Preoperative Assessment for Pulmonary Resection

In the recent past there have been major improvements in the outcomes for high-risk patients having pulmonary resection surgery. This review will focus on these patients, but the general principles apply to patients having any type of intrathoracic surgery and also to patients with severe pulmonary disease having any surgical procedure. An evidence-based strategy will be developed to allow the anesthesiologist to stratify patients according to their risk of perioperative complications and also to allow direct anesthetic management to modify the risk. Because the reality of current anesthetic practice is that these patients are not usually admitted to the hospital preoperatively, an approach will be outlined to evaluate these patients in two stages: first at the time of the initial outpatient consultation and then immediately before anesthesia. To assess the patients preoperatively, it is necessary to have an understanding of the risks specific to this type of surgery (1). The major cause of perioperative morbidity and mortality in the thoracic surgical population is respiratory complications (2). For other types of surgery, cardiac and vascular complications are the leading cause of early perioperative morbidity and mortality.

Initial Preoperative Assessment

Assessment of Respiratory Function

The best assessment of respiratory function comes from a history of the patient's quality of life (3). It is useful to have objective measures of pulmonary function that can be used to guide anesthetic management and to have this information in a format that can be easily transmitted between members of the health care team. There are many factors that determine overall respiratory performance (4). It is useful to think of the respiratory function in three related but somewhat independent areas: respiratory mechanics, gas exchange, and cardiorespiratory interaction.

Respiratory Mechanics. Many tests of respiratory mechanics and volumes show correlation with post-thoracotomy outcome. It is useful to express these as a percent of predicted volumes corrected for age, sex,

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and height (e.g., forced expiratory volume in 1 s, FEV1). Of these, the most valid single test for post-thoracotomy respiratory complications is the predicted postoperative forced expiratory volume in 1 s (ppoFEV1), which is calculated as:

ppoFEV1% = preoperative FEV1%

 \times (1 – % functional lung tissue removed/100)

Nakahara et al. (2) found that patients with a ppoFEV1 >40% had no or minor post-resection respiratory complications. Major respiratory complications were only seen in the subgroup with ppoFEV1 <40% and patients with ppoFEV1 <30% required postoperative mechanical ventilatory support. The use of epidural analgesia has decreased the incidence of complications in the high-risk group (5).

Lung Parenchymal Function. Arterial blood gas data such as $Pao_2 < 60 \text{ mm Hg or } Paco_2 > 45 \text{ mm Hg have}$ been used as cut-off values for pulmonary resection. Cancer resections have now been successfully done or even combined with volume reduction in patients who do not meet these criteria (6). The most useful test of the gas exchange capacity of the lung is the diffusing capacity for carbon monoxide (DLCO). The DLCO correlates with the total functioning surface area of alveolar-capillary interface. The DLCO can be used to calculate a post-resection (ppo) value using the same calculation as for the FEV1. A ppoDLCO <40% of predicted correlates with both increased respiratory and cardiac complications and is relatively independent of the FEV1 (7).

Cardiopulmonary Interaction. The most important assessment of respiratory function is an assessment of the cardiopulmonary interaction. The traditional test is stair climbing (8). The ability to climb 3 flights or more is closely associated with decreased mortality and morbidity; <2 flights is associated with very high risk. Formal laboratory exercise testing with maximal oxygen consumption ($\dot{V}o_2max$) is the "gold standard" for assessment of cardiopulmonary function. Climbing 5 flights of stairs approximates a $\dot{V}o_2max$ of >20 mL \cdot kg⁻¹ \cdot min⁻¹ and <1 flight a $\dot{V}o_2max$ <10 mL \cdot kg⁻¹ \cdot min⁻¹ (9). In a high-risk group of

patients (mean preoperative FEV1 = 41% of predicted), there was no perioperative mortality if the preoperative $\dot{V}o_2max$ was >15 mL \cdot kg⁻¹ \cdot min⁻¹ (10). Alternatives to $\dot{V}o_2max$ include the 6-min walk test (11) and exercise oximetry (12).

