Pneumonectomy and Management of One Lung Ventilation

Pneumonectomy is generally performed for malignancy in patients with variable co-morbidities and involves significant perioperative risk, including respiratory failure, tachyarrhythmias, ischemia and right heart failure and requires planning and initiation of one-lung ventilation to facilitate surgical resection

ANESTHETIC CONSIDERATIONS:

- Will patient tolerate pneumonectomy
- Lung Cancer
  - Tumor compression of the trachea, heart and major vessels
  - Paraneoplastic effects of the tumor
- Co-morbid disease
  - Smoker, COPD, vasculopath, CAD
- Increased perioperative risks:
  - Respiratory failure (including risk of post-pneumonectomy ALI, atelectasis & pneumonia)
  - Arrhythmias (esp. atrial fibrillation)
  - Ischemia
  - Pulmonary HTN / RV dysfunction
- Physiologic changes (esp. hypoxia) during one-lung ventilation & technique for EBT placement
- Postoperative pain and monitoring for complications

ANESTHETIC GOALS:

- General anesthesia with paralysis and controlled ventilation
- One lung isolation with prevention of hypoxemia
- Careful fluid management (maintaining cardiac output but keeping patient on the dry side)
- Prevention of hypothermia
- Treatment of arrhythmias
- Optimal pain management: TEA

HISTORY

- **HEENT**
  - Worry about recurrent laryngeal nerve involvement: hoarseness
  - Identify risk factors for difficult endobronchial tube insertion: previous radiation, pulmonary / airway surgery, infection
- **CVS**
  - Hx of RV dysfunction due to pulmonary HTN, LV function, valvular disease, arrhythmias (CP / SOB, exercise tolerance, palpitations)
- **RESP**
  - Dyspnea / exercise tolerance
  - Cough: hemoptysis (bronchiectasis, tumor, TB), sputum (infection)
  - Wheeze d/t airway obstruction
  - Positional aggravation of cough / dyspnea: variable vs. fixed, intrathoracic vs. extrathoracic
  - Chest / pleuritic pain
  - Concurrent respiratory disease: smoking, COPD
- **MALIGNANCY**
  - **Mass effects**: obstructive pneumonia, lung abscess, SVC syndrome, tracheobronchial distortion, Pancoast's syndrome (rib erosion, shoulder pain radiating down the arm, Horner's syndrome), RLN (hoarseness), phrenic nerve (elevated hemidiaphragm), chest wall / pleura / mediastinal extension, esophagus (dysphagia)
  - **Metabolic effects** (paraneoplastic): Eaton-Lambert syndrome (proximal weakness, muscle pain, absent reflexes, sensitive to NDMR / DMR) , hypercalcemia (high PTH-like hormone), hyponatremia (SIADH), Cushing's syndrome (ACTH)
  - **Metastase**s: brain, bone, liver, adrenal
  - **Medications** (chemo): pulmonary toxicity (bleomycin, mitromycin), cardiac toxicity (doxorubicin), renal toxicity (cisplatin)
  - **Other**: anorexia, weight loss, fever
- **ENDO**
  - Symptoms of paraneoplastic syndrome (hypercalcemia, SIADH → hyponatremia, Cushing's syndrome, myopathy: somnolence / anorexia / N&V / weight loss / signs of water intoxication)
- **HEME** – Anemia, polycythemia, migratory thrombophlebitis
- **MSK** – Eaton-Lambert syndrome, polymyositis

PHYSICAL

- **HEENT**
  - Ease of intubation, distortion of anatomy
- **RESP**
  - Vitals including room air SpO2
  - Nasal flaring, accessory muscle use, indrawing, clubbin, cyanosis
  - Decreased or adventitious breath sounds, prolonged expiratory phase
  - Dullness to percussion / air entry (identify atelectasis / pneumonia)
  - Wheezing (bronchospasm, COPD, mass-related obstruction), crackles (CHF)
  - Ptosis / miosis / anhidrosis (Horner's syndrome secondary to Pancoast tumor)
  - Mass Effects: tracheal compression, facial edema (SVC syndrome)
- **CVS**
  - Sustained HJR, displaced apical pulse
  - Signs of pHTN (RV heave, loud P2), or CHF (JVP, peripheral edema, S3/S4)
  - Hepatomegaly
- **MSK**
  - Weakness (Eaton-Lambert)

