One-lung anaesthesia (OLA) may be indicated in lung, oesophageal, mediastinal and spinal surgery (Table 1). This review examines pre-operative considerations, physiology of one-lung ventilation and anaesthetic management of OLA.

Pre-operative assessment

The aim is to assess the ability of the patient to withstand OLA and possible lung resection. Assessment of both lungs together is performed initially with evaluation of each lung separately in borderline cases. In lung surgery, it is worth assessing each patient as if for a pneumonectomy, since the disease may be unexpectedly extensive and, postoperatively, function of the remaining lung tissue may be impaired due to surgical manipulation, oedema and atelectasis.

History and clinical evaluation

A history of limited exercise tolerance and/or associated cardiac problems increases the risk of peri-operative complications. Patients with shortness of breath at rest or those with pulmonary hypertension and cor-pulmonale (signs of right heart failure) are poor candidates for OLA.

Spirometry

The most sensitive predictor of peri-operative complications is forced expiratory volume in 1 s (FEV₁). A FEV₁ < 2 litres is associated with up to 40% incidence of postoperative respiratory failure. Other predictors of postoperative respiratory complications are summarised in Table 2.

Arterial blood gases

Hypoxaemia at rest (with normal PaCO₂) indicates the likelihood of problems with oxygenation during OLA and the postoperative period.

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**Table 1** Indications for double-lumen intubation

<table>
<thead>
<tr>
<th>ABSOLUTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung isolation (to avoid contamination)</td>
</tr>
<tr>
<td>Infection</td>
</tr>
<tr>
<td>Massive haemorrhage</td>
</tr>
<tr>
<td>Control of ventilation</td>
</tr>
<tr>
<td>Bronchopleural fistula</td>
</tr>
<tr>
<td>Tracheobronchial tree disruption</td>
</tr>
<tr>
<td>Giant unilateral lung cyst/bulla</td>
</tr>
<tr>
<td>Open surgery on main bronchi</td>
</tr>
<tr>
<td>Unilateral bronchopulmonary lavage</td>
</tr>
<tr>
<td>Pulmonary alveolar proteinosis</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RELATIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical access</td>
</tr>
<tr>
<td>Thoracic aortic aneurysm</td>
</tr>
<tr>
<td>Pneumonectomy</td>
</tr>
<tr>
<td>Mediastinal surgery</td>
</tr>
<tr>
<td>Lobectomy</td>
</tr>
<tr>
<td>Oesophagectomy</td>
</tr>
<tr>
<td>Non-thoracic surgery</td>
</tr>
<tr>
<td>Spinal thoracic surgery</td>
</tr>
<tr>
<td>Severe hypoxaemia due to unilateral lung disease</td>
</tr>
</tbody>
</table>

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**Table 2** Predictors of high risk for one-lung anaesthesia

- Poor exercise tolerance
- Pulmonary hypertension
- FEV₁ < 50% predicted or < 2 litre
- FVC < 50% predicted
- MBC < 50% predicted
- RV/TLC > 50%

FEV₁, forced expiratory volume at 1 s; FVC, forced vital capacity; MBC, maximum breathing capacity; RV, residual volume; TLC, total lung capacity.

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Key points

One-lung anaesthesia may be indicated in thoracic, oesophageal and spinal surgery

There is no single predictor of postoperative respiratory failure. All patients require a careful history, examination and respiratory function tests

Double-lumen tubes, bronchial blockers and single-lumen tubes can be used to isolate one lung

Thoracic epidural analgesia improves postoperative pulmonary outcome

Patients require high-dependency care after surgery

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radioisotopic ($^{133}$Xe and $^{99}$Tc) scanning. The predicted postoperative FEV$_1$ can be taken as the pre-operative FEV$_1$ multiplied by the proportion of non-affected lung (as assessed by scan). Predicted postoperative FEV$_1$ < 0.85 litre is associated with a high risk of developing respiratory failure.

**Further tests**

The postoperative situation can be mimicked by occluding the pulmonary blood supply to the affected lung using a pulmonary artery catheter. This tests the compliance of the remaining pulmonary vasculature. The balloon of the catheter is inflated in the artery supplying the affected lung and, if the arterial pressure in the main pulmonary artery increases to > 40 mmHg (5.3 kPa), $P_aCO_2$ increases to > 60 mmHg (8.0 kPa) or $P_aO_2$ decreases to < 45 mmHg (6.0 kPa), then postoperative survival is unlikely. However, this test is invasive with inherent risks and rarely used. When compared with assessment by other less invasive means (i.e. clinical assessment, lung function tests, arterial blood gases), the pulmonary artery occlusion test does not add any significant insight into the suitability of a patient for lung resection.

