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Preanesthetic Assessment for Thoracic Surgery

Peter Slinger and Gail Darling

Key Points

- All patients having pulmonary resections should have a preoperative assessment of their respiratory function in three areas: lung mechanical function, pulmonary parenchymal function, and cardiopulmonary reserve (the "three-legged stool" of respiratory assessment).
- Following pulmonary resection surgery, it is usually possible to wean and extubate patients with adequate predicted postoperative respiratory function in the operating room provided they are "AWaC" (alert, warm and comfortable).
- Preoperative investigation and therapy of patients with coronary artery disease for noncardiac thoracic surgery is becoming a complex issue. An individualized strategy in consultation with the surgeon, cardiologist, and patient is required. Myocardial perfusion, CT coronary angiography, and other advances in imaging are used increasingly in these patients.

- Geriatric patients are at a high risk for cardiac complications, particularly arrhythmias, following large pulmonary resections. Preoperative exercise capacity is the best predictor of post-thoracotomy outcome in the elderly.
- In the assessment of patients with malignancies, the "four M's" associated with cancer must be considered: mass effects, metabolic effects, metastases, and medications.
- Perioperative interventions which have been shown to decrease the incidence of respiratory complications in high-risk patients undergoing thoracic surgery include: cessation of smoking, physiotherapy, and thoracic epidural analgesia.

Introduction

Thoracic anesthesia encompasses a wide variety of diagnostic and therapeutic procedures involving the lungs, airways, and other intrathoracic structures. As the patient population

presenting for noncardiac thoracic surgery has changed, so have the anesthetic techniques required to manage these patients. Thoracic surgery at the beginning of the last century was primarily for infectious indications (lung abscess, bronchiectasis, empyema, etc.). Although these cases still present for surgery in the post-antibiotic era, now the commonest indications are related to malignancies (pulmonary, esophageal and mediastinal). In addition, the last two decades has seen the beginnings of surgical therapy for end-stage lung diseases with procedures such as lung transplantation and lung-volume reduction.

Recent advances in anesthetic management, surgical techniques, and perioperative care have expanded the envelope of patients now considered to be "operable" [1]. This chapter will focus primarily on preanesthetic assessment for pulmonary resection surgery in cancer patients. However the basic principles described apply to diagnostic procedures, other types of nonmalignant pulmonary resections and to other chest surgery. The major difference is that in patients with malignancy the risk/benefit ratio of canceling or delaying surgery pending other investigation/therapy is always complicated by the risk of further spread of cancer during any extended interval prior to resection. Cancer surgery is never completely "elective" surgery.

A patient with a "resectable" lung cancer has a disease that is still local or local-regional in scope and can be encompassed in a plausible surgical procedure. An "operable" patient is someone who can tolerate the proposed resection with acceptable risk. Anesthesiologists are not gate-keepers. Normally, it is not the anesthesiologist's function to assess these patients to decide who is or is not an operative candidate. In the majority of situations, the anesthesiologist will be seeing the patient at the end of a referral chain from Chest or Family Physician to Surgeon. At each stage, there should have been a discussion of the risks and benefits of operation. It is the anesthesiologist's responsibility to use the preoperative assessment to identify those patients at elevated risk and then to use that risk assessment to stratify perioperative management and focus resources on the high-risk patients to improve their outcome (Fig. 2.1). This is the primary function of the preanesthetic assessment. However, there are occasions when the anesthesiologist is asked to contribute his/her opinion whether a specific high-risk patient will tolerate a specific surgical procedure. This may occur preoperatively but also occurs intraoperatively when the surgical findings suggest that a planned procedure, such as a lobectomy, may require a larger resection such as a pneumonectomy. For these reasons it is imperative that the anesthesiologist have a complete preoperative knowledge of the patient's medical status and also an appreciation of the pathophysiology of lung resection surgery. There has been a comparatively small volume of research on the short-term (<6 weeks) outcome of these patients. However, this research area is currently very active and there are several studies which can be used to guide anesthetic management in the perioperative period where it has an influence on outcome.
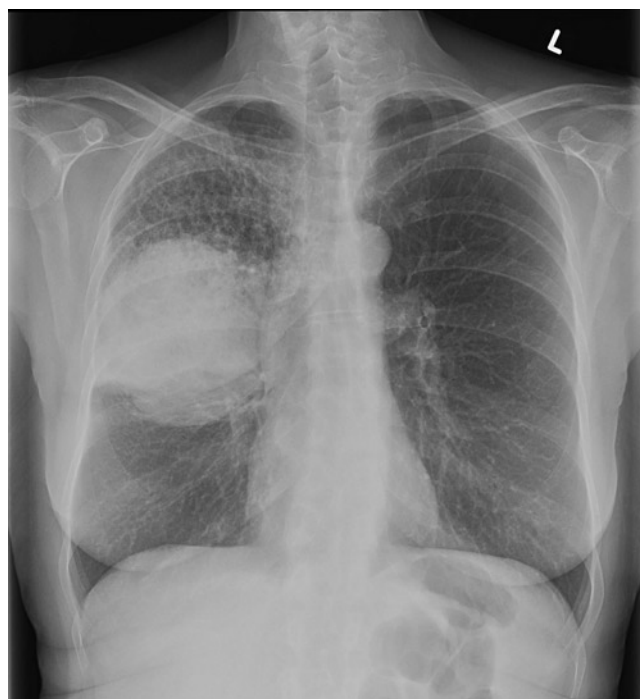

Fig. 2.1. Chest X-ray of a patient with a carcinoma of the right upper lobe scheduled for possible lobectomy or pneumonectomy. The purpose of the preoperative anesthetic assessment of this patient is to stratify the patient's risk and to identify factors which can be managed to improve the perioperative outcome.

An increasing number of thoracic surgeons are now being trained to perform "lung-sparing" resections such as sleeve-lobectomies or segmentectomies and to perform resections with minimally invasive techniques such as video-assisted thoracoscopic surgery (VATS). The postoperative preservation of respiratory function has been shown to be proportional to the amount of functioning lung parenchyma preserved. To assess patients with limited pulmonary function, the anesthesiologist must appreciate these newer surgical options in addition to the conventional open lobectomy or pneumonectomy.

Pre-thoracotomy assessment naturally involves all of the factors of a complete anesthetic assessment: past history, allergies, medications, upper airway, etc. This chapter will concentrate on the additional information, beyond a standard anesthetic assessment, that the anesthesiologist needs to manage a thoracic surgical patient. Practice patterns in anesthesia have evolved such that a patient is commonly assessed initially in an outpatient clinic and often not by the member of the anesthesia staff who will actually administer the anesthesia. The actual contact with the responsible anesthesiologist may be only 10–15 min prior to induction. It is necessary to organize and standardize the approach to preoperative evaluation for these patients into two temporally disjoint phases: the initial (clinic) assessment and the final (day-of-admission) assessment. There are elements vital to each assessment which will be described.

Assessment of Respiratory Function

The major cause of perioperative morbidity and mortality in the thoracic surgical population is respiratory complications. Major respiratory complications such as: atelectasis, pneumonia, and respiratory failure occur in 15–20% of patients and account for the majority of the expected 3–4% mortality [2]. Cardiac complications such as: arrhythmia, ischemia, etc. occur in 10–15% of the thoracic population. Postoperative factors associated with a prolonged length of stay (>14 days) after lobectomy are listed in Table 2.1 [3]. The primary focus for the anesthesiologist is to assess the risk of postoperative pulmonary complications.

The best assessment of respiratory function comes from a detailed history of the patient's quality of life. All pulmonary resection patients should have baseline simple spirometry preoperatively to measure forced expiratory volume in 1 s (FEV1) and forced vital capacity (FVC) (Fig. 2.2) [4]. Simple portable spirometers are available that can be used easily in the clinic or at the bedside to make these measurements (Fig. 2.3). Objective measures of pulmonary function are required to guide anesthetic management and to have this information in a format that can be easily transmitted between members of the healthcare team. Much effort has been spent to try and find a single test of respiratory function that has sufficient sensitivity and specificity to predict outcome for all pulmonary resection patients. It is now clear that no single test will ever accomplish this. It is useful to assess each patient's respiratory function in three related but largely independent areas such as: respiratory mechanics, pulmonary parenchymal function, and cardio-respiratory interaction. These can be remembered as the basic functional units of extracellular respiration, which are to get atmospheric oxygen: (1) into the alveoli, (2) into the blood, and (3) to the tissues (the process is reversed for carbon dioxide removal).
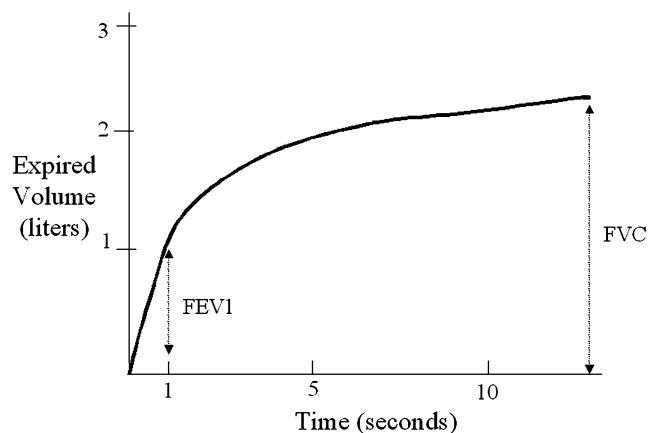

Fig. 2.2. Simple spirometry should be performed in all pulmonary resection patients to assess the forced expiratory volume in 1 s (FEV1) which can then be corrected for the patient's age, sex, and height to give a percentage of the normal predicted value (FEV1%).

Fig. 2.3. An example of a portable handheld spirometer which can be easily used in the preoperative assessment clinic or at the bedside to measure forced expiratory flow volumes.

Table 2.1. Post-lobectomy complications and hospital length of stay (LOS).

	All patients	Length of stay <14 days	Length of stay >14 days	Significant for LOS p value
n	4,979	4,628 (93%)	351 (7%)	
Pneumonia	4%	3%	28%	<0.0001
Atelectasis	4%	2%	21%	<0.0001
ARDS	1%	0.5%	11%	<0.0001
Myocardial infarction	0.4%	0.2%	3%	<0.0001
Ileus	1%	0.6%	18%	<0.0001
Renal failure	1.4%	0.9%	9%	<0.0001
Pulmonary embolus	0.3	0.3%	2%	0.02
Atrial arrhythmias	12%	11%	27%	0.07
Air leak >5 days	10%	8%	36%	<0.0001

Based on data from the Society of Thoracic Surgeons Database, 2002–2006, Wright et al. [3]

Lung Mechanical Function, Spirometry

Many tests of respiratory mechanics and volumes show correlation with post-thoracotomy outcome: FEV1, FVC, maximal voluntary ventilation (MVV), and residual volume/total lung capacity ratio (RV/TLC). For preoperative assessment these values should always be expressed as a percent of predicted volumes corrected for age, sex, and height (e.g., FEV1%). Of these, the most valid single test for post-thoracotomy

respiratory complications is the predicted postoperative FEV1 (ppoFEV1%) [5] which is calculated as:

$$ppoFEV1\% = preoperative\ FEV1\% \times$$
$$(1 - \%\ functional\ lung\ tissue\ removed\,/\,100)$$

One method of estimating the percent of functional lung tissue is based on a calculation of the number of functioning subsegments of the lung removed (Fig. 2.4). Nakahara et al. [6] 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% (although not all patients in this subgroup developed respiratory complications) and 10/10 patients with ppoFEV1 <30% required postoperative mechanical ventilatory support. These key threshold ppoFEV1 values: 40 and 30% are extremely useful to remember when managing these patients. The schema of Fig. 2.4 may be overly complicated and it can be useful to just simply consider the right upper and middle lobes combined as being approximately equivalent to each of the other three lobes with the right lung 10% larger than the left. These data of Nakahara are from work done in the 1980s and subsequent advances, particularly the use of epidural analgesia has decreased the incidence of complications in the ultrahigh-risk (ppo <30%) group [7]. However, a ppoFEV1 value of <40% remains useful as a reference point for the anesthesiologist to identify the patient at increased risk. The ppoFEV1 is the most significant independent predictor of complications among a variety of historical, physical, and laboratory tests for these patients. The usefulness of the ppoFEV1% has been recently revalidated in a study by

Win et al. [8]. However, these authors suggest that with an aging surgical population a threshold value of ppoFEV1 45% is more appropriate.

