One-lung ventilation and oxygenation improvement

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Summary

Indications
Respiratory physiology during OLV
Objectives during OLV
Ventilatory settings to improve oxygenation
  Ventilatory mode
  Tidal volume
  Recruitment maneuvers and PEEP
Introduction

One-lung ventilation, separation of the two lungs through the airway

• **OLV provides:**
  – Improved exposure of surgical field
  – Protection of healthy lung from infected/bleeding one

• **OLV causes:**
  – Difficult airway and ventilatory setting
  – Significant physiologic change
  – Easily development of hypoxemia
Indication for OLV in real life

Avoid spillage or contamination of one lung from the other during surgery
   Infection, Massive hemorrhage

Control of the distribution of ventilation
   Surgical opening of a major conducting airway
   Bronchopleural / cutaneous fistula
   Tracheobronchial tree disruption
   Life-threatening hypoxemia due to unilateral lung disease

Surgical exposure (high-low priority)
   Thoracic aortic aneurysm, Pneumonectomy, giant unilateral lung cyst or bulla
   Upper lobectomy, Mediastinal exposure, Thoracoscopy
   Middle and lower lobectomies and subsegmental resections
   Esophageal surgery, Thoracic spine procedures, Minimal invasive cardiac surgery.

Vs ECCO2R ECMO
Method of isolation: DLT

Robertshaw DLT

Two lumen + cuffs
trachea and mainstem bronchus

Right-sided or left-sided
Univent Tube
Arndt endobronchial blocker

Wire guided Endobronchial Blocker (WEB)
Respiratory physiology during OLV.
V/Q relationship

Diagram showing surgical interference, nondependent lung, dependent lung, gravity, hypoxic pulmonary vasoconstriction, and lung disease.
Two-lung ventilation and OLV

Two lung ventilation

Fractional blood flow
40%
Nondependent lung
\[ \text{PaO}_2 = 400 \text{ mm Hg} \]
\[ \text{Qs/Qt} = 10\% \]

60%
Dependent lung

One lung ventilation

Fractional blood flow
22.5%
Nondependent lung

77.5%
Dependent lung

\[ \text{PaO}_2 = 150 \text{ mm Hg} \]
\[ \text{Qs/Qt} = 27.5\% \]
Atelectasis formation

Pulmonary Atelectasis. Duggan et al. Anesthesiology 2005

Pulmonary mechanisms
- Loss of muscle tone
- High FiO$_2 > 0.8$
- Impaired surfactant function

Cardiac mechanisms
- Heart weight

Abdominal mechanisms
- Cephalic diaphragm displacement
  - General anaesthesia
  - Intra-abdominal pressure (supine)
  - Infra-thoracic pressure
Atelectasis formation

- Hyperinflated areas ($V/Q = \infty$)
- Normally aerated areas ($V/Q = 1$)
- Hypoventilated areas ($V/Q < 1$)
- Collapsed areas ($V/Q = 0$)
Respiratory mechanics

Increases:
- Shunt/Dead Space
- Airway resistance

Decreases:
- Lung volume
- Compliance

ARDS-like condition
Hypoxic Pulmonary Vasoconstriction

Physiology and Anesthetic Implications

Andrew B. Lumb, M.B.B.S., F.R.C.A., Peter Slinger, M.D., F.R.C.P.C.

Anesthesiology 2015;122:932-46.

Norepinephrine
Phenylephrine
Almitrine

Nitric Oxide
Nitrous Oxide
Effects of sevoflurane and propofol on pulmonary shunt fraction during one-lung ventilation for thoracic surgery

Factors responsible for VALI
1- High lung volume associated with elevated transpulmonary pressure and alveolar overdistention (EITP: stress)
2- Repeated alveolar collapse and reopening due to low end-expiratory volume (VT/EELV: strain)

Factors that contribute to, or aggravate injury:
- preexisting lung damage and/or inflammation
- high inspired oxygen concentration
- the level of blood flow
- the local and systemic release of inflammatory mediators

Consensus Conference on VALI in ARDS
Am J Respir Crit Care Med 1998;157:1332-47

Protective Strategy:
Low VT +PEEP
VILI: Volutrauma
VILI: Atelectrauma
Setting Optimal Ventilation in Thoracic Surgery
Setting optimal ventilation.

