Pulmonary function tests in preoperative pulmonary evaluation

Jeng-Shing Wang*,1

Section of Respiratory Medicine, E-Da Hospital & I-Shou University, Kaohsiung, Taiwan

Received 7 May 2003; accepted 21 January 2004

Summary Pulmonary function testing (PFT) has been used to evaluate the risk for postoperative complications since the 1950s. PFT including spirometry, lung volumes, diffusing capacity, oximetry, and arterial blood gases has been used to assess the postoperative risk of lung resection. In selected cases, additional evaluation may include radionuclide lung scanning, exercise testing, invasive pulmonary hemodynamic measurements, and risk stratification analysis. A new index, predicted postoperative product (PPP), was found to have strong predictive ability for mortality. We defined a new useful index, measured product (MP), to predict postoperative complications; MP had similar advantages of PPP. Since diffusing capacity at rest has been shown to be a good predictor of postoperative complications following lung resection, and since exercise testing has been also useful in preoperative evaluation prior to lung resection, we reasoned that evaluation of the effect of exercise on diffusing capacity would be helpful to evaluate the ability of the pulmonary capillary bed to expand and increase its capacity to transfer gas during exercise.

© 2004 Elsevier Ltd. All rights reserved.

Introduction

Currently, about 30% of patients undergoing lung resection develop cardiopulmonary complications with a 30-day mortality varying between 0.6% and 5%,1,2 depending on the extent of lung resection. Recent mortality rates in two recent studies were similar, 6.8% following pneumonectomy and 3.9% following lobectomy in one study,1 and 5.7% after pneumonectomy, 4.4% after bilobectomy, and 1.4% after lesser resection in another study.2

Pulmonary function testing (PFT) has been used to evaluate the risk for postoperative complications since the 1950s. PFT including spirometry, lung volumes, diffusing capacity, oximetry, and arterial blood gases has been used to assess the postoperative risk of lung resection. In selected cases, additional evaluation may include radionuclide lung scanning, exercise testing, invasive pulmonary hemodynamic measurements, and risk stratification analysis.

Preoperative lung evaluation including identifying patients at risk, evaluating the risk, and finding modified factors to decrease risk. This allows surgery to be delayed in high-risk patients, and arranges methods to decrease risk. Modern surgical procedures have decreased complications, and allow high-risk patients to undergo and survive surgery.

Methods used to evaluate patients prior to lung resection

Since the first well-performed study of PFT in candidates for lung surgery was published in 1955,3

*Tel.: +011-886-7-6150011; fax: +011-886-7-6155352.
E-mail address: wangjsh6@hotmail.com (J.-S. Wang).

1Dr. Wang was supported in part by a Fellowship from the British Columbia Lung Association and by the Vancouver General Hospital Foundation.

0954-6111/© 2004 Elsevier Ltd. All rights reserved.

doi:10.1016/j.rmed.2004.01.007
many attempts have been made to establish criteria to predict postoperative mortality and cardiopulmonary complications after lung resection. The criteria used to select patients for major pulmonary resections are based on clinical data, spirometry, more detailed PFT, and cardiac evaluation.

Severe abnormalities detected by spirometry indicate an increased risk of pulmonary resection and should prompt further preoperative evaluation and a critical assessment of the patient’s overall condition. Patients with hypoxemia or hypercapnia are at increased risk for morbidity or mortality after thoracotomy. Lung volume determinations may be helpful, and an increase in the ratio of residual volume to total lung capacity is associated with a high incidence of postoperative pulmonary complications. Previously used tests to evaluate differential function of each lung, such as bronchospirometry and the lateral position test, have been replaced by radionuclide lung scanning with quantitative measurement of the contribution of each lung to pulmonary ventilation and blood flow. The attractive features of radionuclide lung scanning include its ready availability in general hospitals, negligible risk to the patients, and a fairly high degree of accuracy in the prediction of postoperative pulmonary function.

Pulmonary hemodynamic measurements may be useful in selected patients; a right ventricular ejection fraction greater than or equal to 35%, a pulmonary vascular resistance less than 200 dyne s cm⁻⁵⁻¹, and a ratio (pulmonary vascular resistance/right ventricular ejection fraction) less than 5.0 should be associated with low morbidity and mortality after lung resection. A resting saturation of less than 90%, or desaturation greater than or equal to 4% during exercise are significantly predictive of increased mortality and morbidity. Risk stratification analysis, using a multifactorial cardiopulmonary risk index based on conventional cardiac and pulmonary clinical data, was highly predictive of postoperative cardiopulmonary complications.