INVESTIGATIONS

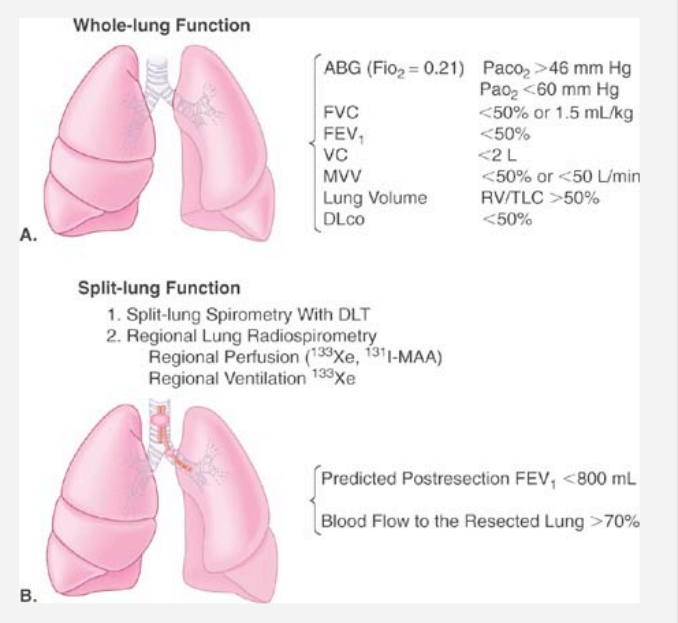

Figure 40-4. The order of tests to determine the cardiopulmonary status of the patient and the extent of lung resection that would be tolerated. **A.** The whole-lung function test is a basic screening test. **B.** The split-lung function tests are regional tests to determine the involvement of the diseased lung to be removed. ABG, arterial blood gas; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; VC, vital capacity; MVV, maximum voluntary ventilation; RV/TLC, residual volume/total lung capacity; DLT, double-lumen tube. DL_{CO}, carbon monoxide diffusing capacity; (Adapted from Neustein SM, Cohen E: Preoperative evaluation of thoracic surgical patients, The Practice of Thoracic Anesthesia. Edited by Cohen E. Philadelphia, JB Lippincott, 1995, p 187, with permission.)

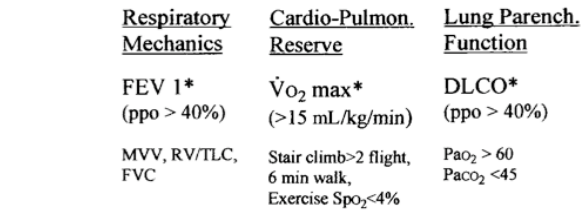

Figure 2. The *three-legged stool* of prethoracotomy respiratory assessment. * = Most valid test (see text). DLCO = diffusing capacity of the lung for carbon monoxide. $\dot{V}o_2$ max = maximal oxygen consumption.

- **Respiratory Mechanics:**
  - Estimation $ppoFEV_1$ = preoperative FEV1% x (1 - % functional lung tissue removed / 100)
    - Right lung = 52-55% of lung function, left lung = 45-48%
  - Individualized $ppoFEV_1$ based on quantitative V/Q scan: ^{133}Xe is inhaled and ^{99}Tc-labeled macro-aggregates IV
    - $ppoFEV_1$ = (preop FEV_1) x (% radioactivity contributed by non-operated lung)
  - $ppoFEV_1$ < 0.8L contraindication to lung resection
  - $ppoFEV_1$% < 40% = major resp complications, < 30% = postop mechanical ventilatory support
- **Lung Parenchymal Function:**
  - Traditionally ↓ resp complications if PaO_2 > 60mmHg, $PaCO_2$ < 45mmHg
  - DLCO correlates with the total functioning surface area of alveolar-capillary interface
  - ppoDLCO > 40% = ↓ resp and cardiac complications
- **Cardiopulmonary Function:**
  - Stair climb: continuous ascent of > 3 flights (flight = 20 steps of 6"/step) of stairs at pt's own pace associated with ↓ mortality / morbidity
  - Gold standard: VO_2 max > 15 cc/kg/min (equivalent to stair climb >2 flights) = ↓ complications
    - $ppoVO_2$ max < 10 cc/kg/min (eqivalent to climbing less than 1 flight of stairs) = 100% mortality
    - 6 min walk test: excellent correlation with VO_2 max
      - < 2000ft = VO_2 max < 15 cc/kg/min and ↓ O_2 Sats
    - Exercise oximetry: ↓ O_2Sats 4% = ↑ risk
- **Increased risk of postop ventilatory failure**
  - FEV_1 < 50% or <2L
  - DLCO < 40%
  - FEV_1 x DLCO <1650
  - RV/TLC ratio > 50%
  - Poor exercise tolerance (METs < 4 or VO_2max < 12 ml/kg/min)
  - Pulmonary HTN
- **Pulmonary Function Testing Cascade**
  - **Stage 1: Whole Lung Function: the following results requires stage 2**
    - ABG: $PaCO_2$ >46, PaO_2 <60
    - Spirometry: FVC <50% (1.5 mL/kg), FEV_1 <50%, VC <2L, MVV <50%, RV/TLC >50%, DLCO <50%
  - **Stage 2: Split Lung Function: surgery is contraindicated:**
    - Split Lung spirometry with DLT: if ppo FEV_1 <0.8L

