PREOPERATIVE EVALUATION

Respiratory

- ***History***

a. ***bronchopulmonary symptoms***
   i. cough, wheeze, sputum
   ii. dyspnoea - inappropriate sensation of insufficient breathing for level of work
   iii. chest ***pain***§
   iv. haemoptysis > 600 ml/day = ***massive***

b. ***management of pulmonary disease***
   i. response to therapy
   ii. determination of adequacy of therapy
   iii. medications - steroids, theophylline, etc.

c. ***extrapulmonary intrathoracic symptoms*** (~ 15%)
   i. pleural → effusion
   ii. chest wall → pain
   iii. oesophageal → dysphagia
   iv. SVC → caval compression syndrome
   v. brachial plexus → arm pain, Horner's syndrome

d. ***extrathoracic metastatic symptoms**** in order of decreasing frequency,

   → brain, skeleton, liver, adrenals, GIT, kidneys, or pancreas

e. ***extrathoracic non-metastatic symptoms***
   - usually a result of paraneoplastic syndromes,
   i. Cushing's syndrome
   ii. SIADH
   iii. carcinoid syndrome
   iv. hypercalcaemia
   v. ectopic GNH secretion
   - muscular → carcinomatous myopathies, Eaton-Lambert syndrome
   - skeletal → finger clubbing & HPOA
   - skin → scleroderma, acanthosis nigrans
   - vascular → thrombophlebitis, DVT's
   - haematologic

NB: there are 4 thoracic structures which result in ***pain***§

→ heart & pericardium, pleura, oesophagus & chest wall

Physical Examination

•

Bedside Pulmonary Function Tests

1.	counting test	- from VC inspiration should be able to reach 20
2.	forced expiratory time	- VC inspiration, forced expiration - listen over trachea with stethoscope & time - normally < 4 seconds
3.	peak flow meter	- technique, effort, age, sex, weight/height dependent - trends more useful, but tables available for comparison

Laboratory Tests

1. CBP & Coags
2. E,C&U, LFT's & bone enzymes
3. Renal function tests
4. Sputum cytology, C&S
5. ECG
6. ***CXR***
    - radiological changes usually antedate symptoms by ~ 7 months
    - with symptoms, the CXR is abnormal in ~ 98%
    - further, the changes are suggestive of tumor in ~ 80%
    - ~ 70% are centrally located
    - at presentation, average size is ~ 3-4 cm
    - other important diagnostic features include,

    i. tracheal deviation/obstruction
    ii. mediastinal mass (SCV, PA, main bronchi)
    iii. pleural effusions
    iv. cardiac enlargement
    v. bullous cyst (rupture, compression)
    vi. air-fluid levels (? abscess, soiling)
    vii. parenchymal changes (V/Q inequality)
7. PFT's - see later

Pulmonary Function Testing

• reasons for performing PFT's include,

1. identification of the ***type*** of lung disease - obstructive vs. restrictive
2. quantification of the ***extent*** of lung disease
3. determination of the ***response*** to therapy
4. monitoring the rate of ***progression***

• the value of PFT's is most clearly demonstrated in those undergoing ***pulmonary resection***
• for other surgery, there is little evidence of benefit as a routine screening technique, in the absence of clinical symptoms
• patients who may be considered for PFT's include,

1. patients with chronic pulmonary disease / symptoms
2. heavy smokers with a history of chronic productive cough
3. patients with chest wall or spinal deformities
4. morbidy obese patients
5. elderly > 70 years
6. patients for thoracic surgery
7. patients for major upper abdominal surgery

NB: the objective of testing is to predict the likelihood of postoperative complications, ***no single test*** is the best predictor of complications

• Hall *et al.* (Chest 1991) showed,

1. single best predictive factor was the ***ASA classification***
2. followed by ***site of incision*** - upper vs. lower abdominal
3. ***age, smoking & obesity*** also ranked highly

NB: ASA grading may have in part been based on PFT's, but ***clinical assessment*** remains the best predictor

• a single spirometric study can provide FVC, FEV_1/FVC, $FEF_{25-75\%}$, PEFR and VC
• "normal" limits are obtained from a sample population (Morris 1971) and the lower limit taken as 1.64 x SEE (SD of the regression line) below the same weight & height on the regression line
• this range should by definition include ~ 95% of the population
• the widely used practice of taking 80% of the predicted value should be avoided
• abnormalities on spirometry correlate with the incidence of postoperative complications
• however the incidence and severity of postoperative complications ***do not*** correlate with the severity of the preoperative lung dysfunction

Test Type	PFT	Risk Limits for ***Pneumonectomy***
Whole-Lung Tests	AGB's Spirometry Lung volumes	• ***hypercapnia*** on room air • FEV_1/FVC £ **50%** • FVC £ **2.0 l** • MBC ≤ 50% • RV/TLC ≥ 50%
Single Lung Tests	Split function tests (R&L)	• Predicted FEV_1 ≤ 0.85 l • PBF > 70% diseased lung
Simulated Pneumonectomy	Balloon occlusion R/L PA	• Mean PAP ≥ 40 mmHg • $PaCO_2$ ≥ 60 mmHg • PaO_2 ≤ 45 mmHg

- ***<u>Inoperability of Bronchial Carcinoma</u>***

1. regional lymph nodes within 2 cm of the hilum
2. malignant pleural effusion - diagnosed by cells
3. recurrent laryngeal nerve involvement
4. phrenic nerve involvement
5. high paratracheal, or contralateral hilar spread
6. distant metastases - brain, liver, adrenals & bone
7. SVC syndrome
8. PA involvement
9. cardiac tamponade
10. bilateral disease

NB: operability also depends upon ***cell type***,
unilateral or pleural spread may be operable with less invasive cell types

■ *Clinical Spirometry*

1. ***vital capacity*** **VC**
   - effort independent, performed without concern for rapidity of exhalation
   - decreases may be associated with restrictive lung disease, following excision, or from extrapulmonary factors, ie. chest wall
2. ***forced vital capacity*** ***FVC***
   - during forced exhalation FVC < VC where significant airway closure occurs
   - principally disorders with increased airway resistance, of destruction of supporting architecture
3. ***forced expiratory volume, 1 second*** FEV_1
   - usually expressed as a percentage of FVC, where FEV_1/FVC > 80%
   - largest observed FEV_1 and FVC from 3 readings are used, even if different curves
   - reduced mainly by increased airways resistance, usually normal in restrictive defects
4. ***forced expiratory flow, 200-1200*** $FEF_{200-1200}$
   maximal expiratory flow rate ***MEFR***
   - peak flow can be measured by drawing a tangent to the steepest part of the curve
   - more commonly the average flow over 1000 ml, after the initial 200 ml of exhalation is used
   - this is slightly lower than the true peak flow, normal values > 500 l/min
   - values < 200 l/min are associated with impaired cough & postoperative sputum retention, atelectasis and infection
   - markedly impaired by obstruction of larger airways & responsive to bronchodilator therapy
   - results are extremely effort dependent
5. ***forced midexpiratory flow, 25-75%*** $FEF_{25-75\%}$
   maximal midexpiratory flow rate ***MMFR***
   - less effort dependent than PEFR, as avoids the initial highly effort dependent part of the expiratory curve
   - however, still affected by patient effort and submaximal inspiration
   - values in healthy young men ~ 4.5-5.0 l/s (300 l/min)
   - abnormal values < 2 l/sec (120 l/min)
   - initially thought to be more sensitive in detecting small airways disease cf. FEV_1, but this has not been supported

■ *Maximum Breathing Capacity* ***MBC***

- patient is instructed to breath as hard & fast as possible for 12 seconds
- extrapolated to 1 minute, expressed as l/min, normal ~ 150-175 l/min
- predominantly affected by increased resistance & correlates well with FEV_1 (MBC ~ FEV_1 x 35)
- 80% of MBC can be maintained for ~ 15 minutes
- affected by patient cooperation & effort

■ ***Respiratory Muscle Strength***

1. P_{Imax} ~ -125 cmH_2O
   < -25 cmH_2O reflects inability to take an adequate inspiration
2. P_{Emax} ~ 200 cmH_2O
   < 40 cmH_2O reflects inability to cough

■ ***Airway Resistance***

• using a body plethysmograph, panting against a closed then open shutter,

1. shutter closed → Boyle's law & lung volume
2. shutter open → R_{AW} calculated from δV and flow
   → $G_{AW} = 1/R_{AW}$
3. ***specific*** airway resistance and conductance are calculated for the given lung volume

NB: a mouthpiece is used to remove the effects of the upper airway,
panting is used to keep the larynx dilated

■ ***Flow Volume Loops***

• differentiation of intrathoracic / extrathoracic obstruction
• the entire inspiratory, plus the immediate expiratory portions of the curve are highly ***effort dependent***
• ratio of expiratory flow:inspiratory flow at 50% TLC ~ 1.0
• upper airway obstruction inspiratory flow is reduced disproportionately & $EF:IF_{50\%}$ > 1.0
• other patterns described on flow-volume loops,

1. ***fixed obstruction***
   - no significant change in airway diameter during inspiration/expiration
   - $EF:IF_{50\%}$ ~ 1.0, with both curves showing a flattened plateau
2. ***variable obstruction***
   i. extrathoracic
      - vocal cord paralysis
      - chronic neuromuscular disorders
      - marked pharyngeal muscle weakness
      - obstructive sleep apnoea syndrome

