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Intraoperative management for thoracic surgery

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The incidence of hypoxemia during one-lung ventilation (OLV) with an inspired oxygen concentration (FiO_2) of 1.0 has declined from levels of 20-25% in the 1970's[1] to approximately 1% today[2]. Two advances in thoracic anesthesia are responsible. First, the routine use of fiberoptic bronchoscopy to position double-lumen tubes. Second, the increased use of balanced anesthesia with lower doses of volatile anesthetic agents.

PROGRESS IN LUNG ISOLATION

The second half of this century has seen refinements of the double-lumen tube (DLT) from that of Carlens[3] to a tube specifically designed for intraoperative use (Robertshaw)[4] with larger, D-shaped, lumens and without a carinal hook. Current disposable polyvinylchloride DLTs have incorporated high-volume low-pressure tracheal and bronchial cuffs[5]. These recent DLT refinements have two major drawbacks: 1) These tubes now require fiberoptic bronchoscopy for positioning[6,7]. 2) A satisfactory right-sided DLT has not yet been designed, to deal with the short (average 2 cm) and variable length of the right main stem bronchus[8]. Recently, there has been a revival of interest in bronchial blockers (BBs) due to several factors: design advances such as the Univent tube[9] and WEB blocker (Cook Catheter Co.)[10], greater familiarity of anesthesiologists with fiberoptic placement of BBs, and cost.

INDICATIONS FOR LUNG SEPARATION

Since it is impossible to describe one technique as best in all indications for one-lung ventilation (OLV), the various indications will be considered separately.

1. *Elective pulmonary resection, right-sided*: This is the commonest adult indication for OLV. The first choice is a left-DLT. There is a wide margin of safety in positioning left-DLTs. With blind positioning the incidence of malposition can exceed 20% but is correctable in virtually all cases by fiberoptic adjustment[11]. A partial resection can proceed to a pneumonectomy, if required, without loss of lung isolation. There is continuous access to the non-ventilated lung (NV-lung) for suctioning, fiberoptic monitoring of position, and continuous positive airway pressure (CPAP). There are differences in the designs of the bronchial cuffs which result in different mean bronchial cuff inflation volumes and pressures during one-lung ventilation. Possible alternatives are: a) Single lumen EBT. A standard 7.5 mm, 32 cm length endotracheal tube (ETT) can be advanced over a fiberoptic bronchoscope (FOB) into the left mainstem bronchus. b) Univent tube or BB. The BB can be placed external to or intra-luminally with an ETT. Lung collapse is frequently unsatisfactory with a BB for a right thoracotomy[12]. A method of using two right-sided BBs (one in the right upper lobe and one in the bronchus intermedius) has been described to deal with this problem[13].
2. *Elective pulmonary resection, left-sided*: a) *Not pneumonectomy*: There is no obvious best choice, between a BB and a left-DLT. The use of a left-DLT for a left thoracotomy is occasionally associated with obstruction of the tracheal lumen by the lateral tracheal wall and subsequent problems with gas exchange in the ventilated lung (V-lung). A right-DLT is an alternate choice, problems with lung isolation and/or positio ning with routine FOB placement occur much less fre quently than previously thought[14].

b) *Left pneumonectomy*. There is no completely satisfactory choice. Any left pulmonary resection may unforeseeably become a pneumonectomy. When a pneumonectomy is foreseen, a right-DLT is the best choice. A right-DLT will permit the surgeon to palpate the left hilum during OLV without interference from a tube or blocker in the left mainstem bronchus. The disposable right-DLTs currently available in North America vary greatly in design depending on the manufacturer (Mallinckrodt, Rusch, Kendall). The Mallinckrodt design is currently the most reliable. All three designs include a ventilating side-slot in the distal bronchial lumen for right upper lobe ventilation. Positioning this slot can be time-consuming. These tubes require relatively high bronchial intra-cuff pressures (40-50 cm H_2O *vs* 20-30 cm H_2O for left-DLTs). However, this is lower than the range of pressures required by a Univent[15] or non-disposable DLTs. Rarely, left lung isolation is impossible in spite of extremely high pressures in the right-DLT bronchial cuff. In these cases a Fogarty catheter can be passed into the left main bronchus after estimation of depth with a FOB. As an alternative, there is no clear preference among a Univent, left-DLT or other bronchial blocker. These will all require repositioning intraoperatively, but this usually is not a major problem.

