). During the measurement period surgical manipulation of the lung was not allowed. Follow up chest x-ray was performed day 1 and day 3 postoperatively. Hemodynamic variables were measured every 5 min and recorded at the same points. CVP was measured every 30 min and recorded at the same points.

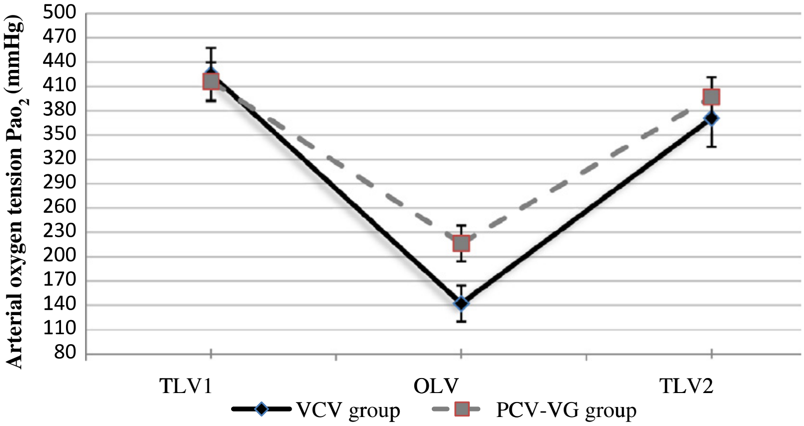
2.1. Statistical analysis

Data were computerized and analyzed using the Statistical Package for the Social Science (SPSS) Version 13. Normality of the distribution of data was assessed by the Kolmogorov-Smirnov test. Changes in hemodynamic and respiratory parameters during TLV and OLV sequences were analyzed using repeated measures analysis of variance (ANOVA) followed by the Scheffef-test, as appropriate. Otherwise, normally distributed continuous variables were compared using the Student's *t*-test. To present the results, mean ± SD were used and a $P < 0.05$ was considered statistically significant.

3. Results

This was a prospective randomized controlled clinical study that was conducted in National Cancer Institute of Egypt (NCI) between August 2010 and December 2010. Among the 40 patients initially enrolled, only two cases in the PCV-VG group was excluded from the study because of massive blood loss and massive blood transfusion and the need for inotropic support, Also one case of VCV group, shows arterial hypoxemia ($Sao_2 < 90\%$) requiring reinflation of the collapsed lung, was excluded. Data were normally distributed. Demographic characteristics, ASA distribution, duration of one-lung anesthesia, duration of surgery, preoperative pulmonary function (FVC and FEV1) and the surgical procedure are summarized in Table 1. There were no statistically significant differences as regard age, weight, duration of one-lung ventilation, duration of surgery, FVC and FEV1.

The peak inspiratory pressures (P_{peak}), the plateau inspiratory pressures (P_{plateau}) and mean inspiratory pressure (P_{mean}) were significantly lower in PCV-VG group compared with VCV group in all stages of the study (Table 2). There was significant increase in all pressure values in OLV compared with TLV1 in the two groups (*P value* < 0.05) (Figs. 1 and 2).



TLV1= Two lung ventilation, 30 min after turning the patient to the lateral decubitus,
OLV = One-lung ventilation, 30 min after initiation of OLV,
TLV2= Two-lung ventilation, 30 min after end of one-lung ventilation,
VCV= volume control ventilation, PCV-VG= pressure control ventilation - volume guarante

Figure 3 Arterial oxygen tension in the two groups at different stages of the study.

Table 3 Arterial blood gases values in the two groups.