Ventilation Perfusion (V/Q) Scintigraphy. Prediction of post-resection pulmonary function can be further refined by assessment of the preoperative contribution of the lung or lobe to be resected using V/Q lung scanning (13). If the lung region to be resected is nonfunctioning or minimally functioning, the prediction of postoperative function can be modified accordingly. This is particularly useful in pneumonectomy patients and should be considered for any patient who has a ppoFEV1 <40%. Other tests of pulmonary function such as split-lung function studies and flow-volume loops have not shown sufficient predictive validity for widespread universal adoption in potential lung resection patients.

Combination of Tests. No single test of respiratory function has shown adequate validity as a sole preoperative assessment. Before surgery an estimate of respiratory function in all three areas: lung mechanics, parenchymal function, and cardiopulmonary interaction should be made for each patient. If a patient has a ppoFEV1 >40% it should be possible for that patient to be extubated in the operating room at the conclusion of surgery assuming the patient is alert, warm, and comfortable ("AWaC"). If the ppoFEV1 is >30%and exercise tolerance and lung parenchymal function exceed the increased risk thresholds, then extubation in the operating room may be possible depending on the status of associated diseases. Those patients in this subgroup who do not meet the minimal criteria for cardiopulmonary and parenchymal function should be considered for staged weaning from mechanical ventilation postoperatively so that the effect of the increased oxygen consumption of spontaneous ventilation can be assessed. Patients with a ppoFEV1 20%-30% and favorable predicted cardiorespiratory and parenchymal function can be considered for early extubation if thoracic epidural analgesia if used. The validity of this approach has been confirmed by the National Emphysema Treatment Trial, which found an unacceptably high mortality for lung volume reduction surgery in patients with preoperative FEV1 and DL_{CO} values <20% of predicted (14).

Intercurrent Medical Conditions

Age. If a patient is 80 yr of age and has a stage I lung cancer, their chances of survival to age 85 yr are better with the tumor resected than without (15). However, the rate of respiratory complications (40%) is double that expected in a younger population and the rate of cardiac complications (40%), particularly arrhythmias, triple that which should be seen in

younger patients. Although the mortality from lobectomy in the elderly is acceptable, the mortality from pneumonectomy (22% in patients >70 yr) (16), particularly right pneumonectomy, is excessive. Pulmonary resection in the elderly should be regarded as a highrisk procedure for cardiac complications and cardiopulmonary reserve is the most important predictor of outcome in this population (17).

Cardiac Disease. Cardiac complications are the second most common cause of perioperative morbidity and mortality in the thoracic surgical population.

Ischemia. Most pulmonary resection patients have a smoking history and already have one risk factor for coronary artery disease (18). Pulmonary resection surgery is an "intermediate risk" procedure in terms of perioperative cardiac ischemia (19). Noninvasive testing is indicated in patients with major (unstable ischemia, recent infarction, severe valvular disease, significant arrhythmia) or intermediate (stable angina, remote infarction, previous congestive failure, or diabetes) clinical predictors of myocardial risk and also in the elderly.

Arrhythmia. Dysrhythmias, particularly atrial fibrillation, are a frequent complication of pulmonary resection surgery (20). Factors known to correlate with an increased incidence of arrhythmia are the amount of lung tissue resected, age, intraoperative blood loss, and intra-pericardial dissection (21). Prophylactic therapy with Digoxin has not been shown to prevent these arrhythmias. Diltiazem has been shown to be effective (22).

Renal Dysfunction. Renal dysfunction after pulmonary resection surgery is associated with a very high incidence of mortality (19%) (23). The factors which are associated with an elevated risk of renal impairment are history of previous renal dysfunction, diuretic therapy, pneumonectomy, postoperative infection, and transfusion.

Chronic Obstructive Pulmonary Disease. Recent advances in the understanding of chronic obstructive pulmonary disease (COPD) that are relevant to anesthetic management include the following:

Respiratory Drive. Many COPD patients have an elevated Paco₂ at rest. To identify these patients preoperatively, all moderate-to-severe COPD patients need arterial blood gas analysis. This CO₂-retention seems to be primarily related to an inability to maintain the increased work of respiration and not to an alteration of respiratory control mechanisms (24). The Paco₂ rises in these patients when supplemental oxygen is administered because a high FIO₂ causes a relative increase in alveolar dead space by the redistribution of lung perfusion and from the Haldane effect (25). However, supplemental oxygen must be administered to these patients postoperatively to prevent hypoxemia. The attendant rise in Paco₂ should be anticipated and monitored.

