The Use of Pulmonary Function Tests in Preoperative Evaluation for Lung Resection

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Summary

Various methods commonly used for testing pulmonary function have been reviewed and some equations outlined for interpreting Pulmonary Function Tests. The use of exercise stress testing, broncho-spirometery, lobar sampling, radio-nuclide ventilation and perfusion studies have been discussed for estimating pulmonary reserve. Finally minimal values of Pulmonary Function Tests have been proposed as criteria for the different types of pulmonary resections, in order to decrease morbidity and mortality.

Introduction

Patients being considered for lung resection fall into two categories: those with infections : (1) lung abscess, (2) fungal disease, (3) pulmonary tuberculosis, (4) bronchiectasis; and those with tumors : both benign and malignant. The type of procedure performed, i.e. segmental resection, lobectomy or pneumonectomy, will depend on the nature and extent of the disease process.

Virtually all surgical procedures carry a risk of respiratory complications. Atelectasis and pneumonia occur in 3–10% of all operations, with the highest incidence of forty to sixty per cent in thoracotomies. When surgery involves resection of functioning lung tissue, there is an added risk of post-operative respiratory failure and cor pulmonale, and overall mortality can be as high as fifteen per cent. Physiological pulmonary function tests help to (1) identify patients who are at increased risk of peri-operative cardiorespiratory complications and provide a rough numeric guess as to the likelihood of complications; (2) determine whether the patient has sufficient respiratory reserve to survive resection of a portion of the lung and (3) determine and treat any reversible components.

The most commonly used method for testing pulmonary function is spirometry. It is simple, reliable and non-invasive. Spirometry measures the volume of

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air that can be inhaled or exhaled by a patient as a function of time, and is recorded as a volume-time trace. Since volume divided by time is flow, information about flow rates can also be obtained from a spirographic tracing.

The volumes measured are :

Total Lung Capacity (TLC)

TLC is the volume of gas in the lungs following a maximal inspiration.

Vital Capacity (VC)

VC is the maximum volume of gas that can be exhaled after a maximal inspiration.

Residual Volume (RV)

RV is the volume of gas left in the lungs after a maximal expiration. Lung volumes are determined by the compliance of the lung and chest wall and the forces applied to it. There are multiple factors therefore which alter lung volumes.

Processes that produce interstitial cellular infiltration and/or fibrosis in the lung tissue will cause a symmetrical reduction in lung volumes by limiting expansion, they may also be limited by a fibrosed pleura, chest wall deformities such as kyphoscoliosis and neuromuscular disorders e.g. Myasthenia gravis.

Total lung capacity is increased in emphysema because of a decrease of elastic recoil of the lung.

Since vital capacity is the difference between TLC and RV, it may either be decreased because of reduction in TLC or an increase in the residual volume. In emphysema and advanced age, the residual volume is abnormally high as a result of airway closure, thus reducing vital capacity.

Flows

While lung volumes provide information about the pulmonary interstitium, pleura, chest wall and neuromusculature, flows primarily describe the state of the airways.

Forced Vital Capacity (FVC)

Forced vital capacity is the volume of gas that can be expired as forcefully and rapidly as possible after a maximal inhalation. The portion of FVC which can be expired in one second is the FEV_1. The FEV_1 is largely a reflection of three factors :– (1) rapidity of expiratory muscle contraction, (2) elastic recoil of lungs and chest wall and (3) the caliber of the larger central airways. Measurement of the flow in the midportion of FVC is the Maximum Mid Expiratory Flow Rate (MMEFR).

MMEFR is thought to be a sensitive indicator of small airway disease. In cigarette smokers, a reduction in MMEFR may be the first sign of obstruction, due to narrowing of the airways.

Lung flows are in part dependent on lung volumes. High flow generation requires maximal lung and chest wall expansion. In patients with restrictive diseases, causing decrease in lung volumes, maximal flows cannot be attained. Thus FVC, FEV_1 and MMEFR may be decreased in the presence of normal airways. The ratio of FEV_1 to FVC helps to detect this clinical situation.

In patients with obstructive airways disease, the FEV_1 tends to be reduced out of proportion to FVC, the ratio of FEV_1/FVC is low: less than 0.75 In patients with normal airways but low lung volumes, the FVC is reduced out of proportion to FEV_1, thus making the ratio greater than 0.75.

Interpreting Pulmonary Function Tests (PFT)

Many equations have been developed over the years to predict the flows and volumes for a given patient based on age, height and sex of the patient. These equations are derived from large epidemiological studies of reportedly normal people. Since there is a wide range of normal values, when evaluating PFT — a clear decrement in function must be observed before the presence of an abnormality is confirmed.

