A Comparative Study for the Lung Mechanics during One-Lung Ventilation in Thoracic Surgeries Using Two Different Modes of Mechanical Ventilation

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Abstract

Background: One-Lung Ventilation (OLV) is a common practice during thoracic surgery. Volume-Controlled Ventilation (VCV) has been considered the conventional approach to mechanical ventilation during OLV; however, recently Pressure-Controlled Ventilation (PCV) has gained interest due to its potential advantages.

Aim: The aim of this study was to compare between PCV and VCV during OLV as regards lung mechanics.

Material and Methods: We studied 50 patients scheduled for thoracic surgery with OLV in the lateral decubitus position. After initial two-lung ventilation with VCV, patients were randomly assigned to one of two groups; in the first group OLV was achieved with PCV (inspiratory pressure to provide a tidal volume of 6mL/kg), and in the second group OLV was achieved with VCV (tidal volume 6mL/kg). Lung mechanics (Peak inspiratory pressure (Ppeak), mean airway pressure (Pmean), and dynamic lung compliance (Cdyn) were measured at different times throughout the procedure.

Results: Peak airway pressure, and mean airway pressure, were significantly increased during OLV in both groups. Dynamic lung compliance was significantly decreased during OLV in both groups.

Conclusion: At constant low tidal volume there is no significant difference in lung mechanics between PCV and VCV during OLV.

Key Words: One-lung ventilation – Pressure-controlled ventilation – Volume-controlled ventilation – Peak airway pressure – Dynamic lung compliance.

Introduction

SELECTIVE ventilation of one lung was first described in 1931 by Gale and Waters and quickly led to increasingly complex lung resection surgery, with the first published pneumonectomy for cancer in 1933 [1].

Volume-Controlled Ventilation (VCV) has been considered the traditional or conventional approach to mechanical ventilation of patients undergoing thoracic surgery and OLV; however, in recent years Pressure-Controlled Ventilation (PCV) has gained renewed interest due to its potential advantages [2,3].

PCV generates lower peak airway pressures and a decelerating flow waveform that might decrease the risk of lung injury, facilitate alveolar recruitment, and improve the distribution of inspired gas [4].

The use of PCV has been suggested to reduce peak airway pressure (Ppeak) and intrapulmonary shunt, thereby limiting the risk of barotrauma [5], however, the potential benefits of PCV over Volume-Controlled Ventilation (VCV) during OLV remains controversial [6].

In current clinical practice, most surgeons would expect lung isolation to facilitate surgical access for the majority of procedures requiring thoracotomy. It is an absolute requirement for thoracoscopic surgery, and many procedures are now performed using Video-Assisted Thoracoscopy (VATS). Other procedures that usually require lung isolation include: Esophageal surgery, surgery of descending thoracic aorta, spinal surgery via thoracotomy and chest wall resection [7].

Ventilators used in the operating room were developed according to the specific requirements of the surgical scenario, thus technology evolved making them intrinsically different from their
The classical anesthesia machine delivers gases to the patient through a closed circuit system, using a bellows system; however most of the manufacturers started to implement technologies derived from the ICU ventilators in the anesthesia machine, introducing modes of ventilation once exclusively available in the ICU [8].

I- Volume controlled ventilation:

Volume controlled continuous mandatory ventilation (V-CMV or VCV) is a time cycled, volume targeted ventilation mode available on all modern ventilators. VCV delivers a desired tidal volume (VT) by means of a constant flow with a square waveform: As a result, the flow of gases increases linearly until the desired tidal volume is achieved [9].

II- Pressure controlled ventilation:

Pressure controlled continuous mandatory ventilation (P-CMV or PCV) is time cycled, pressure-targeted ventilation. In this ventilation mode, the clinician sets a desired inspiratory pressure level, and the machine initiates inspiration delivering a high flow until the desired level of airway pressure is reached. The pressure increase rate can be set in most ventilators. After a short initial phase of high flow, the alveolar pressure starts to equilibrate with the pressure inside the inspiratory limb of the respiratory circuit; therefore, the gas flow needed to maintain the desired inspiratory pressure decreases throughout the inspiration, resulting in a characteristic decelerating pattern in the flow-time waveform, while the pressure-time curve is ideally a square waveform [10].