        - Regional lung Radiospirometry (^{133}Xe): blood flow to resected lung >70%
    - **Stage 3: Unilateral PA Occlusion: poor postop tolerance (variable predictability)**
        - PAP (wedged) >35-40
        - PaO_2 <45 mm Hg
        - $PaCO_2$ > 60 mm Hg
- **Labs**
    - CBC: anemia, infection
    - Lytes / BUN / Cr and Ca^{++}: evidence of renal failure, low Na (SIADH), high Ca, low K (Cushing's)
    - ABG: hypercapnia / hypoxemia
    - Coags: epidural potential for hemorrhage
    - X-match
- **Imaging**
    - **CXR** - signs of CHF, effusions, abscesses, location of mass, tracheobronchial displacement
    - **ECG** - arrhythmia, ST segment, Q or T wave changes; increased RA, RVH
    - **CT**: location of mass (tracheobronchial displacement), predict difficulty in isolating lung (side to side compression of distal trachea)
    - **ECHO**: (for pts with $ppoFEV_1$ < 40% for pneumonectomy) RV dysfunction, pulmonary HTN, LV dysfunction
- **Special**
    - **V/Q**: considered for ppoFEV1< 40%, predicts post op functional lung reserve
    - **Split-lung function**: unilateral exclusion of lobe via EBT, PA cath (insufficient predictive validity)
    - **PFTs**
        - Flow-volume loops: identify behavior of mass (variable or fixed, intrathoracic or extrathoracic)
    - Respiratory, Cardiology, Physiotherapy consults

OPTIMIZATION

- Smoking cessation: > 12-48h ↓ carboxyHb and shifts oxyHb curve to R; > 8wk to ↑ mucociliary function
- Optimize COPD (see also Obstructive Lung Disease Seminar)
    - Respiratory consult
    - Bronchodilators / corticosteroids to dilate airways
    - Mucomyst / humidified air to loosen secretions
    - Perioperative chest physiotherapy to remove secretions
    - Antibiotics for infection
    - Incentive spirometry
    - O_2 to keep PaO_2 > 60 mmHg
- Medical treatment of CAD (anti-HTN, cholesterol lowering, B-blocker) +/- angioplasty / CABG
    - Cardiology / cardiac surgeon consult as required
    - Delay thoracic surgery 4-6 wks post MI
- Consider **antiarrhythmia prophylaxis** (**Procedures w/ ↑ risk**: mediastinal tumor resection or thymectomy, lobectomy, bilobectomy, pneumonectomy, and esophagectomy; **Patient factors w/ ↑ risk**: male sex, increasing patient age > 60, history of CHF, history of arrhythmias, and history of peripheral vascular disease) – **amiodarone** (first choice), diltiazem, verapamil, flecainide, B-blockers, digoxin have been used – small numbers / conflicting results in literature