Normal or close to normal preoperative spirometry and CO pulmonary diffusing capacity (DLCO) data indicate that the patient’s lung function allows for surgery without further testing (Fig. 1). Patients with preoperative forced expiratory volume in one second (FEV₁) <60% predicted or with DLCO <60% predicted, who are likely to require lung resection, should be considered for radionuclide lung scanning to estimate postoperative spirometry and diffusing capacity. Results showing predicted postoperative FEV₁ and predicted postoperative DLCO greater than 40% predicted suggest an acceptable surgical risk, and the patient should be referred accordingly. Patients whose predicted postoperative results are less than 40% predicted, will require exercise testing to assess maximal exercise capacity, maximal oxygen uptake, and oxygen saturation. Patients with a predicted postoperative FEV₁, or predicted postoperative DLCO greater than 35% of predicted values and whose peak exercise oxygen uptake is greater than 15 ml/kg/min could be offered surgery, with the goal of removing the smallest volume of tissue that would be compatible with a cure. Recently, Wyser et al. suggested that the important role of exercise testing maybe just after spirometry and DLCO but before radionuclide scanning. Besides, exercise testing can predict postoperative complications with the same accuracy as radionuclide scanning but at a lower cost in their study.

Clinical evaluation

Clinical factors have been suggested as significant risk factors for postoperative pulmonary complications (Table 1). The most important risk factor is the site of surgery. The closer the surgery is to the diaphragm, the higher the complications. Surgical duration lasting more than 2 h is associated with complications, but not anesthesia. Less complications occur in laparoscopy approach. Age and obesity have no definite association with complications. American Society of Anesthesiology score including sputum cultures, pyrexia, and CXR findings is strong predictor of complications.
Several studies show that nutrition, chronic obstructive pulmonary disease and smoking are risk factors. Epstein has used simple cardiopulmonary risk factors on the base of an index to predict complications (Table 2). These clinical factors alter four major aspects of patient’s respiratory status: lung volume, ventilatory pattern, gas exchange, and respiratory defense mechanisms.

### PFT

Gaensler et al. showed that maximal voluntary ventilation less than 50% of predicted and an FVC less than 70% of predicted were associated with a 40% risk for death. The most common PFT used for prediction is FEV₁, and the percent predicted FEV₁ is a more useful index because it accounts for variability in the gender and size of patients for lung resection. The important determinant of FEV₁ cut-off value is the extent of lung resection. The ability of lung function testing to predict postoperative complications has been variable in previous studies. Patient selection, sample size, choice of endpoints, and the retrospective design of some studies are among the possible reasons for the variable reports. Even in the presence of significantly impaired lung function, most respirologists would err on the side of recommending lung resection for lung cancer in borderline cases, because a decision not to operate almost always will result in death from progressive cancer.

### DLCO

The DLCO recently has been shown to be an independent predictor of postoperative outcome. DLCO was an important predictor of mortality and postoperative complications. Patients with low DLCO had an increased respiratory complication rate after major pulmonary resection. In our retrospective review of 151 pneumonectomy cases done at Vancouver General Hospital from 1992 to 1997, patients with DLCO > 70% predicted had a much lower postpneumonectomy complication rate (27 versus 94%) than patients with DLCO < 70% predicted.

DLCO is a standard PFT used routinely in our institution in the preoperative evaluation of patients for lung resection. Previous studies have shown a clear relationship between a low diffusing capacity and poor postoperative outcome after lung resection. A low DLCO identifies patients with significant emphysema, and reduced pulmonary capillary vascular bed. The mechanisms that would predispose emphysematous lung to develop pulmonary edema, include barotrauma from lung ventilation, hyperperfusion of a diminished pulmonary microvascular bed leading to endothelial damage from increased shear, sequestration of activated neutrophils and platelets, and postoperative pulmonary hypertension due to the decreased pulmonary vascular bed following lung resection. Poor right ventricular-pulmonary arterial vascular coupling as a result of resection of part of the pulmonary vascular tree, loss of vascular compliance due to overdistension of the remaining vessels by hyperperfusion, and occlusion of the pulmonary capillary bed by activated neutrophils and platelets, may impair cardiac function and may lead to arrhythmias.

### Radionuclide lung scanning

This technique has been studied in the literature and found to be useful in preoperative evaluation,
especially prior to pneumonectomy, and in estimating the predicted postoperative FEV1 and DLCO. One would expect that such a determination based on the extent of pulmonary resection, the preoperative FEV1, the preoperative DLCO, and the proportion of perfusion of the lung resected, would be the preferred method. A new index, designated the predicted postoperative product (PPP), obtained by multiplying the percentage of predicted postoperative FEV1 by the percentage of predicted postoperative DLCO, was found by Pierce et al.20 to have the strongest predictive ability for mortality.