Table 1. Anesthetic Considerations in Lung Cancer Patients (the "4 M's")

1.	Mass effects: Obs	tructive pneumonia	a, lung abscess,	SVC syndrome,	tracheobronchial	distortion, Pancoast's
	syndrome, recurre	ent laryngeal nerve	or phrenic nerv	ve paresis, chest	wall or mediastir	nal extension

2. Metabolic effects: Lambert-Eaton syndrome, hypercalcemia, hyponatremia, Cushing's syndrome

3. Metastases: particularly to brain, bone, liver, and adrenal

4. Medications: chemotherapy agents, pulmonary toxicity (Bleomycin, Mitomycin), cardiac toxicity (Doxorubicin), renal toxicity (Cisplatin)

Nocturnal Hypoxemia. COPD patients desaturate more frequently and severely than normal patients during sleep (26). This tendency to desaturate, combined with the postoperative fall in functional residual capacity (FRC) and opioid analgesia places these patients at high risk for severe hypoxemia postoperatively during sleep.

Right Ventricular (RV) Dysfunction. RV dysfunction occurs in up to 50% of COPD patients (27). The dysfunctional RV is poorly tolerant of sudden increases in afterload such as the change from spontaneous to controlled ventilation (28). Pneumonectomy candidates with a ppoFEV1 <40% should have transthoracic echocardiography to assess right heart function. Elevation of right heart pressures places these patients in a high-risk group (29).

Combined Cancer and Emphysema Surgery. The combination of volume reduction surgery or bullectomy in addition to lung cancer surgery has been reported in emphysematous patients who previously would not have met minimal criteria for pulmonary resection because of their concurrent lung disease (30). Although the numbers of patients reported are small, the expected improvements in postoperative pulmonary function have been seen and the outcomes are encouraging. This offers an extension of the standard indications for surgery in a small, well selected, group of patients.

There are four treatable complications of COPD that must be sought and treated at the initial prethoracotomy assessment: atelectasis, bronchospasm, chest infection, and pulmonary edema.

Physiotherapy. Patients with COPD have fewer postoperative pulmonary complications when a program of chest physiotherapy is initiated preoperatively (31). Among COPD patients, those with excessive sputum benefit the most from chest physiotherapy (32). A comprehensive program of pulmonary rehabilitation involving physiotherapy, exercise, nutrition, and education has been shown to consistently improve functional capacity for patients with severe COPD (33). Atelectasis in the postoperative period leads to increased capillary permeability and an inflammatory response with subsequent lung injury if it persists (34); it should be treated with aggressive physiotherapy (35).

Lung Cancer. At the time of initial assessment cancer patients should be assessed for the "4 Ms" associated with malignancy (Table 1): mass effects (36), metabolic abnormalities, metastases (37), and medications. The prior use of medications that can exacerbate oxygen-induced pulmonary toxicity such as bleomycin should be considered (38). Recently we have seen several lung cancer patients who received preoperative chemotherapy with cis-platinum and then developed an elevation of serum creatinine when they received nonsteroidal antiinflammatory analgesics (NSAIDs) postoperatively. For this reason we now do not routinely administer NSAIDs to patients who have been recently treated with cis-platinum.

Smoking Cessation. In nonpulmonary surgery a preoperative smoking cessation program can significantly decrease the incidence of respiratory complications (8 wk abstinence), wound complications (4 wk abstinence) and intraoperative myocardial ischemia (48 h abstinence) (39). However, in thoracic surgical patients, pulmonary complications are decreased in those who are not smoking versus those who continue to smoke up until the time of surgery (40). The perioperative period is a specific stimulus for patients to stop smoking; 55% of patients were found to remain abstinent from smoking 1 yr after angioplasty and 14% after angiography. Physician counseling is a major part of the stimulus (41).