ANESTHETIC OPTIONS

- General anesthetic +/- thoracic epidural
    - If unable to place thoracic epidural (keep trying!! – this is essential), then consider intercostal nerve blocks on ipsilateral side, surgically placed intrapleural catheter or PCA
- Lung Isolation Options
    - **NOTE**: look at the CXR and CT in advance, know the tracheobronchial anatomy, use the FOB for confirmation of placement
    - DLT – L or R sided
        - Optimal to use a device that does not interfere with the ipsilateral airway (ie. for a left pneumonectomy, a right-sided DLT); if a left-sided DLT is used for a left pneumonectomy, it must be withdrawn prior to stapling the bronchus in order to avoid accidental inclusion into the suture line
        - Brodsky Criteria for size and length of DLT:
            - Length of tube:
                - Male / females 170 cm tall: insert tube to a depth of 29 cm
                - For every 10 cm increase in height, increase depth by 1 cm
            - Size based on measured tracheal width:

Width (mm)	Tube (French Gauge)
18	41
16	39
15	37
14	35

    - Bronchial Blocker (Fogarty vascular catheter, wire guided, univent tube)
    - Mainstem Bronchus intubation with single lumen tube or 2 single lumen tubes (5-6 mm ID and > 30 cm length)

ANESTHETIC SETUP

- **Drugs**
    - Ephedrine, phenylephrine, intropes PRN
    - Esmolol / verapamil / digoxin / amiodarone: AF, MAT, PSVT
- **Equipment**
    - FOB, DLT, blockers
    - Epidural catheter set
    - Art-line, CVP, large bore IV: for OLV
    - 5-lead ECG
    - Temperature monitor (esophageal or nasopharyngeal)

- Foley catheter
- +/- flow-volume loop
- +/- PA cath: measurements affected by dependant vs. non dependant lung placement
- +/- TEE

MANAGEMENT OF ANESTHESIA

- **Induction**
  - Thoracic epidural pre-induction is essential
  - Lateral or supine positioning
  - Reactive airways: ketamine best induction agent, avoid histamine releasing NDMR and narcotics
  - Consider etomidate in elderly or cardiovascularly unstable (ketamine can also be considered)
  - If airway normal NDMR may be used although some advocate SCh in all to facilitate rapid securing of airway in patient at risk of desaturation at induction d/t:
    - Atelectasis
    - Effusion
    - Infection
  - Lung isolation / separation w/ DLT vs. blocker (clinical / FOB confirmation pre- and post-positioning)
- **Maintenance**
  - Propofol infusion vs. IH (if concerned about uncoupling HPV with inhalational – halothane worst, isoflurane is suitable in most cases) +/- epidural LA / narcotics
  - Maintain 2 lung ventilation as long as possible (until pleura is open)
  - Air / O_2 (↓ dependent-lung atelectasis) w/ lowest FiO_2 (between 0.6 to 1.0) tolerated
    - High FiO_2 can promote wound healing, prevent N&V, and augment immune responses but increases atelectasis and makes recruitment maneuvers less helpful
    - Avoid N_2O (which will worsen pulmonary HTN, inhibits HPV)
  - **Suggested ventilation parameters for OLV**
    - V_T 5-6 mL/kg
    - Maintain peak airway pressure <35 cmH20
    - Maintain plateau airway pressure <25 cmH20
    - PEEP 5 cmH20 (no added PEEP for patients with COPD)
      - Be aware that PEEP can decrease cardiac output and shunt by compressing vasculature of dependent lung
      - Recent evidence shows that ZEEP (zero end-expiratory pressure) might be worse than PEEP in that it allows collapse & reopening of the alveoli every respiratory cycle & can lead to lung injury (seen in both OLV and ARDS)
    - Respiratory rate 12/min
    - Maintain normal PaCO2, Pa-ETCO2 will usually increase 1-3 mmHg during OLV
    - Volume or pressure controlled ventilation – pressure control for patients at risk of lung injury (bullae, pneumonectomy, post-lung transplantaion, etc.)
  - May need intermittent 2-lung ventilation, intermittent recruitment maneuvers, CPAP or O_2 insufflation to nondependent lung in time of hypoxia (occlusion of the pulmonary artery, either surgical or PA catheter in unresponsive cases)
  - **Fluid management:**
    - Judicious IV fluids: avoid volume overload (< 3 L crystalloid in 24 h) as risk of gravity dependent transudation of fluid into lower lung
    - No fluid administration for third space fluid losses during pulmonary resection
    - Urine output more than 0.5mL/kg/h is unnecessary
  - Avoid re-expansion pulmonary edema to non-dependent lung (in cases where pneumonectomy is not the surgical end-point)
- **Emergence**
  - Extubate early to ↓ risk of barotrauma / pulmonary infection
  - If ppoFEV_1 > 40%, normal extubation criteria
  - If ppoFEV1 30-40% consider extubation based on: exercise tolerance, DLCO, V/Q scan, associated diseases
  - If ppoFEV_1 < 30% + poor exercise tolerance, staged weaning from mechanical ventilation is best