**Physiology of one-lung anaesthesia**

**Lateral decubitus position**

In the lateral decubitus position, blood flow is mainly determined by gravity, with 60% of flow going to the dependent lung. However, ventilation of the anaesthetised patient in the lateral position results in preferential ventilation of the non-dependent (top or operative) lung. Compliance and functional residual capacity of the dependent lung is reduced by the weight of mediastinal contents, elevated position of the paralysed diaphragm and sub-optimal positioning. Abdominal contents pushing up on the dependent diaphragm also contribute to a reduction in compliance. This produces a ventilation/perfusion mismatch.

**Open chest**

When the chest is opened, compliance of the non-dependent lung is increased and this results in relative over-ventilation. Because of more pronounced differential ventilation between the two lungs, ventilation/perfusion mismatch is worsened leading to increased dead-space in the non-dependent and increased shunt fraction in the dependent lung. Alveolar-arterial oxygen gradient is increased.

Blood passing through unventilated alveoli in the non-dependent lung retains carbon dioxide. This is offset by increased elimination of carbon dioxide in the alveoli of the dependent lung. If minute ventilation remains constant, there will be a slow increase in end-tidal carbon dioxide.

In theory, ventilation of only one lung can result in a shunt fraction of up to 50% because of the non-ventilated lung. The resulting hypoxaemia would be severe and could not be compensated for by increasing the inspired concentration of oxygen. However, in practice, several mechanisms operate to reduce the blood flow through the non-ventilated lung and, therefore, reduce the degree of shunt.

Gravity ensures a vertical gradient in the distribution of pulmonary blood flow. Therefore, 60% of blood flow goes to the ventilated (dependent) lung. The collapse of the non-dependent lung and surgical manipulation causes a mechanical obstruction to blood flow through this lung. Also, blood flow through the diseased lung may already be compromised, resulting in a relatively smaller contribution to the total shunt when the lung is collapsed. Another mechanism for shunt reduction is regional hypoxic pulmonary vasoconstriction (HPV) which actively diverts blood flow from hypoxic to well oxygenated lung (see below). It is an active process, triggered by alveolar hypoxia, which results in a 50% reduction in blood flow to the atelectatic lung. Therefore, during one-lung ventilation, blood flow through the non-ventilated lung is reduced to approximately 20%.

**Pulmonary blood flow and hypoxic vasoconstriction during one-lung anaesthesia**

Many factors, including anaesthesia, affect pulmonary blood flow and these are considered below.

**Inhaled anaesthetic agents**

Inhaled anaesthetic agents at MAC < 1 have minimal effect on HPV. For example, the inhibition of HPV is 21% during administration of isoflurane 1 MAC. This would increase blood flow to the collapsed lung (shunt fraction) from 20% to 24%. Nitrous oxide inhibits HPV by approximately 10%.

**Intravenous agents**

There is no inhibition of HPV with propofol, ketamine, fentanyl and thiopental.

**Systemic and pulmonary vasodilators**

Most vasodilators such as glyceryl trinitrate, nitroprusside, dobutamine, β-agonists and nitric oxide inhibit HPV.
Systemic vasoconstrictors
Epinephrine, norepinephrine, phenylephrine and dopamine constrict vessels in the ventilated lung. This diverts cardiac output back to the collapsed lung and increases shunt. More recently, dopamine has been shown to have less effect on HPV and may be the agent of choice if a vasopressor is required.

Inspired oxygen concentration
Increasing inspired oxygen concentration reduces the shunt fraction by decreasing vascular tone in the normal lung, thereby diverting blood flow to the ventilated lung.

Cardiac output
The effects of cardiac output on shunt fraction and oxygenation are complex. Decreased cardiac output may reduce mixed venous oxygen saturation and thus impair arterial oxygen saturation in the presence of significant shunt. On the other hand, an increase in cardiac output increases pulmonary artery pressure which increases perfusion of the non-ventilated lung and, thus, increases shunt fraction.

Positive end-expiratory pressure (PEEP)
PEEP, applied to the ventilated lung, increases pulmonary vascular resistance causing blood to be diverted to the non-ventilated lung and increasing shunt fraction.

Anaesthetic technique for one-lung ventilation
General anaesthesia with controlled ventilation is the technique of choice in patients undergoing OLA. The aim is to decrease airway reflexes and airway irritability, avoid HPV inhibition and maintain normal cardiovascular status. It is also desirable to choose agents which have rapid offset, thus avoiding the need for postoperative ventilation. Total intravenous anaesthesia with propofol has the theoretical advantage of producing less inhibition of HPV but there is little evidence to show much clinical benefit compared with inhalational agents.