Patients and Methods

The study was performed in Kasr Al-Ainy Hospital-cardiothoracic operating theatre between June 2014 and April 2016.

Fifty adult patients undergoing elective lung resection procedures requiring one-lung ventilation through a posterolateral thoracotomy have been included.

Exclusion criteria:

Patients were excluded from the study when they had:

- Uncompensated cardiac condition.
- Hepatic disease (Child B or C).
- Renal disease (pre-operative serum creatinine level more than 1.4mg/dl).
- History of treatment with immunosuppressant drugs within the last 3 months prior to surgery.
- Evidence of pre-operative pulmonary or systemic infection as evidenced by clinical examination, leukocytosis, or fever.
- Previous thoracotomy.
- Patients who declined the consent for Thoracic Epidural Anesthesia (TEA), or in whom TEA was contraindicated or judged difficult will also were excluded.
- Patients who required emergency surgery.

Patients were randomly allocated to receive either Pressure-Controlled Ventilation (PCV group), or Volume-Controlled Ventilation (VCV group) during One-Lung Ventilation (OLV).

Anesthesic management:

Patients were pre-medicated with intravenous midazolam 1-2mg, and monitors were applied.

A thoracic epidural catheter was inserted at T4-5 to T7-8 interspace for intra-and post-operative analgesia management.

After pre-oxygenation, anesthesia was induced with propofol 1-2mg/kg, fentanyl 2 \mu g/kg, and atracurium 0.5mg/kg. Anesthesia was maintained with isoflurane, adjusted to an expired concentration of 1-1.5%.

The trachea was intubated with a double lumen tube (Mallinckrodt-BroncoCath, Tyco Healthcare, Pleasanton, CA) size 39 for male and 37 for female patients. A left double-lumen tubes was chosen unless otherwise indicated. The position of the tube was confirmed by auscultation and fiberoptic bronchoscopy while in the supine position and after turning the patient to the lateral decubitus position.

Initially, Two Lung Ventillation (TLV) with VCV was performed in all patients using an FiO₂ of 0.6, a VT of 6mL/kg (actual body weight), I:E ratio of 1:2, and a ventilator rate of 16/min, which was readjusted to maintain an end-tidal carbon dioxide tension (ETCO₂) of 30 to 35mmHg.

During OLV patients received either PCV or VCV according to the study group: Group PCV: Was initiated with a peak airway pressure that provides an expired VT of 6mL/kg, PEEP of 5cm H₂O and. Group VCV: Patients were ventilated using an expired VT of 6mL/kg, PEEP of 5cm H₂O.
In both groups, the ventilator rate was adjusted to maintain ETCO$_2$ of 30-35mmHg, and FiO$_2$ was increased in increments of 10% up to 1.0 to maintain SpO$_2$ at or above 92%. I:E ratio remained at 1:2.

After completion of surgical resection, both lungs were suctioned and re-inflated. A recruitment maneuver using an airway pressure of 30cm H$_2$O for 30 seconds was performed, and ventilation was resumed using pre OLV values. At the end of the procedure patients were carefully suctioned, and reversal of muscle paralysis was achieved using neostigmine 0.08mg/kg and atropine 0.02mg/kg. Several manual inflations were performed before extubation.

All patients were transferred to the post-operative ICU.

**Data collection:**

1. **Hemodynamic parameters:**
   - A- Mean arterial blood pressure.
   - B- Heart rate.