DISPOSITION & MONITORING

- Post-operative fluid management:
  - Total positive fluid balance in the first 24h perioperative period should not exceed 20mL/kg
  - Urine output more than 0.5 mL/kg/h is unnecessary
  - If increased tissue perfusion is needed post-operatively, it is preferable to use invasive monitoring and inotropes rather than to cause fluid overload
- Pain Control
  - Epidural LA +/- opioid: ↓ MVO_2, ↑ post-thoracotomy pulmonary function over other modalities
  - Options: intercostals / paravertebral blocks, interpleural local anesthetics, NSAIDs, Tylenol, narcotic-based PCA
- Disposition
  - Supplemental O_2 to prevent hypoxemia & observation / monitoring in HDU initially

COMPLICATIONS

- **Intraoperative Problems ("resuscitate and diagnose")**
  - Hypoxia with OLV
    - Manual ventilate, FiO_2 100%, ensure adequate RR, Vt, and vent pressures
    - Ensure HR and BP and monitors and notify surgeon
    - Is DLT in correct position? check clinically and with fibreoptic
    - CPAP to non-dependant
    - PEEP to dependant
    - O_2 insufflation to non-dependant
    - Intermittent 2 lung
    - Clamp non-dependant PA
    - Nitric to dependant lung (cumbersome, slow to setup)

- High airway pressures
  - Manual ventilate, FiO_2 100%, ensure adequate RR, Vt, and vent pressures
  - Ensure HR and BP and monitors and notify surgeon
  - Is DLT in correct position? check clinically and with fibreoptic
  - Bronchospasm: listen for wheeze
  - Aspiration: listen for wheeze and examine pharynx for gastric fluid
  - Secretions: FOB and suction
  - Patient fighting or biting
  - Surgical clamp on airway or traction on lung: talk to surgeon!
- Low BP
  - Ensure HR and BP and monitors and notify surgeon
  - Manual ventilate, FiO_2 100%, ensure adequate RR, Vt, and vent pressures
  - Compression or clamp of main PA, RA, RV: talk to surgeon!
  - Preload: fluids, vasodilation, obstruction to flow, PPV / PEEP, bleed, RV diastolic failure
  - Contractility: ischemia
  - Afterload: anaphylaxis, septic, GA overdose, epidural

- **Postoperative Complications**
  - Respiratory insufficiency
    - D/t gravity dependent pulmonary edema, re-expansion pulmonary edema, atelectasis, secretions, shallow breathing (pain), tension pneumothorax, pneumonitis, ALI/ARDS, airway trauma from intubation
  - Acute lung injury / ARDS 4%
    - Risk factors for postpneumonectomy pulmonary edema and ALI:
      - Right-sided pneumonectomy
      - Increased perioperative iv fluid administration
      - Increased urine output in the postoperative period
      - High intraoperative ventilatory pressure index (combined airway pressure and time)
      - Preoperative alcohol abuse
    - Biphasic presentation: primary form onset during first 72h, secondary or late form appears after 72h and is usually related to other complications such as aspiration, bronchopleural fistula, or surgical complications
    - High mortality rate following pneumonectomy 30-40%
    - Symptomatic management: fluid restrictions, diuretic administration, low ventilatory pressures and tidal volumes (if mechanical ventilation is used) and measures to decrease the PA pressure
  - Arrhythmias (30-40%)
    - Supraventricular dysrhythmias, SVT – most are secondary to atrial fibrillation
    - May be secondary to catecholamine surge and may resolve spontaneously
    - Diltiazem is the most useful prophylactic drug to prevent postthoracotomy SVTs
    - Treatment: beta blockers, amiodarone, CCB, over-drive pacing
    - Hemodynamically patients require cardioversion
    - Correct any electrolyte abnormalities
  - Right heart failure
    - ↑ RV afterload due to an increase in PA pressure and PVR
    - Immediately after pneumonectomy, the RV may dilate and the RV function decreases
  - Post-op MI
  - DVT, PE common (20%)
  - Nerve injury
    - Elevated hemidiaphragm d/t phrenic nerve injury
    - Hoarseness 2° to RLN injury
  - Torsion of lobe / segment on operative side
    - Pulmonary vein obstructs → hemoptysis / infarction
  - Persistent air leak
    - Common following segmental / lobar resections as fissures usually incomplete (stop after a few days)
    - BPF (4%) +/- empyema (5%)
  - Cardiac Herniation
    - Infrequent but can occur when the pericardium is incompletely closed or the closure breaks down
    - Usually occurs immediately or within 24h after chest surgery and is associated with more than 50% mortality
    - Clinical presentation after right pneumonectomy is due to impairment of the venous return to the heart with a concomitant increase in CVP, tachycardia, profound hypotension, and shock; An acute SVC syndrome ensues due to torsion of the heart
    - When cardiac herniation occurs after a left-sided pneumonectomy, there is less cardiac rotation but the edge of the pericardium compresses the myocardium, which may lead to myocardial ischemia, the development of arrhythmias and ventricular outflow tract obstruction
    - Cardiac herniation occurs after chest closure due to the pressure differences between the two hemithoraces, which may result in the heart being extruded through a pericardial defect
    - Management:
      - Consider as dire emergent surgery – early diagnosis and immediate surgical treatment by relocation of the heart to its anatomic position with repair of the pericardial defect or by the use of analogous or prosthetic patch material
      - To minimize the cardiovascular effects, position the patient in the full lateral position with the operative side up
      - 100% FiO2, Check chest tube and ensure it is not on suction
      - Take precautions for a redo-exploration since they have undergone a previous thoracotomy – large-bore iv's and arterial line

