Hypoxemia during Video-Assisted Thoracoscopic Surgery

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Disclosures
No conflicts of interest

Objectives
1. Discuss predictors of hypoxemia during one-lung ventilation (OLV).
2. Discuss strategies to avoid hypoxemia during OLV.
3. Describe the specific problems in treating patients who develop hypoxemia during Video-Assisted Thoracoscopic Surgery (VATS) procedures.

Cases for discussion
1. VATS left upper lobectomy in a patient with moderate COPD and CAD. Progressive hypoxemia develops minutes after initiation of one-lung ventilation (OLV).
2. Bilateral VATS wedge resection for metastases in a patient who previously received bleomycin for a germ cell tumor. Desaturation develops during the VATS procedure on the second lung.
The push towards minimally invasive surgery is continuing in all surgical specialties. In thoracic surgery the use of video-assisted (VATS) or robot-assisted (RATS) thoracoscopic surgery has been described for all types of lung resections (including pneumonectomy), esophageal resections and mediastinal surgery.

1. Predictors for hypoxemia during OLV

The likelihood of hypoxemia during OLV is unchanged irrespective of whether patients undergo thoracoscopic or open procedures. What is different during VATS procedures, is the ability to intervene due to the heightened need for surgical exposure. Knowing which patient is likely to desaturate during VATS is therefore important to raise awareness of potential intraoperative problems and enable preparation for possible therapeutic interventions. This preparation may entail a change in lung isolation device, modifications in the ventilatory technique, availability of pharmacologic agents and possibly a discussion about the surgical approach. The ability to predict the at-risk patient is far from perfect. There are few absolute predictors for difficult oxygenation during OLV beyond the obvious patient with global parenchymal disease and preoperative low oxygen saturation. There are different ways of organizing the factors that predispose to hypoxemia during OLV. Predictors can be grouped based on patient and procedure or lung pathophysiology. Investigations are of limited value in determining the patient at risk.

**Predictors: patient vs procedure**

**Patient:**
- prior contralateral resection
- normal lung function (FEV₁)
- chronic vasodilator therapy
- poor oxygenation preoperatively or on TLV

**Procedure:**
- right-sided surgery
- Supine position
- Vasodilator use
- Excessive volatile anesthetic

**Predictors: lung pathophysiology**

**Poor bilateral lung function**
- poor oxygenation preoperatively or on TLV

**High shunt fraction through operative lung**
- Preferential perfusion to operative lung (right-sided or prior contralateral surgery)
- Impaired HPV (vasodilators)
- Supine position
High shunt fraction through non-operative lung
- De-recruitment/ high elastic recoil (Normal lungs and/or high BMI)

**Predictors: investigations**

**Pulmonary function**
- Normal FEV₁
- Low DlCO

**Arterial blood gas**
- Low pO₂ preoperatively or during TLV

**Ventilation/ Perfusion scan**
- Q >> 50% to operative lung

**Blood count**
- Low hematocrit

2. **Preventative measures to minimize hypoxemia**

Due to the limited ability to access the operative lung for apneic oxygenation or ventilation, prevention of hypoxemia is important. Inhibitors of hypoxic pulmonary vasoconstriction such as hypocapnea, vasodilators or excessive volatile anesthesia have to be avoided. De-recruitment and shunting in the non-operative lung must be avoided using an open-lung strategy with individualized ventilator settings. The approach to OLV has evolved in recent years due to the recognition of the potential for lung injury. PEEP is used in the majority of patients as part of a protective one-lung ventilation strategy, as long as excessive air trapping can be avoided. It has to be recognized that protective lung ventilation optimizes oxygenation and lung function in the postoperative period, however may not provide equivalent oxygenation intraoperatively.

<table>
<thead>
<tr>
<th>Traditional OLV Management</th>
<th>Protective OLV Management</th>
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<tbody>
<tr>
<td><strong>Focus:</strong> Oxygenation</td>
<td><strong>Focus:</strong> Open Lung + ALI avoidance</td>
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<tr>
<td>• F₁O₂ 1.0</td>
<td>• F₁O₂ 1.0 → 0.5-0.8</td>
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<tr>
<td>• V₁ = 10 ml/kg</td>
<td>• V₁ = 10 ml/kg → 4-6 ml/kg</td>
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<tr>
<td>• Normocapnea</td>
<td>• Normocapnea → pCO₂ 40-60 mmHg</td>
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<tr>
<td>• ZEEP</td>
<td>• ZEEP → PEEP 5-10 cmH₂O</td>
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<tr>
<td>• Volume-control</td>
<td>• Volume-control → ? Pressure-control</td>
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Depressed cardiac output due to neuraxial anesthesia, parenteral anesthetic agents or tamponade physiology from CO₂ insufflation will impair mixed venous oxygen concentrations, which is difficult to overcome in the setting of high shunt due to OLV. Restoration of normal cardiac output with inotropic agents (e.g. ephedrine) may be required.
3. Problems associated with the treatment of hypoxemia during VATS

