New Development in Thoracic Anesthesia

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There are several areas in which significant development can be recognized.

1. Alternative methods of lung separation.
2. Video-assisted thoracoscopy (VAT).
3. Nitric oxide in thoracic anesthesia, and modulation of the pulmonary circulation.

Alternative Methods for Lung Separation

Indications for One-Lung Ventilation

Currently, a variety of thoracic surgical procedures such as lobectomy, pneumonectomy, esophagogastrectomy, pleural decortication, bullectomy, and bronchopulmonary lavage are commonly performed. Customarily they are classified either as absolute or as relative (1). The absolute indications include life-threatening complications, such as massive bleeding, sepsis, and pus, where the nondiseased contralateral lung must be protected from contamination. Bronchopleural and broncho-cutaneous fistulae are absolute indications because they offer a low resistance pathway for the delivered tidal volume during positive pressure ventilation. Giant unilateral bullae may rupture under positive pressure, and ventilatory exclusion is mandatory. Finally, during bronchopulmonary lavage for alveolar proteinosis or cystic fibrosis, prevention of the contralateral lung from drowning is necessary. During the last several years video-assisted thoracoscopy (VAT) was introduced to clinical practice. Unlike conventional thoracoscopy, VAT allows for an extensive variety of diagnostic and therapeutic procedures. Improvements in video-endoscopic surgical equipment and a growing enthusiasm for minimally invasive surgical approaches have contributed to its use. In most cases general anesthesia with one-lung ventilation is required. The lung should be well collapsed to allow the surgeon an optimal view of the surgical field and to palpate the lesion in the lung parenchyma. In addition, it is difficult to place the stapler on a lung that is not completely collapsed, and there is an increase in incidence of postoperative air leak in these circumstances. Because of its common use, VAT significantly increases the number of cases that require lung separation. Relative indications, including lobectomies (particularly right upper lobectomies), pneumonectomy, and thoracic aortic aneurysm repair, are primarily for surgical exposure. In practice, the majority of the procedures where DLT is used are in essence a relative indication, and only a small fraction of procedures are absolute.

Methods of Lung Separation

In the past, bronchial blockers and single-lumen endobronchial tubes have been used to achieve lung isolation. These tubes are seldom used today because of technical obstacles, inability to remove secretions from the nonventilated lung, and less than satisfactory performance. In modern practice, endobronchial double-lumen tubes (DLTs) are most widely employed. These tubes have a fixed curvature, are without a carinal hook to avoid tracheal laceration, and reduce the likelihood of kinking. The original nondisposable Robertshaw red rubber tubes are available in small, medium, and large sizes. Numerous manufacturers produce clear, disposable PVC Robertshaw design DLTs, which are available in sizes 35F–41F (Mallinckrodt, Rusch, Portex, Sheridan). Essentially, they consist of similar features with modifications in cuff shape and location. A colored bronchial cuff, commonly blue, permits easy identification by fiberoptic bronchoscopy. The right endobronchial cuff is donut-shaped and allows the right upper lobe ventilation slot to ride over the right upper lobe orifice. In a recent report by McKenna et al. (2), verification of disposable right-sided DLT position with fiberoptic bronchoscopy revealed that the right upper lobe orifice was occluded in 89%. Most authors refrain from using right-sided DLTs simply to avoid potential obstacles. A 37F DLT can be used in most adult females, while 39F DLTs are used in the average adult male. These PVC tubes are currently considered the most popular and are most extensively used to obtain lung separation.