Postoperative Analgesia. The strategy for postoperative analgesia should be developed and discussed with the patient during the initial preoperative assessment. Only epidural techniques have been shown to consistently decrease post-thoracotomy respiratory complications (42,43). Thoracic epidural analgesia is superior to lumbar epidural analgesia because of the synergy that local anesthetics have with opioids in producing neuraxial analgesia. Studies suggest that epidural local anesthetics increase segmental bioavailability of opioids in the cerebrospinal fluid (44) and increase the binding of opioids by spinal cord receptors (45). Only the segmental effects of thoracic epidural local anesthetic and opioid combinations can reliably produce increased analgesia with movement and increased respiratory function after a chest incision (46). In patients with coronary artery disease, thoracic epidural local anesthetics reduce myocardial

Table 2. Initial Preanesthetic Assessment for Thoracic Surgery

- 1. All patients: assess exercise tolerance, estimate ppoFEV1%, discuss postoperative analgesia, D/C smoking
- 2. Patients with ppoFEV1 < 40%: DLCO, V/Q scan, $\dot{V}o_2$ max
- 3. Cancer patients: consider the "4 M's": mass effects, metabolic effects, metastases, medications
- 4. COPD patients: art, blood gas, physiotherapy, bronchodilators
- 5. Increased renal risk: measure creatinine and BUN

Table 3. Final Preanesthetic Assessment for Thoracic Surgery

- 1. Review initial assessment and test results
- 2. Assess difficulty of lung isolation: examine chest radiograph and CT scan

3. Assess risk of hypoxemia during one-lung ventilation:

- High percentage of ventilation or perfusion to the operative lung on preoperative V/Q scan Poor Pao₂ during two-lung ventilation Right-sided surgery
- Good preoperative spirometry (FEV1 or FVC)

oxygen demand and supply in proportion (47), unlike lumbar epidural local anesthetics (48).

At the time of initial preanesthetic assessment the risks and benefits of the various forms of postthoracotomy analgesia should be explained to the patient. Potential contraindications to specific methods of analgesia should be determined such as coagulation problems, sepsis, or neurologic disorders. When it is not possible to place a thoracic epidural because of concerns with patient consent or other contraindications, our current second choice for analgesia is a paravertebral infusion of local anesthetic via a catheter placed intraoperatively in the open hemithorax by the surgeon (49). This is combined with IV patientcontrolled opioid analgesia and NSAIDs.

If the patient is to receive prophylactic anticoagulants and it is elected to use epidural analgesia, appropriate timing of anticoagulant administration and neuraxial catheter placement need to be arranged. ASRA guidelines suggest an interval of 2–4 h before or 1 h after catheter placement for prophylactic heparin administration (50). Low molecular weight heparin (LMWH) precautions are less clear, an interval of 12– 24 h before and 24 h after catheter placement are recommended.

Premedication. Premedication should be discussed and ordered at the time of the initial preoperative visit. The most important aspect of preoperative medication is to avoid inadvertent withdrawal of those drugs that are taken for concurrent medical conditions (bronchodilators, antihypertensives, β-blockers). For some types of thoracic surgery, such as esophageal reflux surgery, oral antacid and H₂-blockers are routinely ordered preoperatively. We do not routinely order preoperative sedation or analgesia for pulmonary resection patients. Mild sedation such as an IV short-acting benzodiazepine is often given immediately before placement of invasive monitoring lines and catheters. In patients with copious secretions, an anti-sialogogue (such as glycopyrrolate) is useful to facilitate fiberoptic bronchoscopy for positioning of a double-lumen tube or bronchial blocker; this can be given IV immediately after placement of the IV catheter. It is a common practice to use short-term IV antibacterial prophylaxis such as a cephalosporin in thoracic surgical patients. If it is local practice to administer these drugs before admission to the operating room, they will have to be ordered preoperatively. Consideration for those patients allergic to cephalosporin or penicillin will have to be made at the time of the initial preoperative visit.

Final Preoperative Assessment

The final preoperative anesthetic assessment for the majority of thoracic surgical patients is carried out immediately before admission of the patient to the operating room. At this time it is important to review the data from the initial pre-thoracotomy assessment (Table 2) and the results of tests ordered at that time. In addition, two other specific areas affecting thoracic anesthesia need to be assessed: the potential for difficult lung isolation and the risk of desaturation during one-lung ventilation (OLV) (Table 3).