VENTILATORY MODE

Pressure-Controlled Versus Volume-Controlled Ventilation


<table>
<thead>
<tr>
<th>Tidal volume (ml)</th>
<th>TLV-VCV</th>
<th>OLV-VCV</th>
<th>OLV-PCV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>708 (112)</td>
<td>714 (111)</td>
<td>710 (114)</td>
</tr>
<tr>
<td>$P_{aw}$ (cm H$_2$O)</td>
<td>21.4 (4.7)</td>
<td>28.3 (5.1)</td>
<td>23.65 (3.85)**</td>
</tr>
<tr>
<td>$P_{p}p_{lot}$ (cm H$_2$O)</td>
<td>15.7 (3.8)</td>
<td>18.5 (4.2)</td>
<td>17.8 (3.7)*</td>
</tr>
<tr>
<td>$P_{maw}$ (cm H$_2$O)</td>
<td>6.7 (1.4)</td>
<td>7.8 (2)</td>
<td>7.95 (1.55)</td>
</tr>
<tr>
<td>$P_{a}O_2$ (kPa)</td>
<td>27.5 (7.9)</td>
<td>28.4 (15.6)</td>
<td>32.3 (14.4)*</td>
</tr>
<tr>
<td>$S_{a}O_2$ (%)</td>
<td>99.1 (0.98)</td>
<td>98.3 (3.1)</td>
<td>98.7 (2.1)</td>
</tr>
<tr>
<td>$P_{a}CO_2$ (kPa)</td>
<td>4.8 (0.77)</td>
<td>5.06 (0.87)</td>
<td>5.05 (0.9)</td>
</tr>
<tr>
<td>$S_{v}O_2$ (%)</td>
<td>80.7 (6.8)</td>
<td>81.2 (8.3)</td>
<td>81.4 (7.23)</td>
</tr>
<tr>
<td>$Q_{s}/Q_{t}$ (%)</td>
<td>16.7 (6.2)</td>
<td>10.2 (10.1)</td>
<td>36.2 (10)*</td>
</tr>
</tbody>
</table>

Conclusion:
Improvement in $PaO_2$ may be explained by flow waveform
Setting optimal ventilation.

VENTILATORY MODE

Pressure-Controlled Versus Volume-Controlled Ventilation

<table>
<thead>
<tr>
<th></th>
<th>TLV-VCV</th>
<th>OLV-PCV</th>
<th>OLV-VCV</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>57</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>VT (mL)</td>
<td>645 ± 103</td>
<td>638 ± 88</td>
<td>645 ± 103</td>
</tr>
<tr>
<td>Ppeak (cm H₂O)</td>
<td>21.60 ± 4.09</td>
<td>19.51 ± 3.62</td>
<td>34.16 ± 5.21</td>
</tr>
<tr>
<td>Plateau (cm H₂O)</td>
<td>13.20 ± 2.63</td>
<td>19.81 ± 3.51</td>
<td>19.81 ± 3.51</td>
</tr>
<tr>
<td>Pmean (cm H₂O)</td>
<td>5.96 ± 1.12</td>
<td>7.79 ± 1.40</td>
<td>8.18 ± 1.65</td>
</tr>
<tr>
<td>Pao₂ (mm Hg)</td>
<td>397.5 ± 68.6</td>
<td>202.1 ± 56.4</td>
<td>206.1 ± 62.4</td>
</tr>
<tr>
<td>Paco₂ (mm Hg)</td>
<td>36.9 ± 3.8</td>
<td>36.4 ± 4.5</td>
<td>36.1 ± 4.2</td>
</tr>
</tbody>
</table>

Conclusion:
The PCV does not lead to improvement in PaO₂
Setting optimal ventilation.
VENTILATORY MODE

Pressure-Controlled Versus Volume-Controlled Ventilation
Montes et al. J Cardiothorac surg 2010; 5:99

VT: 6 ml/Kg
PEEP: 5 cmH2O
RM: No RM

Conclusion:
The PCV does not lead to improvement in PaO2
Setting optimal ventilation.

VENTILATORY MODE

Pressure-Controlled Versus Volume-Controlled Ventilation


VT: 8 ml/Kg
PEEP: 5 cmH2O
RM: No RM

Conclusion:
The PCV does not reduced to bronchial pressure
Setting optimal ventilation.

VENTILATORY MODE

Pressure-Controlled Versus Volume-Controlled Ventilation

No differences in:

• Gas exchange
• Ventilator-induced lung injury (dPAlv)
Setting optimal ventilation.

TIDAL VOLUME

Con: Low Tidal Volumes Are Indicated During One-Lung Ventilation

Thomas J. Gal, MD

2006;103:271-273

need to reduce tidal volumes during one-lung ventilation from those with standard two-lung ventilation. The larger volumes should be maintained because they provide for more controllable and reliable conditions for optimal gas exchange.