Positioning of Double-Lumen Tubes

After intubation of the trachea, bilateral breath sounds should be elicited to confirm that the bronchial cuff is not herniating over and impeding ipsilateral lung ventilation. An important step is to verify that the tip of the bronchial lumen is located in the designated bronchus. One simple way to check is to clamp the tracheal lumen, observe, and auscultate. Usually inspection will reveal unilateral ascent of the ventilated hemithorax. When a left-sided DLT is used, the risk of occluding the left upper lobe bronchus by the bronchial tip advanced too far into the left main bronchus should be kept in mind. Perhaps the most important advance in confirming the proper positioning of DLTs is the introduction of fiberoptic bronchoscopy into clinical practice. It has been recently shown that in DLTs thought to be correctly positioned by inspection and auscultation, subsequent fiberoptic bronchoscopy revealed malpositions in 20%–48% (3). The simplest method to evaluate proper positioning of a left-sided DLT is bronchoscopy via the tracheal lumen. The carina is then visualized, whereas only the proximal edge of the endobronchial cuff should be identified just below the tracheal carina. Bronchoscopy should then be performed via the bronchial lumen to identify the patent left upper lobe orifice (Fig. 1). When using a right-sided DLT, the carina is visualized through the tracheal lumen. More importantly, the right upper lobe bronchial orifice must be identified while the bronchoscope is passed through the right upper-lobe ventilating slot (Fig. 2). This is somewhat difficult to accomplish and requires a relatively skilled endoscopist (4). Several sizes of bronchoscope are available for clinical use: 5.6-, 4.9-, and 3.9-mm external diameter (Olympus, Pentax, Stortz). The 3.9 mm-diameter bronchoscope can be easily passed through a 37F or larger tube, whereas it is a tight fit through a 35F tube (5–7).

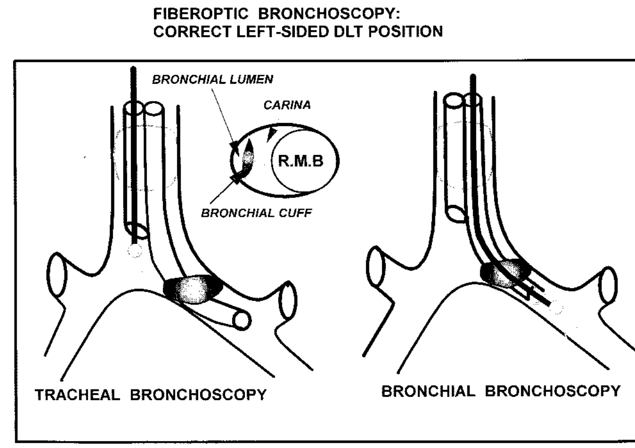

Figure 1. Fiberoptic verification of the correct positioning of a left-sided double lumen tube. The insert is a schematic of the view that should be obtained with tracheal bronchoscopy. RMB = right main bronchus.

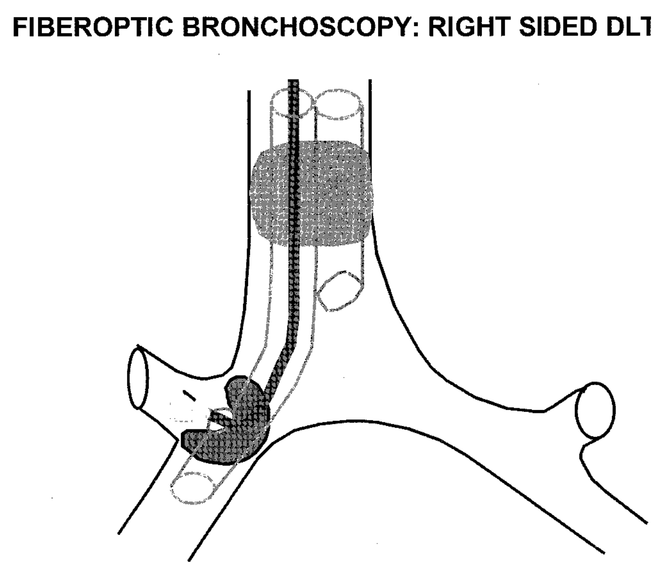

Figure 2. Fiberoptic verification of the correct positioning of a right-sided double-lumen tube.

The Univent Tube

The Univent tube (Univent, Fuji Systems Corp., Tokyo, Japan) is a novel means of achieving bronchial blockade (8). The bronchial blocker technique has been modified so that the bronchial blocker is passed along a single-lumen endobronchial tube. The bronchial blocker is housed in a small anterior lumen containing a thin (2-mm internal diameter) tube with a distal balloon (blocker tube). The blocker tube can be advanced beyond the tip of the tracheal tube into a mainstem bronchus to serve as a blocker (Fig. 3). Before intubation, the blocker cuff is deflated and the blocker is completely retracted into the small lumen. Intubation is carried out as usual with a single-lumen tube. The tracheal tube is than rotated to the side to be occluded and, under direct visualization with a fiberoptic bronchoscope, the blocker is manipulated into the desired mainstem bronchus. To achieve lung separation, the blocker cuff if inflated, under direct vision, to seal the bronchial lumen with 6–7 mL air. The Univent tube has the advantage of using a single-lumen tube instead of a DLT, and there is no need to change over at the end of the procedure if postoperative ventilatory support is required. It is also possible to suction through the blocker lumen or to apply CPAP to improve oxygenation in case of hypoxia. The disadvantages of the tube are as follows: the internal diameter is relatively large, the blocker can dislocate during surgical manipulation, and satisfactory bronchial seal and lung separation are sometimes hard to achieve. Finally, the relatively small diameter of the blocker lumen makes it more difficult to remove secretion. A second generation Univent is now available