In practice a volume flow or diffusing capacity is considered normal if the result is greater than 80% of predicted value; a mild abnormality is deemed present if the result is 60–80% of predicted value; moderate between 40–60% and severe if below 40% of the predicted value.

There is general agreement that the poorer a patient's spirometric performance, the greater the likelihood of peri-operative respiratory complications. It is more difficult however to define cut off values of pulmonary function beyond which a patient is certain to encounter or escape morbidity or mortality.

Published studies tend to report the numbers of patients encountering complications with functions above or below a certain level, and from these numbers some approximation of their predictive value can be derived. Routine spirometry, particularly FEV and RV/TLC measurements, can predict upto 80% of complications.

Vital Capacity (VC)

An abnormal vital capacity can identify upto 30–40% of post-operative deaths. Standards proposed for VC as indicative of increased risk are 50% less than the predicted value or less than 1.5—2 litres; a patient with an abnormal VC has one in three chance of complications and a 12–30% chance of death. Mortality with a VC above these cut offs appears to run 10–15%.

FEV_1

Using an FEV_1 below 2 litres, 75–80% of post-operative deaths can be identified. Mortality in a group with this FEV_1 is 20–45%, while mortality with an FEV_1 above this level is 10%. Olsen[4] in his series made an FEV_1 of less than 800 cc air, an absolute contra-indication to pulmonary resection.

Maximum Voluntary Ventilation (MVV)

MVV is the maximum amount of air that a patient can be expected to move in one minute by voluntary effort. It is a function of restriction, obstruction and effort on the part of the patient. The MVV appears to possess relatively good specificity and sensitivity when compared with other spirometric parameters.

Gaensler[10] reviewed the results of thoracotomies for tuberculosis in 460 patients; fourteen died of respiratory failure: 8 within 30 days of surgery and the rest within six years post-operatively. No early deaths occurred in patients with MVV greater than 50% of predicted value. Post-operative dyspnoea and exertional limitation were linearly related to pre-operative MVV. The poorer the initial function, the greater the ultimate compromise.

Residual Volume (RV) and Total Lung Capacity (TLC)

The ratio of residual volume and total lung capacity has been examined as a predictor of post-operative complications. In chronic emphysema, total lung capacity increases as a result of loss of lung elastic recoil. Airway closure takes place at relatively high lung volumes thus causing air trapping and increased residual volume. The ratio of RV/TLC also increases. In Mittmans series[18] a ratio of residual volume to total lung capacity of over 40% showed a mortality of 30% compared to a mortality of only 7% when the ratio was below 40%. A ratio of 50% showed a mortality of 36%.

Diffusing Capacity

The ability of gases to diffuse across the alveolar capillary membrane can also be used as a test of pulmonary function and post-operative pulmonary reserve.

Since the primary determinant of the diffusing capacity is the alveolar capillary membrane, pulmonary fibrosis, vasculitis, pulmonary emboli, emphysema and pulmonary hypertension will all cause a reduction in the diffusing capacity. Its value as a predictor of post-operative pulmonary reserve is limited.

Arterial Blood Gases

Arterial blood gas measurements consist of the partial pressures of oxygen and carbon dioxide as well as the PH.

The normal PaO_2 declines as a function of age and posture because of increasing airway closure. In a patient aged 70 years, a normal PaO_2 may be as low as 63mmHg. Mechanisms contributing to clinical hypoxaemia include ventilation–perfusion abnormalities and hypoventilation. Diffusion impairment may produce hypoxaemia during exercise when the shortened transit time of erythrocytes through the pulmonary capillary bed is insufficient to permit partial pressure equilibration between alveolus and pulmonary capillary. The primary adverse effect of long-term clinical hypoxaemia is on the heart, particularly the right ventricle, via a hypoxia-mediated increase in pulmonary vascular resistance. The increase in right ventricular pressure and subsequent increase in stroke work will eventually lead to hypertrophy and then failure. The presence of this syndrome of right ventricular failure and pulmonary hypertension secondary to respiratory disease, 'cor pulmonale', is an extremely adverse factor in the prognosis of emphysema and chronic bronchitis.

Directly examined pre-operative PaO_2 at rest was found to be a relatively minor indicator of post-operative outcome. There is usually no increase in complications after surgery in the case of simple hypoxaemia without pulmonary hypertension. Gracey[13] reported no significant difference in the rate of pulmonary complications based on base line PaO_2 or on the response of PaO_2 to a programme of pre-operative preparation.