2. **Respiratory parameters:**
   - A- Peak inspiratory pressure (Ppeak).
   - B- Mean airway pressure (Pmean).
   - C- Dynamic lung compliance (Cdyn), calculated as:

**Tidal Volume (TV)/(Pmean-PEEP):**

Hemodynamic parameters and respiratory measurements were performed before induction (T$_0$), immediately after induction (T$_1$), before OLV (T$_2$), 30 minutes after OLV (T$_3$), before recovery (T$_4$), and one hour after arrival in the ICU (T$_5$).

**Results**

**Demographic data:**

The study included 50 adult patients; 36 males (72%) and 14 females (28%) with mean age of 40±11.1 in PCV group and 43.6±19.0 in VCV group. There was no significant difference between both groups as regards demographic and preoperative data, (Table 1).

**Operative data:**

There was no significant difference between both groups as regards operative data (Table 2).

**Hemodynamics:**

There was no significant difference between both groups as regards hemodynamic parameters during both baseline and subsequent readings.

**A- Heart rate:**

**B- Mean Arterial Pressure (MAP):**

As regard mean arterial blood pressure readings, there was no significant difference between the two groups or compared to baseline readings in each group apart from the readings in T$_3$ in VCV group which was decreased significantly ($p<0.05$).
Lung mechanics:

A- Peak airway pressure (Ppeak):

Table (5): Peak airway pressure (Ppeak).

<table>
<thead>
<tr>
<th></th>
<th>PCV</th>
<th>VCV</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁ (cmH₂O)</td>
<td>26.4±5.5</td>
<td>24.4±3.8</td>
<td>0.52</td>
</tr>
<tr>
<td>T₂ (cmH₂O)</td>
<td>27.6±4.9</td>
<td>24.7±4.3</td>
<td>0.3</td>
</tr>
<tr>
<td>T₃ (cmH₂O)</td>
<td>33.6±5.1†</td>
<td>30.4±5.5†</td>
<td>0.14</td>
</tr>
<tr>
<td>T₄ (cmH₂O)</td>
<td>28.6±6.5</td>
<td>27.3±6.4</td>
<td>0.59</td>
</tr>
</tbody>
</table>

There was no significant difference in Peak airway pressure (Ppeak) measurements between the two groups, however it increased significantly (p<0.05) in both groups at T₃ (30 minutes after OLV) compared to its baseline values.

B- Mean airway pressure (Pmean):

Table (6): Mean airway pressure.

<table>
<thead>
<tr>
<th></th>
<th>PCV</th>
<th>VCV</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁ (cmH₂O)</td>
<td>10.6±1.5</td>
<td>9.8±1.5</td>
<td>0.28</td>
</tr>
<tr>
<td>T₂ (cmH₂O)</td>
<td>10.9±1.7</td>
<td>9.7±1.2</td>
<td>0.09</td>
</tr>
<tr>
<td>T₃ (cmH₂O)</td>
<td>14.3±2.6†</td>
<td>12.1±1.7†</td>
<td>0.05</td>
</tr>
<tr>
<td>T₄ (cmH₂O)</td>
<td>12.2±3.5</td>
<td>11.4±2.6</td>
<td>0.82</td>
</tr>
</tbody>
</table>

There was no significant difference in mean airway pressure (Pmean) measurements between the two groups, however it increased significantly (p<0.05) in both groups at T₃ (30 minutes after OLV) compared to its baseline values.

C- Tidal volume (VT):

Table (7): Tidal volume.

<table>
<thead>
<tr>
<th></th>
<th>PCV</th>
<th>VCV</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁ (ml)</td>
<td>490±52.5</td>
<td>490±45.9</td>
<td>1</td>
</tr>
<tr>
<td>T₂ (ml)</td>
<td>493±51.7</td>
<td>495±49.7</td>
<td>0.79</td>
</tr>
<tr>
<td>T₃ (ml)</td>
<td>479±35.1</td>
<td>510±31.6†</td>
<td>0.05</td>
</tr>
<tr>
<td>T₄ (ml)</td>
<td>510±37.7</td>
<td>510±31.6†</td>
<td>0.66</td>
</tr>
</tbody>
</table>

There was no significant difference in tidal volume (VT) measurements between the two groups, however it increased significantly (p<0.05) in VCV group at T₃, and T₄ compared to its baseline values.
D- Dynamic lung compliance (Cdyn.): The increase in airway pressure during OLV can be explained by the distribution of whole VT to only one lung (ventilated dependent lung), also this lung has a reduced compliance during Lateral Decubitus (LD) position, mostly due to shifted mediastinum and compression by the abdominal contents [11].