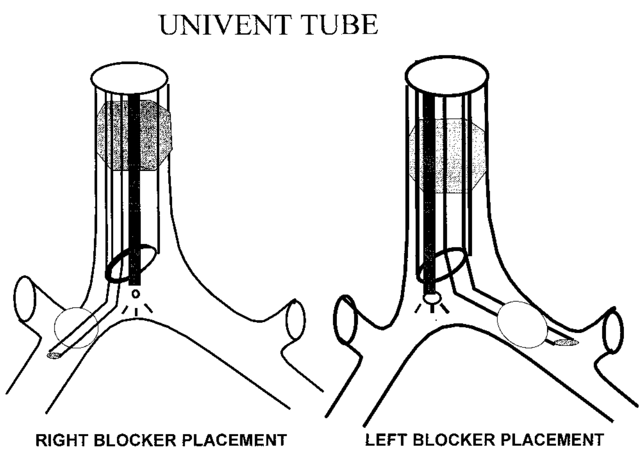

Figure 3. Schematic illustrating placement of a left- and right-sided bronchial blocker of a Univent tubes under fiberoptic guidance. The blocker is well positioned but could easily slide back into the trachea, resulting in obstruction to ventilation.

for clinical use. The blocker is made of silicon that offers higher friction between the blocker and the wall of the channel that hosts the blocker. This allows gradual and controlled movement of the blocker to direct it into the selected bronchus (9–11).

The Use of a Bronchial Blocker

An independently passed bronchial blocker (BB) may be used in conjunction with an SLT to obtain lung isolation or one-lung ventilation, thereby avoiding the use of a difficult tube in a patient with a difficult airway (12,13). The most widely used independent BB is a Fogarty embolectomy catheter, which has occlusion balloons that range in size from 3–8 mL. The FOB is passed down an SLT, visualizing the carina, passing the Fogarty BB into the appropriate main-stem bronchus, and withdrawing the FOB. The Fogarty occlusion catheter comes with a wire stylet in place, and the wire stylet must be curved at the distal end to allow lateral direction to the tip into the desired main bronchus. The catheter balloon is then inflated under direct vision and the FOB is withdrawn. There are several drawbacks to the use of BB, including difficulty in directing the BB into the desired bronchus, particularly the left main bronchus. Because of the shape of the BB balloon it is sometimes difficult to achieve complete occlusion of the main bronchus and creates the inability to effectively suction the airways distal to the blockers. Finally, during the surgical manipulation, the BB may inadvertently slip into the trachea causing life-threatening airway obstruction. Attempts were made to overcome these problems by developing a snare-guided bronchial blocker (Cook Inc., Bloomington, IN) (14). The FB is passed through the loop and guided into the desired bronchus; then the BB is slid over the FB into the selected bronchus. Bronchoscopic visualization confirms blocker placement and occlusion. The string may then be removed, and a 1.8-mm lumen may be used as a suction port or for oxygen insufflation. The disadvantages of this device are its high cost and the inability to reinsert the string once it has been pulled out, thus losing the ability to redirect the BB if necessary. Finally, the external diameter is somewhat larger and requires a large SLT (at least 8.0 mm) to be able to accommodate the BB.

Tube Exchanger

Several tube exchangers are available (Cook Critical Care, Bloomington, IA). All of these airway guides are commercially made, are depth marked in centimeters, are available in a wide range of outer diameters, and are easily adapted for either oxygen insufflation or jet ventilation (15). The airway guide may be used for inserting an SLT, changing an SLT to one of the complex tubes, or simply inserting a complex tube. Critical details to maximize benefit and minimize risk of airway guides are as follows:

1. The size of the airway guide and the size of the difficult tube must be determined and should be tested in vitro before using the airway guide in the patient. The diagram in Figure 4 shows the size of the Cook tube exchanger that can be accommodated with the appropriate DLT size.
2. The airway guide should never be inserted against resistance; the clinician must always be cognizant of the depth of insertion. Two reported perforations of the tracheobronchial tree have occurred.
3. A jet ventilator should be immediately available in case the new tube does not follow the airway guide into the trachea, and the jet ventilator should be preset at 25 psi by the use of an additional inline regulator.
4. Finally, when passing any tube over an airway guide, a laryngoscope should be used to facilitate passage of the tube over the airway guide and past supraglottic tissues.