The treatment options for hypoxemia during OLV have been well described and fall into four broad categories. The most effective form of treatment is to decrease the shunt fraction by applying oxygenation and/or ventilation to the operative lung. Severe hypoxemia should trigger resumption of two-lung ventilation, which is universally effective in reversing hypoxemia. However, other interventions need to be considered first in cases of mild hypoxemia, as TLV will impair visualization to the point where surgery is usually no longer possible.
Points to consider:

1. **Definition of Hypoxemia**
   Rather than a specific oxygen saturation level (absolute hypoxemia) it is important to consider the necessary oxygen saturation for each patient (relative hypoxemia). Chronically depressed oxygen saturations in patients with significant reductions in diffusion lung capacity do not need to be improved upon intraoperatively. Oxygen content and delivery are more important than actual saturation levels in terms of organ perfusion and tissue oxygenation (e.g., brain, myocardium).

2. **Increase FiO₂ towards 1.0**
   Reduced FiO₂ is generally being recommended in light of concern about oxygen toxicity and potential acute lung injury. High FiO₂, however, is required in the setting of significant hypoxemia, both to increase oxygen delivery and to act as a pulmonary vasodilator, which may improve V/Q matching. The benefits of a higher saturation have to be weighed against the risks of oxygen toxicity, which are generally low, except for cases of prolonged OLV and prior bleomycin exposure.

3. **Confirm lung isolation**
   Loss of lung isolation, particularly partial obstruction of the ventilated bronchus will result in hypoventilation and de-recruitment. Fiberoptic bronchoscopy is the gold standard for confirmation of lung isolation, but may not always be required. The need for bronchoscopy will depend on the scenario and the index of suspicion, i.e., side ventilated, isolation device and adequacy of positioning. In many cases, at least transient ‘confirmation’ can be achieved by ensuring that ventilator parameters (pressures and volumes) are unchanged. Fiberoptic bronchoscopy needs to be performed if there is any doubt about device malposition or refractory hypoxemia without any clear diagnosis.

4. **‘Open Lung’ ventilation**
   a. A recruitment maneuver of the non-operative lung is almost universally effective in improving oxygenation (Tusman, 2004). Recruitment may transiently worsen the hypoxemia and may result in hypotension in the hypovolemic patient.
b. PEEP titration

- With traditional high-tidal volume OLV end-expiratory pressure was routinely set at zero. However, with the recognition of Acute Lung Injury and the advent of protective OLV, PEEP has become routine component of OLV in the majority of patients (Lohser, 2008). PEEP may worsen oxygenation if it leads to over-distention of the alveolus.

- The optimal PEEP for oxygenation is the amount that stabilizes the end-expiratory lung volume exactly at FRC. If spirometry is available, PEEP should be titrated to lowest level necessary to achieve the highest possible lung compliance.

- If no spirometry is available, the best PEEP level can be approximated by the response to lung recruitment
  i. If lung recruitment results in improved oxygenation the PEEP level is insufficient and should be increased.
  ii. If there is no improvement in oxygenation with lung recruitment, the PEEP level may be appropriate or excessive. Consider a decrease depending on patients’ lung pathology.
c. Confirm ventilator settings
   • Changes in lung (and chest-wall) compliance may adversely affect the adequacy of the provided minute ventilation. Hypoventilation will predispose to de-recruitment. Higher tidal volumes can be considered in cases of refractory hypoxemia.

d. Consider Pressure Regulated Ventilation
   • Pressure control ventilation appears to be a beneficial component of protective lung ventilation in terms of lung injury prevention. However, there is conflicting evidence as to the effect of PCV on oxygenation during OLV, with only some studies suggesting an oxygenation benefit.

The concept of open lung ventilation originated in the intensive care literature and is an evolution of the management of ARDS patients. It consists of avoiding cyclic recruitment and de-recruitment for lung injury prevention. The additional benefits of an open-lung strategy are that it maintains FRC, optimizes V/Q matching and increases CO₂ elimination in the ventilated lung. While the shunt fraction is primarily determined by the amount of perfusion through the collapsed operative lung, additional shunt through the ventilated lung in excess of the physiologic 5% is often poorly tolerated and entirely preventable. De-recruitment is one of the most common reasons for desaturation during OLV. The dependent ventilated lung is non-compliant due to external compression by abdominal and mediastinal contents. Application of a manual recruitment/ vital capacity maneuver at a pressure of 30-40 cmH₂O will result in improved oxygenation in the majority of patients. Prolonged application of the vital capacity maneuver will result in a reduced cardiac output, which always manifests as a transient dip in saturations, but may also result in significant hypotension. Invasive arterial monitoring is beneficial for any prolonged recruitment maneuver. Recruitment maneuvers are successful in achieving improved oxygenation if de-recruited ventilated lung existed. This by definition means that ventilation, and in particular the amount of PEEP, was insufficient to prevent lung collapse. As such, a positive recruitment maneuver should be followed by up-titration in applied PEEP. A negative response may indicate adequate or excessive PEEP levels. This may be an appropriate time to review the appropriateness of all ventilator settings.

