One-lung anesthesia provides adequate alveolar gas exchange for many surgical procedures. Hypoxic pulmonary vasoconstriction plays an important role in maintaining oxygenation during this procedure. Today’s anesthetist must be familiar with the various aspects of one-lung ventilation: initiation, maintenance and cessation.

One-lung anesthesia was performed first by Gale and Waters in 1932. They devised a curved, single-lumen cuffed tube which could be passed blindly into either mainstem bronchus. This accomplishment spurred the evolution of a variety of endobronchial tubes for one-lung anesthesia over the following years.

One-lung anesthesia has been utilized for thoracic surgery for several decades. The lateral position is used most frequently, with the dependent or ventilated lung down. To enhance surgical exposure, a double-lumen endobronchial tube is inserted to allow the upper nondependent lung to be collapsed.

Over the years, other indications have arisen for one-lung anesthesia that also have called for improvements in the technique. Today, nurse anesthetists must be aware of the indications for one-lung anesthesia, the variety of endobronchial tubes available, methodology and basic pathophysiology, as well as possible complications and their management.

Indications

Indications for one-lung anesthesia are divided into two main areas: absolute indications and relative indications. Absolute indications include cases where it would be necessary to isolate a lung from bleeding or infecting the non-involved lung. Intrapulmonary bleeding can produce engorgement of the lung, causing hypoxemia and possible death.

In cases where a gunshot or stab wound victim presents with perforation of the pulmonary artery, one-lung anesthesia may be a life-saving technique. Another example of a case where one-lung anesthesia would be useful would be a patient who presents with a bronchopleural fistula or a unilateral lung cyst. In such a case, independent ventilation of either lung may be accomplished, minimizing the loss of volume from the fistula. One-lung ventilation also is necessary in cases of alveolar proteinosis or cystic fibrosis, which may necessitate unilateral lavage.

“Quiet lung,” as one-lung anesthesia has been referred to throughout history, may be relatively indicated in such cases as a thoracic aneurysm repair, pneumonectomy, lobectomy (especially upper lobe) or esophageal surgery. In these cases, collapsing a lung may enhance surgical exposure critically and facilitate surgical outcome. Occasionally, a lower lobectomy, biopsy or wedge resection also may necessitate one-lung anesthesia.

Pulmonary function studies

Before commencing anesthesia, a thorough
preoperative evaluation must be made. The most important preoperative pulmonary evaluation data, in terms of assessing anesthesia and operative risks, are the pulmonary function tests. Routine spirometry also should be done preoperatively.

Surgical progress is most favorable when the vital capacity (VC), the forced expiratory volume in the first second (FEV 1.0) and the maximum voluntary ventilation (MVV) are greater than 50% of the predicted normal values.

When obtaining arterial blood gases, PaCO₂ is important, because the patient is considered at risk if hypercapnia exists on room air. If pulmonary function results are poor, a radionuclide perfusion scan involving an intravenous injection of radioactive technetium is performed. Using this method, split pulmonary function studies may be secured yielding the predicted postoperative vital capacity (VC) and forced expiratory volume in the first second (FEV 1.0). Other relevant information, such as the extent of the disease, the proposed surgery and the x-ray findings should be discussed preoperatively.

**Monitoring**

Monitoring is another vital aspect to be considered. Recommended monitors consist of a foley, esophageal stethoscope, transcutaneous pulse oximetry, arterial catheter, continuous electrocardiogram (EKG), central venous pressure (CVP) and pulmonary artery pressure (PAP). In patients with significant heart disease a CVP may be inaccurate, and a PA catheter may be more appropriate for any large anticipated blood loss.

Continuous arterial line monitoring is essential to any gas exchange or hemodynamic problems. The monitoring of oxygen saturation using transcutaneous or pulse oximetry recently has been indicated as a standard of care. Peak inflation and compliance pressures should be scanned frequently to detect a change in tube position, kinking or the need for suctioning. Again, nothing can replace the occasional glance at the surgical field to be sure the lung has been isolated and remains collapsed.

**Endobronchial tubes**

The most commonly used method of producing one-lung anesthesia is a double-lumen endobronchial tube. Basically, it consists of two separate lumens joined together with two openings: one into the main bronchus and one into the trachea. Many tubes—both right and left-sided—are on the market today. A left-sided tube is used when the right lung is to be collapsed and isolated and the left lung is to be ventilated, and vice-versa.

Many practitioners now use only left-sided tubes, which are easier to place because of basic anatomy. The left mainstem bronchus is unbranched for approximately 4 cm, leaving ample space for tube placement. By contrast, the right mainstem bronchus is unbranched for only about 1.5 cm before the point where the right upper lobe bifurcates. The most commonly used left-
sided tubes are the Carlens and Robert Shaw; the most common right-sided tubes are the White, Robert Shaw and Bryce Smith (Figure 2).