Conclusion of the Procedure

Depending on the extent and the length of the procedure and the degree of fluid shift, an airway, initially not classified as difficult, may become difficult secondary to facial edema, secretion, and laryngeal trauma from the initial intubation. In these cases when lung separation is planned, the postoperative period should be considered, and the appropriate tube should be inserted (Fig. 5). Many procedures not considered to be absolute indications for lung separation are lengthy and complex. For example, complex lung resection (with or without chest wall resection), thoracoabdominal esophagogastrectomy, thoracic aortic aneurysm resection (with or without total circulatory arrest), or an extensive vertebral

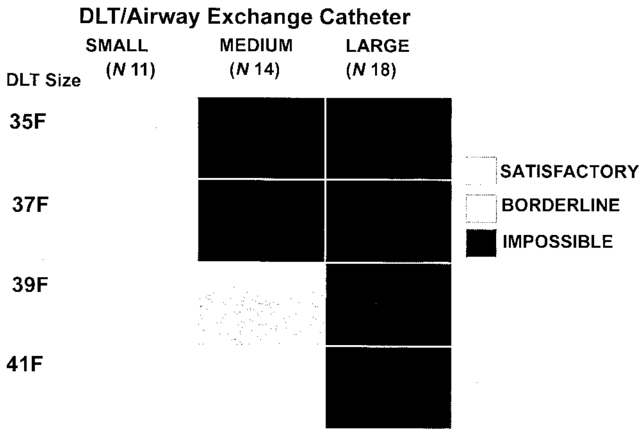

Figure 4. The relation between the various sizes of the tube exchangers and the different sized double-lumen tubes. The equipment should be tested in vitro for compatibility before clinical use.

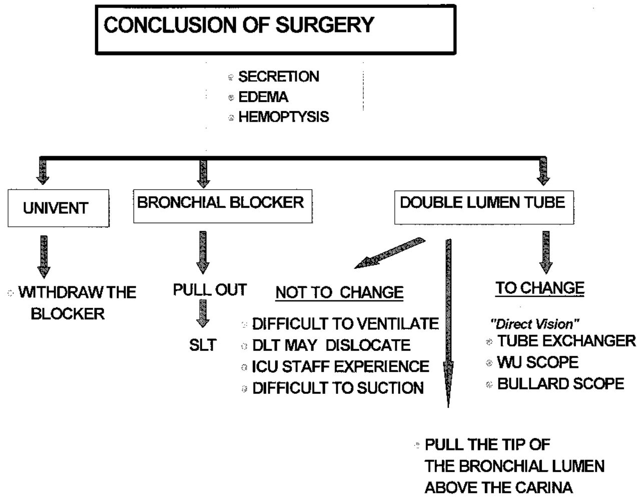

Figure 5. Schematic for tube management at the conclusion of the surgery.

tumor resection may result in facial edema, secretions, and hemoptysis that will require postoperative ventilatory support. Other indications from postoperative ventilatory support are marginal respiratory reserve, unexpected blood loss or fluid shifts, hypothermia, and inadequate reversal of muscle paralysis, will require further ventilator support.

If a Univent tube was used to provide OLV the BB may be fully retracted and the Univent tube can serve as a SLT. If an independent BB was used, then the BB is removed to leave the SLT in place. The problem arises when a DLT was inserted for OLV. With a difficult airway and facial edema the DLT may be left in place. If the DLT is left in place, it is important to keep in mind that the ICU staff is generally less experienced in managing a DLT that may easily become displaced. If the DLT is left in the endobronchial position, then the patient should be paralyzed to avoid malposition of the DLT. Another possibility is to withdraw the DLT to the 19–20 cm mark, so that the endobronchial lumen is above the carina, and to ventilate both lungs through both lumens. It is more difficult to suction through the DLT lumen, and a longer suction catheter is needed to reach the tip of the endobronchial lumen. Extubation directly from the DLT should be considered after diuresis and steroid therapy to allow reduction of the facial edema (16).