      • accompanied by inspiratory stridor & flow resistance
      • $EF:IF_{50\%}$ > 2.0

   ii. intrathoracic
      - tracheal & bronchial tumours
      - tracheomalacia
      - vascular rings, thoracic aortic aneurysm

      • accompanied by expiratory airway compression & ↑ flow resistance
      • inspiration may be normal, with $EF:IF_{50\%}$ < 1.0

NB: differentiation is most accurate in the ***absence*** of diffuse airways disease

■ ***Alveolar-Arterial Oxygen Gradient***

- normal gradient on room air ~ 8 mmHg, increasing with age to ~ 25 mmHg at 70 yrs
- increased commonly in smokers & mild early chronic bronchitis

■ ***Frequency Dependent Compliance***

Def'n: abnormal where C_{Dyn} < 80% of C_{Stat}

- decreases early with small airways obstruction
- both measurements require insertion of an oesophageal balloon, with flow measured by a pneumotachograph,

1. $C_{Stat.}$ - inspiratory slope of a static pressure volume curve at tidal volume
2. C_{Dyn} - $\delta V/\delta P_{IP}$

■ ***Multiple-Breath Nitrogen Washout***

- normal lung behaves as a single compartment, with a single exponential washout curve for N_2
- there is a direct correlation between abnormal N_2 washout and frequency dependent compliance
- uneven distribution of ***time constants*** is believed to be the basis of both
- curve analysis is tedious, requiring computer analysis

■ ***Single-Breath Nitrogen Washout***

- originally described by Fowler in 1949, but adapted to,

1. full inspiration from RV to TLC with 100% O_2
2. expired N_2 concentration measured
3. line of best-fit drawn through the alveolar plateau
4. increase in $[N_2]$/l quantified → δN_2 % per litre
    - i. normal ~ 2% / l
    - ii. smokers ~ 10% / l
    - iii. abnormal in ~ 50% of asymptomatic smokers,
        - therefore ***sensitive*** index of early lung dysfunction
        - ***poor specificity*** due to large number of asymptomatics who do not progress to CAL

- the original technique by Fowler involved only 1000 ml O_2 from FRC and due to preferential ventilation of the bases resulted in a steeper plateau

▪ ***Closing Volume***

Def'n: lung volume in which closure of dependent airways begins, or more precisely, lung volume in which dependent lung units cease to contribute to expired gas, ie.,the beginning of ***phase IV*** of the washout curve to RV

normal values ~ 15-20% of VC, ie. a part of the VC manoeuvre

this is distinct from ***closing capacity***, which is the difference between the onset of ***phase IV*** and zero lung volume = CV + RV, expressed at a % of TLC

- measured by either a ***bolus*** or ***resident gas*** technique

1. bolus technique
   - originally xenon or argon, usually now ***helium***
   - inspiration from RV to TLC creating differential tracer gas composition
   - apical areas contain most of the gas cf. bases
2. resident gas technique
   - also dependent upon a pre-expiration concentration gradient, but
   - i. N_2 already present, and
   - ii. normally little difference in [N_2] between apex & base at TLC
   - therefore, inspiration of O_2 is used to dilute the already present N_2
   - this results in an apical to base concentration difference of ~ 2x
   - may result in smaller values cf. bolus technique in the presence of asthma or bronchoconstriction, probably due to air trapping (??)

- as CV represents a portion of the VC manoeuvre, it is usually expressed as a percentage of such
- expiration must be performed slowly to prevent dynamic airways collapse, ~ 0.5 l/sec
- changes in CV may represent small airways disease, or loss of elastic recoil and parenchymal supportive tissue
- loss of elastic recoil results in the gradual increase in CV with age, such that at 65 yrs CC > FRC
- young children similarly have decreased elastic recoil & relatively increased CC's
- minimal values for CV/CC are seen in late the late second decade
- sensitive marker of early dysfunction, but difficulty defining normal limits

▪ ***Forced Expiratory Flow Rates***

- difficulty defining abnormal flows at low lung volumes
- during expiration early flow resistance is in the ***large airways***, where flow is predominantly turbulent
- comparative curves using He/O_2 show increased flow in the early expiratory phase
- as expiration continues, the site of resistance moves proximally toward the alveoli, where flow is predominanlty laminar, and unaffected by altered gas density (He)
- therefore, at some point, the ***volume of isoflow***, the two curves rejoin
- with small airways disease, flow becomes less density dependent and the difference between maximum flow rates decreases, and the V_{isoV} increases
- normal values for V_{isoV} ~ 10-15% of VC
- values > 25% are abnormal

Cardiovascular

- ***Right Ventricular Function***

• the vast majority of patients are long term smokers with varying degrees of CAL
• this in turn leads to progressive increases in ***pulmonary vascular resistance*** PVR, followed by right ventricular hypertrophy and dilatation
• normal pulmonary vessels can accommodate ~ 2.5x increase in CO without any change in PVR
• in CAL, even small increases in CO, or regional flow after pneumonectomy, result in increased PVR (Miller fig. 50-2)
• normal PFT's do not measure this effect
• the onset of peripheral oedema, ascites, and a positive hepato-jugular reflex indicate the onset of ***cor pulmonale***
• measurements of PVR are normally obtained by measuring mean PA pressure and PCWP at varying degrees of CO during exercise testing
• in addition, balloon occlusion of either main PA realistically estimates RV function post-pneumonectomy
• echocardiography also provides good assessment of RV function

** intra-operatively acute rises in PVR may be due to:

a. hypoxia
b. acidosis
c. spontaneous ventilation
d. PEEP
e. sepsis - especially gram (-)'ve / endotoxin
f. pneumonectomy
g. pulmonary embolism
h. drugs - histamine
 - inotropic agents (increased central blood volume)
i. aspiration / soiling

■ ***Left Ventricular Function***

- independent causes of decreased LVF in patients with lung disease:
    a. coronary artery disease
    b. valvular heart disease
    c. systemic hypertension
    d. raised carboxyhaemoglobin
    e. arterial hypoxaemia and acidosis
    f. deranged intrathoracic pressures
    g. RV dysfunction (ventricular interdependence → ↓ LV compliance)
    h. cardiomyopathy
        i. nutritional
        ii. toxic/metabolic
        iii. infective
        iv. infiltrative - amyloid, carcinomatous
    i. endocrine
        i. hypothyroidism
        ii. Addison's disease

- appropriate investigations, as directed by history, include,
    a. ECG ± exercise
    b. echocardiography ± coronary angiography
    c. thallium scan ± exercise / dipyridamole

- in the presence of significant IHD, CABG should be performed prior to lung resection
- if lung resection is small (wedge resection), the both procedures may be performed simultaneously, otherwise pneumonectomy should follow 4-6/52 post-CABG

NB: the effects of GA induced immunosuppression are difficult to assess, though, the operative risks for a combined procedure are probably greater

Preoperative Preparation

- there are 3 reasons thoracic patients are more prone to respiratory complications,
    1. postoperative complication rate correlates to preoperative respiratory dysfunction
        i. smokers → 6-fold increase
        ii. CAL → 20-fold increase
    2. thoracic surgery impairs lung function in any patient
    3. thoracic incisions inhibit postoperative ventilation

- preoperative care includes the following,
    a. cessation of smoking
    b. bronchodilatation
        - β_2-agonists
        - theophylline ??
        - steroids
        - sodium chromoglycate
    c. loosening of secretions
        - airway hydration
        - systemic hydration
        - mucolytic & expectorant drugs
        - antibiotics
    d. removal of secretions
        - postural drainage
        - coughing
        - chest physiotherapy
    e. preoperative education
        - incentive spirometry
        - exercise
        - weight loss
    f. management of other medical problems

■ ***Chronic Airflow Limitation***

[redacted]

Def'n: ***Asthma:*** ≥ 15% δFEV_1 with
- bronchodilators
- methacholine, histamine challenge

Chronic bronchitis: morning cough with sputum production for > 3 months of the year for 2 successive years

Emphysema: diminished gas transfer interface (area), ↓ DL_{CO}

- ***Atopy***

  i. asthma
  ii. eczema
  iii. allergic rhinitis
  iv. conjunctivitis

- ***Smoking***

1. produces both chronic bronchitis & emphysema, but little reversible airways disease
2. decreased ciliary function & sputum clearance
3. immunoparesis
4. increased frequency of upper & lower respiratory tract infections
5. raised COHb - chronic tissue hypoxia
   - polycythaemia
6. nicotine - hypertension, ↑ SAP, ↑ DAP, ↑ PVR
7. accelerated atherosclerosis
8. increased platelet adhesiveness
9. major risk factor for ischaemic heart disease
10. increased peripheral vascular disease
11. increased bronchogenic carcinoma > 10 pkt/years (1 pkt/yr = 20/d)

- ***Respiratory Disease Processes***

1. genetic - CF, α_1-antitrypsin deficiency
2. airflow obstruction
3. infective - bacterial, viral, fungal, protozoal, ricketsial, opportunistic
4. neoplastic - primary or secondary
5. vascular
6. immunological - idiopathic pulmonary fibrosis, hypersensitivity pneumonitis (EAA)
7. reactive - ARDS
8. occupational - silicosis, asbestosis

INTRAOPERATIVE MANAGEMENT

Intraoperative Monitoring

- normal monitors, as per any case,
    i. FiO_2
    ii. apnoea alarm
    iii. disconnect alarm
    iv. $ETCO_2$
    v. SpO_2
    vi. ECG ± V_5
    vii. NIBP ± IABP