Pro: Low Tidal Volume Is Indicated During One-Lung Ventilation

Peter Slinger, MD, FRCPC

2006;103:268-270

In conclusion, ALI may occur in selected patients, particularly after pneumonectomy. Its occurrence is unpredictable, its cause is likely multifactorial, and its development is associated with frequent operative morbidity and mortality. Given the low risks, lung-protective ventilation using low-tidal volumes and the selective use of PEEP would seem to be a logical choice for management of OLV for thoracic surgery in the era of infrequent hypoxemia and continuous arterial oxygen saturation monitoring.
Setting optimal ventilation.

**TIDAL VOLUME**

*Intraoperative Tidal Volume as a Risk Factor for Respiratory Failure after Pneumonectomy*

Fernández-Pérez et al. Anesthesiology 2006

170 pneumonectomy patients. Retrospective study of cases
Setting optimal ventilation.

TIDAL VOLUME

**Protective Ventilation Influences Systemic Inflammation after Esophagectomy**

Michelet et al. Anesthesiology 2006

52 Esophagectomy patients. Prospective

VT: 6 vs 9ml/Kg
PEEP:5 vs 0 cmH2O
RM: No RM

Conclusion:
• Reduces inflammation
• Reduces ELWI
• Reduces ICU LOS
Setting optimal ventilation.

TIDAL VOLUME

Ventilatory Protective Strategies during Thoracic Surgery

Effects of Alveolar Recruitment Maneuver and Low-tidal Volume Ventilation on Lung Density Distribution

Kozian et al. Anesthesiology 2011

<table>
<thead>
<tr>
<th></th>
<th>OLV 5 ml/kg Expiration</th>
<th>OLV 5 ml/kg Inspiration</th>
<th>Difference Expiration-Inspiration</th>
<th>OLV 10 ml/kg Expiration</th>
<th>OLV 10 ml/kg Inspiration</th>
<th>Difference Expiration-Inspiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Lung Volume, ml</td>
<td>382 ± 38†</td>
<td>521 ± 20‡</td>
<td>137 ± 30</td>
<td>409 ± 73§</td>
<td>690 ± 99∥</td>
<td>281 ± 87#</td>
</tr>
<tr>
<td>Atelectasis, %</td>
<td>8 ± 3†</td>
<td>4 ± 1‡</td>
<td>-4 ± 3</td>
<td>7 ± 2§</td>
<td>2 ± 1∥</td>
<td>-5 ± 3</td>
</tr>
<tr>
<td>Poorly Aerated, %</td>
<td>72 ± 1†</td>
<td>34 ± 10‡</td>
<td>-38 ± 17</td>
<td>74 ± 3§</td>
<td>14 ± 4∥</td>
<td>-60 ± 23#</td>
</tr>
<tr>
<td>Normally Aerated, %</td>
<td>19 ± 2†</td>
<td>63 ± 10‡</td>
<td>44 ± 11</td>
<td>19 ± 1§</td>
<td>84 ± 4∥</td>
<td>65 ± 16#</td>
</tr>
</tbody>
</table>
Setting optimal ventilation.

TIDAL VOLUME

Always related to predicted body weight

Calculate ideal body weight:

Men: \( PBW \text{ (kg)} = 50 + 0.91 \text{ (height in cm-152)} \)

Women: \( PBW \text{ (kg)} = 45.5 + 0.91 \text{ (height in cm-152)} \)

NO DISCUSSION: Low Tidal Volume
Setting optimal ventilation.

RECRUITING MANEUVERS

Lung Recruitment Improves the Efficiency of Ventilation and Gas Exchange During One-Lung Ventilation Anesthesia

Physiological effects of a lung-recruiting strategy applied during one-lung ventilation

Alveolar recruitment improves ventilation during thoracic surgery: a randomized controlled trial

Setting Individualized Positive End-Expiratory Pressure Level with a Positive End-Expiratory Pressure Decrement Trial After a Recruitment Maneuver Improves Oxygenation and Lung Mechanics During One-Lung Ventilation
Setting optimal ventilation.

RECRUITING MANEUVERS

Tusman, Belda CACC 2010

Static maneuvers:
CPAP of 40 cmH2O applied for 10-30 s

Cycling maneuvers:
PCV (10-15 cmH2O in normal lungs) for VT ≤ 8ml/kg + PEEP increments in steps of 5 cmH2O, from 5 to 20.
Setting optimal ventilation.