If it is decided to change the DLT to an SLT, it should not be accomplished blindly. A tube exchanger should be used to preserve access to the airways as discussed above. The tube exchange may be performed under direct vision using a Bullard or a Wu scope (17). With these scopes the tube exchanger or stylet can be placed under direct vision, through the vocal cords, alongside the existing tube to allow passing an SLT over.

Video-Assisted Thoracoscopy

Improvements in video-endoscopic surgical equipment and a growing enthusiasm for minimally invasive surgical approaches have brought video-assisted thoracoscopy (VAT) to the practice of surgery for diagnostic and therapeutic procedures. Most of these procedures require general anesthesia and a well-collapsed lung, and should be included as an absolute indication for OLV. The variety of the surgical procedures performed by VAT are summarized in Table 1. The patient population tends to be either very healthy, undergoing diagnostic procedures or at high-risk, undergoing VAT to avoid detrimental thoracotomy. In the latter, the less invasive procedure will decrease the risk of postoperative morbidity and mortality. Patients with advanced cardiopulmonary disease, malignancy, and heavy smoking history deserve extensive preoperative evaluation and optimization. The advantage of VAT are summarized in Table 2. Intraoperative monitoring in these high-risk patients should be the same as for thoracotomy. A small incision in the chest wall permits the insertion of the video camera and surgical instruments. In most cases, general anesthesia with one lung ventilation is required (18–21).

The lung should be well collapsed to allow the surgeon an optimal view of the surgical field and to palpate the lesion in the lung parenchyma. Inability to maintain differential lung separation will prevent the procedure from being performed through the thoracoscope, and open thoracotomy will be necessary. Because it may take 30 min for the lung to collapse, it is advisable to initiate OLV immediately after endobronchial intubation. In some cases, CO_2 is insufflated to facilitate visualization, at <10 cm H_2O with a flow of <2 L/min. Higher pressures may cause mediastinal shift with cardiovascular compromise. Some thoracoscopic procedures may be very lengthy, and adequate

Table 1. Indications For Video-Assisted Thoracoscopy

Diagnostic	Therapeutic
Pleural disease	Pleural disease
Effusions	Pleurodesis
Tuberculosis	Decortication
Mesothelioma	Empyemectomy
Staging	Parenchymal disease
Lung cancer	Pneumothorax, blebectomy
Esophageal cancer	Wedge resection
Parenchymal disease	Lung volume reduction
Intertitial fibrosis	Pericardial disease
Solitary nodules	Stripping, window
Mediastianal tumor	Mediastinal disease
Metastatic	Thymectomy, chylothorax
Lymphomas	Esophageal surgery
Pericardial disease	Vagotomy, heller myotomy
Biopsy	Antireflux procedures
Effusions	Sympathectomy
	Hyperhidrosis, RSD

RSD = reflex sympathetic dystrophy.

Table 2. Advantages of Video-Assisted Thoracoscopy

Less invasive/smaller incision
Less postoperative pain
Faster recovery and discharge
Reduce postoperative morbidity
The ribs are not spread
Reduce risk of respiratory depression
Better tolerated by high-risk patients
Reduce cost
Reduce incidence of atelectasis from splinting, decrease coughing and deep breathing, retained secretion
More attractive for the patient
More attractive for the surgeon
V/Q mismatch/Hypoxia
Minimal access surgery
Minimally invasive surgery

hydration, temperature maintenance, and proper positioning in the lateral decubitus are essential (22,23). Finally, treatment of hypoxemia may be difficult during VAT. The best maneuver to improve oxygenation during one-lung ventilation is by the application of 10 cm H_2O CPAP to the collapsed lung. Application of positive end-expiratory pressure to the dependent lung may be inefficient because of blood flow diversion from the dependent lung. Unfortunately, application of positive pressure CPAP is impossible during VAT since it will significantly interfere with the surgeon's ability to access the surgical field. Potential problems of using VAT are summarized in Table 3.

In a very small, select group of patients VAT may be performed under regional anesthesia to avoid the need for endobronchial intubation using an intercostal block or epidural. Patients for regional VAT should be carefully selected and the risk-benefit should be considered. The procedure should be of short duration and simple and patent airways should be easy to establish in case of an emergency. The apex of the lung and the pleura are poorly blocked by the intercostal nerve block. Therefore, procedure such as pleural abrasion should be done under general anesthesia. Finally, the awake patient breathing spontaneously with an open chest may develop hypoxemia and hypercarbia from paradoxical breathing and hypotension from mediastinal shift. These may be treated by applying slight positive pressure by mask (Table 4).