- optionally, depending upon the degree of physiological distortion,
    a. manual ventilation
    b. arterial cannulation
        - arterial BP
        - serial AGA's
        - in line P_{aO2}/P_{aCO2}
        - PPV induced δBP (hypovolaemia)
    c. CVP
    d. Swan-Ganz Catheter
        - PA_{mean}
        - PCWP
        - serial CO
        - mixed venous P_{O2}
        - CVP
    e. in line arterial/mixed venous P_{CO2} & P_{O2}
    f. right-left transpulmonary shunt
    g. ventilation dead space
    h. aortic pulse pressure contour

NB: e - h. → research only

■ ***Pulmonary Arterial Catheterization & Thoracotomy***

- PA catheters float into the right lung ~ 90%
- thus, in the left lateral position, the catheter may be in,

  a. an unventilated lung, one lung ventilation

  b. West's zone 1 or 2 if large tidal volumes are employed during two lung ventilation

- conversely, in the right lateral position the catheter will most likely be in zone 3

- ** there are three situations which effect PA catheter readings,

  1. PA catheter in the ***non-dependent lung***, one lung ventilation,

     → both CO and mixed P_{vO2} will be ***below*** real values

  2. PA catheter in the ***non-dependent lung***, two lung ventilation,

     → PEEP or CPAP will result in PCWP # LAP

  3. PA catheter in the ***dependent lung***, two lung ventilation,

     → PCWP ~ LAP irrespective of CPAP or PEEP

■ ***Effects of Anaesthetics on HPV***

• the normal response of the pulmonary vasculature to atelectasis is an increase in PVR, mediated almost entirely by ***hypoxic pulmonary vasoconstriction*** HPV
• thus, inhibition of HPV in the non-ventilated, non-dependent lung should be prevented
• a large number of studies have been performed to assess the effects of various agents on HPV, these include,

a. in vitro preparations
b. in vivo, not intact (pumped perfused lungs)
c. in vivo, intact
d. human volunteers

• most work has been done with ***halothane***
• inhibition of HPV in both (a.) and (b.) preparations is an almost universal finding
• however, the more physiological preparations have shown ***little or no effect***
• factors which may be responsible for this difference include,

a. presence / absence of pulsation pressure
b. perfusion fluid composition
c. size of the perfusion circuit
d. intact reflex arcs (baroreceptor)
e. absence of bronchial blood flow (essential for ANS activity)
f. humoral influences ($H_{1/2}$, PG's)
g. species differences

• thus, the fundamental property of the halogenated agents is to diminish HPV
• however, in anaesthetised man some other factor acts to lessen this effect

■ ***Effects of Anaesthetic Agents on PaO2 One Lung Ventilation***

- controlled studies with isoflurane in canine preperations have shown a dose-dependent decrease in P_{aO2}
- during normal ventilation in the lateral position, gravity creates a perfusion gradient, such that the non-dependent right lung receives only 45% of the CO, c.f. 55% in the erect and supine positions
- similarly, the non-dependent left lung receives only 35% of the CO
- following atelectasis of the non-dependent lung, HPV should reduce flow to that lung by a further 50%, or a left/right mean of 20% of CO

> ***NB:*** ignoring the normal 1-3% shunt, this creates an ***obligatory shunt*** **~ 20%**

- at a FiO_2 = 1.0, this would lead to a P_{aO2} ~ 280 mmHg, given a normal metabolic rate
- Domino *et al*. found that the decrease in HPV could be approximated by the equation,

$$\delta HPV\% \sim (22.8 \times F_{A.ISO}) - 5.3$$

- which at 1 MAC (1.15%) leads to a reduction in HPV of ~ 21%, leaving a 40% reduction with a resultant shunt ~ 24% and a P_{aO2} ~ 205 mmHg
- clinical studies with both halothane and isoflurane, administered at 1 MAC either before or after IV anaesthesia, during stable one lung ventilation, showed no significant δP_{aO2}
- in addition, no significant changes occurred in CO, PVR, or mixed P_{vO2}

Comparison of Anaesthetic Agents for Thoracic Surgery

■ ***Volatile Agents***

• the volatile agents are a good choice for thoracic anaesthesia for a number of reasons,

1. GA with controlled ventilation is the safest method for the majority of thoracic surgery
2. the volatile agents decrease airway irritability
   → inhibition of bronchoconstriction ± nonspecific bronchodilatation
3. they allow a FiO_2 ~ 1.0 without loss of anaesthesia, c.f. N_2O-O_2-narcotic-relaxant
4. the rate of elimination is greater than narcotics,
   thereby decreasing the risk of postoperative hypoventilation
5. at ~ 1 MAC they provide reasonable cardiovascular stability
6. they show ***no significant*** reduction of P_{aO2} during one lung ventilation

■ ***Intravenous Agents***

• the narcotics, especially fentanyl, have a number of desirable properties,

1. haemodynamic stability
2. may allow ventilation into the postoperative period
3. as a supplement to the volatile agents, allow a reduction in the inspired concentration
4. in high dose allow a FiO_2 ~ 1.0
5. do not inhibit HPV

• ***ketamine***, in conjunction with N_2O + relaxant may be used for thoracic anaesthesia
• though not ordinarily used for elective procedures, ketamine is useful for the induction of anaesthesia in emergency cases,

1. due to its sympathomimetic properties
2. its rapid onset of action enabling use with a full stomach
3. the reduction of bronchospasm in asthmatics
4. no significant effect on P_{aO2} in one lung ventilation

Spontaneous Ventilation During Thoracotomy

▪ ***Mediastinal Shift***

- in the lateral position, spontaneous ventilation (SV) with a closed chest, intrapleural pressure (P_{IP}) is less negative in the dependent lung
- however, there is still a negative pressure each side of the mediastinum
- with the chest open, the combined effect of atmospheric pressure and the weight of the mediastinum result in its displacement into the dependent hemithorax
- during inspiration, the reduction in P_{IP} increases the pressure gradient and the mediastinum descends further, with a resultant reduction in tidal volume
- this movement can also result in decreased venous return and activation of sympathetic reflexes, resembling acute hypovolaemia

▪ ***Paradoxical Respiration***

- as the non-dependent lung is at atmospheric pressure, as inspiration occurs, further collapse of the lung is observed as air enters the dependent lung
- this is accentuated by the increase in volume of the non-dependent hemithorax with diaphragmatic descent

Controlled Two Lung Ventilation

• in the lateral decubitus position (LDP) the vertical gradient is less than in the erect posture, thus ***zone 1*** is ordinarily ***reduced***
• redistribution of CO still occurs with left-right perfusion approximating,

a. L-LDP → right PA blood flow ~ 45% of CO (erect ~ 55%)

b. R-LDP → left PA blood flow ~ 35% of CO (erect ~ 45%)

• as for the erect position, P_{IP} also varies such that ventilation is greater to the dependent lung
• the weight of the abdominal contents pushes the dependent hemidiaphragm higher, giving it a mechanical advantage c.f. the non-dependent side

NB: overall the LDP ***does not*** significantly alter the mean V/Q ratio

• the V/Q ratio does decrease from upper to lower segments, as for the erect and supine positions
• with the induction of anaesthesia, the distribution of ***perfusion*** is not significantly altered
• however, ***ventilation*** is redistributed with a greater fraction entering the non-dependent lung
• this results from,

1. the GA induced decrease in FRC shifts both lungs leftward on the pressure volume curve, with a relative increase in compliance of the non-dependent lung
(Miller 50-10,11 p1540)
2. muscular paralysis removes the mechanical advantage of the dependent hemidiaphragm
3. the weight of the mediastinum physically impedes expansion of the dependent lung
4. the weight of the abdominal contents impedes descent of the dependent hemidiaphragm
5. suboptimal positioning effects

• this relative increase in ventilation to the non-dependent lung is further increased by opening the hemithorax
• however, perfusion remains similarly distributed, the effects of atmospheric P_{IP} being negligible
• compliance of the upper lung is further increased along with the increase in V/Q mismatch
• poor mucociliary clearance and ***absorption atelectasis*** with higher FiO_2 values may further decrease ventilation to the dependent lung

One Lung Anaesthesia / Ventilation

- ***Indications Absolute***

a. ***isolation*** to prevent spillage or contamination
   i. infection
   ii. massive haemorrhage
   iii. ? tumor

b. control of ***distribution of ventilation***
   i. bronchopleural fistula
   ii. bronchopleural cutaneous fistula
   iii. surgical opening of a major conducting airway
   iv. giant unilateral lung cyst or bulla
   v. tracheobronchial tree disruption

c. unilateral bronchopulmonary ***lavage***
   i. alveolar proteinosis
   ii. rarely in asthma or cystic fibrosis

- ***Indications Relative***

a. surgical exposure (high priority)
   i. thoracic aortic aneurysm
   ii. pneumonectomy
   iii. upper lobectomy
   iv. thoracoscopic procedures ? absolute indication

b. surgical exposure (low priority)
   i. middle/lower lobectomies
   ii. subsegmental resections
   iii. oesophageal resections
   iv. thoracoscopy
   v. procedures on the thoracic spine

c. post-removal of chronic occluding unilateral pulmonary emboli

One Lung Anaesthesia / Ventilation

• in general, three techniques are available for the ventilation of one lung,

1. double lumen tubes
2. bronchial blockers
3. endobronchial intubation, SLT

• the former have become the most commonly used because they,

a. are more easily placed
b. allow rapid and repeated conversion between one and two lung ventilation
c. allow suction to both lungs
d. allow the application of CPAP to the non-ventilated lung

• there are two main disadvantages to double lumen tubes,

1. suctioning may be less effective through a narrow lumen tube
2. the narrow lumen increases airway resistance

