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PULMONARY FUNCTION TESTS (PFTs): A REVIEW

Rajesh Singh Bista[*1], A. Vikneswari[1], V.J. Divya[1], Sini Joseph[1]

[*1]Department of Pharmacy Practice, Bharathi College of Pharmacy, Mandya, Karnataka, India.

ABSTRACT

Through this article a description about the indications for performing PFTs, contraindications and an overview about commonly done pulmonary function tests have been provided. Pulmonary function tests are valuable investigations in the management of patients with suspected or previously diagnosed respiratory disease. They aid diagnosis, help monitor response to treatment and can guide decisions regarding further treatment and intervention. These tests are important in the initial evaluation of respiratory disorders and help in planning therapy as well as predicting prognosis with a reasonable accuracy. Normal values of these tests differ from population to population and with difference in methods and apparatus used. This article describes the working principles of major tests including spirometry, peak flowmetry, body plethysmography, arterial blood gases measurement, and ergospirometry.

KEYWORDS

Spirometry Flow Volume Curves, Arterial blood gases and Ergospirometry.

Author for Correspondence:

Rajesh Singh Bista,
Department of Pharmacy Practice,
Bharathi College of Pharmacy,
Mandya, Karnataka, India.

Email: avikneswari11@gmail.com

INTRODUCTION

Pulmonary function tests are valuable investigations in the management of patients with suspected or previously diagnosed respiratory disease. They aid diagnosis, help monitor response to treatment and can guide decisions regarding further treatment and intervention. They provide important information relating to the large and small airways, the pulmonary parenchyma and the size and integrity of the pulmonary capillary bed. Although they do not provide a diagnosis per se, different patterns of abnormalities are seen in various respiratory diseases which helps to establish a diagnosis[1].

General considerations, indications and contraindications of pulmonary function tests

Guidelines for performing and interpreting PFTS have been published both by the European Respiratory and American Thoracic Societies[2-7]. Indications for performing PFTS are listed in below table. Performing PFTS is generally safe but specific contraindications exist. These are also listed below.

A sitting position is typically used at the time of testing to prevent the risk of falling and injury in the event of a syncopal episode, although PFTS can be performed in the standing position. Patients are advised not to smoke for at least one hour before testing, not to eat a large meal two hours before testing and not to wear tight fitting clothing as under these circumstances results may be adversely effected[1]. Normal or predicted ranges of values are obtained from large population studies of healthy subjects. Values are taken for people matched for age, height, sex and where appropriate ethnicity. PFTS should be performed three times to ensure that the results are reproducible (less than 200ml variation) and accurate. Dynamic studies are performed first (spirometry, flow volume curves, peak expiratory flow rates), followed by lung volumes, bronchodilator testing and finally diffusion capacity[1].

Once quality has been assured, the next steps involve a series of comparisons that include comparisons of test results with reference values based on healthy subjects, comparisons with known disease or abnormal physiological patterns (i.e. obstruction and restriction), and comparisons with self, a rather formal term for evaluating change in an individual patient. A final step in the lung function report is to answer the clinical question that prompted the test.

Interpretation of PFTs is usually based on comparisons of data measured in an individual patient or subject with reference (predicted) values based on healthy subjects. Predicted values should be obtained from studies of ‘‘normal’’ or ‘‘healthy’’ subjects with the same anthropometric (e.g. sex, age and height) and, where relevant, ethnic characteristics of the patient being tested. Ideally, reference values are calculated with equations derived from measurements observed in a representative sample of healthy subjects in a general population. Reference equations can also be derived from large groups of volunteers, provided that criteria for normal selection and proper distribution of anthropometric characteristics are satisfied. Criteria to define subjects as ‘‘normal’’ or healthy have been discussed in previous ATS and European Respiratory Society (ERS) statements[8].