        - A single-lumen ETT is used since time is crucial
            - Avoid PPV (will push heart into empty chest)
            - Ketamine + lido spray for spontaneously breathing intubation
        - Vasopressors and inotropes or both are required to support the circulation while exploration takes place
        - Consider use of TEE after resuscitation and relocation of the heart during pericardial patch repair to prevent excessive compression of the heart by the repair
        - In general, patients undergoing an emergency thoracic reexploration remain intubated and are transferred to ICU postoperatively
    - High mortality
    - DDx:
        - Massive intrathoracic hemorrhage
        - Pulmonary embolism
        - Mediastinal shift from improper chest drain management
- Ruptured bronchus (massive air leak or tension pneumothorax)
    - Same as BPF management
    - Operative side up
    - 100% O_2
    - Immediately notify surgeon and prepare OR
    - Check chest tube: may have to intermittently clamp to provide ventilation to lung

PATHOPHYSIOLOGY

Pneumonectomy

- Vast majority of pneumonectomies for malignancy: lung or metastatic tumor; male:female 2:1
- 10-30% of curative resections for lung cancer are pneumonectomies
- Benign: mycobacteria, fungus, infection / necrosis
- Perioperative risks:
    - Mortality 5-10% within 30 days (one of the highest for "elective" surgeries)
    - Cardiac morbidity significant
    - Morbidity / mortality higher after right pneumonectomy, more complex procedures (sleeve 12% / completion 20%) and some benign diseases
    - Mortality for trauma 60-100%
- Perioperative concerns:
    - Pulmonary reserve / pulmonary HTN / edema after resection
    - Concomitant CV disease
    - Cardiac arrhythmias common postop
    - Perioperative Thromboembolic events 26%
    - Benign disease: neovascularization, high-pressure bronchial system bleed; soiling of contralateral lung
- Overview
    - Mortality of untreated non-small cell lung cancer is 100%; effective treatment is surgery
    - Paraneoplastic syndromes are not a contraindication
    - Effective treatment for drug-resistant TB
    - Last resort for traumatic injury: resection in hypovolemic shock → persistent high PVR and right heart failure: pulmonary vasodilators, NO may be tried

Lung Isolation Indications

Barash:

Table 40-1 Indications for One-Lung Ventilation

ABSOLUTE

1. Isolation of each lung to prevent contamination of a healthy lung
    a. Infection (abscess, infected cyst)
    b. Massive hemorrhage
2. Control of distribution of ventilation to only one lung
    a. Bronchopleural fistula
    b. Bronchopleural cutaneous fistula
    c. Unilateral cyst or bullae
    d. Major bronchial disruption or trauma
3. Unilateral lung lavage
4. Video-assisted thoracoscopic surgery