• the two most commonly used types of double lumen tubes are the ***Robertshaw***, which has largely replaced the older ***Carlens***
• the former coming in right and left-hand types
• the Carlens possesses a carinal hook which has the following problems,

a. may result in increased difficulty with insertion
b. possible laryngeal trauma
c. amputation of the hook after insertion
d. malposition caused by the hook
e. physical interference during pneumonectomy

• both lumens are oval shaped and may impede the passage of a suction catheter

• the original Robertshaw DLT was introduced in 1962 and was made of reuseable red rubber
• both lumens are D-shaped, though larger than those of the Carlens DLT
• on the R-sided tube the endobronchial cuff is slotted to enable ventilation of the RUL bronchus

French Guage	41	39	37	35	28[1]
Internal Diameter (mm)	6.5	6	5.5	5	4.5

[1] only available as the L-hand type

• now also made from clear disposable plastic, similar to the Broncocath®
• the cuffs are colored blue to facilitate in fibreoptic intubation and the end of each tube has a black radiopaque line to allow assessment by CXR

- a similar DLT is made by ***Bronchocath***, which has several advantages,
    a. the R-sided tube allows the cuff to ride away from the RUL bronchus, minimizing obstruction
    b. the large internal/external diameter ratios reduce resistance and facilitate suctioning

- due to possible obstruction of the RUL, a L-sided tube is preferable for all cases requiring one lung ventilation, except where carinal or proximal left main bronchial lesions may lead to trauma
- if clamping of the left main bronchus is required the tube may be withdrawn at the time of clamping and used c.f. a single lumen tube

Checklist For Correct Tube Function

1. gently inflate both cuffs	• tracheal cuff ~ 5-7 ml • bronchial cuff ~ 2-3 ml
2. ventilate both lungs[1]	• bilateral AE • correct compliance • maintenance of SpO_2 & $ETCO_2$
3. clamp tracheal lumen	• check unilateral ventilation • check apical ventilation[2] • adjust & check for leak around bronchial cuff
4. clamp bronchial lumen	• check unilateral ventilation • adjust & check for leak around tracheal cuff

NB: clinically correct positioning of a DLT, subsequent fibreoptic examination will reveal malposition in **~ 48%** and in 25% of cases there will be some problem in either deflating or reinflating the non-dependent lung

1 unilateral AE normally indicates both lumens → main stem bronchus

2 absent apical AE indicates lumen too far in main stem bronchus

- the easiest way of precisely checking the position of a DLT is to pass a paediatric sized fibreoptic bronchoscope down the tracheal lumen
- the distance between the right and left lumen tips of a L-Robertshaw tube is ~ 70 mm, whereas the average length of the left main stem bronchus is ~ 50 mm
- therefore, it is possible for the tracheal opening to be above the carina and have the LUL bronchus obstructed
- ideally, the blue plastic of the bronchial cuff should be visible just below the carina
- this applies to any of the manufactured tubes, given the wide range of values for the left main stem bronchus in extensive studies
- excessive inflation of the bronchial cuff may result in either cuff herniation, carinal deviation, or luminal constriction, ∴ readjust cuff inflation by leak, as per J. Roberts
- looking down the bronchial lumen of a R-DLT, the right middle-lower lobe bronchial carina should be visible and, more importantly, the ventilation slot for the RUL should be visible

Fibreoptic DLT Intubation

- alternatively the fibreoptic bronchoscope may be used to insert a DLT by,
    1. inserting the DLT until the tracheal cuff passes just beyond the cords
    2. ventilation is then continued c.f. a SLT
    3. the bronchoscope is passed through the bronchial lumen into the desired bronchus and the DLT advanced
    4. the scope is then inserted down the tracheal lumen to check the final position

Complications of DLT Intubation

- apart from the impediment to gas exchange, the tubes themselves may cause problems,
    a. tracheobronchial tree disruption, in decreasing order,
        i. the Carlens tube
        ii. red rubber Robertshaw tube
        iii. red rubber White tube
        iv. the disposable low-pressure plastic cuff tubes
    b. traumatic laryngitis
    c. suturing of a pulmonary vessel to the DLT

Relative Contraindications to DLT Intubation

a. a full stomach
b. an airway lesion within the tube length
c. patients for whom the 35F is too large and the 28F too small
d. patients with potential problem airways
    i. receding jaw
    ii. bull neck
    iii. prominent maxilla and incisors
    iv. anterior larynx
e. critically ill, already intubated patients

- separation of the lungs under these circumstances is still possible, either by fibreoptic placement of a ***bronchial blocker***, or ***endobronchial intubation*** with a SLT

Bronchial Blockers

- this technique is frequently required for children, in which the smallest DLT is too large
- the smallest DLT is a **L-sided 28F**, which may be used in the range 10-14 years, or 35-45 kg
- bronchial blockers which are balloon tipped luminal catheters have the advantage of allowing injection of O_2, or suctioning through the lumen
- occasionally these require rigid bronchoscopy for placement
- the high pressure spherically inflated balloons have the tendency to ride proximally out of the bronchus into the trachea
- a frequently used device in adults is a **Fogarty embolectomy catheter** with a 3 ml balloon
- this catheter possesses a stylet so a curvature may be placed distally
- one method of placement is to pass this alongside a SLT and then into the desired bronchus under fibreoptic vision, using a self-sealing elbow connector
- dedicated SLT's exist with a channel for the catheter in the anterior wall, allowing insertion of the SLT and placement of the bronchial blocker simultaneously, Univent®
- this may be done blindly or fibreoptically
- in very small children (< 10 kg) a catheter with a balloon volume of 0.5-1.0 ml should be used

■ ***Disadvantages of Bronchial Blockers c.f. DLT's***

a. inability to ventilate the lung distal to the blocker

b. inability to suction the lung distal to the blocker

c. increased placement time

d. definite need for a rigid or fibreoptic bronchoscope

e. increased incidence of proximal migration →
   - i. failure of isolation and potential soiling
   - ii. partial tracheal obstruction

f. the low volume high pressure balloons may result in mucosal ischaemia

Endobronchial Intubation with Single Lumen Tubes

- in the presence of ***acute haemoptysis*** the fastest way to isolate the lungs may be the passage of an uncut SLT
- right main bronchial (RMB) intubation will occur most often if the tube is simply advanced until moderate resistance is felt
- left main bronchial (LMB) intubation may be accomplished either,

  a. ***blindly***, with the patients head to the right and the tube rotated posteriorly 180°, once beyond the larynx

  b. ***fibreoptically***, with a self sealing elbow connector

  NB: RMB intubation usually occludes the upper lobe bronchus and may result in severe hypoxaemia due to the large shunt

- use of the fibreoptic bronchoscope in the presence of massive haemorrhage may be exceedingly difficult

PHYSIOLOGY OF ONE LUNG VENTILATION

• one lung ventilation creates,

1. an ***obligatory shunt*** - through the non-dependent lung, plus
2. the ***effective shunt*** - though the ventilated dependent lung

• consequently the $P_{A\text{-}aO2}$ gradient increases with one lung ventilation
• due to the different slopes of the blood CO_2 and O_2-dissociation curves, CO_2 elimination is relatively compensated and elimination does not present a major problem
• the factors which alter the amount of obligatory shunt include,

a. gravity

b. pre-existing disease - decreased vascular X-sectional area
- decreased HPV (CAL c.f. normal)

c. surgical interference - compression
- retraction
- ligation

d. HPV * major effect within the range 30-70% hypoxic lung

NB: numerous studies have shown that the ***obligatory shunt*** thought the non-dependent lung is ~ 20-30% c.f. the expected 40-50%

■ ***Blood Flow to the Dependent Ventilated Lung***

• despite the increased blood flow due to gravity and diversion of flow from the non-ventilated lung, areas of atelectasis or low V/Q may also exist preoperatively, or develop during anaesthesia
• the development of a hypoxic compartment in the dependent lung may result from,

a. effects of the lateral decubitus position - gravity, mediastinum, diaphragm
- suboptimal positioning

b. absorption atelectasis in areas of low V/Q with a high FiO_2

c. reduced removal of secretions

d. increased fluid transudation in the lowermost segments

• ***regional alveolar hypoxia*** in the dependent lung results in HPV with increased vascular resistance and diversion of blood flow to the non-dependent lung → ***reverse steal***
• other factors which increase vascular resistance in the dependent lung include,

a. a reduction in FiO_2 (from 1.0-0.5-0.3), and

b. a reduction in core body temperature

▪ ***Blood Flow to the Non-Dependent Non-Ventilated Lung***

• the following are relevant factors pertaining to HPV, subsequently affecting the non-dependent lung blood flow and shunt,

a. with low V/Q, atelectasis, or nitrogen ventilation, virtually ***all*** of the reduction in blood flow is due to HPV, mechanical factors are insignificant

b. the ***distribution*** of alveolar hypoxia does not affect the degree of HPV, all regions respond similarly

c. decreasing the **FiO$_2$** decreases HPV (reverse steal)

d. HPV is maximal at a normal **P_{vO2}** - decreasing at either high or low values

e. HPV is maximal at normal **PA pressure** - high or low PA pressures will reduce HPV

f. most systemic ***vasoconstrictors*** → decrease HPV - reverse steal
   i. adrenaline
   ii. dopamine
   iii. phenylephrine
   iv. ephedrine

g. most systemic ***vasodilators*** → decrease HPV - steal
   i. sodium nitroprusside
   ii. nitroglycerine
   iii. several calcium channel antagonists
   iv. dobutamine
   v. β_2-agonists (salbutamol, ritodrine, isoproterenol)
   vi. adenosine
   vii. glucagon

h. ***hypocapnia*** directly inhibits regional HPV
   hypercapnia directly enhances regional HPV

i. selective **PEEP** to normoxic ventilated lung will decrease HPV (reverse steal)

j. ***high frequency ventilation*** of the ventilated lung is associated with lower mean airway pressures and enhanced HPV