Patients with ppoFEV1 values <40% can be operated on with acceptable morbidity and mortality in certain circumstances. Linden et al. [9], reported on a series of 100 patients with ppoFEV1 <35% who had lung resections for cancer with only one mortality and with a 36% complication rate. Whenever possible, these patients had VATS procedures and thoracic epidural analgesia (TEA). The authors propose an absolute lower limit of acceptability for resection as a ppoFEV1 <20%. It should be appreciated that this report is from a center with a very high volume of thoracic surgery and surgical outcomes for lung cancer are correlated to the volume of surgery. High-volume hospitals had complication and mortality rates (20 and 3% respectively) that were approximately one-half of low-volume hospitals (44 and 6%) [10].

The actual measured postoperative FEV1 will not be the same as the ppoFEV1 for several reasons. First, it is impossible to predict the actual intraoperative surgical trauma to the chest wall and residual lung segments. Most patients will have FEV1 values immediately postoperatively that are less than the ppoFEV1 and these will improve over a period of 6 months [11]. Second, emphysematous patients will tend to have a lung-volume reduction effect on the residual lobe(s) and may exceed their ppoFEV1 if a hyperinflated lobe is resected. The actual postoperative FEV1 has been shown to be a better predictor of outcome than the ppoFEV1 however, the actual postoperative FEV1 is not available preoperatively.

Absolute predicted postoperative values for FEV1 were used in the past to assess patients. Absolute limits for ppoFEV1 such as 0.8 L were suggested as the lower limits of acceptability for resection. However, absolute values for pulmonary function tests do not take into consideration the wide variation in the size of patients who present for thoracic surgery. An absolute FEV1 result of 1 L for an 80-year-old male 5 ft. (152 cm) height is normal (100% of predicted) but an FEV1 of 1 L for a 6 ft. (183 cm) 50-year-old male is severely abnormal (24% predicted). It is important always to consider patients' spirometry results as a percentage of their predicted normal.

Patients at increased risk of respiratory complications (ppoFEV1 <40%) should have complete pulmonary function testing in a pulmonary function laboratory which will include an assessment of lung volumes and airway resistance (Fig. 2.5). These are more sensitive than a simple examination of the FEV1 to FVC ratio to distinguish between obstructive versus restrictive lung pathologies and will confirm the clinical diagnosis of the underlying lung disease. Also, this permits for optimization of intraoperative management during both two-lung and one-lung ventilation by individualization of settings for mechanical ventilation depending on the lung pathology [12]. There are two basic methods of measurement of lung volumes: insoluble gas dilution and plethysmography (Fig. 2.6). Plethysmography is the common method used in pulmonary function laboratories to measure lung volumes
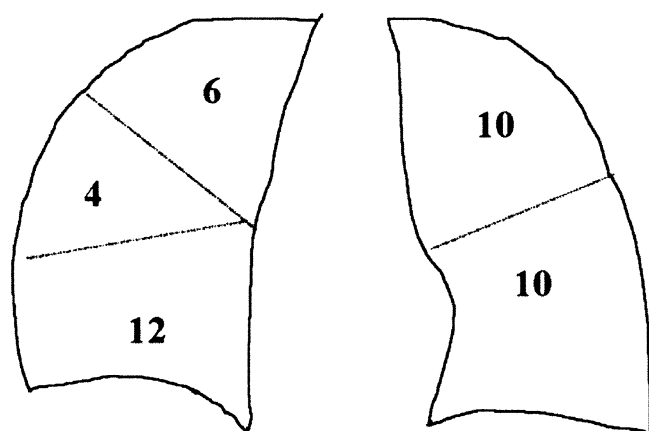

FIG. 2.4. The number of subsegments of each lobe are used to calculate the predicted postoperative (ppo) pulmonary function. There are 6, 4, and 12 subsegments in the right upper, middle, and lower lobes. There are 10 subsegments in both the left upper and lower lobes, for a total of 42 subsegments. Following removal of a functioning right lower lobe, a patient would be expected to lose 12/42 (29%) of their respiratory reserve. If the patient has a preoperative FEV1 (or DLCO) 70% of predicted, the patient would be expected to have a ppoFEV1 = 70% × (1 − 29/100) = 50%.

Fig. 2.5. Complete pulmonary function testing will provide data on lung volumes and capacities to differentiate obstructive from restrictive diseases. *FRC functional* residual capacity; *IC* inspiratory capacity; *RV* residual volume; *SVC* slow vital capacity; *ERV* expiratory reserve volume; *TV* tidal volume; *IRV* inspiratory reserve volume; *TLC* total lung capacity. Measuring closing volume and closing capacity requires insoluble gas washout techniques and is not included in routine pulmonary function testing. However, an appreciation of the variable relationship between closing capacity and FRC and the effects of anesthesia on FRC is essential for the anesthesiologist to understand the changes in gas exchange that occur during anesthesia. (Reprinted from Patterson [101], with permission).
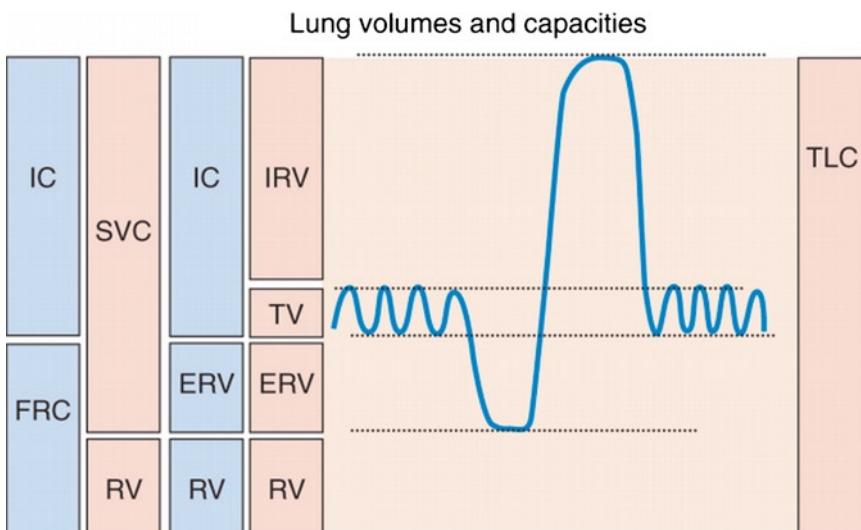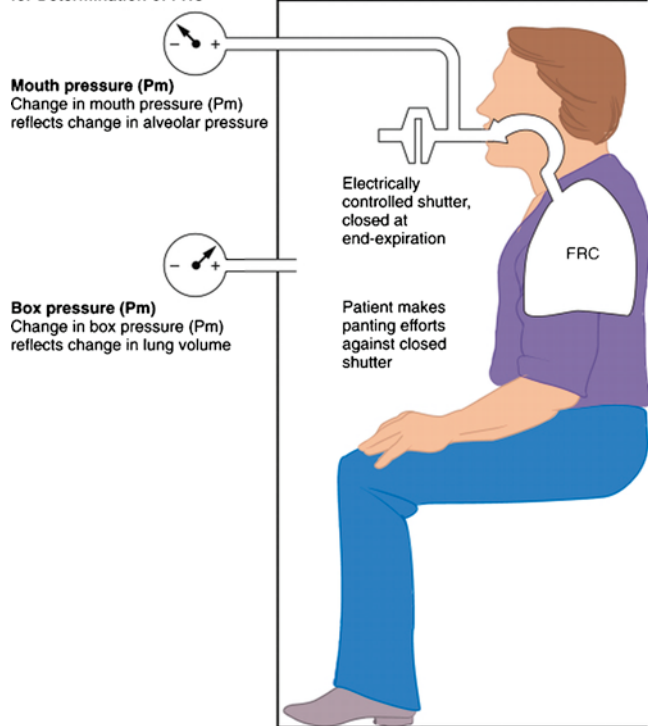
Fig. 2.6. Measurement of lung volumes is commonly performed with whole body plethysmography with the patient seated in an airtight box. Lung volumes can be calculated from changes in the airway and box pressure since the volume of the box is known. (Reprinted from Patterson [101], with permission).

and has largely replaced insoluble gas dilution techniques. The difference (plethysmography-dilution) in measured lung volumes between the two techniques can be used to estimate the volume of bullae in the lung. Previously, maximal breathing capacity was also used to assess patients for pulmonary resection. This simple test was used in the era of pulmonary resection for tuberculosis and has been replaced by modern spirometry.

Pulmonary Parenchymal Function

As important to the process of respiration as the mechanical delivery of air to the distal airways is the subsequent ability of the lung to exchange oxygen and carbon dioxide between the pulmonary vascular bed and the alveoli. Traditionally, arterial blood gas data such as PaO_2 <60 mmHg or $PaCO_2$ >45 mmHg have been used as cut-off values for pulmonary resection. Cancer resections have now been successfully performed, or even combined with volume reduction, in patients who do not meet these criteria, although they remain useful as warning indicators of increased risk. The most useful test of the gas exchange capacity of the lung is the diffusing capacity for carbon monoxide (DLCO). The DLCO is a reflection of the total functioning surface area of alveolar-capillary interface. This simple noninvasive test which is included with spirometry and plethysmography by most pulmonary function laboratories is a useful predictor of perioperative morbidity and mortality [13]. The corrected DLCO can be used to calculate a post-resection (ppo) value using the same calculation as for the FEV1 (Fig. 2.7). A ppoDLCO <40% predicted correlates with both increased respiratory and cardiac complications and is, to a large degree, independent of the FEV1. The National Emphysema Treatment Trial has shown that patients with a preoperative FEV_1 or DLCO <20% had an unacceptably high perioperative mortality rate [14]. These can be considered as the absolute minimal values compatible with successful outcome. Complete pulmonary function testing, as performed in a pulmonary function laboratory generates a report with often >15 test results (Fig. 2.8); of these results the two most valid tests for the anesthesiologist to use to assess perioperative risk are the percent predicted FEV1 and DLCO.

Cardiopulmonary Interaction

The final and perhaps most important assessment of respiratory function is an assessment of the cardiopulmonary interaction. Formal laboratory exercise testing is currently the "gold standard" for assessment of cardiopulmonary function [15] and the maximal oxygen consumption (VO_2 max) is the most useful predictor of post-thoracotomy outcome. The test is performed on a bicycle ergometer or treadmill. Resting measurements are made for 3–5 min. Three minutes of unloaded
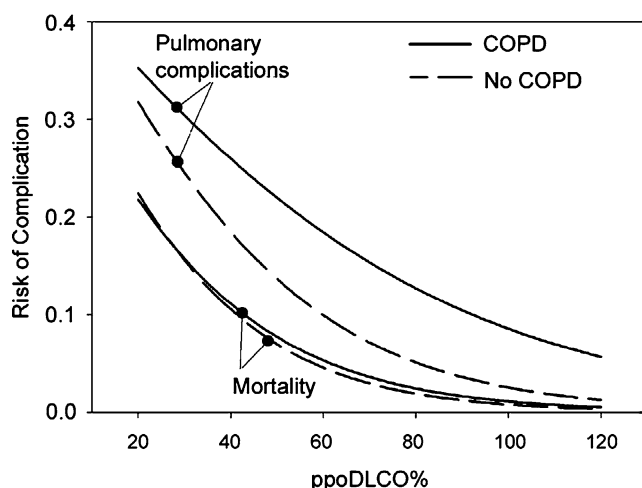

FIG. 2.7. Regression lines for the risk of pulmonary (*upper lines*) or fatal (*lower lines*) complications versus predicted postoperative diffusing capacity for carbon monoxide (ppoDLCO%) following lung resection in patients with (*solid lines*) and without (*dashed lines*) chronic obstructive pulmonary disease (COPD). Note that both morbidity and mortality increase sharply when the ppoDLCO falls below a threshold value of 40% (Reprinted from Ferguson and Vigneswaran [13], with permission).

cycling is performed as a warm-up period. The workload is incremented at a rate designed to allow reaching maximum work capacity in 8–12 min. The test continues to a point of symptom limitation (e.g., severe dyspnea) or discontinuation by medical staff (e.g., significant ECG abnormalities) or achievement of maximum predicted heart rate. Estimated VO_2 max is based on the patient's age, sex, and height. For sedentary males it is estimated as VO_2 max (mL/min) = (height (cm) − age (years)) × 20, i.e., for a 50-year-old male, height 170 cm, weight 70 kg, the predicted VO_2 max = ((170 − 50) × 20)/70 = 34 mL/kg/min. For a sedentary woman, age 50, 160 cm, 60 kg, estimated VO_2 max = ((160 − 50) × 14)/60 = 26 mL/kg/min (for comparison: the highest VO_2 max recorded is 85 mL/kg/min by the American cyclist Lance Armstrong in 2005 [16]).