Spirometry

Spirometers are non-invasive diagnostic instruments for screening and basic testing of pulmonary function. Two essential questions of pulmonary function testing (PF testing) can be answered by spirometry:

1. What is the size of lung volume which can be inspired *or* expired?
2. What is the time it takes to exhale this volume, or what is the flow rate during exhalation?

Flow rates and resulting volumes are measured by connecting a spirometry sensor through a mouthpiece to the test subject’s mouth. The most common and internationally standardized test consists of an evaluation of forced expiration after a complete inhalation, allowing the determination of forced vital capacity (FVC) and the forced expired volume during the first second (FEV1). Although FVC and FEV1 are the most common, dozens of parameters can be derived when evaluating forced expiration, all describing the shape and size of recorded traces and loops. Besides forced spirometry, slow spirometry, i.e., the recording of slow inspiration and expiration at tidal breathing, may also be recorded, offering determination of lung-volume subdivisions such as tidal volume (VT), inspiratory and expiratory reserve volume (IRV and ERV), as well as inspiratory capacity (IC)[9].

Spirometry is the most frequently used measure of lung function and is a measure of volume against time. It is a simple and quick procedure to perform: patients are asked to take a maximal inspiration and then to forcefully expel air for as long and as quickly as possible (a forced vital capacity manoeuvre). Measurements that are made include:-

• Forced expiratory volume in one second (FEV1)

• Forced vital capacity (FVC)
• The ratio of the two volumes (FEV1/FVC)[1].

Types of Spirometers

There are many different types of spirometer with costs varying from 100-3,000 Euros/50-2,000 USD.

1. **Bellows or rolling seal spirometers** are large and not very portable, and are used predominantly in lung function laboratories. They require regular calibration with a 3-liter syringe and are very accurate.

2. **Electronic desktop spirometers** are compact, portable, and usually quick and easy to use. They have a real-time visual display and paper or computer printout. Some require calibration with the 3-liter syringe; others can be checked for accuracy with the syringe but require any changes to be performed by the manufacturer. Generally they need little attention other than cleaning. They maintain accuracy over years and are ideal for primary care.

• Small, inexpensive **hand-held spirometers** provide a numerical record of blows but no printout. It may be necessary to look up predicted values in tables, but some include these in their built-in software. Recent models allow pre-programming of patient details so that the spirometer also gives percent predicted values. These are good for simple screening and are accurate for diagnosis if the more expensive desktop form is impractical or too expensive.

Many spirometers provide two forms of traces. One is the standard plot of volume exhaled against time. The other is a plot of flow (L/sec) on the vertical axis versus volume expired (L) on the horizontal axis. This is a flow–volume trace and is most helpful in diagnosing airway obstruction[10].

Spirometric data are viewed as graphs called **spirograms**. Measurements of exhaled volume (in liters), time (in seconds), and airflow rates (in liters per sec) are determined and displayed on the spirograms. There are two types of spirograms that will be used in the spirometry component:

Volume-Time

The basic volume vs. time curve contains points corresponding to the FEV1 and FVC.

Flow-Volume

The expiratory flow vs. volume curve displays instantaneous airflow rates as a function of volume exhaled. This curve also contains points corresponding to the PEF and FVC[11].

Methodology of Spirometry

Lung-Volume Subdivisionss

Pulmonary gas transport depends on the filling capacity of the lungs with breathing gas and the speed and uniformity of gas distribution. Markers of lung filling are the lung-volume subdivisions, which are measured at slow breathing, while flow rates are of minor interest. When two or more volume subdivisions are combined, lung capacities result. The most important role in PF testing is played by vital capacity (VC), the volume of complete inspiration (IVC) or slow expiration volume (EVC), both directly accessible by spirometry. At the end of a deep expiration, residual lung volume (RV) remains in the lungs, which can be determined by gas dilation methods or body plethysmography only. Consequently, the sum of VC and residual volume (RV) determines the volume at the end of a complete inspiration and is called the total lung capacity (TLC), an important measure of maximum lung volume.

