Tests of pulmonary function before thoracic surgery

Neil G Britton
Matthew Stagg

Abstract

Respiratory function declines following surgery due to atelectasis. After thoracic surgery, there is an even greater decline due to resection and lung handling. Patients undergoing thoracic surgery often have concomitant respiratory disease and testing pulmonary function preoperatively allows: diagnosis and optimization of lung disease; counselling of patients accurately to obtain truly informed consent and guide the multidisciplinary team to the best operation. Tests of pulmonary function can be divided into tests of mechanical function, tests of parenchymal function, tests of cardiorespiratory reserve and function, and anatomical tests. When these tests are combined with knowledge of the lobes resected they allow predicted postoperative values to be calculated. Evidence-based guidelines show which investigations should be performed preoperatively and risk-stratify patients for postoperative dyspnoea, morbidity and mortality.

Keywords Cardiopulmonary exercise test; lung function tests; preoperative assessment; spirometry; thoracic surgery

Royal College of Anaesthetists CPD Matrix: 3G00

Learning objectives

After reading this article, you should be able to:
- explain why tests of pulmonary function are necessary
- list what tests are commonly performed
- describe how common tests are performed
- discuss how these tests are used to guide surgery and counsel patients

Why do pulmonary function tests before thoracic surgery?

Thoracic surgery remains high-risk surgery despite advances in anaesthetic and surgical technique (30-day mortality for lobectomy 2.3% and 5.8% for pneumonectomy[1]). Atelectasis is common after thoracic surgery and is thought to predispose to pneumonia and respiratory failure in the acute phase. Post-treatment dyspnoea can lead to significant morbidity, disability and decreased quality of life.

Patients for thoracic surgery will generally have concomitant pulmonary disease or abnormal respiratory function, such that they would be at risk of postoperative complications from any anaesthetic or surgical insult. Thoracic surgery however necessitates the handling, and often resection of, lung tissue and a thoracotomy incision which causes a reduction in static and dynamic lung volumes as well as function. Often these reductions exceed the volume of lung resected. Reduction in static volumes and gas-exchange function may result in inadequate ventilation and oxygenation whilst reduced dynamic volumes can impair ability to cough, clear secretions and therefore lead to further atelectasis and pneumonia.[2]

Preoperative pulmonary function testing allows: diagnosis and severity scoring of pulmonary comorbidities; potential optimization; counselling of patients about the risks of short-term pulmonary complications and long-term dyspnoea and thus informed consent.

Tests of pulmonary function can be divided into four areas: respiratory mechanics, parenchymal function, cardiorespiratory reserve and anatomical. Together these four areas combine to enable predictions of postoperative function.

Tests of respiratory mechanics

Gas must move in and out of alveoli for gas exchange to take place, with obstructive and restrictive disease processes limiting this function.

Spirometry is a common, non-invasive and versatile test of mechanical functions and volumes of the lungs. A patient breathes via a mouth piece, with nose clipped, through the spirometer which records flows and volumes over time. Plotting of volume against time for a maximal forced expiration from total lung capacity to residual volume gives FEV_1 (the volume expired in 1 second) and FVC (forced vital capacity) (Figure 1).

Plotting of flow against volume for a complete cycle of maximal expiration and inspiration gives the flow–volume loop, which allows VC (vital capacity) and PEF (peak expiratory flow) to be derived as well as evaluating the degree of obstructive and restrictive disease and the presence of significant extra-thoracic obstruction (Figure 2). To obtain TLC (total lung capacity) a helium dilution test is used to interrogate the residual volume left after full expiration.

Values obtained are reported as absolute values and as compared to values derived from healthy population studies and vary with age, race, weight and height. FEV_1 and FVC should be more than 80% of that predicted, and the ratio of FEV_1/FVC greater than 0.8.

Arterial partial pressure of carbon dioxide ($PaCO_2$) is inversely related to minute volume, and so may be used as a surrogate marker of adequacy of ventilation preoperatively. An elevated $PaCO_2$ may indicate abnormal ventilation.

Tests of parenchymal function

Gases must diffuse across the alveolar capillary membrane for normal function and parenchymal function tests assess and quantify performance of the lung at this process. Oxygen content

Neil G Britton FRCA *is an ST7 in Anaesthesia in the North West Deanery, UK. No conflicts of interest are declared.*

Matthew Stagg FRCA FFICM *is a Consultant in Cardiothoracic Anaesthesia and Intensive care at the Lancashire Cardiac Centre, Blackpool, UK. No conflicts of interest are declared.*