- ***Miscellaneous Causes of Hypoxaemia During One-Lung Ventilation***

a. malfunction of the O_2 delivery system/anaesthesia machine
b. gross hypoventilation of the dependent lung
c. malfunction of the dependent lung airway lumen (secretions)
d. malposition of the DLT
e. absorption atelectasis of the non-dependent lung with a high FiO_2
f. any factor which decreases P_{vO2} - decreased CO
   - increased MRO_2

Conventional Management of One-Lung Ventilation

a. maintain two-lung ventilation as long as possible
b. use $FiO_2 = 1.0$
   i. dependent lung vasodilatation
   ii. oxygen toxicity unlikely
   iii. large V_T and intermittent PEEP decrease atelectasis
c. commence one lung ventilation with V_T ~ 10 ml/kg
   i. below this atelectasis increases
   ii. above this pulmonary resistance increases
   iii. range 8-15 ml/kg → minimal effects
d. adjust minute volume to P_{aCO2} ~ 40mmHg
   i. V_T = 10 ml/kg → ~ 20% decrease in V_A c.f. two-lungs
   ii. thus ***respiratory rate*** should increase ~ 20%
e. continuously monitor
   i. FiO_2
   ii. V_T
   iii. $ETCO_2$? check arterial-$ETCO_2$ gradient against AGA's
   iv. SpO_2

Differential Management of One-Lung Ventilation

Selective Dependent Lung PEEP

• the use of PEEP in the dependent lung has two opposing effects,

a. increased lung volume and decreased atelectasis

b. increased small airways compression and raised PVR

• this theory of opposition is supported by the additive effects of increasing V_T and PEEP in decreasing P_{aO2} during one lung ventilation
• consequently studies have shown either an increase, decrease or no change in P_{aO2}
• in those patients with significantly diseased dependent lungs the beneficial effects (increased FRC and V/Q) are dominant
• whereas in patients with normal lungs the increase in PVR is detrimental
• thus, there is effectively a narrow therapeutic margin
• other studies have shown that high V_T's, variations in the I:E ratio and intermittent manual hyperventilation are not beneficial to P_{aO2} during one lung ventilation

Selective Non-Dependent Lung CPAP

• this results in only slight but constant distention of the non-dependent lung
• the institution of **CPAP ~ 10 cmH_2O** has no significant effects on blood flow and significantly improves oxygenation
• higher levels of CPAP (< 15cm) may act, in addition to allowing oxygen transfer in the non-dependent lung, by increasing PVR and diverting blood to the dependent lung where exchange of both O_2 and CO_2 may occur
• ??? what effects on HPV, surely this would be decreased in the non-dependent lung
• in all studies to date, 5-10cmH_2O of CPAP has significantly improved P_{aO2}
• CPAP should be applied during the ***deflation phase*** of a large V_T, so as to maintain uniform expansion of alveoli, with no need to overcome ***critical opening pressures***
• oxygen insufflation from zero airway pressure has no significant effect in increasing P_{aO2} in either human or canine preparations

Differntial Lung PEEP/CPAP

• with the application of PEEP to the dependent ventilated lung and CPAP to the non-dependent lung, the distribution of perfusion is not nearly as important as with simple one-lung ventilation
• oxygenation is similarly improved with two lung ventilation, with PEEP to the dependent lung and ZEEP to the non-dependent lung
• similar increases in oxygenation have been found in patients in ITU's with essentially unilateral lung disease
• ventilation with a SLT ± PEEP/CPAP resulting in no significant improvement, or a decrease in oxygenation
• subsequent use of a DLT and differential ventilation, either PEEP/PEEP, PEEP/CPAP, or CPAP/CPAP, significantly improving oxygenation
• ideally, differential PEEP should attain ***equal FRC's***

Combined Management of One-Lung Ventilation

a. maintain two-lung ventilation as long as possible

b. dependent lung:

   i. FiO_2 = 1.0

   ii. V_T = 10 ml/kg

   iii. V_M = P_{aCO2} ~ 40 mmHg

   iv. PEEP = 0-5 cmH_2O

c. continuously monitor

   i. FiO_2

   ii. V_T

   iii. $ETCO_2$

   iv. SpO_2

d. IF severe ***hypoxaemia*** occurs,

   i. check position of DLT

   ii. check haemodynamic status

   iii. non-dependent lung CPAP

   iv. dependent lung PEEP ~ 5-10 cmH_2O

   v. intermittent two lung ventilation

   vi. clamp PA early (pneumonectomy)

High Frequency Ventilation (HFV) in Thoracic Surgery

- normal IPPV delivers large V_T's ~ 10-15 ml/kg, at rates usually ~ 30 bpm
- HFV delivers small V_T's ≤ 2 ml/kg at rates between 60-2,400 bpm
- this can be delivered through small catheters and possesses three possible advantages in thoracic surgery,

1. **Major Conducting Airway Surgery**
    - if the trachea, carinal area or a main stem bronchus are to be resected, the passage of a small airway tube causes less interference with the surgical field
    - both ***high frequency jet ventilation*** HFJV and ***high frequency positive pressure ventilation*** HFPPV have been successful under these circumstances
    - ***high frequency oscillatory ventilation*** HFOV delivered through a standard SLT results in "mediastinal bounce" and impedes surgery

2. **Bronchopleural Fistula**
    - due to the smaller volumes used, the leak through pathological low resistance paths should be less
    - consequently mediastinal and interstitial emphysema may be minimized
    - HFV has been used successfully in cases where high V_M-IPPV has been unable to maintain normocarbia (strange choice of endpoint !!)
    - the reduction in leak is directly related to the reduction in mean airway pressure
    - when peak and mean pressures are reduced by HFV, the leak is also reduced
    - however, if these are increased by HPV, then the leak is also increased
    - therefore, prior to and with the application of HFV pressures should be measured

3. **To Minimize Movement of The Operative Field**
    - theoretically, the lower peak inspiratory pressure and smaller tidal volumes should result in smaller movements of the lung
    - HFV to the non-dependent lung improves oxygenation in much the same way as CPAP, however requires considerably more equipment
    - selective dependent lung HFV may improve oxygenation, presumably due to lower extra-vascular resistance, c.f. IPPV

Low Flow Apnoeic Ventilation

- an adequate P_{aO2} can be maintained for ~ 20 minutes, especially if 5-10 cmH_2O CPAP is applied
- the P_{aCO2} rises during this period,

NB: ~ 6 mmHg in the first minute due to the ***washin*** of venous blood, then
~ 3-4 mmHg/min thereafter proportional to metabolism

- although severe degrees of hypercarbia and respiratory acidosis can be tolerated by fit young patients, it would appear a safe period for apnoeic ventilation would be ~ 10 min

MAJOR COMPLICATIONS OF THORACIC SURGERY

• the major serious early complications include,

1.	respiratory insufficiency	~ 4%	mortality ~ 50%
2.	major haemorrhage	~ 3%	mortality ~ 25%
3.	bronchial disruption	~ 2-3%	chronic BPF
4.	right heart failure		
5.	patent foramen ovale with R→L shunt		
6.	neural injuries		
7.	herniation of the heart		

▪ ***Respiratory Insufficiency***

• acute respiratory insufficiency, occurring within 30 days of surgery, is the ***most common*** complication of pulmonary resection
• at a large USA centre, an incidence of 4.4% following resection for bronchial carcinoma, with a ***mortality*** ~ 50%
• the incidence is greater following ***right pneumonectomy*** than left, as less functional lung remains
• factors which may contribute to hypoxaemia and hypercarbia include,

a. soiling of the remaining lung during surgery
b. pulmonary oedema 2° to the decreased vascular bed

▪ ***Postoperative Ventilation***

• the vast majority of patients may be safely extubated in the operating room or in recovery
• those requiring continued ventilatory support should be,

a. reintubated with a SLT
b. commenced at a tidal volume ~ 12 ml/kg
c. given IMV to maintain a P_{aCO2} ~ 40 mmHg
d. given an initial FiO_2 between 50-100%
e. monitored by CXR and AGA's

• this will usually require a respiratory rate of 8-12 bpm
• the patient may breath, though, this frequently is not sufficient for minute ventilation
• FiO_2's > 50% are toxic to the lung over time and the initial aim is to reduce the FiO_2 to < 50%, while maintaining a P_{aO2} > 60 mmHg
• this may initially be attained by the administration of PEEP
• PEEP should be titrated to the P_{aO2} in increments of 2.5-5.0 cmH_2O, allowing time for stabilisation of respiratory mechanic and haemodynamic variables, ie.,

a. peak inspiratory pressure and pulmonary compliance
b. HR, rhythm, BP, CVP, and CO