3. *Thoracoscopy:* Lung biopsies, wedge resection, bleb/bullae resections, even some lobectomies can be done using this technique. Video-assisted thoracoscopic surgery (VATS) under general anesthesia requires OLV[16]. During open thoracotomy the lung can be compressed by the surgeon to facilitate collapse prior to inflation of a bronchial blocker. This is not possible during thoracoscopy. The operative lung deflates more easily when the NV-lung lumen of a DLT is opened to atmosphere than via the 2 mm suction channel of a Uni vent tube. A left-DLT is preferred for thoracoscopy of either hemithorax[17]. Spontaneous ventilation without lung isolation is an alternative in some patients[18].
4. *Pulmonary hemorrhage*: Instances of life threatening pulmonary hemorrhage can occur due to a wide variety of causes (Aspergillosis, Tuberculosis, PA catheter trauma, etc). The anesthesiologist is often called to deal with these cases outside the operating suite. The primary risk for these patients is asphyxiation, and first line treatment is lung isolation. There are several problems associated with using any sort of bronchial blocker in the acute situation: a) It is often not known which side to occlude. b) Visualization below the vocal cords to aid placement is difficult. c) After the blocker is placed there is no access to the involved lung to monitor bleeding. In patients with pulmonary hypertension, endobronchial blockade can lead to lobar rupture from continued bleeding[19]. A left-DLT avoids these problems[20]. Tracheobronchial hemorrhage from blunt chest trauma will usually resolve with suctioning, only rarely is lung isolation necessary[21]. PA catheter-induced hemorrhage during weaning from bypass should be dealt with by resumption of full bypass, bronchoscopy, and lung isolation. Weaning may then proceed without pulmonary resection in some cases[22,223].
5. *Bronchopleural fistula*: The anesthesiologist is faced with the triple problem of avoiding tension pneumothorax, ensuring adequate ventilation, and protecting the healthy lung from the fluid collection in the involved hemithorax. Management depends on the site of the fistula and the urgency of the clinical situation. For a peripheral bronchopleural fistula in a stable patient, some form of BB such as a Univent tube may be acceptable. For a large central fistula, and in urgent situations, the rapidest and most reliable method of securing one-lung isolation and ventilation is a DLT. In life threatening situations, a DLT can be placed in the awake patient with direct FOB guidance[24].
6. *Purulent secretions*: Lung abscess, hydatid cysts, etc. Lobar or segmental blockade is the ideal. Loss of lung isolation in these cases is not merely a surgical inconvenience, but may be life threatening. Univent tubes can be used for lobar blockade. A secure technique in these cases is the combined use of a bronchial blocker and a DLT[25].
7. *Non-pulmonary thoracic surgery*: Thoracic aortic and esophageal surgery require OLV. Since there is no risk of V-lung contamination, a left-DLT or a BB are equivalent choices.
8. *Bronchial surgery*: An intra-bronchial tumor, bronchial trauma, or a bronchial sleeve resection during a lobectomy require that the surgeon have intra-luminal access to the ipsilateral mainstem bronchus. Either a single lumen EBT[26] or a DLT in the V-lung is preferred.
9. *Upper airway abnormalities*: It is occasionally necessary to provide OLV in patients who have abnormal upper airways due to previous surgery, trauma, etc. A BB may be useful in some of these patients. Smaller DLTs (28 and 26 Fr) are available, but will not permit passage of a FOB of the diameter commonly used to monitor positioning (3.5 - 4.0 mm). An ETT designed for microlaryngoscopy (5 - 6 mm ID and > 30 cm length) can be used as an EBT, with FOB positioning. If the patient's trachea can accept a 7.0 mm ETT, a Fogarty catheter (8/10 Fr venous thrombectomy catheter with a 4 cc balloon) can be passed through the ETT via a fiberoptic bronchoscopy adapter for use as a BB[27].
10. *Unilateral lung lavage[28], independent lung ventila tion, and lung transplantation:* are all best accomplis hed with a left-DLT.
11. *Pediatrics*: The increased use of thoracoscopy in chil dren has caused an increase in the need to provide one-lung isolation in pediatric anesthesia. New BBs are being developed to meet this demand[29].

AVOIDING AIRWAY TRAUMA

Iatrogenic injury has been estimated to occur in 0.5 - 2 per 1000 cases with DLTs[30].

a) The majority of difficult endobronchial intubations can be predicted from viewing the chest x-ray[31] or CT scan[32]. There is no substitute for the anesthesiologist assessing the film him/herself prior to induction.

b) Use of an appropriate size tube. Too small a tube will make lung isolation difficult. Too large a tube is more likely to cause trauma. Useful guidelines for DLT sizes in adults are: females height < 1.6 m (63 inch): 35 Fr; females ≥ 1.6 m: 37 Fr; males < 1.7 m (67 inch): 39 Fr; and males ≥ 1.7 m: 41 Fr. Tracheobronchial dimensions correlate with height[33]. The average depth at insertion, from the teeth, for a left-DLT is 29 cm in an adult and varies ± 1 cm for each 10 cm of patient height above/below 170 cm.