4. Optimize oxygen delivery
   a. normalize cardiac output
   b. confirm adequate hemoglobin

Inadequate oxygen delivery due to low cardiac output and/or low hemoglobin concentration must be ruled out. Transfusion will rarely be necessary or justified
for maintenance of oxygenation. Cardiac output support, however, is more commonly necessary. Anesthetic agents and neuraxial sympatholysis commonly depress cardiac output, which may not be tolerated in the frail, elderly, hypovolemic patient. Avoidance of excessive anesthetic depth and correction of severe hypovolemia will often suffice. Occasional support with inotropic agents (e.g. ephedrine) may be necessary and will help to minimize fluid administration. Supra-normal cardiac outputs are not indicated and may be detrimental for oxygenation.

Mixed venous oxygen desaturation worsens the tolerance of high shunt fractions. (Note the degree of right-shift and flattening of the iso-shunt lines at lower mixed venous oxygen levels).

**Fig. 3. Theoretical relationships between Pao₂ and Pio₂ for different values of shunt at two different values of arterio-venous O₂ content difference. Note that curves are displaced but their pattern is unaltered.**

Benatar SR et al, BJA 1973

5. CPAP/ Partial ventilation of the operative lung
   a. CPAP
      - DLT: with commercially available CPAP circuit or AMBU bag + PEEP valve
      - Blocker: similar to DLT with adapter, or a stopcock system (see below)

Sasano, J Anesth 2009
b. Oxygen insufflation
   - into the entire operative lung via oxygen ‘jet’
     i. Bronchial blocker: stopcock setup (as above)
     ii. DLT: see figure below

![Diagram of oxygen insufflation](image1.png)

- into a subsegment using the fiberoptic bronchoscope

![Diagram of fiberoptic bronchoscope](image2.png)

c. High-frequency ventilation
   - CPAP-mode or actual ventilator mode depending on the driving pressures.

d. Lobar collapse (i.e. lobar recruitment on the operative side)

e. Intermittent TLV and apnea

Partial ventilation, or apneic oxygenation, of the operative lung is well known for thoracotomy procedures, however often considered contraindicated in the thoracoscopy setting. Partial lung reinflation is required for these techniques in order for oxygen to be delivered past the conducting airway, which may interfere with surgical exposure. In order to not impair the surgical procedure,
reinflation can be limited to a subsegment of the lung that is remote to the surgical site or be minimal applied across the entire lung. Any reinflation should be monitored in real-time on the surgical monitors. After reinflation, oxygen can be delivered via CPAP circuit, fiberoptic bronchoscope, modified oxygen flush or high-frequency jet ventilation.

On rare occasions, actual lung isolation is not essential. Ventilation of a lobe on the operative side may rarely be possible using subsegmental blockade with a bronchial blocker. More commonly, particularly for peripheral procedures such as wedge resections, TLV and intermittent apnea may be possible.

7. Pulmonary blood flow manipulation
   a. optimize HPV
      • avoid inhibitors: hypocapnea, hypothermia, vasodilators, vapor anesthetics >> 1 MAC (consider TIVA)
      • consider potentiation with: almitrine, phenylephrine or vasopressin

   b. pulmonary vasodilation in the ventilated lung
      • inhaled Nitric oxide, Flolan, Alprostadil

   c. PA clamp
      • Flow can be restricted with an atraumatic clamp or distortion of the PA anatomy with a sponge stick

Hypoxic pulmonary vasoconstriction has to be maintained and all inhibitors should be avoided. Pharmacologic manipulation of pulmonary blood flow and HPV has been described for VATS. However, it is not without risk, should be done with invasive monitoring and likely is only indicated in exceptional cases.

8. Conversion to thoracotomy
   Despite our best efforts, some patients may be hard to oxygenate with the limited options that are available during thoracoscopic procedures. Furthermore, some of the partial ventilation techniques may worsen surgical exposure to the point that surgical progress is slowed and the risk of complications increased. While a conversion may be undesirable, the morbidity of persistent hypoxia outweighs that of a thoracotomy incision.

References