Variable	VCV group (n = 19)			PCV-VG group (n = 18)		
Set time points	TLV1	OLV	TLV2	TLV1	OLV	TLV2
Pao_2 (mmHg)	424.75 ± 32.85	142.35 ± 22.25 ($P < 0.001$)*	370.85 ± 35.22 ($P < 0.001$)*	416.35 ± 23.34	216.45 ± 22.27 ($P < 0.001$)* ($P < 0.001$)†	396.95 ± 24.16 ($P = 0.019$)* ($P = 0.013$)†
Pco_2 (mmHg)	33.05 ± 2.42	34.65 ± 2.35	32.8 ± 2.31	33.55 ± 1.93	34.60 ± 2.19	33.15 ± 2.39
Sao_2 (%)	99.2 ± 0.8	99.1 ± 0.91	99.0 ± 1.1	99.3 ± 0.9	98.6 ± 1.2	99.0 ± 1.0
PH	7.36 ± 0.04	7.37 ± 0.03	7.35 ± 0.04	7.35 ± 0.02	7.36 ± 0.04	7.35 ± 0.02

Data are presented as mean ± SD.
TLV1 = two lung ventilation, 30 min after turning the patient to the lateral decubitus position.
OLV = one-lung ventilation, 30 min after initiation of OLV.
TLV2 = two-lung ventilation, 30 min after reestablishing TLV.
Pao_2 = arterial oxygen tension, Pco_2 = arterial carbon dioxide tension, Sao_2 = arterial oxygen saturation.
VCV = volume control ventilation, PCV-VG = pressure control ventilation- volume guaranteed.
[*] P value < 0.05 compared with two-lung ventilation1 (TLV1) in the same group (within group comparison)
[†] P value < 0.05 compared with VCV group at the same time point.

There was significant decrease in the mean Pao_2 values during OLV compared with TLV1 in the two groups (P *value* < 0.05). Yet the Pao_2 was significantly higher in the PCV-VG group at OLV compared to the OLV in VCV group (Table 3, Fig. 3). The mean Pao_2 values increased significantly after lung inflation in the two groups comparably; however it is still significantly higher in PCV-VG group. Also Pao_2 was significantly lower in TLV2 than TLV1 in both groups (P *value* < 0.05) (Table 3).

All hemodynamic variables did not differ significantly at any stage of the study except heart rate which was higher during OLV in both groups (Table 4).

Regarding chest X-ray four patients of VCV group and three of PCV-VG group had basal lung collapse in the first post-operative, all except one patient in PCV-VG group were improved in third post-operative day.

4. Discussion

In our study we found that arterial oxygenation was better during OLV in PCV-VG group when compared to VCV group, we also found highly significant decrease in peak and plateau inspiratory pressures in PCV-VG group compared to VCV group and there was mild change in the mean inspiratory pressure between groups.

These results may be explained by the decelerating flow in the PCV-VG mode that may result in better alveolar ventilation with more homogenous distribution of gases inside the alveoli and better alveolar recruitment reducing intra and post-operative atelectasis. But still some degree of residual atelectasis may occur which explain the reduced oxygenation in both groups after lung inflation when compared with data before OLV. Also high inspiratory pressures during OLV in VCV group may lead to barotrauma and an increase in the vascular resistance of the dependent lung. This may increase the shunt flow through nondependent (nonventilated) lung by diverting blood flow to it. The final result of excessive inspiratory pressures in the dependent (ventilated) is to lower arterial oxygenation.

Exposure to elevated inspiratory pressures during OLV has also been identified as strong predictor of ALI in patients undergoing thoracic surgery [6]. However, it is unclear which of the commonly measured pressures is more relevant in the development of complications. The P_{peak} is a reflection of the dynamic compliance of the respiratory system and depends on factors such as tidal volume, inspiratory time, endotracheal size, and bronchospasm. In contrast, $P_{plateau}$ relates to the static compliance of the respiratory system (ie, chest wall and lung compliance) and is considered a better reflection of alveolar pressure so there is a strong correlation between $P_{plateau}$ and ALI. There does not appear to be a $P_{plateau}$ level that is truly safe, $P_{plateau}$ less than 25 cm H_2O are achievable in most patients with a well positioned endobronchial tube [7]. On the other hand, P_{mean} correlates with alveolar ventilation and gas oxygenation [8].