Carbon Dioxide

Arterial $PaCO_2$ is a function of Co_2 production and alveolar ventilation. Alveolar ventilation is determined by minute ventilation and dead space ventilation. A rise in $PaCO_2$ can be compensated for by an increase in minute ventilation. This is limited by the work of breathing which is a function of the compliance of the lung and airway resistance as well as the rate and depth of breathing. When the demands of CO_2 production or increased dead space require a work of breathing greater than 55%, maximum hypercapnia and respiratory acidosis will ensue.

Individuals can compensate for hypercapnia by increasing renal retention of bicarbonate and thus modify respiratory caused acidosis. Even with compensation, however, the presence of hypercapnia suggests that the demands placed on the lung by disease are more than the respiratory apparatus can cope with.

It has been suggested that CO_2 retention becomes apparent when FEV_1 falls below 800–1000 cc. For this reason an FEV_1 of 800 cc has been used as an arbitrary criteria for exclusion of resectional surgery. A $PaCO_2$ of greater than 45 mmHg has been used as a warning of post-operative respiratory difficulty. Since thoracic surgery will further impair an already compromised respiratory system, hypercapnia poses a significant risk factor.

Patients with obstructive lung disease, that is with abnormal lung flows, frequently have a mixture of reversible and irreversible airway obstruction. If the reversible component can be treated before surgery, post-operative morbidity can be decreased. The greater the reversible component, the better the overall prognosis. Bronchodilators are used to assess the reversibility of airway obstruction. FEV_1 and FVC are the most valuable indices of broncho-dilator response. Patients presenting for surgery of FEV_1 of less than 2 litres and RV/TLC of more than 40% are given a course of bronchodilators and chest physiotherapy for 48–72 hours to optimise lung function and retested. A 15–20% change in flows is considered significant.

Persistent abnormality indicates the need for a more specific evaluation. The maximum voluntary ventilation and exercise studies appear to offer sufficient specificity to reduce the operative risk to about 10% when these studies are within normal limits.

Exercise Stress Testing

Patients with marginal but compensated cardiopulmonary function can be thrown into a decompensated state when stressed. Exercise stress testing can, therefore, be used to measure ventilatory reserve before pulmonary resection.

The most formal analysis of the predictive value of exercise for pneumonectomy was done by Reichel. Despite the small population recorded 25 patients, the separation and prediction was striking enough and so Reichel exercise test is widely used. It is the only protocol published to exceed 90% sensitivity.

Candidates for pneumonectomy are placed on a treadmill and made to lk 2 minutes each at staged intervals of speed and elevation. The test lasts ırteen minutes. The work output is measured in Watts work = Speed (M/Sec) Wt. (Kg) × (1 + [–9 80665 Sin (Arctan % grade)]).

Patients with angina and EKG changes are excluded from the test. Failure complete a 60 Watts protocol calls for more definitive studies, to estimate ual post-operative function.

Among available techniques, bronchospirometry, lobar sampling and radio-lide ventilation and perfusion studies are all capable of estimating within 15% of actual post-operative FEV_1 and therefore pulmonary reserve. Since the exchanging function of the lung is ultimately determined by blood flow and ıtilation, radio-nuclide perfusion and ventilation studies should represent the roach of choice.

nclusion

Since no one parameter is absolute, the following set of criteria is pro-ed as minimal values of pulmonary function for various types of pulmonary ction that result in minimal morbidity and low mortality.

umonectomy

MVV .... greater than 55% of predicted
FEV_1 .... greater than 2 litres
MMEFR .... greater than 1.6 liters
Predicted Residual FEV_1 .... greater than 0.8 litres
Ability to complete Reichel stress test

ectomy

MVV .... greater than 40% of predicted
FEV_1 .... greater than 1 litre
MMEFR .... greater than 0.6 litres

tive Wedge or Segmental Resection

MVV .... 35–45% of predicted
FEV_1 .... 0.6 litres
MMEFR .... 0.6 litres

These criteria were applied to 500 thoracotomies in a series by Miller, JI., Grossman, G. and Hatcher: 46 pneumonectomies, 196 lobectomies, 248 segmental resections and 10 open lung biopsies. Complications developed in 18 patients: 16 had dysrhythmias and 2 pulmonary emboli. There were two deaths in the pneumonectomy group in the post-operative period of four weeks: a mortality of 4.4%. There was no death in the lobectomy group and one death in the segmental resection group.

When the FEV_1 is less than 0.6 litres and MVV less than 35% of predicted value, surgery is contraindicated except in life threatening emergencies.

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