Table 3. Video-Assisted Thoracoscopy

Lung separation (DLT, Univent, Blocker)
CPAP Application interfere with the surgeon view
Need a well collapsed lung (optimal view)
CO_2 insufflation at 2 L/min (10–12 cm H_2O) to enhance lung collapse
Cardiovascular compromise from one-lung ventilation: possible hypoxia compression by the gas
Hypercarbia/gas embolism/arrhythmias
Extended operative time
Limited evaluation of the surgical field/pathology, incomplete staging
Limited vascular control, pleural seeding,
Limited access to the patient head
The table is maximally flexed to widen the intercostal spaces
Two or three separate incision (trocras)
Need chest tube postoperatively
Decortication, pleurectomy, pleurodesis are painful: PCA/Intercostal block
A-line/CVP/$ETCO_2$

DLT = double-lumen tube; CPAP = continuous positive airway pressure; PCA = patient-controlled analgesia.

Approximately 9% of VATS patients experience some complications (24). These include hemorrhage, subcutaneous emphysema, empyema, recurrent pneumothorax, pulmonary edema and pneumonia. Dissemination of tumor at the thoracostomy tube site is also possible. Persistent postoperative air leaks are common. Any structure that the surgeon manipulates or resects can be damaged. Some patients may experience impaired gas exchange during and after the procedure. The pneumothorax created during VATS, especially when associated with CO_2 insufflation into the closed chest, can result in hypercarbia and inadequate ventilation, hemodynamic instability, and even gas venous embolism. Common to all VATS procedures is the need to be able to convert to an open thoracotomy rapidly when necessary. Atrial arrhythmias, especially supraventricular tachycardia and atrial fibrillation occur after all pulmonary resections and the incidence is similar after VATS or thoracotomy (25).

Nitric Oxide in Thoracic Anesthesia, and Modulation of the Pulmonary Circulation

Nitric oxide (NO) is an important endothelium-derived relaxing factor. It is produced by the endothelium from l-arginine via a metabolic pathway that

Table 4. VAT Using Intercostal Block

Modified intercostal block
(optional ipsilateral stellate ganglion block)
The apex and the pleura are poorly blocked
Sedation: Remifentanyl/propofol drip
The procedure should be of short duration (<1 h)
Easy to establish airways in case of emergency
The patient breathing spontaneously breathing with an open chest
May develop hypoxia and hypercarbia from paradoxical breathing
Hypotension from mediastinal shift
Treat by applying a positive pressure (face mask)
No CO_2 insufflation!!

requires NO synthase, and NO diffuses into subjacent vascular smooth muscle to cause relaxation and vasodilatation. NO combines intracellularly with the heme present in guanylate cyclase. This activation of the guanylate cyclase led to smooth muscle relaxation through the synthesis of guanosine 3,5-cyclic monophosphatase (cGMP). Clinically used nitrovasodilatators such as nitroprusside and nitroglycerin exert their effects by releasing NO intracellularly. In addition to regulating vascular tone, endogenously produced NO is important in regulating several other physiologic functions, including platelet aggregation, neurotransmission, and antitumor and antimicrobial activity. Inhaled NO (5–80 ppm) has been shown to decrease pulmonary vascular resistance (26).

NO has a selective dilating effect on the pulmonary circulation without effecting the systemic circulation. Because inhaled NO is quickly inactivated by the hemoglobin in the vascular lumen, it has direct systemic effects. The half-life of NO is between 110–130 ms. Thus, exogenous inhaled NO may diffuse from the alveoli to pulmonary vascular smooth muscle and produce pulmonary vasodilatation, but any NO that diffuses into blood will be inactivated before it can produce systemic vasodilatation. Since NO distributes directly into the alveoli, it is a selective microvasodilator only of those capillary adjacent to ventilated alveoli, and therefore improves V/Q matching. This effect is in contrast to NTP or NTG, which, when given IV, cause a nonselective capillary dilation of poorly ventilated alveoli, which result in deterioration of oxygenation (27). These properties of NO on the pulmonary circulation are used in a variety of clinical applications. Frostell et al. (27) described the effect of inhaled NO during hypoxia in human volunteers, inhaled NO selectively reversed HPV without causing systemic vasodilatation. A major application of inhaled NO is in congenital heart disease associated with pulmonary hypertension with large left-to-right shunts and pulmonary hypertension.