- each increment usually requires 0.5-1.0 hr for stabilization
- levels of PEEP > 20-25 cmH_2O should not be used, areas of lung resistant to expansion should be obvious on CXR and may be suctioned by bronchoscopy
- if the patient requires, to maintain a P_{aO2} > 60 mmHg,

  a. FiO_2 > 50% or,

  b. PEEP > 10 cmH_2O → it is illogical to make them spontaneously ventilate

- patients requiring PEEP > 10 cmH_2O have an excessive work of breathing, fatigue and fail
- thus, the second aim is to reduce the level of PEEP to < 10 cmH_2O
- this is usually attained by a number of the following,

  a. general respiratory toilet and posturing

  b. aggressive chest physiotherapy

  c. bronchoscopy ± suctioning and lavage

  d. antibiotics (following M,C&S)

  e. bronchodilator therapy

  f. steroids

  g. diuretics

  h. ionotropic agents

  i. adequate pain relief (see below)

  j. respiratory muscle support - perfusion pressure
- aminophylline

- once the FiO_2 is < 50%, PEEP < 10 cmH_2O and the P_{aO2} is > 60 mmHg, then the patient should be encouraged to perform more ventilatory work by decreasing the IMV rate
- the rapidity with which the IMV rate can be reduced is directly related to the vital capacity (VC) and peak inspiratory force (PIF)
- as the IMV rate is decreased the patient should be monitored for,

  a. spontaneous respiratory rate (SRR)

  b. vital capacity

  c. PIF

  d. P_{aCO2}

- when IMV is withdrawn too rapidly the following may occur,

  a. SRR increases dramatically

  b. a sensation of dyspnoea

  c. deterioration of the AGA's

  d. an decrease in VC and PIF

  e. hypertension and tachycardia, ± dysrhythmias

■ *Criteria For Extubation*

1.	FiO_2	<	50%
2.	PEEP	<	10 cmH_2O
3.	P_{aO2}	>	60 mmHg
4.	P_{aCO2}	<	50 mmHg
5.	IMV	≤	4 bpm
6.	VC	≥	15 ml/kg (~ 30 ml/kg for two lungs)
7.	SRR	<	20-30 bpm

8. a resolving CXR (ie. no new findings)
9. no other major organ system failure or instability

NB: post-extubation respiratory care, physiotherapy, coughing, exercises, drug treatment, etc., continues

■ *Major Haemorrhage*

- bleeding necessitating emergency thoracotomy occurs in ~ 1-3%
- in this group the ***mortality* ~ 23%**
- apart from frank bleeding from the chest drain, the haematocrit of the drainage fluid may also be useful for slower cases of bleeding
- the usual Hct of drainage fluid is < 20%, values higher than this should raise the suspicion of haemorrhage

■ *Bronchial Disruption*

- the development of a ***bronchopleural fistula*** carries a high mortality, ≤ 23% as recently as 1978
- the signs & symtpoms depend on,

  a. the size of the disruption
  b. the presence of a chest drain
  c. the presence of any type of fluid within the hemithorax

- a functioning chest tube, if not present should be immediately inserted to prevent the development of a ***tension pneumothorax*** & the sump should be closed surgically ASAP
- the development of a ***chronic fistula*** can be expected to occur in 1-3% of pneumonectomies
- most are evident within the first two weeks, and may run a fulminating course including,

  a. sepsis
  b. empyema
  c. purulent sputum, and
  d. respiratory insufficiency

• factors which predispose to a chronic fistula include,

a. preoperative ***irradiation***

b. ***infection***

c. residual ***neoplasm*** at the site of resection

d. the presence of a long or ***avascular stump***

■ ***Right Heart Failure***

• factors which further increase right heart afterload, in addition to resection, predispose to failure,

a. hypoxaemia

b. acidosis

c. vasoconstrictor drugs

d. fluid overload

• the diagnosis of selective right heart failure is made when RA pressure exceeds LA pressure (PCWP) in the presence of a low CO
• ***pulmonary hypertension***, with a pulmonary diastolic-PCWP gradient, will also usually be present, along with the clinical signs of low CO
• the management is the same as for LHF,

a. optimisation of preload

b. optimisation of afterload

c. inotropic support

d. control of HR

■ ***Right-Left Shunt***

• many adult patients have a probe-patent foramen ovale at autopsy
• the incidence is highest (~ 35%) in the first three decades, decreasing by the ninth decade (~ 20%)
• functional opening of the valve may occur when RA pressure exceeds LA pressure
• this may be confirmed by dye dilution studies, or contrast two dimensional echocardiography
• management is best achieved by returning the usual gradient between left and right atria

■ ***Neural Injuries***

• during radical hilar dissection, the vagus, recurrent laryngeal and phrenic nerves may be traumatised
• aside from clamping of the thoracic aorta and spinal ischaemia, there are two other causes of paraplegia after thoracotomy,

a. damage to the spinal branches of the intercostal arteries

b. surgical dissection and communication between the pleural and epidural spaces

Herniation of The Heart

• this occurs when the surgeon has opened the pericardium to facilitate wider dissection of the hilar region vessels
• the defect is unable to be closed post-resection and there are reports of herniation into either hemithorax → ***mortality* ~ 50%**
• functional impairment includes,

a. SVC syndrome
b. IVC syndrome, cardiovascular collapse
c. distal tracheal obstruction
d. pulmonary venous obstruction and oedema
e. myocardial ischaemia and dysrhythmias

• diagnosis is made by the presence of the defect, the appearance of the above symptoms/signs and a CXR may reveal the apex of the heart directed at a lateral chest wall
• management involves immediate re-exploration, and reversal of three factors which may predispose to herniation, plus other supportive measures,

1. the ventilated, non-surgical lung should be dependent
2. avoidance of high ventilation pressures/volumes
3. discontinuation of suction to the empty hemithorax

4. pharmacological support of the circluation
5. injection of 1-2 l of air into the empty hemithorax

MANAGEMENT OF POSTOPERATIVE PAIN

- postoperative patients normally attempt to prevent stretching of the skin incision by ***splinting***, contracting their expiratory muscles during inspiration to prevent thoracic excursion, and expiring rapidly
- this greatly reduces VC, basalar expansion and their ability to cough
- in addition to the standard methods of pain relief, three methods are particularly effective for post-thoracotomy pain,

  a. epidural narcotics

  b. interpleural regional analgesia

  c. cryoanalgesia

Epidural Narcotic Administration

- this method of pain relief possesses a number of advantages,

  a. no sensory, sympathetic or motor blockade

  b. reasonably predictable analgesia

  c. better quality of pain relief c.f. parenteral narcotics

  d. a longer duration of pain relief c.f. parenteral narcotics

- placement of the catheter prior to anaesthesia, using a small test dose of local anaesthetic is the preferred technique
- there are several peculiar aspects to thoracic epidural use,

  a. placement carries significant risks,
     i. dural puncture
     ii. spinal cord damage

  b. the method is also useful following severe chest trauma, or for intractable cancer pain

  c. side effects are relatively few,
     i. urinary retention is rare, patients usually have IDC's
     ii. nausea & vomiting
     iii. pruritis

  d. catheters may be left in situ for up to 5 days without tolerance developing

  e. failure of pain relief is usually associated with catheter misplacement

  f. lumbar placement is equally successful, though, requires increased quantities of narcotic and larger dilutent volumes

  g. the lipophillic narcotics require catheter placement in proximity to the required dermatome

  h. measurements of pulmonary function are increased to an equal or greater extent than with parenteral narcotics

Interpleural Regional Analgesia

• this method has been used for the treatment of pain due to chest trauma, thoracic and abdominal surgery, pancreatitis and other conditions
• it is usually accomplished by the placement of an ***epidural catheter*** between the parietal and visceral pleura and local anaesthetic infused
• usually ***bupivacaine*** 0.25-0.5% with adrenaline
• anaesthesia is thought to relate to,

a. diffusion of LA through the parietal pleura to the intercostal nerves
b. blockade of the intrathoracic sympathetic chain
c. direct action on nerve endings within the pleura

• for thoracic surgery the catheter is usually placed by the surgeon immediately below the level of the incision
• less commonly the ***chest tube*** may be used for the instillation
• there are a number of conflicting reports regarding the efficacy and best protocols for the institution of interpleural blockade
• a number of studies, in adults and children, have shown ***potentially toxic*** serum concentrations of bupivacaine, both with intermittent bolus and continuous infusion techniques

• Miller raises the following as issues requiring assessment,

a. determination of the optimal volume/concentration of LA
b. bolus vs. continuous infusion techniques
c. which anaesthetic is most appropriate in terms of efficacy/toxicity ratio
d. is the diaphragm directly affected, or affected via the phrenic nerve
e. does significant blockade of cardiac sympathetic outflow occur
f. could bupivacaine diffuse across the pericardium and result in direct myocardial toxicity
g. must patients be nursed in the supine position, and if so, does this significantly affect pulmonary function
h. for patients with chest tubes, is clamping required and if so for how long can this procedure be tolerated and what level of nursing care is required during this period
i. what, in addition to the following are contraindications to this procedure,
    i. LA allergy
    ii. recent thoracic infection
    iii. pulmonary fibrosis
    iv. pleural fluid (blood or serous)
j. the efficacy of the technique c.f. parenteral/epidural narcotics

• at present the conflicting literature regarding the technique render it unrecommendable at this point in time

Cryoanalgesia

- direct application of sub-zero temperatures to the intercostal nerves
- provides protracted analgesia by disruption of the ***nerve axons***, without damage to the ***epineurium***
- recovery of function begins at 2-3 weeks and full recovery takes from 1-3 months
- currently used N_2O cryoprobes operate at ~ -60°C
- most pain experienced by these patients is in the shoulder and arm and relates to pleural irritation from the thoracic tubing
- once the chest-tubes are removed at ~ day 3, these patients experience minimal discomfort
- return of sensation occurs at a median of 13 days postoperatively
- this method provides similar improvement in respiratory function as parenteral and epidural narcotics, usually with less side effects