The PPP is a new concept including values of ventilatory function (FEV1), gas transfer (DLCO), lung perfusion (radionuclide scanning), and the resected lung into a single index. This index allows a patient with a value below the threshold for one criterion based on FEV1 or DLCO to be accepted for surgery on the basis of a good value in the other. Because this index uses percentage predicted rather than absolute values for FEV1 and DLCO, it can apply to patients of either gender across a wide range of age, and height. A value <1650 by this index was predictive of 7 of 8 deaths in the series of Pierce et al.20 and of all 3 of the deaths in the series of Markos et al.,31 so values <1650 could be considered as indicating a high risk of mortality.

However, we calculated the predicted postoperative values (without radionuclide scanning) for FEV1 and DLCO from the surgical excision of functional lung segments using the modified formula of Nakahara et al.,32 predicted postoperative (ppo) FEV1 determined in this manner has been used in a recent study.33 We also used this formula to calculate ppo DLCO. We validated the use of this formula in our study in the 33 patients who had postoperative lung function testing; the calculated values of ppo FEV1 and DLCO% predicted were very similar and not statistically significantly different from the actually determined values.34 The ppo values for FEV1 and DLCO enabled us to calculate PPP from the preoperative data in all patients. The calculated PPP was also useful in predicting postoperative complications.

We defined a new useful index from spirometry and DLCO, measured product (MP), obtained by multiplying the percentage of predicted measured preoperative FEV1 (from spirometry) by the percentage of predicted measured preoperative DLCO (from DLCO) to predict postoperative complications.34 This simple and easy index MP (from spirometry and DLCO) had similar advantages of PPP, such as using percentage predicted rather than absolute values and allowing a patient with a value below the threshold for one criterion based on FEV1 or DLCO to be accepted for surgery on the basis of a good value in the other. A value <5000 by this index was predictive of 40 of 62 complications in our study,34 so values <5000 could be considered as indicating a high risk of complications.

A predictive respiratory complication quotient, combining predicted postoperative FEV1 and DLCO together with the alveolar-arterial oxygen gradient after a 2-min step climb in an index, of less than 2200 is related with increased risk for pulmonary complications and mortality.35 The usefulness of quantitative computed tomography scanning of the chest comparing various techniques for estimating predicted postoperative function was confirmed,36 but perfusion studies remained the most accurate.

Progressive exercise testing

Exercise testing stresses the entire cardiopulmonary and oxygen delivery systems and assesses the reserve that can be expected and may be needed after surgery.37 and therefore may be useful in the preoperative evaluation of patients with lung cancer.38 Cardiopulmonary exercise testing has been used extensively in the evaluating patients with lung disease or dyspnea on exertion, in assessing occupational impairment or disability, as an integral component of pulmonary rehabilitation,39 and in evaluating ambulatory patients with heart failure being considered for cardiac transplantation.40 The ability to exercise adequately has also been used to assess the cardiopulmonary risk of lung resection.37 Previous work has suggested that an inability to perform minimal exercise or to complete an exercise task is associated with an increased risk for complications after lung resection.41 The theoretical value of exercise testing is that it stresses the entire cardiopulmonary and oxygen delivery systems, and assesses its physiological capacity, which could enable one to determine the reserve that can be expected and may be needed after surgery. According to Olsen37 in 1989, the value of exercise testing had not yet been substantiated completely, and the relationship between preoperative exercise function and postoperative outcome needed validation.

Patients incapable of exercising may be at increased risk because of severe underlying cardiopulmonary disease. Such disease may go unrecognized preoperatively, because exercise and cardiopulmonary stress may be limited by noncardiopulmonary factors, only to become obvious during the stress of the perioperative state. Noncardiopulmonary factors limiting exercise, such as impaired joint motility, muscle weakness or amputation, arthritis or leg pain, claudication,
dementia, or the inability to follow instructions, may independently contribute to increased postoperative risk. Exercise testing measures not only cardiopulmonary fitness, but also nonphysiologic factors, such as determination, perseverance, and willingness to cooperate. An inability to cooperate with postoperative care, or a low threshold for tolerance of discomfort could lead to retained secretions and an increased incidence of postoperative complications. Such patients may develop hypoxemia and increased work of breathing, which might not only lead to pulmonary complications due to retained secretions, but could also precipitate arrhythmias or congestive heart failure.

