Pressure-Controlled versus Volume-Controlled Ventilation during One-Lung Ventilation: Effect on Oxygenation, Lung Mechanics, and Inflammatory Response

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Abstract

Background: One-lung ventilation (OLV) is a common practice during thoracic surgery; however it can induce hypoxemia, lung injury, and release of inflammatory mediators by different mechanisms.

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 oxygenation, lung mechanics and lung injury.

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 6 mL/kg), and in the second group OLV was achieved with VCV (tidal volume 6 mL/kg). Lung mechanics and blood gases were measured at different times throughout the procedure and 2 bronchoalveolar lavage (BAL) samples were obtained from the ventilated lung for measurement of IL-6, one before, and the second 30 minutes after OLV.

Results: There were no significant differences in the measured parameters between both groups during OLV, apart from SaO_2 that was significantly lower in VCV group.

Peak airway pressure, mean airway pressure, and $PaCO_2$ were significantly increased during OLV in both groups.

Dynamic lung compliance and PaO_2 were significantly increased during OLV in both groups.

Conclusion: At constant low tidal volume there is no significant difference in lung mechanics or BAL IL-6 between PCV and VCV during OLV; however SaO_2 was significantly higher in PCV group compared to VCV group during OLV.

Key words: One-lung ventilation, pressure-controlled ventilation, volume-controlled ventilation, lung mechanics, blood gases, lateral decubitus.

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List of abbreviations

ALI: Acute lung injury
APRV: Airway Pressure Release Ventilation
ARDS: Acute respiratory distress syndrome
ARM: Alveolar recruitment maneuvers
BAL: Bronchoalveolar lavage
BB: Bronchial blocker
BIPAP: BI-Level Positive Airway Pressure
Cdyn.: Dynamic lung compliance
COX: Cyclooxygenase
CPAP: Continuous positive airway pressure
CPET: Cardiopulmonary exercise testing
Cstat.: Static lung compliance
DLT: Double lumen tube
ELISA: Enzyme-linked immune-sorbent assays
ERV: Expiratory reserve volume
FiO_2: Fraction of inspired oxygen
FOB: Fiber-optic bronchoscope
FRC: Functional residual capacity
HFJV: High Frequency Jet Ventilation
HFOV: High Frequency Oscillatory Ventilation
HFPPV: High frequency positive-pressure ventilation
HFV: High Frequency Ventilation
HPV: Hypoxic pulmonary vasoconstriction
IBW: Ideal body weight
ICU: Intensive Care Unit
IMV: Intermittent mandatory ventilation
IRV: Inspiratory reserve volume
LD: Lateral decubitus
MAPK: Mitogen-activated protein kinase
MAP: Mean airway pressure
MV: Mechanical ventilation
NO: Nitric Oxide
OLV: One-lung ventilation
OR: Operating Room
PAO_2: Alveolar Oxygen tension
PCV: Pressure-controlled ventilation
PEEP: Positive End Expiratory Pressure
PIP: Peak inspiratory pressure
Ppeak: Peak airway pressure

Pplateau: Plateau airway pressure
PRVC: Pressure regulated volume control
PSV: Pressure-support ventilation
ROS: Reactive oxygen species
RV: Residual volume
SIMV: Synchronized intermitted mandatory ventilation
SLT: Single lumen tube
SpO_2: Oxygen saturation
TEA: Thoracic epidural anesthesia
TIVA: Total intravenous anesthesia
TLC: Total lung capacity
TLV: Two-lung ventilation
VATS: Video-assisted thoracoscopy
VC: Vital capacity
VCV: Volume-controlled ventilation
VILI: Ventilator-induced lung injury
V/Q: Ventilation:perfusion ratio
VT: Tidal volume
ZEEP: Zero End Expiratory Pressure

Introduction

One-lung ventilation (OLV) is a common practice during thoracic surgery involving pulmonary resection to facilitate surgical exposure. For many years, arterial hypoxemia during OLV was considered the most important problem for the anesthesiologist. At present, there is increasing concern about the effects of ventilator settings on acute lung injury (ALI). [1, 2]