ANAESTHESIA FOR SPECIAL THORACIC PROCEDURES

Mediastinoscopy

• the technique involves the passage of a blunt instrument through a suprasternal notch incision, through a plane on the anterior and lateral walls of the trachea
• the instrument passes posterior to the aortic arch and allows examination and biopsy of the superior mediastinal lymph nodes,

a. anterior and lateral mainstem bronchial lymph nodes
b. anterior subcarinal lymph nodes
c. anterior and lateral paratracheal lymph nodes

• thymic and anterior mediastinal pathology is not examinable by this method as these structures are anterior to the major vessels
• ***previous mediastinoscopy*** is an absolute contraindication, as the plane of dissection is lost
• relative contraindications include,

a. the SVC syndrome
b. severe tracheal deviation
c. cerebrovascular disease
d. thoracic aortic aneurysm

• the procedure may be performed under local anaesthesia
• however, GA with paralysis is preferable to prevent coughing and straining which produces venous engorgement
• an ***armoured tube*** should be considered in cases of tracheomalacia
• the head-up position minimises venous engorgement, however increases the likelihood of ***air embolism***

• the principal considerations are observation for complications, which include, in approximate order of frequency,

a. vascular compression - innominate artery
- right subclavian and carotid aa.
- aorta
→ hypotension ± reflex bradycardia (aorta)

b. haemorrhage ± hypovolaemia

c. pneumothorax ± tension

d. dysrhythmias 2° to mechanical stimulation

e. tracheal compression

f. recurrent laryngeal nerve injury (~ 50% permanent)

g. infection

h. tumour implantation in the would

i. phrenic nerve injury

j. oesophageal injury

k. air embolism (reduced by IPPV, CPAP)

l. transient hemiparesis (or other CVA)

• if an arterial line is used, the ***right radial artery*** is preferable
• alternatively, a pulse oximeter may give a crude guide to vascular compression

Thoracoscopy

- thoracoscopy (pleuroscopy) permits examination of the intrathoracic cavity
- usually this is performed only after closed-chest pleural or lung biopsy has failed to delineate the pathology
- the surgeon may use a thorascope, laparoscope, or mediastinoscope
- the procedure may be done with local, regional or general anaesthesia
- partial collapse of the operative side lung occurs and facilitates the procedure

→ ***controlled pneumothorax***

- this may be detrimental in those patients with marginal pulmonary function
- changes in P_{aO2}, P_{aCO2}, and cardiac rhythm are usually minimal, even when LA and spontaneous ventilation are used
- under no circumstances should gas be forced into the pleural cavity under pressure to facilitate exposure
- the use of a high FiO_2 is desirable to help compensate for the reduction in lung volume
- local anaesthesia may be supplemented by,

  a. intercostal nerve blocks, 2 spaces above and below the level of the incision, posterior enough to block parietal pleura

  b. ipsilateral stellate ganglion block, to lessen the cough reflex which often accompanies manipulation of the hilum

- IPPV through a SLT significantly interferes with visualization, therefore one lung ventilation with a DLT is usually employed
- the duration of the procedure is usually short enough not to require special monitoring of cardiorespiratory function, though, in patients with severely compromised function this may still be required
- complications are generally rare, the ensuing pneumothorax rarely requires insertion of a chest tube

Tracheal Resection

• if technically feasible, tracheal resection is indicated for,

a. primary obstructing tumours (usually carcinoma)

b. stenosis secondary to trauma (prolonged intubation)

• patients with operable tumours may have either,

a.	segmental resection with 1° anastomosis	~ 80%
b.	segmental resection with prosthetic reconstruction	~ 10%
c.	segmental resection with T-tube stent	~ 10%

• segmental resection may include carinal or laryngeal resection
• adjuncts to surgery include,

a. pre/postoperative radiotherapy

b. preoperative laser tumour debulking

c. internal radioactive seed irradiation

• unless airway obstruction is imminent, preoperative pulmonary function should be tested
• severe airway disease, indicating a likelihood for postoperative ventilation is a relative contraindication
• the combined effects of IPPV and the presence of the ETT cuff at the suture line increase the likelihood of wound dehiscence
• preoperative evaluation should also include,

a. chest tomograms, CAT scans

b. bronchoscopy

c. AGA's & routine PFT's

d. flow-volume loops → upper airway obstruction,
intrathoracic, or extrathoracic obstruction

• the ***left radial artery*** should be used for cannulation, as the right innominate artery is crossed by the trachea and may be compromised during surgery

• a large variety of ventilation techniques have been described, these generally fall into,

a. ***standard orotracheal intubation***
   - passed distal to the lesion intraoperatively by the surgeon
   - completion of the anastomosis may then be difficult

b. ***distal tracheal stump intubation*** ± either main bronchus
   - performed with armoured ETT's by the surgeon, connected to a separate circuit
   - these are then withdrawn after the posterior wall is completed and the original SLT advanced distal to the anastomosis prior to completion of the anastomosis

NB: ** disadvantages of these complex airway manipulations include,

i. soiling of the lung with blood/debris
ii. obstruction to the surgical field
iii. the occasional need for one-lung ventilation

→ these may be in part over come by,

a. HFJV through the stenotic lesion
b. HFPPV
c. Cardiopulmonary Bypass

• the last of these, while removing many of the problems associated with ventilation, carries the significant risk of intrapulmonary haemorrhage which mitigates against its routine use
• helium/oxygen breathing mixtures significantly reduce airflow resistance, however, the reduction in FiO_2 is usually undesirable

Giant Bullous Emphysema & Lung Cysts

• a ***bulla*** is defined as an air-filled, thin-walled space within the lung which is the result of destruction of alveolar tissue
• the walls are composed of connective tissue septa and the area usually represents the end-stage of emphysematous destruction

• ***air cysts*** are similar, however, have their own ***epithelial margins*** and may be associated with either COAD, or no other pulmonary pathology

• surgical resection is indicated for,

1. intolerable breathlessness with full medical therapy
2. rapidly expanding lesions
3. repeated pneumothorax
4. significant compression of otherwise normal lung

• anaesthesia for these patients carries a number of ventilatory hazards,

a. as most of these patients COAD, one-lung ventilation carries significant risks of hypoxia, hypercarbia and pneumothorax on the ventilated side
(these risks are greater if there is bullous disease on the non-operative side)

b. IPPV of a communicating cyst may greatly increase alveolar dead space, unless V_M is proportionately increased

c. N_2O diffusion into a non-communicating cyst may cause significant embarrassment to the remaining lung

d. cysts with "valve" communication may tension and significant embarrassment to the remaining lung

e. IPPV may cause cyst rupture and pneumothorax, usually with tension
(decompression creating a bronchopleural-cutaneous fistula and a dramatic fall in V_A)

f. post-resection, the presence of multiple small air leaks creates a similar condition to (e) above

• many of the problems associated with IPPV of a communicating lung cyst may be reduced by the use of HFV, using a frequency such that the relative impeadance of cyst is greater than the normal lung tissue
• management is usually with a DLT, allowing differential management of the two lungs with respect to PEEP, CPAP, HFV, etc.
• mechanical ventilation in patients with a history of pneumothorax or bilateral bullous disease carries the risk intraoperative pneumothorax
• this may be overcome by either,

a. allowing spontaneous ventilation, though, the majority of these patients will not maintain adequate ventilation under anaesthesia, or

b. gentle IPPV by hand, using low inflation pressures

• the presence of extensive bullous disease may make the diagnosis of pneumothorax difficult, due to minimal breath sounds
• the main signs being,

a. an increasing peak inspiratory pressure
b. tracheal shift
c. hypotension disproportionate to anaesthetic depth

Unilateral Bronchopulmonary Lavage

• sometimes used in the treatment of pulmonary ***alveolar proteinosis***, to remove the massive accumulation of alveolar lipoproteinaceous material (thought to be surfactant)
• this collects due to failure of the normal mechanism of clearance, rather than enhanced formation
• the disease results in,

a. progressive alveolar consolidation
b. decreased pulomonary compliance
c. increased shunt and arterial hypoxaemia
d. increased work of breathing

• infrequently lavage may be performed for severe asthma, cyctic fibrosis, or inhalation of radioactive dust
• for the management of pulmonary alveolar proteinosis, unilateral lavage is performed with a DLT, followed by the other lung after several days rest
• patients usually show subjective improvement which correlates well with the P_{aO2} and CXR
• some patients require lavage every few months, whereas other remain in remission for years
• the disease may eventually completely remit

• preoperative ventilation-perfusion scans indicate which lung is most severely affected and this is usually lavaged first, allowing ventilation to be supported by the better lung
• if involvement is equal, then the ***left lung*** is lavaged first, allowing the larger right lung to support ventilation
• a left sided DLT is preferred due to greater ease of insertion and the better seal which may be attained between the lungs
• the cuff should maintain **~ 50 cmH_2O** seal pressure prior to lavage
• the usual technique is to use 100% O_2 / volatile / relaxant / IPPV / DLT
• lavage may be carried out using oxygenated perfluorocarbon, thus maintaining some gas exchange though the lavaged lung

• patient position is important,

a.	lavaged lung non-dependent	→	minimises shunt flow increases the risk of spillage
b.	lavaged lung dependent	→	maximises shunt flow decreases the risk of spillage
c.	supine position	→	compromise between the two