There are some basic differences in the various tubes. The Carlens is well known for its carinal hook that insures its proper site when it is placed. The Robert Shaw is similar to the Carlens, except there is no hook. It is more flexible and has thinner walls with larger lumens. The White (right-sided) also has a hook to catch the carina, as well as an additional hook 1.5 cm from the carinal hook to allow ventilation of the right upper lobe (Figure 2).

**Intubation**

Placement of these tubes can be difficult during advancement through the larynx and down the trachea, because of their larger than standard diameter and the shape of their tips. Prior to intubation both cuffs should be tested, the tube assembled, the stylet inserted and the clamps available to confirm position. A backup single-lumen endotracheal tube should be available.

Usually the patient is induced under general anesthesia, and a muscle relaxant of choice is given prior to intubation. The endobronchial tube usually is placed with the distal curvature upward, or anterior, when the tip is directed through the vocal cords. Then the tube is rotated toward the bronchus, where it is intubated and advanced until some resistance is met (Figure 3).

Proper positioning may be confirmed by passing a fiber-optic bronchoscope down the right lumen of the endobronchial tube. When looking down the right lumen, the anesthetist should have a clear view of the carina and the upper surface of the left endobronchial cuff just as it begins to balloon into view from the left mainstem bronchus. The cuff should not balloon so much that it causes the left cuff to herniate over the carina or the carina to impinge on or compromise the right mainstem bronchus orifice. Next, the anesthetist should see the bronchial carina and minimal narrowing of the left lumen. Confirming endobronchial tube placement with direct vision under flexible bronchoscopy soon may be established as a standard of care. Presently, the Machida pediatric fiber-optic bronchoscope and the Olympus BF₂ bronchoscope both have adequate length and suction channels to be used with double lumen tubes.

Proper placement of the endobronchial tube also can be checked by inflating the tracheal cuff and auscultating bilateral, equal breath sounds. Then the endobronchial cuff should be inflated to permit listening for breath sounds bilaterally. When the left side of the tube (endobronchial cuff) is clamped, the corresponding left breath sounds should disappear; normal breath sounds should be heard on the right. Alternate clamping to the right, and the opposite effect should be evident. Be sure to recheck tube placement after the patient has been
positioned for surgery, usually in the lateral position. Finally—check and double-check.

The most frequent problem encountered when positioning a left endobronchial tube is inserting the tube too deeply, excluding the right lung from ventilation. Right-sided tubes present the problem of excluding the right upper lobe from ventilation because of the shortness of the right mainstem bronchus. They also are displaced easily when the patient is put in the lateral position. Failure of the lung to collapse, high respiratory resistance, hypoxia, hypotension and bradycardia all are signs of trouble. In any case, the anesthetist may be forced to ventilate both lungs.

Complications from the use of the double-lumen tube are rare and seldom serious. Extremely rare complications of tracheobronchial rupture have been reported with the use of Carlens and Robert Shaw tubes. These complications have been attributed to factors such as improper positioning of the tube, inappropriate tube size and overinflation of the bronchial cuff. Any cardiovascular instability, subcutaneous emphysema or inadequate ventilation should alert the anesthetist to a possible airway insult. A final diagnosis intraoperatively can be made only by bronchoscopy. Tracheal and laryngeal trauma probably are the most frequently encountered complications.

**Institution of one-lung ventilation**

Instituting one-lung anesthesia is fairly simple. As a rule, both lungs should be ventilated as long as possible. To begin one-lung anesthesia, allow both lungs to deflate and clamp the operative side of the double-lumen tube. Ventilatory pressures will rise. This produces right-to-left transpulmonary shunt to the non-dependent, non-ventilated lung. Preexisting pulmonary disease may cause further alveolar collapse and shunting. The non-ventilated lung shunts 20-25% of the cardiac output during one-lung anesthesia.

An autoregulatory mechanism called hypoxic pulmonary vasoconstriction (HPV) causes the most drastic decrease in blood supply to the non-dependent lung by increasing vascular resistance, thereby providing more blood to the dependent

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**Figure 3**

*Advancement of Robert Shaw endobronchial tube.*

Distal curvature initially concave anteriorly

Rotated 90°-proximal curve concave anteriorly

Advance until resistance is met

lung for oxygenation. As a result, minimal shunt flow through the hypoxic lung occurs. If HPV did not take place, the amount of shunt would be 40-50% of the total cardiac output. Normal amounts of HPV can increase PaO$_2$ levels and prevent dangerous arrhythmias from occurring. The HPV response is optimal when pulmonary vascular pressures are normal.

Gravity works passively in favor of HPV to increase blood flow to the ventilated down lung. Surgical retraction of non-dependent lung tissue and vessels also passively decreases non-dependent blood flow. On the other hand, most ventilation-perfusion abnormalities can be eliminated when the pulmonary artery is clamped. This clamping directly eliminates shunt flow, causing a marked rise in PaO$_2$ to occur.