The period of OLV could cause lung injury by number of mechanisms: first, during lung collapse, blood flow to the lung is significantly reduced and lung ischemia-reperfusion injury could occur with subsequent spread to the dependent lung, [3] secondly, it is common practice to ventilate the dependent lung with a high FiO_2, usually 1.0. This could lead to the generation of reactive oxygen species (ROS) that could injure both the ventilated and the collapsed lungs, and thirdly, pulmonary capillary stress failure occurs when the pulmonary micro vascular bed is subjected to increased pressure. [4]

During OLV most pulmonary blood flow enters the ventilated lung and could produce capillary injury,[5] therefore, OLV induces the production and release of pro-inflammatory substances (including IL-6) into the alveoli of the ventilated lung,[6] although both lungs are affected, the inflammatory response, and hence pro-inflammatory cytokines, is significantly higher in the ventilated lung after OLV. [7]

The lung has many macrophages, in both the alveolar and the interstitial spaces. Activated macrophages are potent producers of cytokines and are likely to be an important cause of ALI. [8]

Among the cytokines of first discovery is IL-6, which is still a subject of intensive investigations today because of its ubiquity and functional diversity. [9]

Cytokines are small-molecular-weight peptides which are synthesized and released by many cells, including neutrophils, monocyte, macrophages, pulmonary, epithelial, and pulmonary endothelial cells. [10]

During OLV, the mechanical ventilation with increased tidal volume and airway pressure can induce a pro-inflammatory reaction in the ventilated lung. [11]The accessibility of the lung to the technique of bronchoalveolar lavage (BAL) has also provided insight into the local changes in cytokines and inflammatory mediators in lung injury. [12]

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. [13, 14]

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. [15]

The use of PCV has been suggested to reduce peak airway pressure (Ppeak) and intrapulmonary shunt, thereby limiting the risk of barotrauma, [16] however, the potential benefits of PCV over volume-controlled ventilation (VCV) during OLV remains controversial. [17]

We therefore hypothesize that by limiting peak airway pressures, and the better recruitment of alveoli, PCV would improve oxygenation and would decrease lung injury after OLV.

Aim of the work

The aim of this study is to compare between PCV and VCV during one-lung ventilation as regards oxygenation, lung mechanics and lung injury.

One-lung ventilation

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. [18]

Hypoxemia used to be the primary concern during OLV; however, hypoxemia has become less frequent due to more effective lung isolation techniques and the use of anesthetic agents with little or no detrimental effects on hypoxic pulmonary vasoconstriction (HPV). Acute lung injury (ALI) has replaced hypoxia as the chief concern associated with OLV. [13]

The duration of OLV is a major determinant of ALI as the minimal stress using "protective" parameters becomes significant if exposure is prolonged. Anesthesiologists have a limited control over the duration of OLV as it is mostly determined by the surgical procedure; however, initiation of OLV should occur as close to pleural opening as possible (except for thoracoscopic procedures), and two-lung ventilation (TLV) should resume as early as possible. [19]

Relevant respiratory anatomy

The knowledge of certain aspects of thoracic anatomical arrangements is of great importance to the thoracic anesthetist as it assists in the correct positioning of endobronchial tubes, the identification of diseased lobes, in an understanding of the proposed surgery, and also the potential complications that might occur. [20]

Trachea:

It is a conduit for air and exhaled gases arises from the lower border of the larynx at approximately the level of cervical vertebra C6.

The trachea descends in line with the vertebra and moves slightly to the right and posteriorly in doing so; it consists of 16–20 C-shaped cartilaginous rings that provide a semi-rigid structure. Posteriorly the longitudinal trachealis muscle (non-striated) completes the tube.

The average length of the trachea in an adult male is 15 cm and bifurcation occurs at the level of thoracic vertebra T4.

The usual antero-posterior diameter in adults is about 20mm. [20]

The bronchi and bronchial tree:

The bronchial tree and its divisions are illustrated in (Figure 1).

The right main bronchus compared to the left is shorter and descends more vertically, i.e. at 25◦ compared to 45◦. This leads to a tendency for endobronchial tubes to favor entry to the right side.