We suggested that PCV-VG have advantages on both VCV and PCV as the ventilator controls peak inspiratory pressure, within preset limits, to achieve the target VT. In this fashion, the ventilator automatically compensates for changes in lung mechanics to maintain the set TV. This approach effectively combines advantages of volume-controlled and

Table 4 Hemodynamic variables in the two groups

Variable	VCV group ($n = 19$)			PCV-VG group ($n = 18$)		
Set time points	TLV1	OLV	TLV2	TLV1	OLV	TLV2
MAP (mmHg)	89.45 ± 22.34	91.24 ± 19.75	88.43 ± 24.36	89.46 ± 18.75	87.95 ± 23.47	93.16 ± 31.45
HR (b/min)	75.24 ± 15.36	95.35 ± 14.27 ($P < 0.001$)*	77.62 ± 18.27	75.42 ± 13.86	96.26 ± 8.67 ($P < 0.001$)*	78.04 ± 12.84
CVP (cmH_2O)	9.4 ± 2.3	10.1 ± 2.7	8.6 ± 2.2	9.1 ± 1.7	9.6 ± 1.4	9.1 ± 2.1

Data are presented as mean ± SD.
TLV1 = two lung ventilation, 30 min after turning the patient to the lateral decubitus position.
OLV = one-lung ventilation, 30 min after initiation of OLV.
TLV2 = two-lung ventilation, 30 min after reestablishing TLV.
MAP = mean arterial pressure, HR = heart rate, CVP = central venous pressure.
VCV = volume control ventilation, PCV-VG = pressure control ventilation-volume guaranteed.
* P value < 0.05 compared with two-lung ventilation1 (TLV1) in the same group (within group comparison)

pressure-limited ventilation, and ensures that the minimal pressure necessary to achieve the desired TV is used. So the potential beneficial effects of PCV-VG during OLV are the use of lower inspiratory pressure and a decelerated flow that could reduce the lung damage and might improve recruitment and the distribution of inspired gas.

Up to our knowledge there were no studies comparing PCV-VG with VCV; however there were many literatures concerning the comparative effects of PCV and VCV on intraoperative inspiratory pressures and arterial oxygenation during OLV which showing inconsistent results.

Regarding comparison between PCV and VCV Tugrul et al. found a statistically significant decrease in P_{peak} and $P_{plateau}$ and improved oxygenation and intrapulmonary shunt with PVC compared to VCV in patients undergoing thoracotomy using a VT of 10 mL/kg during TLV and OLV. The findings were more relevant in subjects who had poor preoperative lung function [9]. In a subsequent study, Senturk and colleagues showed that PCV with a PEEP of 4 cmH_2O was associated with an improvement in oxygenation compared to VCV and zero PEEP[10].

On the contrary, Unzueta et al. [11] who found that PCV offered no advantage over VCV for improving oxygenation during OLV in patients with normal preoperative lung function. These results are consistent with those recorded by Heimberg et al. [12] in patients undergoing cardiac surgery with OLV periods. Similarly, the study performed by Pardos et al. [13] revealed no differences in intraoperative arterial oxygenation, inspiratory plateau pressure and mean pressure. Again, the only difference between VCV and PCV was the peak inspiratory pressure that was lower in the later.

Moreover, Choi et al. [14] compared PCV vs. VCV during OLV in the prone position for robot-assisted esophagectomy. There were no differences in arterial oxygen tension, inspiratory pressures, dynamic lung compliance or physiological dead space during OLV between PCV and VCV in the prone position. Finally, Montes and colleagues found that in patients without severe lung disease undergoing thoracic surgery with OLV, lung protective strategies using "low VT" combined with PEEP was safe and effective and PCV (vs. VCV) decreases peak inspiratory pressure maintaining similar blood oxygenation indices [15].

Limitations of our study were the small sample size, and lack of a more informative CT chest for assessment and follow up of post-operative lung atelectasis.

5. Conclusion

In conclusion, in patients undergoing thoracic surgery with OLV, pressure controlled volume guaranteed mode of ventilation seemed to be a better approach compared to volume controlled ventilation. Further studies is required to evaluate the effect of addition of positive end expiratory pressure to the pressure controlled volume guaranteed mode to prevent the occurrence of atelectasis during one lung ventilation.

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