RELATIVE

1. Surgical exposure—high priority
    a. Thoracic aortic aneurysm
    b. Pneumonectomy
    c. Lung volume reduction
    d. Minimally invasive cardiac surgery
    e. Upper lobectomy
2. Surgical exposure—low priority
    a. Esophageal surgery
    b. Middle and lower lobectomy
    c. Mediastinal mass resection, thymectomy
    d. Bilateral sympathectomies

One Lung Ventilation and Difficult Airway:

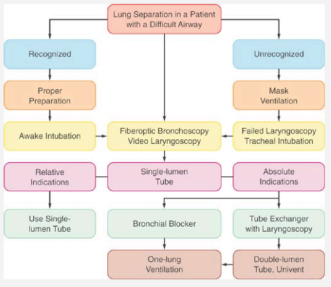

Figure 40-14. Lung separation in a patient with a difficult airway. LMA, laryngeal mask airway. (Adapted from Cohen E, Benumof JL. Lung separation in the patient with a difficult airway. Curr Opin in Anesthesiol 1999; 12: 29, with permission.)

- **OLV during anesthesia for thoracotomy**
  - Physiology of one-lung ventilation
    - Blood flow continues to upper lung creating true shunt (no alveolar ventilation)
    - This shunt is major cause of hypoxemia during OLV
      - Although alveoli with low V/Q ratios in dependent lung also contribute
    - Venous admixture of oxygenated blood from dependent lung and poorly oxygenated blood from the non-dependent lung occurs in left atrium lowering PaO_2
    - Venous admixture (or shunt – Qs/Qp) increases from ~10-15% in 2-lung ventilation to 30-40% in OLV
    - PaO_2 can be maintained in most patients with FiO_2 of 50-100%
  - Physiologic consequences of lateral decubitus position
    - Blood flow is preferentially to the dependent lung
    - 60% CO to dependent & 40% CO to non-dependent (with 2 lung ventilation)
  - Hypoxic pulmonary vasoconstriction (HPV)
    - Normally protective causing vascular constriction in poorly ventilated areas of the lung and thereby reducing shunt
    - HPV response should decrease the blood flow by 50% and shunt the remaining 50% to the non-operative, ventilated lung
    - Combining this with the lateral position should reduce blood flow to non-ventilated lung to 20%
    - **Inhalational agents** uncouple HPV in a dose related manner but at doses of 1 MAC do not inhibit HPV enough to cause a significant decrease in PaO_2 during OLV in the lateral position
    - **Intravenous Agents**
      - Narcotics are thought to NOT inhibit regional HPV
      - Ketamine – minimal effect on HPV
      - Propofol – minimal effect on HPV
  - Cardiac Output
    - Reduction of CO during OLV causes a reduction in mixed venous oxygen content
    - CO can decrease for a number of reasons during thoracotomy
      - Blood loss / fluid depletion
      - High inflation pressures
      - PEEP to dependent lung
- **Predictors of low arterial oxygen saturation during OLV:**
  - Right sided operation
  - Low oxygen saturation during 2 lung ventilation prior to OLV
  - High (or more normal) FEV_1 preoperatively
  - See management above

Barash:

Table 40-2 Clinical Approach to One-Lung Ventilation (OLV) Management

1. Use FIO_2 of 1.0
2. Ventilate with a TV of 6–8 mL/kg with PEEP 5 cm H_2O
3. Respiratory rate to maintain $PaCO_2$ between 35 and 40 mm Hg
4. Check the DLT/endobronchial blocker position subsequent to the lateral decubitus positioning
5. If peak airway pressure exceeds 40 mm Hg during OLV, DLT/endobronchial blocker malposition should be excluded
6. For hypoxemia, apply CPAP 10 cm H_2O to the nondependent lung (not during VAT)
7. If additional correction of hypoxemia is necessary add PEEP 5–10 cm H_2O to the ventilated lung
8. Frequent recruiting maneuvers
9. Avoid fluid overload
10. TIVA may be preferable to inhalation anesthetics
11. If necessary, intermittently inflate and deflate the operated lung

TV, tidal volume; PEEP, positive end-expiratory pressure; DLT, double-lumen tube; CPAP, continuous positive airway pressure; VAT, video-assisted thoracoscopy; TIVA, total intravenous anesthetic.

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