The concept that the pulmonary circulation can be modulated by the administration of NO to selective

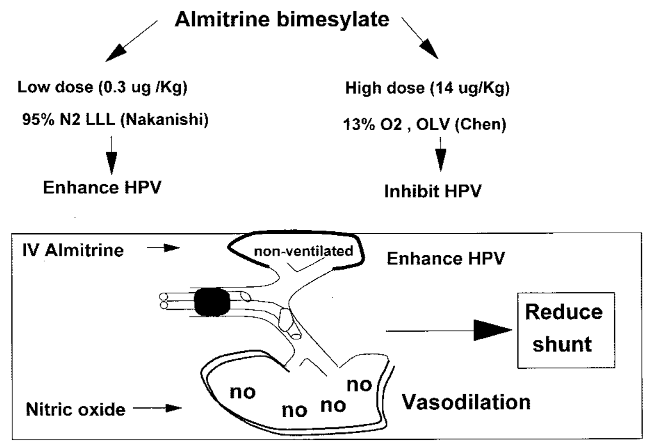

Figure 6. Modulating the pulmonary circulation with the combination of Almitrine bimesylate IV and inhaled nitric oxide (NO) during one-lung ventilation.

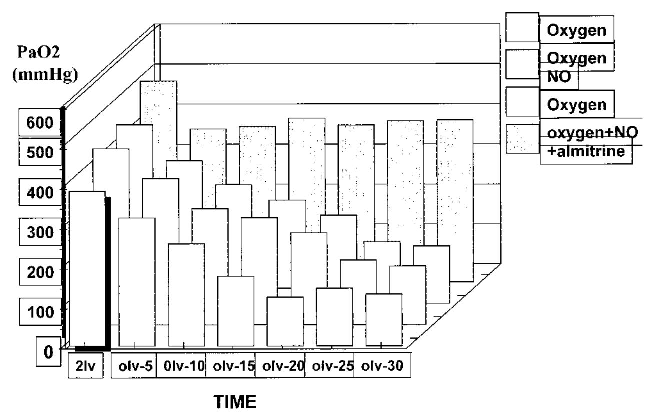

Figure 7. The effects of inhaled nitric oxide and in combination with IV almitrine on arterial oxygenation (Pa_{O_2}) during one-lung ventilation (OLV) in patients undergoing thoracoscopic procedures.

areas of the lung may be important during one-lung ventilation. In theory, the administration of NO during OLV for thoracotomy will cause vasodilatation of that lung. This will enhance the effect of HPV in the nondependent lung to increase blood flow to the dependent lung and reduce the degree of shunt. Preliminary studies during OLV present mixed results. Booth et al. (28) administered NO at 40 ppm to nine patients during OLV and reported improvement in oxygenation during OLV compare with a control group of six patients (26.8 Pka vs 12.6 Pka). More recently, Wilson et al. (29) found no improvement in six patients by the administration of NO at 40 ppm. Qs/Qt did not change in these patients with normal PVR. The beneficial effect of NO is limited in the absence of hypoxemia and pulmonary vasoconstriction. Most likely, patients with hypoxemia and elevated pulmonary pressure during OLV will benefit from the application of NO.

One of the most interesting future concepts in keeping adequate oxygenation during OLV is the ability to modulate the lung circulation. Almitrine bimesylate, a peripheral chemoreceptor agonist, increases pulmonary hypoxic vasoconstriction in low doses. In fact, inhaled NO and IV almitrine have been combined with additive effects on gas exchange. In case of OLV, use of the combination maximizes the HPV of the nondependent lung while dilating the dependent lung to practically eliminate the transpulmonary shunt (Fig. 6). The theory was tested by Moutafis et al. (30) in 20 patients undergoing thoracoscopic lung resection. The patients that received the combination of almitrine and NO had almost no decrease in Pao_2 during OLV. That is important for those patients with a marginal respiratory reserve who are unable to maintain oxygenation on OLV (Fig. 7). Finally, it would be useful during VAT where the application of CPAP to the nondependent lung interferes with the surgeon's ability to view the surgical field.

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