The combination of general anaesthesia with intra-operative thoracic epidural anaesthesia can be helpful because it avoids the need for large doses of opioids. A large meta-analysis has shown a significant reduction in postoperative atelectasis, pulmonary infections and overall pulmonary complications in those patients receiving thoracic epidural analgesia. Alternatively, a paravertebral catheter can be sited, either directly by the surgeon or percutaneously by the anaesthetist. If the catheter is sited during surgery, intercostal blocks can be used to provide reliable analgesia for the start of surgery, thus avoiding the need for intra-operative opioids.

Intra-operative collapse and handling of the lung impair pulmonary capillary function which continues in the postoperative period rendering the non-ventilated lung prone to the development of pulmonary oedema. Therefore, care is required in fluid management of these cases and intra-operative hypotension should be treated by judicious use of fluids and vasopressors.

Practical conduct of one-lung anaesthesia

Techniques of lung separation

Double lumen tube
Double lumen tubes (DLT) are used most commonly since they afford independent control of each lung for the purpose of ventilation or suction. Also, they allow continuous positive airway pressure (CPAP) to be applied to the non-ventilated lung, as well as allowing the anaesthetist to switch rapidly between one- and two-lung ventilation when necessary. The DLT (left- and right-sided) has two lumens; one lumen is placed in the bronchus and the other in the trachea. The bronchial cuff effects a separation between the two lungs and the tracheal cuff achieves a separation of the lungs from the environment. Disposable tubes are available in sizes ranging from 26 Fr to 41 Fr (internal diameter 4.0–6.5 mm per lumen). Recommended sizes are 39–41 Fr (male) and 37–39 Fr (female). A 26 Fr is suitable for children of 8–10 years of age and weighing 25–35 kg.

The right main bronchus is shorter than the left. Therefore, a left-sided DLT is used more commonly because of the lower risk of obstructing the right upper lobe bronchus. The bronchial cuff of the right-sided DLT incorporates a side opening for ventilating the right upper lobe. Care must be taken to ensure the alignment between the side opening in the bronchial cuff and the aperture of the right upper lobe bronchus. Correct positioning should be confirmed by auscultation over right upper lobe and by the use of a fibre-optic bronchoscope. Contra-indications to a left-sided tube are proximal left main stem bronchus lesions which may be damaged by the tube. A left-sided pneumonectomy is a relative contra-indication but, if necessary, a left-sided tube can be used and pulled back prior to clamping of the main stem bronchus.

The DLT has two curves. During insertion, the distal curve is positioned so that its concave surface lies anteriorly. Once the bronchial tip has passed through the larynx, the stylet is removed, the tube is rotated by 90° and advanced into the appropriate bronchus. The correct position of the tube is confirmed by
Fig. 1 Differentiation of a malpositioned left-sided double lumen tube by auscultation

<table>
<thead>
<tr>
<th>Lumen clamped</th>
<th>Cuffs</th>
<th>Left side</th>
<th>Right side</th>
<th>Left side</th>
<th>Right side</th>
<th>Left side</th>
<th>Right side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracheal lumen</td>
<td>Both inflated</td>
<td>Air entry</td>
<td>Reduced air entry</td>
<td>Air entry</td>
<td>Air entry</td>
<td>Reduced air entry</td>
<td>Air entry</td>
</tr>
<tr>
<td>Bronchial lumen</td>
<td>Both inflated</td>
<td>Reduced air entry</td>
<td>Reduced air entry</td>
<td>Reduced air entry</td>
<td>Reduced air entry</td>
<td>Reduced air entry</td>
<td>Reduced air entry</td>
</tr>
<tr>
<td>Bronchial lumen</td>
<td>Bronchial cuff deflated</td>
<td>Air entry</td>
<td>Reduced air entry</td>
<td>Air entry</td>
<td>Air entry</td>
<td>Reduced air entry</td>
<td>Air entry</td>
</tr>
</tbody>
</table>

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**One-lung anaesthesia**

A combination of visual inspection, auscultation and use of a paediatric fibre-optic bronchoscope (3.6–4.2 mm outside diameter). This is usually at a depth of 29 cm in males and corresponds to a depth at which the bronchial cuff is just visible below the carina. The lobar anatomy should be identified at bronchoscopy and ventilation checked in all lung areas. Visual confirmation of tube position should be re-checked after placing the patient in the lateral decubitus position and a note made of the depth at the teeth. A method for determining the position of a malpositioned double lumen tube is illustrated in Figure 1.