The risk of morbidity and mortality is unacceptably high if the preoperative VO_2 max is <15 mL/kg/min [17]. Few patients with a VO_2 max >20 mL/kg/min have respiratory complications. Exercise testing is particularly useful to differentiate between patients who have poor exercise tolerance due to respiratory versus cardiac etiologies (Fig. 2.9). More recently, the anaerobic threshold measured during exercise testing has been suggested as a predictor of postoperative complications [18]. The anaerobic threshold is the exercise level at which lactate begins to accumulate in the blood and anaerobic metabolism begins. The anaerobic threshold is approximately 55% of VO_2 max in untrained individuals but rises to >80% in trained athletes. The anaerobic threshold can be documented by repeated blood lactate analysis during exercise or by a threshold increase in CO_2 production above the initial respiratory quotient (ratio of CO_2 production to O_2 consumption, commonly approximately 0.8). A threshold value for AT of <11 mL/kg/min has been suggested as a marker for increased risk but this has not been well validated [19].

FIG. 2.8. A copy of the Pulmonary Function Laboratory test report for a patient with severe emphysema. Of the 15 different results in this report the two results highlighted, the percent predicted FEV1 and DLCO, are the most useful tests for the anesthesiologist assessing a patient for possible pulmonary resection. This patient had taken a bronchodilator immediately before the test so the usual post-bronchodilator (Post BD) test was not repeated. *Pred. val.* predicted value corrected for the patient's age, sex, and height. *Obs.* patient's measured result; *VA* the single-breath dilutional estimate of TLC from the DLCO.

Test Performed		Pred.val.	Pre BD Obs.	Pre BD %Pred.val.	Post BD Obs.	Post BD %Pred.val.	
Total Lung Capacity	(TLC), L	4.2	7.4	175	----	----	
Functional Residual Capacity	(FRC), L	2.6	6.2	239	----	----	
Inspiratory Capacity	(IC), L	1.6	1.2	74	----	----	
Vital Capacity	(VC), L	2.4	1.5	63	----	----	
Residual Volume	(RV), L	1.8	5.9	322	----	----	
RV/TLC Ratio	(RV/TLC), %	43	80	184	----	----	
Forced Vital Capacity	(FVC), L	2.4	1.5	62	----	----	
Forced Exp. Volume in 1 sec.	(FEV1), L	1.7	0.6	34	----	----	
FEV1/FVC Ratio	(FEV1/FVC), %	71	39	55	----	----	
Max. Exp. Flow @ 50% VC	(V50), L/sec	2.4	0.17	7	----	----	
Max. Exp. Flow @ 25% VC	(V25), L/sec	1.2	0.07	6	----	----	
Mid Expiratory Flow 25-75%	(FEF 25-75), L/sec	2.0	0.2	12	----	----	
Airway Resistance	(Raw), cmH2O/L/sec	0.7	2.5	387			
Max. Voluntary Ventilation	(MVV), L/min	50	----	----			
Lung Diffusion Capacity	(DLco), ml/min/mmHg	12.6	7.5	59			Normal limits: 75-125%
VA @ BTPS from DLco	(VA@BTPS), L	4.2	2.5	60			

NOTE: %Pred. values are BOLD when outside of normal limits. (All except Raw & DLco values.)
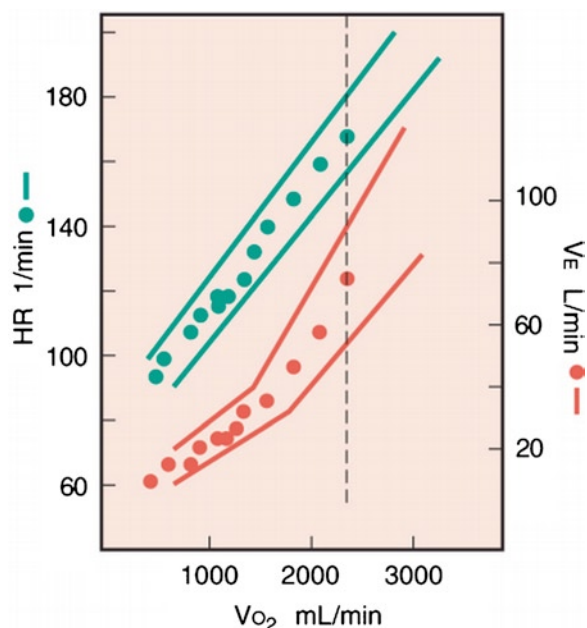
FIG. 2.9. A normal cardiopulmonary exercise test result. As the patient exercises, the increase in oxygen consumption (*horizontal axis*) is plotted against the heart rate (*green dots, left vertical axis*) and the minute ventilation (*V*$_E$, *orange dots, right vertical axis*). Normal responses for heart rate and ventilation lie within the *green and orange lines*. The *vertical dashed line* is the predicted upper limit of normal based on age. Patients with primarily cardiac causes for exercise limitation will show an excessive increase in heart rate with exercise. Patients with primarily respiratory limitation will show a disproportionate increase in ventilation. Patients with pulmonary vascular disease will have both abnormal heart rate and ventilation responses. (Reprinted from Patterson [101], with permission).

Complete laboratory exercise testing is time-consuming and thus expensive. It is generally not cost-effective to use as a routine part of the preoperative assessment for all pulmonary resection patients. Several alternatives have been demonstrated to be valid surrogate tests for pre-thoracotomy assessment. The distance that a patient can walk during a 6-min test (6MWT) shows an excellent correlation with VO$_2$ max and requires little or no laboratory equipment (Fig. 2.10). For patients with moderate or severe COPD, the 6MWT distance can be used to estimate the VO$_2$ max by dividing by a figure of 30 (i.e., 600 m distance is equivalent to a VO$_2$ max of $600/30 = 20$ mL/kg/min) [20]. Some centers also assess the fall in oximetry (SpO$_2$) during exercise. Patients with a decrease of SpO$_2$ >4% during exercise (stair climbing 2 or 3 flights or equivalent) [21] are at increased risk of morbidity and mortality. Post-resection exercise capacity can also be estimated based on the amount of functioning lung tissue removed (see Fig. 2.4). An estimated ppoVO$_2$ max <10 mL/kg/min can be considered a contraindication to pulmonary resection. In a small series [22] mortality was 100% (3/3) patients with a ppoVO$_2$ max <10 mL/kg/min.

The traditional, and still useful, test in ambulatory patients is stair climbing [23]. Stair climbing is done at the patient's own pace but without stopping and is usually documented as a certain number of flights. There is no exact definition for a "flight" but 20 steps at 6 in/step is a frequent value. The ability to climb five flights correlates with a VO$_2$ max >20 mL/kg/min and climbing two flights corresponds to a maximal oxygen consumption (VO$_2$ max) of 12 mL/kg/min. A patient unable to climb two flights is extremely at high-risk [24].

After pulmonary resection there is a degree of right ventricular dysfunction that seems to be in proportion to the amount
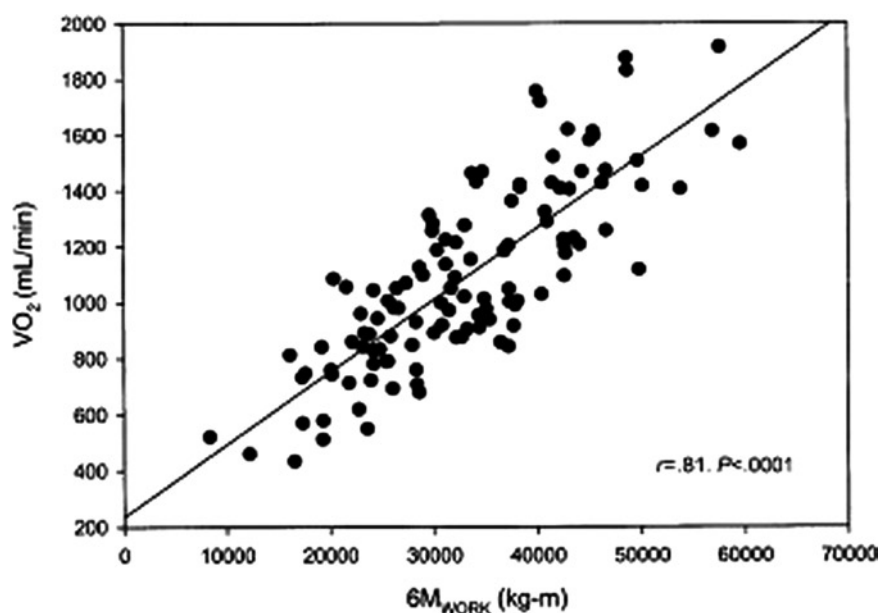
FIG. 2.10. The maximal oxygen consumption VO$_2$ (mL/min) shows a strong correlation with work (6M_{work}) for patients with moderate or severe COPD during a 6 min. walk test. Work = distance traveled × weight (kg × m). A 70 kg patient who walks 450 m does 31,500 kg/m of work which correlates with an estimated VO$_2$ max of 1,100 mL/min (or 16 mL/kg/min). A simple estimate of the VO$_2$ max can be made by dividing the 6-min walk distance by 30 (i.e., 450 m/30 = 15 mL/kg/min). (Reprinted from Carter et al. [20], with permission.).

of functioning pulmonary vascular bed removed. The exact etiology and duration of this dysfunction remains unknown. Clinical evidence of this hemodynamic problem is minimal when the patient is at rest but is dramatic when the patient exercises leading to elevation of pulmonary vascular pressures, limitation of cardiac output, and absence of the normal decrease in pulmonary vascular resistance usually seen with exertion [25].

Regional Lung Function

Prediction of post-resection pulmonary function can be further refined by assessment of the preoperative contribution of the lung or lobe to be resected by imaging of regional lung function [26]. If the lung region to be resected is nonfunctioning or minimally functioning, the prediction of postoperative function can be modified accordingly [27]. This is particularly useful in pneumonectomy patients and regional lung function imaging should be ordered for any potential pneumonectomy patient who has a preoperative FEV1 and/or DLCO <80% (i.e., ppo values <40% predicted). Regional lung function imaging can be performed by three techniques: radionuclide ventilation/perfusion (V/Q) lung scanning, pulmonary quantitative
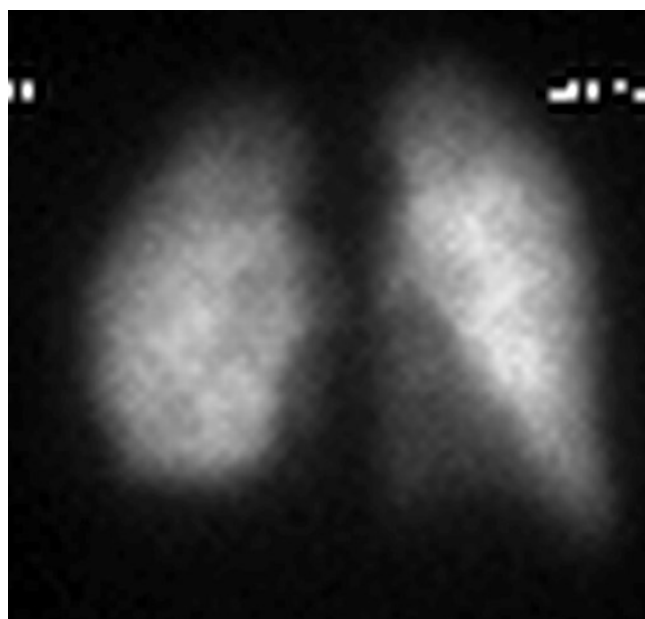

Fig. 2.11. Perfusion scan of a patient with a right lung tumor being assessed for possible pneumonectomy. The perfusion of the right lung was 37% and the left 63%. Preoperative FEV1=74% predicted and DLCO=70%. Based on the anatomic number of subsegments to be excised the predicted postoperative (ppo) FEV1 = $74 \times 22/42 = 39\%$ and the ppoDLCO = $70 \times 22/42 = 37\%$. Using the regional lung imaging to predict postoperative values, the ppoFEV1 = $74 \times 0.63 = 47\%$ and the ppoDLCO = $70 \times 0.63 = 44\%$, which are above the threshold values for increased perioperative risk.

CT-scanning, or three-dimensional dynamic perfusion magnetic resonance imaging (MRI).