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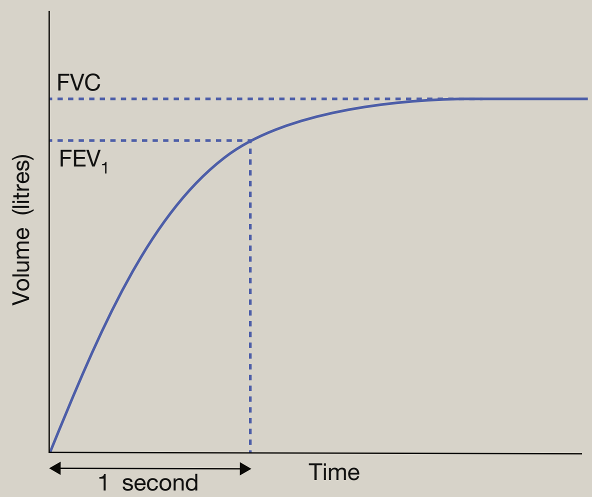
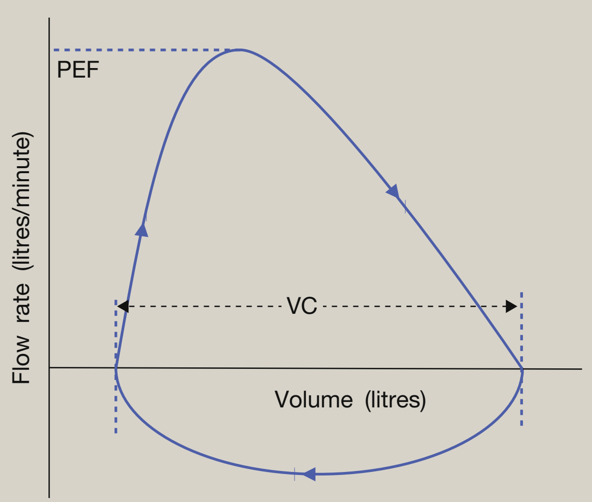


FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity.

Figure 1 Forced vital capacity curve.



PEF, peak expiratory flow;
VC, vital capacity.

Figure 2 Flow-volume loop during inspiration and expiration.

of blood is dependent on this process (to a much greater degree than carbon dioxide) and so low saturation of arterial oxygen (SaO_2) or partial pressure of oxygen (PaO_2) will reflect poor parenchymal function. However, the relationship is difficult to quantify and there may be significant reduction in parenchymal function before reduction in SaO_2 or PaO_2.

Diffusion (or total) capacity of the lung for carbon monoxide (DLCO/TLCO) is a more invasive but quantifiable test of alveolar capillary membrane function. Carbon monoxide (CO) is used because haemoglobin has over 400 times the affinity for CO as oxygen and so, at low inspired concentrations, CO uptake is diffusion limited. Different methods are possible but each involves breathing 0.3% carbon monoxide (CO) and measuring inspired and expired fraction of gases. In the commonly used single breath technique 0.3% CO with 10% helium is inhaled and held for 10 seconds. Helium does not diffuse and so the ratio of CO to helium allows calculation of DLCO and total lung capacity. DLCO is expressed as the amount of CO diffusing per minute per unit of pressure (mmol/minute/kPa). DLCO is decreased by diseases that impair the alveolar capillary membrane, such as pulmonary fibrosis, but also by diseases or surgeries that decrease total lung area. To compensate for this the transfer coefficient (KCO) is sometimes given, which is corrected for lung volume. KCO is expressed as the amount of CO diffusing per minute per unit of pressure per unit volume (mmol/minute/kPa/litre). DLCO is given as absolute values and as a percentage predicted, based on age, gender, height, exercise and altitude. For preoperative assessment DLCO is a better tool than KCO.

Tests of cardiorespiratory reserve and function

Recovery from surgery requires an elevated oxygen delivery from approximately 110 ml/m_2 to approximately 170 ml/m_2 whilst oxygen extraction falls, thus cardiac output may need to increase 2.5-fold for the postoperative period.[3] Tests of cardiorespiratory function attempt to predict a patient's ability to elevate their metabolism, cardiac output, and VO_2 for a prolonged period without requiring anaerobic respiration and thus attempt to predict a patient's risk of postoperative morbidity and mortality.

Cardiorespiratory exercise testing

Cardiorespiratory exercise testing (CPET)[3] is a non-invasive test whereby a patient uses a bicycle ergometer (arm-ergometers are available for those unable to cycle) to gradually increase work done whilst CO_2 and O_2 are measured on a breath-by-breath basis. SpO_2, non-invasive blood-pressure and ECG are recorded. The test may be terminated by the patient due to exhaustion, breathlessness or chest pain. Or terminated by the operator if ST changes or significant arrhythmias are detected, or all values required are obtained. VO_{2Peak} is the maximal rate of oxygen utilised (VO_2) during the test, measured as ml/minute/kg. Except in trained and motivated individuals VO_{2Peak} is limited by motivation rather than a true physiological limitation of O_2 uptake, which is known as the maximal uptake of O_2 (VO_{2Max}).

Anaerobic threshold (AT), which is the VO_2 at a workload where demand for O_2 exceeds supply, is not motivation dependent and is easily achieved since it occurs at around 50% of VO_{2Max}. It may, therefore, be a better test value to compare between individuals. However, the majority of studies for thoracic surgery, and thus guidelines, have used VO_{2Peak}.

Values of AT less than 11 ml/minute/kg and VO_{2Peak} less than 15 ml/minute/kg are considered high risk for thoracic surgery. Whilst values of VO_{2Peak} greater than 20 ml/minute/kg or over 75% predicted are necessary for pneumonectomy and less than 10 ml/minute/kg or under 35% predicted precludes any resection.

Other tests

Attempts have been made to use simpler tests to measure fitness. The Six-minute Walk Test (6MWT) involves recording how far a

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