RECRUITING MANEUVERS

Stepwise increases in PEEP
Time to adapt haemodynamics
Help to diagnose and treat an unrecognized hypovolaemic state.
Lower pulmonary tissue stress
Increments in pressure and volume spread progressively within more and more ‘recruited’ tissue

PEEP titration phase
helps to detect the level of PEEP
Setting optimal ventilation.

PEEP

Should always be used

Improves ventilatory efficiency
Decreases VILI

Arbitrarily set at 5 cmH2O
- Slinger et al. Anesthesiology 2001
- Fujirawa et al. J Clinic Anesth 2001
- Valenza et al. Eur J Anesthesiol 2004 (10 cmH2O)
- Tusman et al. Anesth Analg 2004
- Michelet et al Br J Anesth 2005
- Ren et al. An Intensive Care 2008
- Park et al. Eur J Anesthesiol 2011
- Unzueta et al. Br J Anesth 2012 (8 cmH2O)
Setting optimal ventilation.

PEEP

Setting Individualized Positive End-Expiratory Pressure Level with a Positive End-Expiratory Pressure Decrement Trial After a Recruitment Maneuver Improves Oxygenation and Lung Mechanics During One-Lung Ventilation

Ferrando et al. Anesth Analg 2014
Dynamic RM + PEEP titration in VCV during OLV

Unpublished data
### Table 3. Blood Gas and Cardiac Index

<table>
<thead>
<tr>
<th></th>
<th>Bilateral-lung ventilation</th>
<th>One-lung ventilation, prerecruitment maneuver</th>
<th>One-lung ventilation after PEEP</th>
<th>20</th>
<th>End one-lung ventilation</th>
<th>End bilateral-lung ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>7.36 (0.4)a</td>
<td>7.38 (0.5)</td>
<td>7.37 (0.4)</td>
<td></td>
<td>7.35 (0.4)</td>
<td>7.35 (0.6)</td>
</tr>
<tr>
<td>Study</td>
<td>7.32 (0.3)</td>
<td>7.34 (0.4)</td>
<td>7.34 (0.5)</td>
<td></td>
<td>7.32 (0.5)</td>
<td>7.31 (0.6)</td>
</tr>
<tr>
<td>P-value</td>
<td>0.02</td>
<td>0.06</td>
<td>0.1</td>
<td></td>
<td>0.06</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Pao2 (mm-Hg)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>436 (84)</td>
<td>229 (87)b</td>
<td>280 (67)c</td>
<td></td>
<td>231 (85)a</td>
<td>438 (139)</td>
</tr>
<tr>
<td>Study</td>
<td>439 (88)</td>
<td>240 (102)b</td>
<td>301 (79)c</td>
<td></td>
<td>306 (73)c</td>
<td>501 (99)</td>
</tr>
<tr>
<td>P-value</td>
<td>0.92</td>
<td>0.46</td>
<td>0.08</td>
<td></td>
<td>0.007</td>
<td>0.17</td>
</tr>
<tr>
<td><strong>Paco2 (mm-Hg)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>42 (4)a</td>
<td>42 (4)b</td>
<td>42 (6)b</td>
<td></td>
<td>40 (5)a</td>
<td>43 (7)a</td>
</tr>
<tr>
<td>Study</td>
<td>48 (6)</td>
<td>46 (7)</td>
<td>48 (5)</td>
<td></td>
<td>49 (6)</td>
<td>52 (8)</td>
</tr>
<tr>
<td>P-value</td>
<td>0.005</td>
<td>0.04</td>
<td>0.006</td>
<td></td>
<td>0.001</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>CI (l min⁻¹·m⁻²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>2.6 (0.7)</td>
<td>2.5 (0.5)</td>
<td>2.7 (0.6)</td>
<td></td>
<td>2.5 (0.3)</td>
<td>2.6 (0.6)</td>
</tr>
<tr>
<td>Study</td>
<td>2.8 (0.7)</td>
<td>2.7 (0.4)</td>
<td>2.8 (0.5)</td>
<td></td>
<td>2.7 (0.5)</td>
<td>3.0 (0.6)</td>
</tr>
<tr>
<td>P-value</td>
<td>0.38</td>
<td>0.06</td>
<td>0.46</td>
<td></td>
<td>0.34</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Small differences in PaCO2  
Better PaO2  
No changes in CO
### Table 4. Ventilatory Variables