Ventilation/perfusion lung scanning is the gold standard. Regional ventilation is assessed by scanning after inhalation of a radiolabeled insoluble gas (commonly xenon-133). Regional lung perfusion is assessed by scanning after intravenous injection of radiolabeled particles that are trapped in the pulmonary capillaries (commonly: technetium-99 m macroaggregated albumin) (Fig. 2.11). Actual postoperative lung function has shown a high correlation with predicted values based on preoperative V/Q scanning for FEV1 ($r=0.92$), DLCO ($r=0.90$) and VO$_2$ max ($r=0.85$). Prediction is more accurate for post-pneumonectomy versus post-lobectomy values. If there is a discrepancy between the ventilation and perfusion scan results, it is preferable to use the result which attributes the larger proportion of ventilation or perfusion to the diseased lung to estimate the post-resection pulmonary function (i.e., worst case scenario).

Quantitative CT lung scans can be used to estimate post-resection values [28]. Each CT slice is quantified for areas of normal parenchyma, emphysema, and atelectasis. The contribution of each lobe or lung can be estimated based on the volume of normal parenchyma and then used to predict postoperative lung function. Quantitative CT primarily focuses on areas of ventilation and is more accurate for post-lobectomy versus post-pneumonectomy values. Predicted postoperative values for FEV1 and DLCO were comparable to those derived from V/Q scans but less accurate for VO$_2$ max. This is a newer technique than V/Q scanning and requires specific imaging expertise. However, due to the routine preoperative CT scanning of most pulmonary resection patients it may become more available.

Dynamic MRI uses estimates of regional pulmonary blood volume to assess regional blood flow [29]. This is the newest of the three techniques and is not widely used. It has shown a high level of correlation between predicted and actual values for postoperative FEV1. It has not been assessed for predicting DLCO or VO$_2$ max.

Split-Lung Function and Other Lung Function Tests

A variety of methods have been described to try and simulate the postoperative respiratory situation by preoperative unilateral exclusion of a lung or lobe with an double-lumen tube or bronchial blocker and/or by pulmonary artery balloon occlusion of a lung or lobe artery [30]. These tests have not shown sufficient predictive validity for universal adoption in lung resection patients. Lewis et al. [31] have shown that in a group of patients with COPD (ppoFEV1 <40%) undergoing pneumonectomy, there were no significant changes in the pulmonary vascular pressures intraoperatively when the pulmonary artery was clamped but the right ventricular ejection fraction (RVEF) and cardiac output decreased. Echocardiography

may offer more useful information than vascular pressure monitoring in these patients [32]. Split-lung function studies have been replaced in most centers by a combined assessment involving, spirometry, DLCO, exercise tolerance, and imaging of regional lung function.

Combination of Tests

No single test of respiratory function has shown adequate validity as a sole preoperative assessment. Prior to surgery, an estimate of respiratory function in all three areas: lung mechanics,

The "3-legged" Stool of Pre-thoracotomy Respiratory Assessment

Respiratory Mechanics	Cardio-Pulmon. Reserve	Lung Parench. Function
FEV 1* (ppo > 40%)	VO2 max.* (>15ml/kg/min)	DLCO* (ppo > 40%)
MVV, RV/TLC, FVC	Stair climb>2flight, 6 min walk, Exercise SpO2<4%	PaO2 > 60 PaCO2 <45

(* most valid test)

FIG. 2.12. The "three-legged stool" of pre-thoracotomy respiratory assessment involves evaluation of lung mechanical function, pulmonary parenchymal function, and cardiopulmonary interaction for each patient. The most valid test in each area is denoted by *asterisk*. The threshold values below which risk increases are in parentheses. *ppo* predicted postoperative value as a percent of the patient's predicted normal value; *FEV 1* forced expiratory volume in 1 s; *MVV* maximal voluntary ventilation; *RV/TLC* residual volume/total lung capacity ratio; *FVC* forced vital capacity; *VO$_2$ max.* maximal oxygen consumption; *SpO$_2$* pulse oximetry; *DLCO* lung diffusing capacity for carbon monoxide. PaO$_2$ and PaCO$_2$ values in mmHg.

parenchymal function, and cardiopulmonary interaction should be made for each patient. These three aspects of pulmonary function form the "three-legged stool" which is the foundation for pre-thoracotomy respiratory assessment (Fig. 2.12). These data can then be used to plan intra- and postoperative management (Fig. 2.13) and also to alter these plans when intraoperative surgical factors necessitate that a resection becomes more extensive than foreseen. 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"). Patients with a ppoFEV1 <40% will usually comprise about one fourth of an average thoracic surgical population. If the ppoFEV1 is >30% and exercise tolerance and lung parenchymal function exceed the increased risk thresholds then extubation in the operating room should be possible depending on the status of associated medical conditions. 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 cardio-respiratory and parenchymal function can be considered for early extubation if thoracic epidural analgesia (TEA) is used, or if the resection is performed with VATS. Otherwise, these patients should have a postoperative staged weaning from mechanical ventilation. In the borderline group (ppoFEV1 30–40%) the presence of several associated factors and diseases which should be documented during the preoperative assessment will enter into the considerations for postoperative management (see below).

Jordan and Evans have outlined a protocol for planned elective admission of pulmonary resection patients to the intensive care unit postoperatively [33]. In their scheme, patients age >70 years or with fibrotic lung disease or with positive cardiovascular risk assessment or with an elevated ASA score or poor lung function (preoperative FEV <47%) would be admitted to ICU. Others would go to the recovery unit then a monitored ward bed.
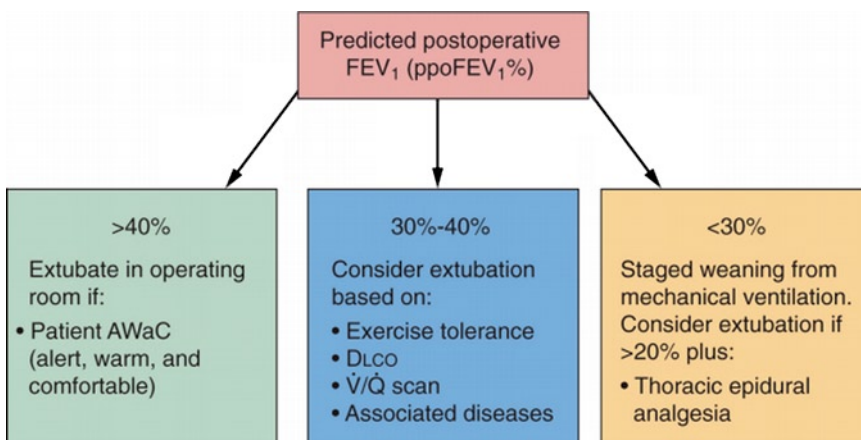
FIG. 2.13. Anesthetic management guided by preoperative assessment and the amount of functioning lung tissue removed during surgery. *V/Q* scan = ventilation/perfusion lung scan or other regional lung imaging.

Predicted postoperative FEV₁ (ppoFEV₁%)

>40%	30%-40%	<30%
Extubate in operating room if: • Patient AWaC (alert, warm, and comfortable)	Consider extubation based on: • Exercise tolerance • DLCO • V̇/Q̇ scan • Associated diseases	Staged weaning from mechanical ventilation. Consider extubation if >20% plus: • Thoracic epidural analgesia

Concomitant Medical Conditions

Cardiac Disease

Cardiac complications are the second most common cause of perioperative morbidity and mortality in the thoracic surgical population. The commonest major cardiac complications are myocardial ischemia/infarction and arrhythmias.

Ischemia

Since the majority of pulmonary resection patients have a smoking history, they already have one risk factor for coronary artery disease (other factors include male sex, heredity, diabetes, obesity, high blood pressure and elevated cholesterol). Elective pulmonary resection surgery is regarded as an "intermediate risk" procedure in terms of perioperative cardiac ischemia [34]. The overall documented incidence of post-thoracotomy ischemia is 5% and peaks on day 2–3 postoperatively (Fig. 2.14) [35]. Beyond the standard history, physical and electrocardiogram, further routine testing for cardiac disease does not appear to be cost-effective for all prethoracotomy patients.

For patients with a history suggesting coronary artery disease the preoperative pathways for cardiac investigation prior to pulmonary resection are becoming increasingly complex (Fig. 2.15). The American College of Cardiology and American Heart association have developed algorithms for cardiac investigations in these patients. Patients with intermediate clinical predictors of increased cardiac risk (stable angina, diabetes, etc.) who have adequate functional capacity do not need further cardiac investigation prior to pulmonary surgery. Patients with these intermediate predictors and poor functional capacity should have noninvasive testing of myocardial perfusion at rest and during stress. The estimate of myocardial perfusion can be performed by nuclear medicine (technetium sestamibi or thallium injection) or transthoracic echocardiography at rest and during stress. The stress can be either with exercise or by injection of a coronary vasodilator (dipyridamole) or an inotrope (dobutamine). Based on the results from

studies in vascular surgery [36], it can be extrapolated that patients with normal perfusion or who have areas of reversibility in <20% of myocardial segments can proceed to surgery without further cardiac investigation. For patients who have a result on myocardial perfusion testing that is inconclusive, CT coronary angiography is a noninvasive option (Fig. 2.16) [37]. CT angiography has a high sensitivity for coronary stenosis but is less specific. Thus, a patient with a normal CT coronary angiogram can proceed to surgery. However, an abnormal CT coronary angiogram will then require further investigation which will probably necessitate cardiac catheterization.

For patients who have major reversibility on a myocardial perfusion test, the diagnostic and therapeutic pathway is less clear. The standard recommendation is to proceed to cardiac catheterization. However, in individual circumstances it could be an option to proceed with a minor diagnostic procedure (such as an endobronchial ultrasound or mediastinoscopy) first if there is a reasonable possibility that the patient may not have a resectable cancer. Or, it may be considered to proceed with the pulmonary resection with very tight perioperative hemodynamic control since it is not clear that coronary intervention improves perioperative outcome in patients who are not clear candidates for intervention outside the perioperative period [38]. The wisdom of elective perioperative β-blockade in these patients is debatable [39]. β-blockade may decrease the perioperative cardiac risk but increase the risk of stroke. Patients who have an indication for β-blockade apart from the perioperative context should be started and continued on these medications perioperatively, appreciating that many thoracic surgical patients have reactive airways disease that may be exacerbated by β-blockade. The use of β-blockers otherwise should be guided by specific hemodynamic indications.

For patients who require coronary catheterization, the results may necessitate angioplasty with or without stenting or coronary artery bypass surgery before or at the same time as pulmonary surgery (see Chap. 32). It is very important that the interventional cardiologist be made aware of the patient's diagnosis and the perioperative context prior to angiography. If bare metal coronary stents are placed, the patent will require dual antiplatelet therapy with a thienopyridine and aspirin for
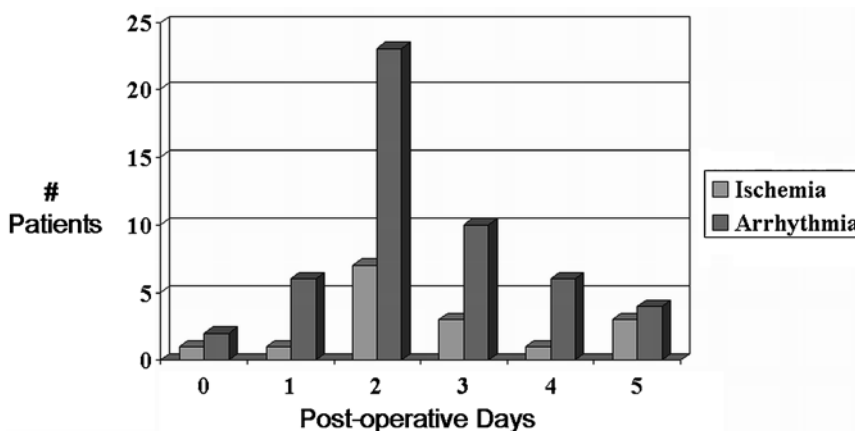

FIG. 2.14. Number (*hash*) of patients (total *n* >300) who developed myocardial ischemia or arrhythmias postoperatively following pulmonary resections for lung cancer. Both the incidence of arrhythmia (primarily atrial fibrillation) and ischemia peak on postoperative day 2. (Based on data from von Knorring et al. [35]).

FIG. 2.15. An algorithm for cardiac risk assessment prior to noncardiac thoracic surgery based on Fleisher et al. [34] (see text). *OR* operating room (i.e., proceed with surgery without further cardiac investigation). *Cath.* coronary catheterization. Once a patient is found to have an abnormal result on noninvasive testing of myocardial perfusion, choosing the optimal pathway becomes complicated and requires a combined consultation with the surgeon, cardiologist, and patient.