It ends when the right upper lobe orifice branches out after 2.5 cm. This lobe consists of three segments (apical, anterior and posterior). The right upper lobe orifice is directed at 90◦ from the right main bronchus and may need some bronchoscopic maneuvering to visualize. Occasionally this lobe may arise higher, even from the trachea. [20]

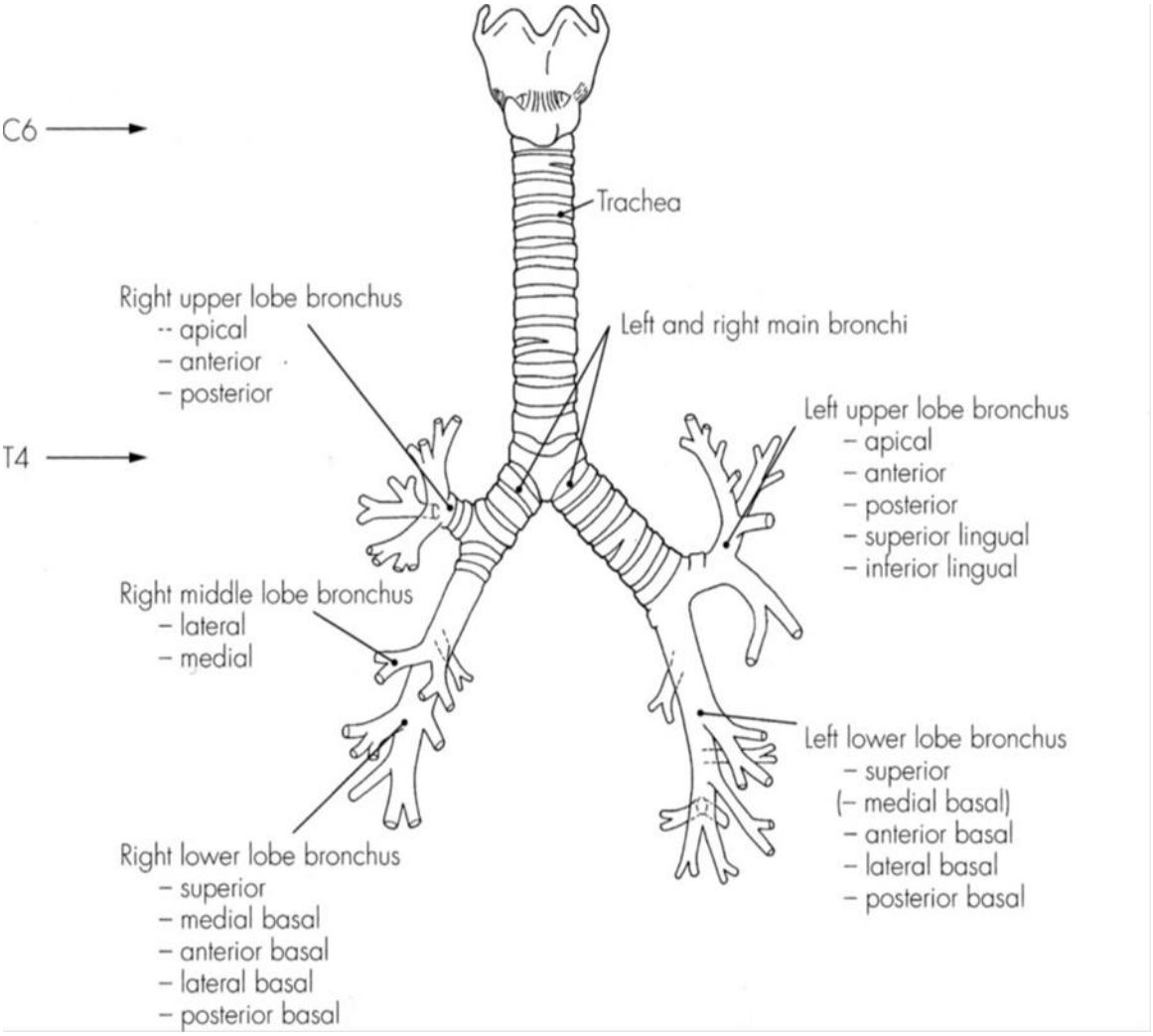

Figure 1: The bronchial tree. [20]

Bronchopulmonary segments:

The right lung consists of 3 lobes and 10 bronchopulmonary segments and the left lung consists of 2 lobes and 9 segments. (Figure 2)

The 19 segments considered as being discrete physiologically functional units, as each segment has its own separate arterial supply, venous, and lymphatic drainage. In the case of a lobectomy, the surgeon will have to ensure correct isolation of each of these vessel types to avoid venous congestion or ischemia of other parts of the lung.