<table>
<thead>
<tr>
<th>Time</th>
<th>PCV (ml/cmH2O)</th>
<th>VCV (ml/cmH2O)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_1</td>
<td>24.2±6.0</td>
<td>26.1±6.0</td>
<td>0.49</td>
</tr>
<tr>
<td>T_2</td>
<td>22.6±4.9</td>
<td>24.3±7.4</td>
<td>0.19</td>
</tr>
<tr>
<td>T_3</td>
<td>17.3±3.0†</td>
<td>21.4±5.9†</td>
<td>0.07</td>
</tr>
<tr>
<td>T_4</td>
<td>23.3±7.1†</td>
<td>25.2±2.8†</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Data are presented as mean ± standard deviation.
†: p<0.05 compared to baseline.
Cdyn.: Dynamic lung compliance.
PCV: Pressure-Controlled Ventilation.
VCV: Volume-Controlled Ventilation.

There was no significant difference in dynamic lung compliance (Cdyn.) measurements between the two groups, however it decreased significantly (p<0.05) in both groups at T_3 (30 minutes after OLV) compared to its baseline values.

Discussion

Our study compared 2 modes of mechanical ventilation (PCV vs. VCV) during OLV in patients requiring OLV in the lateral position in thoracic surgeries. We measured and compared hemodynamic parameters, and lung mechanics at the beginning of the procedure, during OLV, after resuming TLV, and 1 hour after extubation.

After collecting and analyzing data, we found that there is no statistically significant difference between both groups regarding lung mechanics, however; peak airway pressure (Ppeak) and mean airway pressure (Pmean) were significantly increased in both groups during OLV. On the other hand, dynamic lung compliance was significantly decreased in both groups during OLV.

Our results are in accordance with, Pardo P. et al. [4], who compared between the use of PCV and VCV during OLV with the same VT of 8mL/kg. They found that during OLV, there were no differences in airway plateau pressure, or mean airway pressure between both groups.

Our results are also in accordance with, Rozé H. et al. [5], who measured airway pressure simultaneously in the breathing circuit and main bronchus of the dependent lung after 20 minutes of OLV using VCV followed by PCV at constant VT. They found that mean airway pressure and plateau airway pressures (Pplateau) were unaffected by the change in ventilation mode, and found no significant differences in alveolar ventilation or hemodynamics between both modes of ventilation, however they found that PCV resulted in a minimal reduction in peak airway pressure (Ppeak) and small reduction in bronchial airway pressure during OLV at constant VT compared to VCV and that difference was probably not clinically significant.

In contrast to our results, Lin F. et al. [12], found that in PCV group, Ppeak was significantly higher in VCV group, however they didn't find significant difference in Pplateau or mean airway pressure during OLV.

Further studies to determine the impact of the loco-regional inflammatory response after thoracic surgery and its clinical relevance with a longer postoperative observation period are recommended.
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We would also like to investigate the immuno-modulatory effects of different anesthetics as a tool to prevent ALI during OLV.

Conclusion:
In conclusion, our study demonstrated that there was no significant difference between PCV and VCV during OLV as regards hemodynamic parameters, and lung mechanics.

There was statistically significant decrease in dynamic lung compliance during OLV compared to baseline in both groups.

There was statistically significant increase in Ppeak, and mean airway pressure during OLV compared to baseline in both groups.

References