Cardiac Risk Assessment for Pulmonary Resection
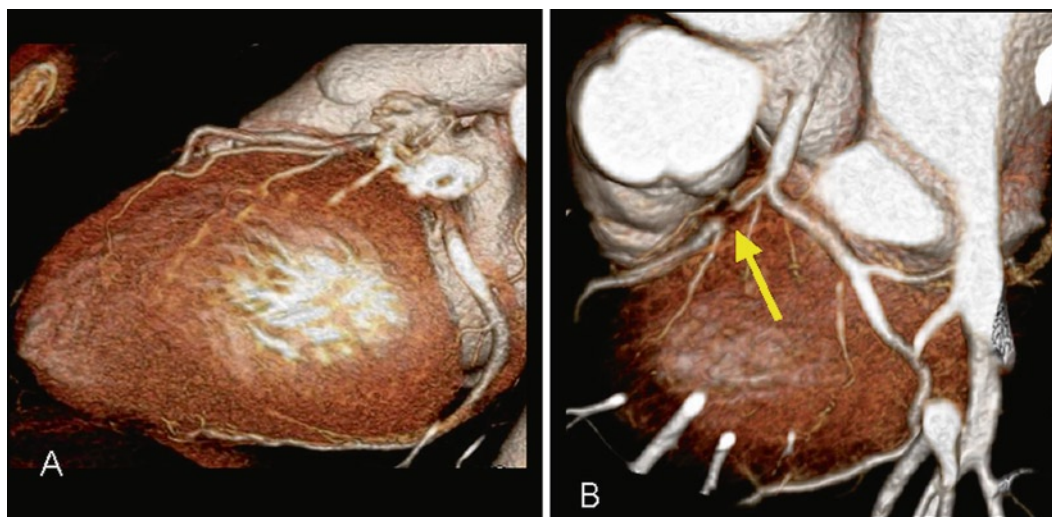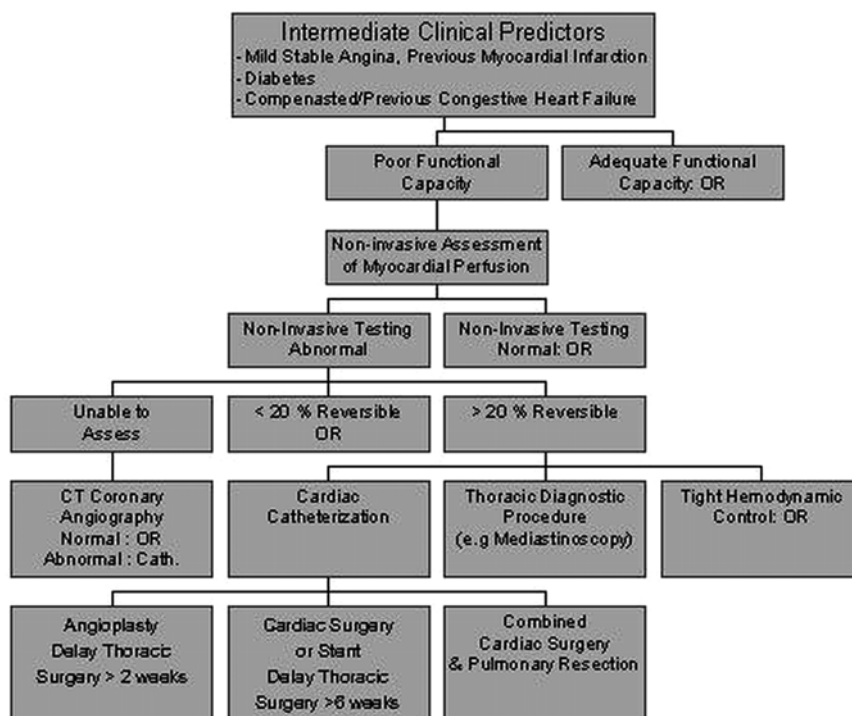

FIG. 2.16. *CT* Coronary angiograms of two different patients. (**a**) A lateral view of the left ventricle showing a normal left anterior descending (seen superior to the left ventricle in this view) and circumflex (seen to the right of and then below the left ventricle) coronary arteries. Patients with normal coronary arteries on CT angiography do not need further investigation for myocardial ischemia. (**b**) A view of the left ventricle from above in a patient with a lesion in the left anterior descending artery (*arrow*) just distal to the bifurcation of the left main coronary artery. This patient will require invasive coronary catheterization to determine the precise severity of the lesion and possibly for percutaneous intervention such as stenting. (Images courtesy of Dr. Elsie Nguyen, Department of Medical Imaging, Toronto General Hospital).

4–6 weeks before the thienopyridine can be stopped (and the aspirin continued) preoperatively. In some cases, this is an acceptable delay before a major pulmonary resection or other thoracic surgery. However, if drug-eluting stents are placed the risk of stent stenosis, which is often fatal, is

unacceptable if dual antiplatelet therapy is discontinued in the first 12 months [40]. This is generally not an acceptable delay for cancer surgery.

Timing of lung resection surgery following a myocardial infarction is always a difficult decision. Limiting the delay

to 4–6 weeks in a medically stable and fully investigated and optimized patient seems acceptable after myocardial infarction. The anesthesiologist needs to appreciate that the preoperative assessment and the therapeutic options for patients with significant coronary artery disease presenting for lung surgery is becoming very complicated and no single algorithm can be applied given the complexities of each individual case and the local availability of diagnostic equipment and personnel. Each of these patients needs to be managed by a team consultation that includes the thoracic surgeon, the cardiologist, the anesthesiologist, and the patient and family. The management of a patient who is discovered to have an incidental lung lesion during preoperative assessment for coronary artery or cardiac valvular surgery is discussed in Chap. 32.

Arrhythmias

The management of post-thoracotomy arrhythmias is discussed in Chap. 44. Arrhythmias are a common complication of pulmonary resection surgery and the incidence is 30–50% of patients in the first week postoperatively when Holter monitoring is used [41]. Of these arrhythmias, 60–70% are atrial fibrillation. Several factors correlate with an increased incidence of arrhythmias, these include: extent of lung resection (pneumonectomy 60% vs. lobectomy 40% vs. non-resection thoracotomy 30%), intra-pericardial dissection, intraoperative blood loss, and age of the patient. Extrapleural pneumonectomy patients are a particularly high-risk group [42].

Two factors in the early post-thoracotomy period interact to produce atrial arrhythmias.

1. Increased flow resistance through the pulmonary vascular bed due to permanent (lung resection) or transient (atelectasis, hypoxemia) causes, with attendant strain on the right side of the heart.
2. Increased sympathetic stimuli and oxygen requirements, maximal on the second postoperative day as patients begin to mobilize.

In pneumonectomy patients vs. lobectomy patients, followed for 24 h. with RVEF catheters, there was a significant fall of RVEF on the first postoperative day. This was accompanied by an increase in right ventricular size and in pulmonary artery pressures. Pneumonectomy patients did not demonstrate the early postoperative increase in oxygen delivery, oxygen consumption, or cardiac index as seen in lobectomy patients [43]. This suggests that in some pneumonectomy patients the right heart may not be able to increase its output adequately to meet the usual postoperative stress. Transthoracic echocardiographic studies have shown that pneumonectomy patients develop an increase in right ventricular systolic pressure as measured by the tricuspid regurgitation jet (TRJ) on postoperative day 2 but not on day 1. An increase in TRJ velocity has been associated with post-thoracotomy supraventricular tachyarrhythmias [32]. Patients with COPD are more resistant to pharmacologic rate control when they develop post-thoracotomy atrial fibrillation and often require multiple drugs [44].

A wide variety of antiarrhythmics have been tried to decrease the incidence of atrial arrhythmias after lung surgery. The best known of these are digoxin preparations. It has been demonstrated that digoxin does not prevent arrhythmias after pneumonectomy or other intrathoracic procedures. Other agents which have been tried to prevent post-thoracotomy arrhythmias include: β-blockers, verapamil, and amiodarone. All of these agents decrease arrhythmias in thoracic patients. However, they are all associated with side effects that preclude their widespread application in this surgical population. At present, diltiazem is the most useful drug for post-thoracotomy arrhythmia prophylaxis [45]. It seems that atrial arrhythmias are only a symptom of the dysfunctional right heart and preventing the symptom does not solve the underlying problem. In one study [46] patients who subsequently developed atrial tachyarrhythmias could be identified in the early postoperative period by their right ventricular response to the withdrawal of supplemental oxygen. On the first postoperative day, a decrease of FiO_2 from 0.35 to 0.21 caused a significant rise of right ventricular end-diastolic pressure (RVEDP) in the patients who subsequently developed arrhythmias. TEA with local anesthetics has been suggested to decrease the incidence of arrhythmias. This effect is theorized to be due to increasing the myocardial refractory period, decreasing ventricular diastolic pressures, and improving endocardial/epicardial blood flow ratios [47]. However, the evidence for this is limited.

Age

Perioperative management of the geriatric patient for thoracic surgery is discussed in Chap. 25. There is no maximum age that is a cut-off for pulmonary resection surgery. In one series, the operative mortality in a group of patients 80–92 years of age was 3%, a very respectable figure [48]. However, the rate of respiratory complications (40%) was double that expected in a younger population, and the rate of cardiac complications (40%), particularly arrhythmias, was nearly triple that which would be seen in younger patients. In the elderly, thoracotomy should be considered a high-risk procedure for cardiac complications and cardiopulmonary function is the most important part of the preoperative assessment. An algorithm for the cardiac assessment of the geriatric patient for thoracic surgery is presented in Fig. 2.17. Exercise tolerance seems to be the primary determinant of outcome in the elderly [49]. The ACC/AHA guidelines [34] suggest that with adequate functional capacity, patients with "intermediate" predictors of coronary artery disease do not need further cardiac assessment. However, this recommendation should not be extrapolated to elderly patients. The ACC/AHA guidelines define "adequate functional capacity" as four metabolic equivalents (METS). One MET is the basal resting energy output which is commonly equated to an oxygen consumption of 3.5 mL/kg/min. Four METS is the equivalent of climbing one flight of stairs (Table 2.2) which does not represent an adequate level of exercise capacity for a geriatric patient for major pulmonary resection. The elderly should have, as a minimum cardiac
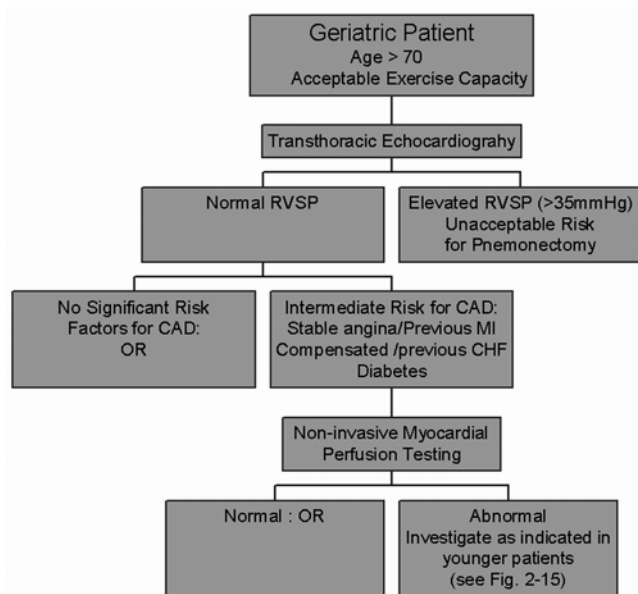
FIG. 2.17. An algorithm for preoperative cardiac investigation in a geriatric patient prior to pulmonary resection surgery. *RVSP* right ventricular systolic pressure estimated by echocardiography; *CAD* coronary artery disease; *OR* operating room (i.e., proceed with surgery without further cardiac investigation).

TABLE 2.2. Energy consumption in metabolic equivalents (METS) of various activities.

Activity	METS
Sitting quietly	1
Walking 1 block	2
Playing the accordion	2
Climbing 1 flight stairs	4
Sexual intercourse [a]	6
Bowling [a]	8
Ice Hockey	8
Running 6 mph	10
Cross country ski racing	14

MET=basal oxygen consumption=3.5 mL/kg/min

Based on data from Hlatky et al. [102]; Fleisher et al. [34]; Ainsworth et al. [103]

[a]Bowling and sexual intercourse are given fewer METS in some classifications

investigation, a transthoracic echocardiogram, to rule out pulmonary hypertension. Although, the mortality resulting from lobectomy among the elderly is acceptable, the mortality from pneumonectomy, particularly right pneumonectomy, is excessive [50]. Geriatric patients with intermediate risk indictors of coronary artery disease should also have noninvasive myocardial perfusion testing.

Renal Dysfunction

Renal dysfunction following pulmonary resection surgery is associated with a high mortality. Gollege and Goldstraw [51]

TABLE 2.3. Factors associated with an increased risk of post-thoracotomy renal impairment.