**Exercise DLCO**

Since diffusing capacity at rest has been shown to be a good predictor of postoperative complications following lung resection, and since exercise testing has been also useful in preoperative evaluation prior to lung resection, we reasoned that evaluation of the effect of exercise on DLCO would be helpful to evaluate the ability of the pulmonary capillary bed to expand and increase its capacity to transfer gas during exercise. Lack of an adequate increase in DLCO during exercise would imply inability of the pulmonary capillary bed to increase with increasing cardiac output during exercise, and would suggest increased likelihood of impairment in gas exchange following lung resection. The evaluation of the effect of exercise on DLCO has not been previously used in the preoperative evaluation of patients scheduled for lung resection.

The recent literature and our retrospective review clearly demonstrated that DLCO is an important predictor of postoperative complications. During physical exercise, both the respiratory and cardiovascular systems are under stress because of the increased oxygen requirement of the working muscles and the increased carbon dioxide elimination. An increase in this gas exchange implies a close coupling of pulmonary ventilation and cardiovascular circulation. The response of the cardiovascular and respiratory systems to the increased gas exchange and ventilatory and circulatory requirements in the postoperative period may be evaluated by preoperative exercise testing, which would be expected to be useful in the preoperative evaluation of patients with lung cancer. The mechanisms for the increased DLCO during exercise include more homogeneous distribution of red-cell transit time within the capillary network as flow increases, dilatation of pulmonary blood capillaries, recruitment of previously nonperfused pulmonary capillaries, more homogeneous vertical distribution of pulmonary blood flow, greater utilization of existing alveolar and capillary surface as lung volume and pulmonary blood flow increase, and increased arterial perfusion pressure. Thus, exercise may serve to identify subjects with subtle diffusing defects who may still have a DLCO in the “normal” range at rest, but show limitation during exercise. The use of exercise DLCO in addition to clinical data, spirometric values, and lung function assessments may result in improved prediction of postoperative outcome following lung resection.

Our results suggested that the best variables in predicting complications were exercise DLCO and ppo exercise DLCO also (unpublished data). We measured diffusing capacity at rest and during exercise in 57 patients undergoing resection for lung cancer. Patients developing complications had a lower diffusing capacity at rest, a smaller increase in diffusing capacity during steady-state exercise at 70% of maximum workload, and a lower maximal oxygen consumption than did patients without complications. The best predictor of complications was the failure of diffusing capacity while exercising to increase by more than 10% of resting value: sensitivity, 78%; specificity, 100%.

The DLCO increase during exercise was most conservative for estimating the function loss postoperatively (unpublished data). It suggests that the DLCO increase during exercise is more accurate in estimating functional status. Thus, the decrease in exercise capacity after lung resection cannot be reflected by conventional lung function that overestimates the function loss.

**Further considerations**

The extent of pulmonary resection a patient can tolerate should be determined preoperatively and is based on both PFT and the patient’s performance status. The size and location of the lesion by computerized tomograph scan of the chest, and bronchoscopy are helpful in determining how much lung will be required for complete resection. Once the amount of lung that is required for resection is determined and the FEV₁ and DLCO have been assessed, the surgeon must decide if the patient can tolerate resection. Prophylactic interventions may be used to decrease the risk of perioperative morbidity or mortality (Table 3). Preoperative prophylactic interventions include smoking cessation, breathing training, antibiotics, expectorants, bronchodilator therapy, and weight reduction.
Intraoperative management includes limited anesthesia and thoracotomy times, intermittent hyperinflation to prevent atelectasis, better control of secretions, prevention of aspiration, and maintenance of bronchodilatation. Postoperative measures include incentive spirometry, mobilization of secretions, early ambulation, cough encouragement, and adequate pain control.

There have been significant advancements in understanding cardiopulmonary physiology, surgical technique, perioperative care, and nonsurgical treatment modalities. Hypercapnia as a barrier to lung resection has been overcome by successfully resecting lung tissue of selected patients in chronic respiratory failure. Video-assisted thoracoscopic surgery may minimize postoperative thoracic cage impairment and may further reduce perioperative complications. Lung volume resection surgery at the same time as surgery for lung cancer can improve recovery of postoperative lung function.

Patients whose lung function is below the safe preoperative limits for lung resection should not be completely rejected for surgical therapy, because without surgery the outlook for lung cancer is poor. They should be on intensive therapy to improve lung function. They should be counseled as to the risks of death or prolonged disability from surgery, given other treatment options, and offered an attempt at resection using all the postoperative management skills if the risk for surgery is not considered prohibitive. However, the previous concept of threshold values for preoperative variables should be applied cautiously, especially since lung volume resection surgery for emphysema applied at the same time as surgery for lung cancer may enable patients with poor lung function due to emphysema to undergo surgery for limited lung cancer.

**Acknowledgements**

The author thanks the guidance and support provided by Dr. Raja Abboud in helping him to review and revise this manuscript.

**References**