Difficult Endobronchial Intubation. Anesthesiologists are familiar with the clinical assessment of the upper airway for ease of endotracheal intubation. In a similar fashion, each thoracic surgical patient must be assessed for the ease of endobronchial intubation. At the time of the preoperative visit, there may be historical factors or physical findings that lead to suspicion of difficult endobronchial intubation (previous radiotherapy, infection, prior pulmonary or airway surgery). In addition, there may be a written bronchoscopy report with detailed description of anatomical features. However, fiberoptic bronchoscopy is not totally reliable for estimating potential problems with endobronchial tube positioning (51). The single most useful predictor of difficult endobronchial intubation is the plain chest radiograph (52).

The anesthesiologist should view the chest films him/herself before induction of anesthesia because neither the radiologist's nor the surgeon's report of the radiograph is made with the specific consideration of lung isolation in mind. A large portion of thoracic surgical patients will also have had a computed tomographic (CT) chest scan done preoperatively. As anesthesiologists have learned to assess radiographs for potential lung-isolation difficulties, it is also worthwhile to learn to examine the CT scan. Distal airway problems not detectable on the plain chest film can sometimes be visualized on the CT scan: a side-to-side compression of the distal trachea, the so-called "sabersheath" trachea can cause obstruction of the tracheal lumen of a left-sided double-lumen tube during ventilation of the dependent lung for a left thoracotomy (53). Similarly, extrinsic compression or intraluminal obstruction of a main stem bronchus, which can interfere with endobronchial tube placement, may only be evident on the CT scan. The major factors in successful lower airway management are anticipation and preparation based on the preoperative assessment.

Prediction of Desaturation During OLV. In the vast majority of cases it is possible to determine those patients who are most at risk of desaturation during OLV for thoracic surgery. The factors that correlate with desaturation during OLV are listed in Table 3. Identification of those patients most likely to desaturate allows the anesthesiologist and surgeon to make a more informed decision regarding the use of OLV intraoperatively. In patients at high-risk of desaturation, prophylactic measures can be used during OLV to decrease this risk. The most useful prophylactic measure is the use of continuous positive airway pressure (CPAP) 2–5 cm H₂O of oxygen to the nonventilated lung (54). Because this often tends to make the surgical exposure more difficult, particularly during video-assisted thoracoscopic surgery (VATS), it is worthwhile to identify those patients who will require CPAP early so that it can be discussed with the surgeon and instituted at the start of OLV.

The most important predictor of Pao₂ during OLV is the Pao₂ during two-lung ventilation. Although the preoperative Pao₂ correlates with the intraoperative OLV Pao₂, the strongest correlation is with the intraoperative Pao₂ during two-lung ventilation in the lateral position before OLV (55,56). The proportion of perfusion or ventilation to the nonoperated lung on preoperative V/Q scans also correlates with the Pao₂ during OLV (57). If the operative lung has little perfusion preoperatively because of unilateral disease, the patient is unlikely to desaturate during OLV.

The side of the thoracotomy has an effect on Pao_2 during OLV. The left lung being 10% smaller than the right, there is less shunt when the left lung is collapsed. In a series of patients the mean Pao_2 during

left thoracotomy was approximately 70 mm Hg higher than during right thoracotomy (58).

Finally, the degree of obstructive lung disease correlates in an inverse fashion with Pao₂ during OLV. Other factors being equal, patients with more severe airflow limitation on preoperative spirometry will tend to have a better Pao₂ during OLV than patients with normal spirometry (59). The etiology of this seemingly paradoxical finding is related to the development of auto-positive end-expiratory pressure during OLV in the obstructed patients (60). Patients with normal healthy lungs with good elastic recoil and patients with increased elastic recoil such as those with restrictive lung diseases tend to benefit from applied positive end-expiratory pressure during OLV whereas those with COPD do not (61).

Summary

Recent advances in anesthesia and surgery have made it so that almost any patient with a resectable lung malignancy is now an operative candidate given a full understanding of the risks and after appropriate investigation. This necessitates a change in the paradigm that we use for preoperative assessment. Understanding and stratifying the perioperative risks allows the anesthesiologist to develop a systematic focused approach to these patients, both at the time of the initial contact and immediately before induction, which can be used to guide anesthetic management.

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