Previous history of renal impairment
Diuretic therapy
Pneumonectomy
Postoperative infection
Blood loss requiring transfusion
Preoperative cisplatin chemotherapy

reported a perioperative mortality of 19% (6/31) in patients who developed a significant elevation of serum creatinine in the post-thoracotomy period, compared to 0% (0/99) in those who did not show any renal dysfunction. The factors which were associated with an elevated risk of renal impairment are listed in Table 2.3. Nonsteroidal anti-inflammatory agents (NSAIDS) were not associated with renal impairment in this series but are clearly a concern in any thoracotomy patient with an increased risk of renal dysfunction. The high mortality in pneumonectomy patients from either renal failure or postoperative pulmonary edema emphasizes the importance of fluid management in these patients [52] and the need for close and intensive perioperative monitoring, particularly in those patients on diuretics or with a history of renal dysfunction. Increased preoperative creatinine is associated with an increased incidence of prolonged postoperative endotracheal intubation after lung resection [53].The importance of renal dysfunction, either preoperative dialysis or a serum creatinine value >2 mg/dL (>175 μmol/L), as a predictor for prolonged length of stay after lobectomy was reconfirmed in an analysis of the Society of Thoracic Surgery database for the period 2002–2006 [3].

Chronic Obstructive Pulmonary Disease

The most common concurrent illness in the thoracic surgical population is chronic obstructive pulmonary disease (COPD) which incorporates three disorders: emphysema, peripheral airways disease, and chronic bronchitis. Any individual patient may have one or all of these conditions, but the dominant clinical feature is impairment of expiratory airflow [54]. Assessment of the severity of COPD has traditionally been on the basis of the FEV1% of predicted values. The American Thoracic Society categorizes Stage I >50% predicted FEV1% (this category previously included both "mild" and "moderate" COPD), Stage II: 35–50%, and Stage III <35%. Life expectancy may be less than 3 years in Stage III patients >60 years of age. Stage I patients should not have significant dyspnea, hypoxemia, or hypercarbia and other causes should be considered if these are present. A complete discussion of perioperative management of patients with COPD is presented in Chap. 24. Of specific importance in the preoperative assessment of the patient with COPD prior to pulmonary resection is to assess for chronic carbon dioxide retention and to initiate therapy for any potentially treatable complications of COPD.

Carbon Dioxide Retention

Many stage II or III COPD patients have an elevated $PaCO_2$ at rest. It is not possible to differentiate these "CO_2-retainers" from non-retainers on the basis of history, physical examination, or spirometric pulmonary function testing [1]. This CO_2-retention seems to be more related to an inability to maintain the increased work of respiration (W_{resp}) required to keep the $PaCO_2$ normal in patients with mechanically inefficient pulmonary function and not primarily due to an alteration of respiratory control mechanisms [55]. The $PaCO_2$ rises in these patients when a high FiO_2 is administered due to a relative decrease in alveolar ventilation [56] and an increase in alveolar dead space and shunt by the redistribution of perfusion away from lung areas of relatively normal V/Q matching to areas of very low V/Q ratio because regional hypoxic pulmonary vasoconstriction (HPV) is decreased [57] and also due to the Haldane effect [58]. However, supplemental oxygen must be administered to these patients postoperatively to prevent the hypoxemia associated with the unavoidable fall in functional residual capacity (FRC). The attendant rise in $PaCO_2$ should be anticipated and monitored. To identify these patients preoperatively, all stage II or III COPD patients need an arterial blood gas. Also, it is important to know the patient's baseline preoperative $PaCO_2$ to guide weaning if mechanical ventilation becomes necessary in the postoperative period.

Preoperative Therapy of COPD

There are four treatable complications of COPD that must be actively sought and therapy begun at the time of the initial pre-thoracotomy assessment. These are: atelectasis, bronchospasm, respiratory tract infections, and pulmonary edema (see Table 2.4). Atelectasis impairs local lung lymphocyte and macrophage function predisposing to infection [59]. Pulmonary edema can be very difficult to diagnose by auscultation in the presence of COPD and may present very abnormal radiological distributions (unilateral, upper lobes, etc.) [60]. Bronchial hyperreactivity may be a symptom of congestive failure [61] or may represent an exacerbation of reversible airways obstruction. All COPD patients should receive maximal bronchodilator therapy as guided by their symptoms. Only 20–25% of COPD patients will respond to corticosteroids. In a patient who is poorly controlled on sympathomimetic and anticholinergic bronchodilators, a trial of corticosteroids may be beneficial [62]. It is not clear if corticosteroids are as

Table 2.4. Concurrent problems that should be treated prior to anesthesia in COPD patients.

Problem	Method of diagnosis
Bronchospasm	Auscultation
Atelectasis	Chest X-ray
Infection	History, sputum analysis
Pulmonary edema	Auscultation, chest X-ray

beneficial in COPD as they are in asthma, pharmacotherapy for reactive airway diseases is discussed in Chap. 8.

Physiotherapy

Patients with COPD have fewer postoperative pulmonary complications when a perioperative program of intensive chest physiotherapy is initiated preoperatively [63]. Among COPD patients, those with excessive sputum benefit the most from chest physiotherapy. Among the different modalities available (cough and deep breathing, incentive spirometry, PEEP, CPAP, etc.) there is no clearly proven superior method. The important variable is the quantity of time spent with the patient and devoted to chest physiotherapy. Family members or non-physiotherapy hospital staff can easily be trained to perform effective preoperative chest physiotherapy and this should be arranged at the time of the initial preoperative assessment. Even in the most severe COPD patient, it is possible to improve exercise tolerance with a physiotherapy program. Little improvement is seen before one month. In one small study, eight patients who had been refused pulmonary resection on the basis of poor pulmonary function were enrolled in a 4-week program of pulmonary rehabilitation. After the program, the mean 6-min walk test distance for the group increased 29% and the mean FEV1 increased 5%. All eight patients then had lobectomies without any perioperative mortality [64].

Comprehensive 8–12 week programs of pulmonary rehabilitation involving physiotherapy, exercise, nutrition, and education have been clearly shown to improve functional capacity for patients with severe COPD [65]. These longer programs are generally not an option in resections for malignancy although for nonmalignant resections in severe COPD patients, rehabilitation should be considered. The National Cancer Institute is currently funding a randomized trial to investigate the benefits of a short-term (4 week) program of preoperative pulmonary rehabilitation [66].

Smoking

Pulmonary complications are decreased in thoracic surgical patients who cease smoking for >4 weeks before surgery [67]. Carboxyhemoglobin concentrations decrease if smoking is stopped >12 h [68]. It is extremely important for patients to avoid smoking postoperatively. Smoking leads to a prolonged period of tissue hypoxemia. Wound tissue oxygen tension correlates with wound healing and resistance to infection. Wound healing is improved in patients who stop smoking >4 weeks preoperatively [69]. There is no rebound increase in pulmonary complications if patients stop for shorter (<8 week) periods before surgery [70]. The balance of evidence suggests that thoracic surgical patients should be counseled to stop smoking and advised that the longer the period of cessation, the greater the risk-reduction for postoperative pulmonary complications [71].

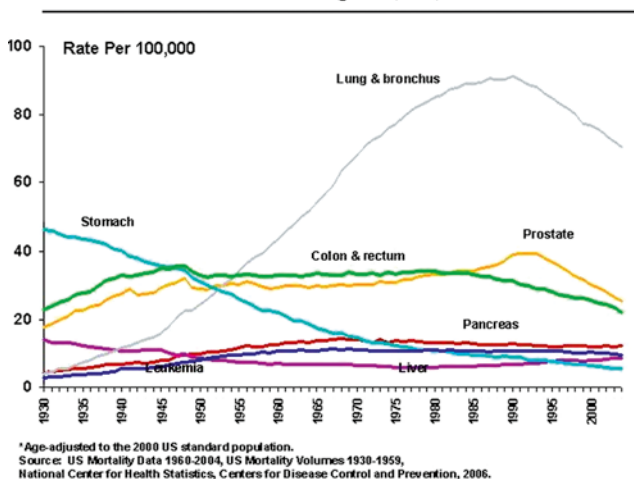## Perioperative Considerations in Thoracic Malignancies

The majority of patients presenting for major pulmonary surgery will have some type of malignancy. Because the different types of thoracic malignancies have varying implications for both surgery and anesthesia, it is important for the anesthesiologist to have some knowledge of the presentation and biology of these cancers. By far, the most common tumor is lung cancer. It is estimated that at present rates over 210,000 new cases of lung cancer occur in the United States annually. Of these only 26% will be resectable. However, this represents >55,000 patients/year who can be offered potentially curative surgery [72]. Lung cancer is currently the leading cause of cancer deaths in both sexes in North America subsequent to the peak incidence of smoking in the period 1940–1970
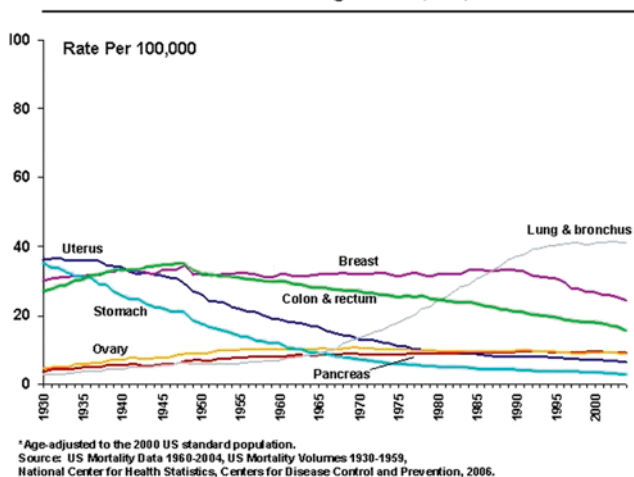
FIG. 2.18. Age adjusted mortality rates for men (**a**) and women (**b**) in the United States 1930–2004. Respiratory malignancies have become the leading cause of cancer deaths in both sexes. (Based on data from Vital statistics of the United States: 2008. www.cancer.org).

(Fig. 2.18) [73]. The mortality rate from lung cancer has shown a slight decrease in the last decade for men but has continued to rise in women.

Lung cancer is broadly divided into: small-cell lung cancer (SCLC) and non-small cell lung cancer (NSCLC), with about 75–80% of these tumors being NSCLC. Other less common and less aggressive tumors of the lung include the carcinoid tumors (typical and atypical) and adenoid cystic carcinoma. In comparison to lung cancer, primary pleural tumors are rare. They include the solitary fibrous tumors of pleura (previously referred to as benign mesotheliomas) and malignant pleural mesothelioma (MPM). Asbestos exposure is implicated as a causative effect in up to 80% of MPM. A dose-response relationship is not always apparent and even brief exposures can lead to the disease. An exposure history is often difficult to obtain because the latent period before clinical manifestation of the tumor may be as long as 40–50 years.

Tobacco smoke (both primary and second-hand) is responsible for approximately 90% of all lung cancers and the Epidemiology of lung cancer follows the Epidemiology of cigarette smoking with approximately a three-decade lag time [74]. Other environmental causes include asbestos and radon gas (a decay product of naturally occurring uranium) which act as co-carcinogens with tobacco smoke. For a pack-a-day cigarette smoker, the lifetime risk of lung cancer is approximately 1 in 14. Smoking cessation reduces the risk of lung cancer but never to that for never smokers. Assuming that current mortality patterns continue, cancer will pass heart disease as the leading cause of death in North America in this decade.

Non-Small Cell Cancers

This pathologically heterogeneous group of tumors includes squamous cell, adenocarcinoma, and large-cell carcinoma with several subtypes and combined tumors (Table 2.5). This represents the largest grouping of lung cancers and the vast majority of those that present for surgery. They are grouped together because the surgical therapy, and by inference the anesthetic implications, is similar and depends on the stage of the cancer at diagnosis (Tables 2.6 and 2.7). Survival can approach 80% for stage I lesions. Unfortunately, these represent only a small minority of the potentially resectable lesions. Overall 5-year survival with surgery for NSCLC approaches

TABLE 2.5. Frequency of cell types of primary lung cancers.

Histologic type	Proportion
Adenocarcinoma	40%
Squamous cell	27%
Small cell	19%
Large cell	8%
Bronchoalveolar cell	4%
Mixed adeno/squamous	2%
Carcinoid	1%
Adapted from Barrera et al. [70]	

TABLE 2.6. Proposed revised non-small cell lung cancer staging[a].