**Bronchial blockers**

Indications for bronchial blockers include children for whom a DLT is too large, distorted airway anatomy and patients in whom a DLT is difficult to insert. It is also worth considering for the patient at risk of aspiration who is to be ventilated postoperatively as they avoid the need for a hazardous endotracheal tube change.

The bronchial blocker is a single lumen tube with a balloon-tipped endoluminal catheter. The catheter is advanced into either of the main bronchi under bronchoscopic vision and the bronchial lumen is occluded by inflating the balloon. The central lumen of the bronchial blocker permits suction and insufflation with oxygen. The disadvantage of a bronchial blocker is that ventilation of the blocked side cannot be achieved without losing isolation of the two lungs.

**Endobronchial intubation with a single lumen tube**

This is useful in small children. It is also the quickest method of effectively separating the lungs in an emergency (e.g. severe haemoptysis). Normally, an uncut endotracheal tube will intubate the right main bronchus but if the right lung is bleeding, a left main bronchial intubation is facilitated by turning the patient’s head to the right and inserting the endotracheal tube with the concavity of the tube facing posteriorly.

**Intra-operative management of one-lung anaesthesia**

In addition to routine monitoring, invasive blood pressure, CVP, temperature and pressure–volume loops should be monitored. Two-lung anaesthesia should be maintained for as long as possible but the ability to provide one-lung anaesthesia in the lateral decubitus position should be checked prior to the start of surgery. Pressure–volume loops are very helpful in monitoring changes in lung compliance during surgery.

Initially, during one-lung ventilation, a tidal volume of 10 ml kg⁻¹ is suggested. If airway pressure is excessively high (> 30 cmH₂O), the tidal volume should be reduced and respiratory rate increased. An increase in respiratory rate of 20% helps to maintain minute ventilation and, therefore, elimination of carbon dioxide. Permissive hypercapnia to spare barotrauma should be considered.
Management of hypoxaemia during one-lung ventilation

The following sequence can be applied to correct hypoxaemia:

• Increase inspired concentration of oxygen to 100%

• Check the position of the double lumen tube and exclude cuff herniation. Ensure patency and use suction to remove secretions. Plastic tubes become very soft at body temperature and are prone to kinking

• Check the breathing circuit, connections and anaesthetic machine

• If ventilation of the lung is difficult and associated with high pressures, check the position of tube with a fibre-optic scope

• Ensure adequate cardiac output

• Insufflate oxygen to the non-ventilated lung. In the non-ventilated lung, tidal ventilation of approximately 150 ml occurs because of transmitted pressure changes from the ventilated hemithorax. An oxygen reservoir with no expiratory pressure valve can be applied to the non-ventilated side of the DLT with an oxygen flow rate of 1 litre min⁻¹. A T-piece can be used for this purpose

• Apply CPAP of 5–10 cmH₂O to the non-ventilated lung. This level of CPAP only slightly distends the lung (50–100 ml) and does not cause haemodynamic instability or interfere with surgery. CPAP facilitates oxygen uptake in the non-ventilated lung and also causes a mechanical diversion of blood flow to the ventilated lung. One method of applying CPAP to the non-dependent lung is to connect a Waters C circuit with a PEEP valve to the appropriate lumen of the DLT

• Consider application of PEEP to the ventilated lung. Minimal PEEP (5–10 cmH₂O) applied to the dependent lung increases PaO₂ by increasing functional residual capacity and shifting the lung up to a steeper part of the pressure/volume compliance curve. However, PEEP increases pulmonary vascular resistance, diverting blood flow from the ventilated lung. Therefore, the benefit of PEEP in the dependent lung must be balanced against the increased shunt through the non-ventilated lung

• Intermittent inflation of the collapsed lung may be necessary if all other manoeuvres fail to correct hypoxaemia. It requires co-operation from the surgical team

• Clamping the appropriate pulmonary artery effectively removes the shunt through the ventilated lung

Postoperative period

Before resuming two-lung ventilation, the bronchus of the non-ventilated lung should be suctioned and the lung fully inflated. A postoperative chest X-ray should be performed in recovery to exclude pneumothorax, haemothorax, misplaced chest drain and collapse. Common complications in the postoperative period include sputum retention, collapse, consolidation and oedema on the operative side. Adequate pain relief and ability to cough are the most important factors in preventing chest complications. Continuous thoracic epidural analgesia or continuous paravertebral analgesia are the methods of choice for pain relief.

Patients should be nursed in a high-dependency area where meticulous attention is required in managing oxygen therapy, pain relief, physiotherapy, inhaler therapy, chest drains and fluid balance.

Key references


See multiple choice questions 59–61.