c) Avoid nitrous oxide: Nitrous oxide 70% can increase the bronchial cuff volume from 5 to 16 ml intraoperatively[35].

d) Inflate the bronchial cuff/blocker only to the minimal volume required for lung isolation and for the minimal time. This volume is usually < 3 ml. Inflating the bronchial cuff does not stabilize the DLT position when the patient is turned to the lateral position[36].

e) Endobronchial intubation must be done gently and with fiberoptic guidance if resistance is met. A significant number of case reports are from cases of esophageal surgery where the elastic supporting tissue may be weakened and predisposed to rupture from DLT placement.

OTHER COMPLICATIONS

Malpositioning: Initial malpositioning of DLTs with blind placement can occur in over 30%[37] of cases. Verification and adjustment with FOB immediately prior to initiating OLV is mandatory since these tubes will migrate during patient positioning[38]. Malpositioning after the start of OLV due to dislodgment is more of a problem with bronchial blockers than DLTs. Complications during thoracic anesthesia may not be defensible if a FOB is not used[39].

Airway resistance: The resistance from a 37 Fr DLT exceeds that of a #9 Univent by < 10%. These flow resistance's are both less than a 8.0 mm ID ETT but exceed a 9.0 mm ETT. For short periods of postoperative ventilation and weaning, airflow resistance is not a problem with a modern PVC DLT[40].

MANAGEMENT OF ONE-LUNG ANESTHESIA

The major cause of hypoxemia is the shunt of de-oxygenated blood through the non-ventilated lung. Factors which influence this shunt are hypoxic pulmonary vasoconstriction (HPV), gravity, the pressure differential between the thoraces and lung volume. HPV is inhibited by essentially all volatile anesthetics. Isoflurane/Desflurane/Sevoflurane are equivalent and less inhibitory than Enflurane or Halothane. Oxygenation with < 1 MAC Isoflurane/Desflurane/Sevoflurane is equivalent to total intravenous anesthesia.

Manipulating the ventilating pressures and tidal volumes during one-lung anesthesia can improve the oxygenation for individual patients. Patients with chronic obstructive pulmonary disease (COPD) have better oxygenation during OLV with pressure-controlled *vs* volume-controlled ventilation.

A third of the 35-40% shunt during OLV is due to ventilation-perfusion mismatch in the ventilated dependent lung. Factors under the control of the Anesthesiologist can influence this dependent-lung shunt. An excess of intravenous crystalloids can rapidly cause desaturation of the pulmonary venous blood draining the dependent lung. Also, the use of nitrous oxide will lead to increased dependent-lung atelectasis since it causes greater instability of poorly ventilated lung regions than oxygen. A recruitment maneuver to the ventilated lung at the start of OLV improves oxygenation[41].

Several factors allow prediction of the risk of hypoxemia developing during OLV[42]. First, the A-aO_2 gradient during two-lung ventilation. Second, the side of lung collapse during OLV. The mean PaO_2 level is 70 mmHg higher for left vs. right thoracotomies. Third, patients with good preoperative spirometric pulmonary function tests tend to have lower PaO_2 values during OLV than patients with poor spirometry. This is related to auto-PEEP in patients with poor spirometry.

Continuous positive airway pressure (CPAP) to the non-ventilated lung is the first-line of defense and treatment[43]. Useful increases in oxygenation can be achieved with 1-2 cm H_2O CPAP applied to the fully inflated lung[44]. Maintaining cardiac output during OLV increases PaO_2 via maintaining mixed venous oxygen content since these patients have a large shunt. PEEP to the ventilated lung decreases PaO_2 in the majority of patients during OLV. A minority of patients, usually those with normal[45] or supra-normal (pulmonary fibrosis, obesity) lung elastic recoil benefit from dependent-lung PEEP[46]. HFJV is useful for non-pulmonary intra-thoracic surgery. An intravenous infusion of Almitrene (a pulmonary vasoconstrictor) can restore PaO_2 during OLV to levels close to these during two-lung ventilation[47].

Ventilatory management during OLV needs to be individualized depending on the patient's underlying lung pathology. Initial strategies should now include: tidal volumes in the 4-6 ml/kg range, limiting plateau airway pressures to 25 cm H_2O and adding PEEP 5 cm H_2O to patients without auto-PEEP. The use of the traditional large tidal volumes (10-12 ml/kg) and high airway pressures during one-lung ventilation may be associated with acute lung injury following pulmonary resection[48].

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