Stage IA	T1a,b	N0	M0
Stage IB	T2a	N0	M0
Stage IIA	T1a,b	N1	M0
	T2a	N1	M0
	T2b	N0	M0
Stage IIB	T2b	N1	M0
	T3	N0	M0
Stage IIIA	T1,T2	N2	M0
	T3	N1,N2	M0
	T4	N0,N1	M0
Stage IIIB	T4	N2	M0
	Any T	N3	M0
Stage IV	Any T	Any N	M1a,b

T1a: ≤2 cm; T1b: >2–≤3 cm

T2a: >3 cm, ≤5 cm; T2b: >5–7 cm

T3: >7 cm

T3: invasion of chest wall, diaphragm, mediastinal pleura, phrenic nerve, parietal pericardium, tumor in the main bronchus <2 cm from the carina

T3: separate tumor nodule in the same lobe (satellite)

T4: invades mediastinum, heart, great vessels, trachea, recurrent laryngeal nerve, esophagus, vertebral body, carina,

T4: separate tumor nodule in different ipsilateral lobe

N0

N1: metastasis in ipsilateral peribronchial, hilar or intrapulmonary nodes

N2: metastasis in ipsilateral mediastinal nodes, or subcarinal nodes

N3: metastasis in contralateral mediastinal nodes or ipsilateral or contralateral supraclavicular/scalene nodes

M1a: malignant pleural effusion, malignant pericardial effusion, separate tumor nodule in contralateral lung

M1b: distant metastases

[a]Modified from Goldstraw et al. [104]

TABLE 2.7. Indications for surgery in non-small cell lung cancer.

Stage I A and B	Primary resection, no postoperative chemo/radiotherapy
Stage II	Primary resection, adjuvant postoperative chemotherapy
Stage IIIA, N2 (for patients with N2 disease identified at thoracotomy: postoperative chemotherapy, possibly radiation)	Definitive chemo/radiotherapy, in select patients induction chemo/radiotherapy followed by resection in patients with stable or responding disease
Stage IIIB	Surgery rarely indicated. Chemo/radiotherapy
	Resection of select T4, N0–1, M0 tumors
Stage IV	Palliative therapy. Possible exception: selected patients with a resected isolated cerebral metastasis

40%. This seemingly low figure must be viewed in the light of an estimated 5-year survival without surgery of <10%.

Although it is not always possible to be certain of the pathology of a given lung tumor preoperatively, many patients will have a known tissue diagnosis at the time of preanesthetic assessment on the basis of prior cytology, bronchoscopy, mediastinoscopy, or transthoracic needle aspiration. This is useful information for the anesthesiologist to obtain preoperatively. Specific anesthetic implications of the different types of lung cancer are listed in Table 2.8.

TABLE 2.8. Anesthetic considerations for different types of lung cancer.

Type	Considerations
Squamous cell	Central lesions (predominantly)
	Mass effects: obstruction, cavitation
	Hypercalcemia
	Hypertrophic pulmonary osteoarthropathy.
Adenocarcinoma	Peripheral lesions
	Metastases (distant)
	Growth hormone, corticotropin
Small cell	Central lesions (predominantly)
	Few surgically treatable
	Paraneoplastic syndromes
	Lambert–Eaton syndrome
	Fast growth rate
	Early metastases
Carcinoid	Proximal, intra-bronchial
Benign (predominantly)	No association with smoking
	5-year survival >90%
	Carcinoid syndrome (rarely)
Mesothelioma	Intraoperative hemorrhage
	Direct extension to diaphragm, pericardium, etc.

Adenocarcinoma

Adenocarcinoma is currently the most common NSCLC in both sexes. These tumors tend to be peripheral and often metastasize early in their course, particularly to brain, bone, liver, and adrenal. They often invade extra-pulmonary structures, including chest wall, diaphragm, and pericardium. The majority of Pancoast tumors (see Chap. 29) are now due to adenocarcinomas. A variety of paraneoplastic metabolic factors can be secreted by adenocarcinomas such as growth hormone and corticotropin. Hypertrophic pulmonary osteoarthropathy is particularly associated with adenocarcinoma.

Squamous Cell Carcinoma

This is the subgroup of NSCLC most strongly linked to cigarette smoking. The tumors tend to grow to a large size and metastasize later than others. They tend to cause symptoms related to local effects of a large tumor mass with a dominant endobronchial component, such as: cavitation, hemoptysis, obstructive pneumonia, superior vena cava syndrome, and involvement of mainstem bronchus, trachea, carina, and main pulmonary arteries. Hypercalcemia is specifically associated with this cell type due to elaboration of a parathyroid-like factor and not due to bone metastases.

Bronchioloalveolar Carcinoma

This is a subtype of adenocarcinoma that is not related to cigarette smoking. In its early stages it lines the alveolar membrane with a thin layer of tumor cells without destroying the alveolar architecture. Bronchioloalveolar carcinoma (BAC) can present as an isolated peripheral lesion, as multifocal disease

(often in both lungs), or as pan-lobar disease (sometimes with production of enormous quantities of mucous). It is the tumor most often identified in low-dose CT scan screening studies and has >90% 5-year survival if treated early, but behaves similar to adenocarcinoma in more advanced stages. Because of its low potential to spread outside of the lungs, multifocal BAC may be treated by lung transplantation in selected cases [75].

Large-Cell Undifferentiated Carcinoma

This is the least common of the NSCLCs. They tend to present as large, often cavitating, peripheral tumors. Their rapid growth rate may lead to widespread metastases, similar to adenocarcinoma.

Small-Cell Lung Cancer

This tumor of neuroendocrine origin is considered metastatic on presentation and is usually regarded as a medical, not a surgical disease [76]. The staging system differs from NSCLC and is divided simply into limited stage and extensive stage. Limited disease is defined as disease confined to one hemithorax that may be encompassed by one radiotherapy field. Treatment of limited stage SCLC with combination chemotherapy (etoposide/cisplatin or cyclophosphamide/doxorubicin/vincristine) gives objective response rates in over 80% of patients. In addition, these patients typically receive radical radiotherapy to the primary lung tumor and prophylactic cranial irradiation. Despite this initial response, the tumor invariably recurs and is quite resistant to further treatment. The overall survival rate is no better than 10%. Extensive stage disease is treated with chemotherapy and palliative radiation as needed.

There are two situations in which surgery for SCLC might be considered. The rare instance in which a solitary pulmonary nodule is diagnosed as SCLC, should be treated with surgical resection followed by chemotherapy. Salvage resection of a residual mass following chemotherapy for limited stage disease may offer some long-term survival in selected cases. Many of these patients will have mixed SCLC/NSCLC in which the small cell component has responded to chemotherapy and the non-small cell component is then resected. Also, patients with treated SCLC have an increased rate of second primary lung cancers, usually non-small cell lung cancer.

SCLC is known to cause a variety of paraneoplastic syndromes due to the production of peptide hormones and antibodies. The commonest of these is hyponatremia, usually due to an inappropriate production of antidiuretic hormone (SIADH). Cushing's syndrome and hypercortisolism through ectopic production of adrenocorticotropic hormone (ACTH) are also commonly seen.

A well known but rare neurologic paraneoplastic syndrome associated with small-cell lung tumors is the Lambert–Eaton myasthenic syndrome due to impaired release of acetylcholine from nerve terminals. This typically presents as proximal lower limb weakness and fatigability that may temporarily improve with exercise. The diagnosis is confirmed by electromyography (EMG) showing increasing amplitude of unusual action potentials with high-frequency stimulation and by serum antibodies. Similar to true myasthenia gravis patients (see Chap. 15), myasthenic syndrome patients are extremely sensitive to nondepolarizing muscle relaxants. However, unlike true myasthenics, they respond poorly to anticholinesterase reversal agents [77]. Clinical differences between myasthenia and the myasthenic syndrome are discussed in Chap. 15 [78]. Diaminopyridine has been reported to be useful both as a maintenance medication and to reverse residual postoperative neuromuscular blockade in these patients [79]. Other treatments of the Lambert–Eaton syndrome include: plasmapheresis, immunoglobulin, and guanidine. It is important to realize that there may be subclinical involvement of the diaphragm and muscles of respiration. TEA has been used following thoracotomy in these patients without complication. These patients' neuromuscular function may improve following resection of the lung cancer. A patient with a lung cancer and unusual symptoms of weakness should be referred to a Neurologist to rule out myasthenic syndrome. Nondepolarizing muscle relaxants should be avoided during anesthesia in these patients.

Carcinoid Tumors

Carcinoid tumors are low grade neuroendocrine malignancies and may be typical or atypical. Typical carcinoid tumors are most commonly found in the central airways and may present with obstructive symptoms or hemoptysis. Bronchoscopic biopsy or resection may cause significant bleeding. Five-year survival following resection for typical carcinoid exceeds 90%. Lymph node metastases are not as common as systemic metastasis. The carcinoid syndrome, which is caused by the ectopic synthesis of vasoactive mediators, is usually seen with carcinoid tumors of gut origin that have metastasized to the liver or rarely large primary pulmonary carcinoid tumors. Atypical carcinoid tumors are more often peripheral and are more aggressive and have a reduced survival rate. They often metastasize both regionally and systemically. Perioperative management of intrathoracic atypical carcinoid tumors is discussed in Chap. 15. These tumors can precipitate an intraoperative hemodynamic crisis or coronary artery spasm even during bronchoscopic resection [80]. The anesthesiologist should be prepared to deal with severe hypotension that may not respond to the usual vasoconstrictors and will require the use of the specific antagonists Octreotide or Somatostatin [81].

Pleural Tumors

Solitary fibrous tumors of pleura are usually large, space occupying masses that are usually attached to visceral pleura. They can be either benign or malignant, but most are easily resected with good results.

MPMs are strongly associated with exposure to asbestos fibers. Their incidence in Canada has almost doubled in the past 15 years. With the phasing out of asbestos-containing products and the long latent period between exposure and diagnosis, the peak incidence is not predicted for another 10–20 years. The tumor initially proliferates within the visceral and parietal pleura, typically forming a bloody effusion. Patients present with shortness of breath or dyspnea on exertion, dry cough or pain. Thoracentesis often relieves the symptoms but rarely provides a diagnosis. Pleural biopsy by video-assisted thoracoscopy is most efficient way to secure a diagnosis and talc poudrage is performed under the same anesthetic to treat the effusion.

MPMs respond poorly to therapy and the median survival is less than one year. In patients with very early disease, extrapleural pneumonectomy may be considered but it is difficult to know whether survival is improved. Recently, several groups have reported improved results with combinations of radiation, chemotherapy, and surgery. Extrapleural pneumonectomy is an extensive procedure that is rife with potential complications, both intra- and postoperative [82]. Blood loss from the denuded chest wall or major vascular structures is always a risk. Complications related to resection of diaphragm and pericardium are additional added risks to that of the pneumonectomy. Perioperative management for extrapleural pneumonectomy is discussed in Chap. 28.

Preoperative Assessment of the Patient with Lung Cancer

At the time of initial assessment, cancer patients should be assessed for the "4-M's" associated with malignancy (Table 2.9): mass effects, metabolic abnormalities, metastases, and medications. The prior use of medications which can exacerbate oxygen-induced pulmonary toxicity such as bleomycin, should be considered [83]. Bleomycin is not used to treat primary lung cancers but patients presenting for excision of lung metastases from germ-cell tumors will often have received prior bleomycin therapy. Although the association between previous bleomycin therapy and pulmonary toxicity from high inspired oxygen concentrations is well documented, none of the details of the association are understood (i.e., safe doses of oxygen or safe period after bleomycin exposure). The safest anesthetic

TABLE 2.9. Anesthetic considerations in lung cancer patients (the "4 M's").

Mass effects: obstructive pneumonia, lung abscess, SVC syndrome, tracheobronchial distortion, Pancoast's syndrome, recurrent laryngeal nerve or phrenic nerve paresis, chest wall or mediastinal extension
Metabolic effects: Lambert–Eaton syndrome, hypercalcemia, hyponatremia, Cushing's syndrome
Metastases: particularly to brain, bone, liver, and adrenal
Medications: chemotherapy agents, pulmonary toxicity (Bleomycin, Mitomycin), cardiac toxicity (Doxorubicin), renal toxicity (Cisplatin)

management is to use the lowest FiO_2 consistent with patient safety and to closely monitor oximetry in any patient who has received bleomycin. We have seen lung cancer patients who received preoperative chemotherapy with cisplatin, which is mildly nephrotoxic, and then developed an elevation of serum creatinine when they received NSAIDs postoperatively. For this reason, we do not routinely administer NSAIDs to patients who have been treated recently with cisplatin.