**Maintenance of one-lung ventilation**

During one-lung anesthesia, it is important that ventilatory settings be the same as for two-lung ventilation. The tidal volume should be no greater than 10 ml/kg, otherwise it will increase shunting to the upper lung. The functional residual capacity (FRC) of the lower lung will be decreased because of physical compression by the mediastinum from above and abdominal contents pushing against the diaphragm from below.

Maintenance of the lateral decubitus position can cause fluid to transudate into the dependent lung, causing decreased lung volume and increased airway closure. The dependent lung may have hypoxic compartments resulting from low ventilation to perfusion ratios or atelectasis. If severe hypoxemia occurs, the nondependent lung may be ventilated intermittently.

The respiratory rate with one-lung anesthesia should be set to yield a PaCO$_2$ of around 40 mmHg. Gray states that if the total minute ventilation is kept constant when switching to one-lung ventilation, no significant rise in PaCO$_2$ will occur. Sometimes a 20% increase in respiratory rate may be required. PaO$_2$ may fall as a result of the V/Q shunt, which has significantly increased. The upper lung now is getting a large blood supply with no ventilation. FIO$_2$ should be kept near 100 mmHg, if possible.

Administration of 100% O$_2$ and application of PEEP to the clamped lung may be necessary. One hundred percent O$_2$ may be administered by a method called insufflation, which is accomplished by hooking up an O$_2$ tank to some tubing and inserting the tubing into the appropriate endobronchial lumen. PEEP may be added to the clamped lung by another anesthesia machine or by any of several other adaptable systems.

One such system has been proposed by Beth Israel Hospital in Boston. It consists of oxygen tubing connected on one side to a flowmeter, with the other side fitted to the septum of a Portex swivel adapter holding an aneroid manometer that will measure airway pressure. The manometer then is connected to flexible rubber extension tubing with an elbow connector and a pop-off valve nearest the patient. CPAP can be adjusted by altering the oxygen flow rate and/or adjusting the pop-off valve.

A study done by Obara, et al. suggests that PEEP be applied to both the dependent and non-dependent lungs as a means of decreasing intrapulmonary shunt and improving arterial oxygenation during one-lung anesthesia.

The risk associated with the use of PEEP is excessive impingement upon the intraalveolar vessels, which increases pulmonary vascular resistance and cardiac output and diverts blood away from the ventilated lung to the non-ventilated lung. Low levels of PEEP, 5-10 cm H$_2$O, are suggested as being the most therapeutic. However, the amount of PEEP that provides maximal oxygenation with the fewest side effects for each individual patient must be determined by trial and error.

In a study by Rees and Wansbrough, it was demonstrated that patients receiving oxygen insufflation to the non-ventilated lung had a higher PaO$_2$ and significantly lower intrapulmonary shunting. The peak increase occurred after 45 minutes. Overall, the goal is to have blood flowing where it has some chance to participate in gas exchange with alveoli that are expanded with oxygen.

Another important aspect of one-lung anesthesia is the way anesthetics affect HPV. Sykes and others have shown in previous studies that inhalational anesthetic agents in clinical concentrations decrease HPV. Other studies have demonstrated that halothane and isoflurane do not inhibit HPV significantly during one-lung anesthesia.

By contrast, vasodilator agents have been shown to inhibit regional HPV.

The use of a variety of volatile anesthetic agents, together with surgical manipulations, may result in a decrease in cardiac output. A combination of decreased cardiac output, hypotension and shunting may lead to severe hypoxemia. Therefore, hypotension must be treated aggressively during one-lung anesthesia using whatever interventions are necessary to restore perfusion pressure.

**Emergence**

At the conclusion of one-lung anesthesia, the anesthetist is faced with the decision as to how to extubate. The combination of prolonged anesthesia and surgery may result in respiratory complica-
tions. With pulmonary resection, lung compliance and diffusion capacity are reduced, and abnormalities in gas exchange also may be apparent. It is essential to keep the patient intubated until arterial blood gases are optimal. PaO\(_2\) should be > 70 torr and PaCO\(_2\) < 50 torr with spontaneous ventilation, except in cases of COPD. The patient should exhibit hemodynamic stability, reversal of drugs and adequate ventilatory mechanics.

In cases involving previous histories of CHF, CAD, prolonged shock, marginal pulmonary reserve, extreme obesity, intraoperative lung trauma, an unstable chest cage or extremely prolonged anesthesia or surgery, mechanical ventilation is paramount.\(^{11}\)

Before taking the patient to the recovery room the double-lumen tube should be changed to a single-lumen, and mechanical ventilation should be instituted as needed.

**Conclusion**

With the perfection of one-lung anesthesia, some of the most difficult procedures may be performed with ultimate surgical exposure. Selective lung ventilation may be achieved precisely and safely. Endobronchial tube placement may be confirmed with the use of a fiber-optic bronchoscope. Various monitoring devices such as pulse oximeters, PA lines and arterial lines have refined the monitoring and maintenance of hemodynamics and ventilatory parameters during one-lung anesthesia. However, nothing will replace the presence of a vigilant, nurse anesthetist during one-lung anesthesia.

**REFERENCES**


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