• postoperatively, (and during the procedure), the patient requires chest physiotherapy, incentive spirometry etc.
• intermittent large tidal volumes are required to maintain alveolar expansion due to the differential compliance of the two lungs postoperatively
• compliance of the lavaged side being reduced by the procedure

Central Mediastinal Tumours

• the structures at the confluence of the superior, anterior and middle mediastinum are the,

a. tracheal bifurcation
b. middle portion of the SVC
c. main pulmonary artery
d. aortic arch
e. parts of the cephelad surface of the heart

• in adults, the majority of tumors in this region are ***hilar lymph node*** involvement from bronchial carcinoma or lymphoma
• in children, the masses are usually benign bronchial cysts, oesophageal duplication, or teratoma
• the most common intraoperative complication with these tumors is ***airway obstruction***, though compression of the other structures may occur,

■ ***Compression of the Tracheobronchial Tree***

• these are most often lymphomatous, therefore tissue diagnosis should be undertaken prior to radiotherapy, or chemotherapy
• obstruction is commonly life threatening, as this occurs at the level of the bifurcation and is distal to an ETT
• the change from SV to IPPV frequently precipitates obstruction in these patients
• obstruction may also occur due to impingement of the ETT against the tumor, or due to thick secretions
• thus, if at all possible biopsy under ***local anaesthesia*** should be encouraged
• lymphomatous tumors usually show dramatic regression with radiotherapy and/or chemotherapy
• ideally these should be employed prior to general anaesthesia
• if GA is required prior to other therapy and the airway is in doubt, ie. the patient has dyspnoea or intolerance of the supine position, an awake fibreoptic intubation and inspection of the bronchial tree is advisable

• if the patient is asymptomatic then assessment by CAT scan, flow-volume loops and echocardiography should be performed
• intubation should be with an ***armoured ETT***
• spontaneous ventilation may be preferable as neuromuscular blockade may be avoided

■ ***Compression of the PA and/or Heart***

• this is rare as these structures are virtually protected by the aortic arch
• general management is the same as above
• measures to maintain venous return, PA pressure and CO, such as volume loading and the use of ketamine should be considered

■ ***Superior Vena Cava Syndrome***

• the ***causes*** of this syndrome, in order of frequency, are,

1. bronchial carcinoma ~ 87%
2. malignant lymphoma ~ 10%
3. benign causes ~ 3%
    i. idiopathic mediastinal fibrosis
    ii. CVC hyperalimentation or pacemaker catheter induced thrombosis
    iii. mediastinal granuloma
    iv. multinodular goitre

• the classical ***features*** of SVC syndrome include,

i. distended upper body veins (pressure may be ≤ 40mmHg)
ii. oedema of the head, neck and upper extremities
iii. venous collateral channels on the abdominal wall
iv. cyanosis
v. respiratory symptoms: dyspnoea, cough, orthopnoea
vi. CNS symptoms: altered mentation, headaches

• the majority are treated with radiotherapy/chemotherapy prior to anaesthesia
• however, patients with near complete obstruction, or those unresponsive to radiotherapy / chemotherapy require surgical bypass
• these procedures are usually technically very difficult
• preoperative assessment should centre around the ***airway***, as similar degrees of oedema can be expected in the pharynx and larynx
• further, external compression of the trachea by fibrosis, or involvement of the recurrent laryngeal nerve may be present
• the most significant intraoperative problem is ***bleeding***, which is exacerbated by the high venous pressures and distorted anatomy
• thus, cross-matched blood should be readily available
• when the obstruction is not relieved, such as after diagnostic procedures, there is a high incidence of postoperative respiratory obstruction requiring re-intubation and IPPV

EMERGENCY THORACIC PROCEDURES

Massive Haemoptysis

• defined arbitrarily as blood loss,

a. between 200-600 ml expectorated per 24 hours, or
b. resulting in acute airway obstruction, or
c. resulting in acute hypotension

• more than 90% of cases are due to ***chronic infection***, as inflammation leads to profuse vascularisation of the high pressure bronchial circulation
• any subsequent erosion of these vessels results in significant bleeding
• the most common causes are,

1. TB
2. bronchiectasis / pulmonary abscess
3. bronchial neoplasms

• resections for haemoptysis > 600 ml/24 hrs carry a high mortality rate ~ 15-20%
• this is better than conservative management, which averages up to 75%
• surgery is probably ***indicated*** in those patients who,

a. require multiple transfusion
b. show progressive deterioration of pulmonary function
c. continue to bleed despite adequate medical management

• surgery is probably ***contra-indicated*** in those patients who,

a. have inoperable bronchial carcinoma
b. fail to have their bleeding site localised
c. have severe bilateral pulmonary disease
d. have severe debilitating systemic disease

• most patients should have a ***rigid bronchoscopy***, due to the greater ease of ventilation and suctioning
• upper lobe bleeding may require the use of a flexible scope
• moderate bleeding may be controlled through the bronchoscope
• prevention of soiling of the innocent lung may be achieved by the use of a bronchial blocker, such as a balloon-tipped Fogarty catheter
• if the patient is deemed inoperable, then bronchial ***embolisation*** may be attempted

- ***Anaesthesic Principals***

1. preoxygenation and ventilation with 100% O_2
2. several large bore IV canulae should be inserted
3. the patient should be cross-matched + baseline CBP
4. the patients coagulation profile should be checked
5. antibiotics should be commenced preoperatively
6. adequate suctioning should be available
7. ***on induction*** the bleeding lung should be ***dependent***, and anti-aspiration measures should be employed
8. alternatively, in the patient with massive haemoptysis, an awake, semi-upright intubation may be required
9. separation of the two lungs,
   - DLT
   - SLT + bronchial blocker
10. IPPV with regular intermittent suctioning
11. after the airway is secured and the lungs ***separated***, the bleeding lung should be in the ***non-dependent*** position

- these patients are frequently ***hypovolaemic***, therefore induction should follow adequate volume replacement and should be achieved with either a small dose of STP or ketamine, or alternatively use narcotics
- if a SLT is already in place, consideration should be given to,

a. replacing it with a DLT
b. the addition of a bronchial blocker
c. endobronchial intubation

- the majority of these patient should be ventilated postoperatively

Bronchopleural Fistula

• this may result from,

a. rupture of a lung abscess, bronchus, bulla, cyst, or parenchymal tissue
b. erosion of a bronchus by carcinoma or chonic inflamation
c. breakdown of a suture line following pulmonary resection

• post resection the diagnosis is usually made by,

a. the appearance of ***dyspnoea***
b. subcutaneous ***emphysema***
c. contralateral deviation of the trachea
d. disappearance of fluid levels on the CXR

• persistent air leaks, purulent drainage, and expectoration of purulent material frequently occur
• after removal of the chest tube, fever, purulent sputum, and a new fluid level on CXR are diagnostic
• post-pneumonectomy patients may be treated by resuturing of the stump
• this is best achieved with adequate drainage and antibiotic therapy

• in non-postpneumonectomy cases, providing the lung will re-expand, the leak can usually be controlled by insertion of a chest tube
• larger leaks usually require surgical resection
• similarly, when associated with chronic empyema, this is best drained preoperatively

• ***spontaneous pneumothorax*** is pathologically similar to B-P fistula and there are three situations where definitive surgical management is indicated,

1. where a ***chest tube fails*** to effect re-expansion
(this is in effect a B-P fistula)
2. following a ***second ipsilateral***, or ***first contralateral*** pneumothorax
3. where recurrence may be either ***life-threatening*** or grossly inconvenient to the patient
(recurrence rate ~ 10-25%)

• management is either by ***chemical pleurodesis***, or ***pleurectomy***

- there have been a number of non-surgical approaches to management of B-P fistula,
    a. HFV
    b. pleural cavity PEEP = intrathoracic PEEP
    c. unidirectional chest tube valves

- if the leak is small a standard SLT may be employed and IPPV will likely be adequate
- if IPPV is found to be inadequate, the the tube should be replaced with a DLT and differential lung ventilation employed
- for those associated with abscess or chonic empyema the use of a DLT is highly desirable
- for those patients unable to tolerate a DLT, either bronchial blockers or an endobronchial intubation may be employed

Anaesthetic Considerations

1. determination of the size of the fistula
2. presence of infection
3. associated medical condition
4. assessment of the airway / ease of intubation
5. O_2 requirement

Lung Abscess and Empyema

- aspiration secondary to alcoholic obtundation is the most common cause
- other predisposing factors include,
    - a. other substance abuse
    - b. prior pneumonia
    - c. lung carcinoma
    - d. immunosuppressive drugs or disease
    - e. diabetes mellitus
    - f. the presence of a distant septic focus
    - g. CAL

- all of these causes of lung abscess may lead to spread to the pleural cavity and the formation of an empyema
- empyema may also result from,
    - a. infection of a haemothorax
    - b. following diagnostic or therapeutic thoracentesis

- either of these may erode a bronchus and lead to a B-P fistula
- cases without abscess may be treated by drainage procedures, however should these fail, or should an abscess be present, then formal resection is indicated
- management with a DLT is imperative to prevent soiling of the unaffected lung
- collapse also greatly facilitates resection and drainage
- the cuff seal should be adequately tested to ^{3} **50 cmH_2O** and the position should be checked fibreoptically prior to movement to the lateral decubitus position

Blunt Thoracic Trauma

- Devitt *et al.* reported on 780 patients addmitted with blunt thoracic trauma in Canada,
    a. 333 required urgent operation within 24 hours of admission
    b. including those dead on arrival, total mortality = 102 ~ 13%
    c.