Postoperative Analgesia

The strategy for postoperative analgesia should be developed and discussed with the patient during the initial preoperative assessment; a full discussion of postoperative analgesia is presented in Chap. 46. Many techniques have been shown to be superior to the use of on-demand parenteral (intramuscular or intravenous) opioids alone in terms of pain control [84]. These include the addition of neuraxial blockade, intercostal/paravertebral blocks, interpleural local anesthetics, NSAIDs, etc. to narcotic based analgesia. Only epidural techniques have been shown to consistently have the capability to decrease post-thoracotomy respiratory complications [85, 86]. It is becoming more evident that TEA is superior to lumbar epidural analgesia. This seems to be due to the synergy which local anesthetics have with opioids in producing neuraxial analgesia. Studies suggest that epidural local anesthetics increase segmental bioavailability of opioids in the cerebrospinal fluid [87] and also that they increase the binding of opioids by spinal cord receptors [88]. Although lumbar epidural opioids can produce similar levels of post-thoracotomy pain control at rest, only the segmental effects of thoracic epidural local anesthetic and opioid combinations can reliably produce increased analgesia with movement and increased respiratory function following a chest incision [89, 90]. In patients with coronary artery disease, thoracic epidural local anesthetics seem to reduce myocardial oxygen demand and supply in proportion [91].

It is at the time of initial preanesthetic assessment that the risks and benefits of the various forms of post-thoracotomy 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 due to problems with patient consent or other contraindications, a reasonable second choice for analgesia is a paravertebral infusion of local anesthetic via a catheter placed intraoperatively in the open hemithorax by the surgeon [92]. This is combined with intravenous patient controlled opioid analgesia and NSAIDS whenever possible.

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 [93]. Low molecular weight heparin (LMWH) precautions are less clear, an interval of 12–24 h before and 24 h after catheter placement is 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 which are taken for concurrent medical conditions (bronchodilators, antihypertensives, β-blockers, etc.). For some types of thoracic surgery, such as esophageal reflux surgery, oral antacid and/or H_2-blockers or proton-pump inhibitors are routinely ordered preoperatively. We do not routinely order preoperative sedation or analgesia for pulmonary resection patients. Mild sedation such as an intravenous short acting benzodiazepine is often given immediately prior to placement of invasive monitoring lines and catheters. In patients with copious secretions, an antisialogogue (such as glycopyrrolate) is useful to facilitate fiberoptic bronchoscopy for positioning of a double-lumen tube or bronchial blocker. To avoid an intramuscular injection this can be given orally or intravenously immediately after placement of the intravenous catheter. It is a common practice to use short-term intravenous antibacterial prophylaxis such as a cephalosporin in thoracic surgical patients. If it is the local practice to administer these drugs prior to admission to the operating room they will have to be ordered preoperatively. Consideration for those patients allergic to cephalosporins or penicillin will have to be made at the time of the initial preoperative visit.

Initial Preoperative Assessment

The anesthetic considerations which should be addressed at the time of the initial preoperative assessment are summarized in Table 2.10. Patients need to be specifically assessed for risk factors associated with respiratory complications, which are the major cause of morbidity and mortality following thoracic surgery. Risk factors which can be modified preoperatively are listed in Table 2.11 [94].

TABLE 2.10. Initial preanesthetic assessment for thoracic surgery.

For all patients: assess exercise tolerance, simple spirometry: estimate ppoFEV1%, discuss postoperative analgesia, smoking cessation

Patients with ppoFEV1 <40%: full pulmonary function testing to include DLCO, Ventilation/perfusion lung scan if possible pneumonectomy, exercise testing

Cancer patients: consider the "4 M's": mass effects, metabolic effects, metastases, and medications

COPD patients: physiotherapy, bronchodilators, arterial blood gas if moderate or severe COPD

Increased renal risk: measure creatinine

TABLE 2.11. Probability for preoperative interventions to reduce the risk of pulmonary complications.

Risk factor	Intervention	Probability
Smoking	Cessation >8 weeks	++++
	Cessation <8 weeks	+
Exacerbation of COPD or asthma	Steroids, bronchodilators, and delay elective surgery	++++
	Antibiotics indicated by sputum	+++
Stable COPD or asthma	Physiotherapy	++++
	Bronchodilators	+++
	Rehabilitation	++
Obesity	Physiotherapy	++++
	Weight loss	++
Malnutrition	Oral nutrition program	++

++++=Multiple studies confirming; +++=both some data plus physiologic rationale supporting; ++=either some data or good physiologic rationale; +=limited data or physiologic rationale
Based on data from Liu and Mulroy [93]

TABLE 2.12. Final preanesthetic assessment for thoracic surgery.

Review initial assessment and test results
Assess difficulty of lung isolation: examine preoperative chest imaging
Assess risk of hypoxemia during one-lung ventilation

Final Preoperative Assessment

The final preoperative anesthetic assessment for the majority of thoracic surgical patients is carried out immediately prior to admission of the patient to the operating room. At this time it is important to review the data from the initial prethoracotomy assessment 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 (Table 2.12).

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 which lead to suspicion of difficult endobronchial intubation (previous radiotherapy, infection, previous pulmonary or airway surgery). In addition, there may be a written bronchoscopy report with a detailed description of anatomical features. The most useful predictor of difficult endobronchial intubation is the plain chest X-ray (Fig. 2.19).

The anesthesiologist should view the chest imaging him/herself prior to induction of anesthesia since neither the Radiologist's nor the Surgeon's report of the X-ray is made with the specific consideration of lung isolation in mind. A large portion of thoracic surgical patients will also have had a chest CT-scan done preoperatively. As anesthesiologists have learned to assess
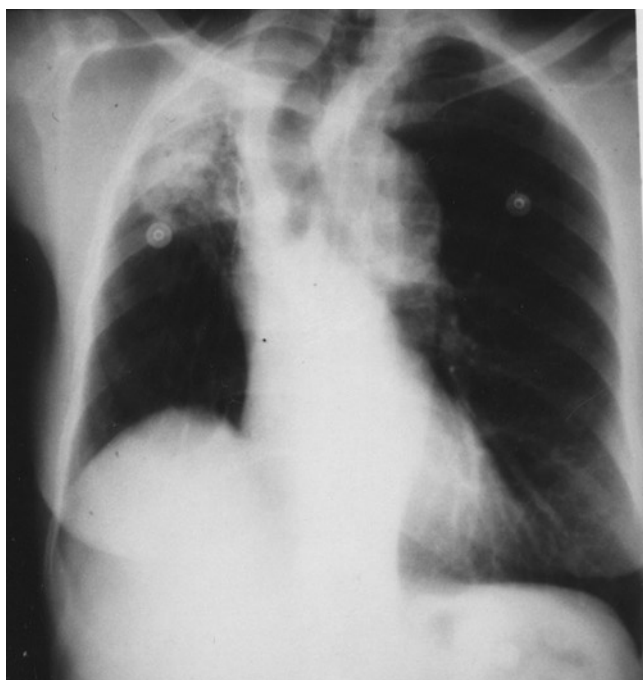
FIG. 2.19. Preoperative chest X-ray of a patient with a history of previous tuberculosis, right upper lobectomy, and recent hemoptysis presenting for right thoracotomy possible completion pneumonectomy. The potential problems positioning a left-sided double-lumen tube in this patient are easily appreciated by viewing the X-ray but are not mentioned in the Radiologist's report. The Anesthesiologist must examine the chest imaging him/herself preoperatively to anticipate problems in lung isolation.

X-rays 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 "saber-sheath" trachea can cause obstruction of the tracheal lumen of a left-sided double-lumen tube during ventilation of the dependent (right) lung for a left thoracotomy [95]. Similarly, extrinsic compression or intra-lumenal obstruction of a mainstem 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. Management of lung isolation in patients with difficult upper and lower airways is discussed in Chap. 17.

Prediction of Desaturation During One-Lung Ventilation

In the vast majority of cases it is possible to identify preoperatively those patients which are most at risk of desaturation during one-lung ventilation (OLV) for thoracic surgery. The factors which correlate with desaturation during OLV are listed in Table 2.13. In patients at high-risk of desaturation, prophylactic measures can be used during OLV to decrease

TABLE 2.13. Factors which correlate with an increased risk of desaturation during one-lung ventilation.

High percentage of ventilation or perfusion to the operative lung on preoperative *V/Q* scan
Poor PaO_2 during two-lung ventilation, particularly in the lateral position intraoperatively
Right-sided thoracotomy
Normal preoperative spirometry (FEV1 or FVC) or restrictive lung disease
Supine position during one-lung ventilation

this risk. The most useful prophylactic measures are the use of continuous positive airway pressure (CPAP) 2–5 cm H_2O of oxygen to the non-ventilated lung and/or positive end-expiratory pressure (PEEP) to the dependent lung.

The most important predictor of PaO_2 during OLV is the PaO_2 during two-lung ventilation, specifically the intraoperative PaO_2 during two-lung ventilation in the lateral position prior to OLV [96]. The proportion of perfusion or ventilation to the nonoperated lung on preoperative *V/Q* scans also correlates with the PaO_2 during OLV [97]. If the operative lung has little perfusion preoperatively due to 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 mmHg higher than during right thoracotomy [98]. Finally, the degree of obstructive lung disease correlates in an inverse fashion with PaO_2 during OLV. Other factors being equal, patients with more severe airflow limitation on preoperative spirometry will tend to have a better PaO_2 during OLV than patients with normal spirometry (see Chap. 6) [99].

Assessment for Repeat Thoracic Surgery

Patients who survive lung cancer surgery form a high-risk cohort to have a recurrence of the original tumor or to develop a second primary. The incidence of developing a second primary lung tumor is estimated at 2%/year. The use of routine postoperative follow-up screening with low-dose spiral CT scans will probably increase the rate of early detection of recurrent or repeat primary tumors [100]. Patients who present for repeat thoracotomy should be assessed using the same framework as those who present for surgery the first time. Predicted values for postoperative respiratory function based on the preoperative lung mechanics, parenchymal function, exercise tolerance, and the amount of functioning lung tissue resected should be calculated and used to identify patients at increased risk.

Clinical Case Discussion

Case: A 65-year-old male presents for anesthesia preoperative assessment (Fig. 2.20). He is scheduled for a bronchoscopy/mediastinoscopy and right pneumonectomy. He is a smoker who presented to his family doctor 2 weeks ago after minor

Fig. 2.20. Chest X-ray of a 65-year-old male, with carcinoma involving the right middle and lower lobes, being assessed for possible right pneumonectomy.

hemoptysis. He has no significant known comorbidities and past history is otherwise unremarkable. A fine needle biopsy has confirmed the diagnosis of non-SCLC. The anesthesia team will need to decide if the patient will tolerate the proposed procedure and if so, then what management strategies can be used to improve the perioperative outcome.

Questions: apart from routine preoperative assessment for major surgery:

What pulmonary function evaluation is indicated?

What cardiac investigations are indicated?

What specific anesthetic considerations are related to the patient's lung cancer?

What other system function should be documented?

Pulmonary function evaluation: lung mechanical function (spirometry: FEV1), pulmonary parenchymal function (DLCO), exercise capacity, and ventilation/perfusion scan (see Sect. "Assessment of Respiratory Function").

Cardiac evaluation: ECG (echocardiography and stress testing not indicated) (see Sect. "Cardiovascular Disease").

Considerations related to lung cancer: tumor mass effects, metabolic (paraneoplastic) effects, metastases, and adjuvant medications

Other systems: renal function

Will the patient tolerate the procedure?

Results of investigations: FEV1 65%, DLCO 70%, exercise tolerance: the patient can climb four flights of stairs without stopping. *V/Q* scan R/L 40/60 for both *V* and *Q*. Other investigations are all within normal limits.

Predicted postoperative (ppo) FEV1 and DLCO will be in the range of 30–35% and adjusted for the *V/Q* scan possibly higher. These indicate increased risk but acceptable

survival given the patient's age <70. A bilobectomy could be considered for elderly or high-risk patients (see Sect. "Age").

What management strategies will improve the patient's outcome?

Smoking cessation.

Pre- and postoperative chest physiotherapy.

TEA has not been clearly proven to improve outcomes in patients with normal pulmonary function, but does improve function in moderate and severe COPD. This patient's risk of respiratory complications may be improved by either thoracic epidural or paravertebral analgesia (see also Chap. 46).

Moderate perioperative fluid restriction and lung-protective ventilation are associated with a decreased risk of postoperative acute lung injury particularly after pneumonectomy (see also Chap. 10).

Calcium channel blockers may be associated with a decreased risk of postoperative atrial fibrillation (see also Chap. 44).

Preoperative β-blockade, statins, or α-2 blockers are not proven to decrease cardiac ischemic risks in this patient at low risk of perioperative ischemia.

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