<table>
<thead>
<tr>
<th></th>
<th>Bilateral-lung ventilation</th>
<th>One-lung ventilation, prerecruitment maneuver</th>
<th>One-lung ventilation 20 min after PEEP</th>
<th>End one-lung ventilation</th>
<th>End bilateral-lung ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Static compliance (mL-cm·H$_2$O$^{-1}$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>53 (21)</td>
<td>33 (7)$^p$</td>
<td>35 (7)$^a$</td>
<td>33 (6)$^g$</td>
<td>49 (24)</td>
</tr>
<tr>
<td>Study</td>
<td>49 (13)</td>
<td>33 (8)$^p$</td>
<td>50 (11)$^c$</td>
<td>48 (10)$^c$</td>
<td>56 (19)</td>
</tr>
<tr>
<td>$P$-value</td>
<td>0.60</td>
<td>0.96</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.39</td>
</tr>
<tr>
<td><strong>Physiologic dead-space volume/tidal volume</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0.63 (0.4)</td>
<td>0.65 (0.8)</td>
<td>0.62 (0.8)</td>
<td>0.65 (0.8)</td>
<td>0.65 (0.3)</td>
</tr>
<tr>
<td>Study</td>
<td>0.65 (0.4)</td>
<td>0.69 (0.5)</td>
<td>0.64 (0.5)</td>
<td>0.64 (0.5)</td>
<td>0.66 (0.3)</td>
</tr>
<tr>
<td>$P$-value</td>
<td>0.10</td>
<td>0.06</td>
<td>0.10</td>
<td>0.27</td>
<td>0.55</td>
</tr>
<tr>
<td><strong>Alveolar dead-space volume/alveolar tidal volume</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0.31 (0.2)</td>
<td>0.32 (0.5)</td>
<td>0.31 (0.4)</td>
<td>0.33 (0.4)</td>
<td>0.33 (0.1)</td>
</tr>
<tr>
<td>Study</td>
<td>0.32 (0.2)</td>
<td>0.34 (0.2)</td>
<td>0.31 (0.1)$^c$</td>
<td>0.31 (0.1)$^c$</td>
<td>0.32 (0.1)</td>
</tr>
<tr>
<td>$P$-value</td>
<td>0.11</td>
<td>0.14</td>
<td>0.81</td>
<td>0.56</td>
<td>0.79</td>
</tr>
<tr>
<td><strong>Peak inspiratory pressure (cm·H$_2$O)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>21 (4)</td>
<td>26 (4)$^p$</td>
<td>26 (6)</td>
<td>26 (6)</td>
<td>24 (6)</td>
</tr>
<tr>
<td>Study</td>
<td>19 (4)</td>
<td>26 (5)$^p$</td>
<td>27 (6)</td>
<td>27 (6)</td>
<td>26 (9)</td>
</tr>
<tr>
<td>$P$-value</td>
<td>0.16</td>
<td>0.67</td>
<td>0.31</td>
<td>0.41</td>
<td>0.53</td>
</tr>
<tr>
<td><strong>Tidal volume (mL)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>8 (0)</td>
<td>6.7 (0.4)$^p$</td>
<td>6.8 (0.4)</td>
<td>6.8 (0.4)</td>
<td>7.8 (0.1)</td>
</tr>
<tr>
<td>Study</td>
<td>8 (0)</td>
<td>6.7 (0.5)$^p$</td>
<td>6.4 (0.8)</td>
<td>6.4 (0.8)</td>
<td>7.6 (0.7)$^c$</td>
</tr>
<tr>
<td>$P$-value</td>
<td>0.72</td>
<td>0.09</td>
<td>0.05</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td><strong>Ventilatory rate (breaths/min)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>13(1)</td>
<td>15(1)$^p$</td>
<td>16(1)</td>
<td>16(1)</td>
<td>15(1)</td>
</tr>
<tr>
<td>Study</td>
<td>13(1)</td>
<td>15(2)$^p$</td>
<td>17(2)</td>
<td>17(2)</td>
<td>15(3)</td>
</tr>
<tr>
<td>$P$-value</td>
<td>0.69</td>
<td>0.27</td>
<td>0.53</td>
<td>0.47</td>
<td>0.62</td>
</tr>
</tbody>
</table>

RM + PEEP: No changes in Compliance (compared to baseline)
**Summary**

**Indications OLV:** Isolate one lung from the other  
Control of the distribution of ventilation: Airway surgery  
Surgical exposure (high-low priority)  
**Techniques:** DLT, Univent, Bronchial blockers

**Physiology:** Lung ARDS-like  
**Main objectives of MV during OLV:**  
- Guarantee gas exchange  
- Avoid ventilator-induced lung injury  
**Volume or pressure controlled ventilation**  
**Low tidal volume (5-6 ml/kg PBW)**  
**Cycling recruitment maneuvers**  
  (opening pressure 40 cmH₂O)  
**PEEP Individualized to best Crs**