As a rule each segment is pyramidal shaped and receives a single branch of the pulmonary artery to perfuse the alveoli. [20]

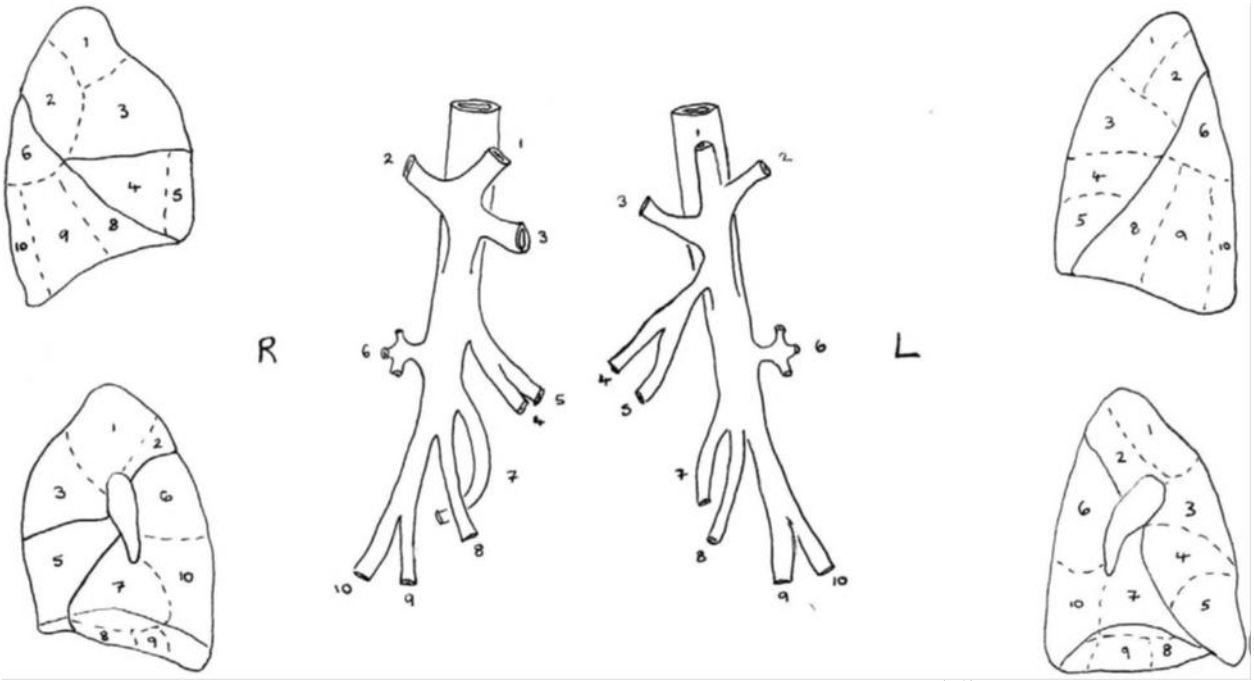

Figure 2: The bronchopulmonary segments. [20]

Relevant respiratory physiology:

Respiratory volumes:

The volume in the lungs at maximal inspiration is the total lung capacity (TLC; approximately 6 liters in adults). Its subcomponents are: inspiratory reserve volume (IRV), tidal volume, expiratory reserve volume (ERV), and residual volume (RV). The first three components comprise the vital capacity (VC) and the latter two comprise the functional residual capacity (FRC) (Figure 3).

These volumes and capacities increase with body size and are smaller in females.[20]

Dead space:

Gas exchange in the respiratory system only occurs in the alveoli. The part of the airway that does not participate in gas exchange is called the dead space.

The total dead space consists of the "anatomical" dead space and the "physiological" dead space. The "anatomical" dead space consists of the mouth, nose, pharynx, trachea and main bronchi, and is equivalent to approximately 150 ml. Physiological dead space is the alveoli that ventilated but not perfused. [20]

Lung Compliance:

Compliance is defined as the volume change per unit pressure change and is usually expressed in ml. /cmH2O

Compliance = $\Delta V/\Delta P$

It is classified into chest wall, lung or total lung compliance.