Vital capacity consists of the subdivisions

• Tidal volume (*V*T), the volume ventilated during a regular breathing cycle.
• Expiratory reserve volume (ERV), the volume that can be exhaled from breathing baseline, i. e., at the end of a regular breathing cycle.
• Inspiratory reserve volume (IRV), the volume which can be inhaled above the inspiratory breath of a regular *V*T cycle.
• Inspiratory capacity (IC), i.e., the sum of VT and IRV. As for TLC and RV, the functional residual capacity (FRC), being the sum of RV and ERV, can be determined by more elaborate methods. As of lung-volume subdivisions is time consuming and diagnostically less significant, subdivisions will be evaluated in combination with the more relevant FRC.

Forced Spirometry

Forced expiration(forced expiratory volume in the first second (FEV1) and forced vital capacity) not

only delivers important information about an existing pulmonary obstruction in the sense of reduced airway diameter but may also indicate a loss in lung retraction, parallel to diminished lung elasticity and enhanced airway instability. Reduced elasticity mirrors the loss of functional tissue structure, resulting in reduced surface area for gas exchange and accompanied by a high demand in ventilation at reduced maximum oxygen uptake. In contrast to the predominantly practiced forced expiration, forced inspiration can be used for differential diagnosis of extrathoracic obstruction, e.g., tracheal stenosis. Being technically less demanding, the recording of a forced spirogram prevailed traditionally; today the flow–volume loop is registered together with the spirogram. The time-based spirogram offers observation of expiratory time, typically 3 s in a healthy subject but maybe as long as 10–20 s in an obstructed patient. As the forced spirogram represents the shape of an exponential function, analysis of its form requires a certain understanding of the underlying pulmonary mechanics. In contrast, the flow–volume loop represents a linearization of the exponential expiratory decay, as an exponential and its derivative are recorded against each other. In a healthy person the rise to peak flow is steep, while the decay is (quite) straight. The very obvious deviation from a straight line towards a concave shape means a reduction in flow, which is easy to interpret.

Tests of forced expiration:

- Peak Expiratory Flow Rate (PEFR**)**

The peak flow sustained over a 10msec period at the beginning of a forced expiratory manoeuvre can be measured sing wrights peak flow meter (or the inexpensive mini wright meter). From a position of full inspiration, air is forcibly expired across a pivoted vane (wright's) or a lightweight piston (mini wright) both of which are spring loaded and cased. The displacement of the vane or piston is proportional to maximum flow rate[13].

Practical Considerations

The quality of most pulmonary functions tests, in particular forced expiration, depends on the cooperation of the test subject and the (incentive) instructions of the operator. After preparing the spirometer, verification or calibration, and insertion of a new mouthpiece or breathing filter, the testing procedure is explained to the subject. Before and during spirometry, breathing maneuvers are further supported by the operator, and the subject should be motivated to maximize forcing efforts and exhale completely. The subject, wearing a nose clip, should be able to breathe free and unhindered through the mouthpiece and should be encouraged to practice before recording starts. All tests should be carried out in the same body position, generally sitting. In screening and industrial testing, also a standing position is adequate. In children and seniors, use of a mouthpiece with a sealing lip is recommended. A smaller, pediatric mouthpiece should be applied in children. Unless disposable flow sensors are used, a disposable filter attached to the sensor is mandated, both as a hygienic requirement and a preventive measure to avoid intrusion of sputum into the flow sensor. Both the ERS and ATS have issued recommendations in which at least daily volume calibration using a calibration syringe is mandated. In a calibration-free device, volume verification should be carried out at least once a month.

Slow Vital Capacity and Volume Subdivisions Instructions

The subject breathes at resting baseline. After a couple of breaths, the operator gives instructions for a slow, continuous, maximum inspiration followed by a slow, maximum expiration, followed again by a complete inspiration. The cycle should be repeated again. Parameters from repeated tests should not deviate by more than 5%.

Forced Spirometry and Flow–Volume Loops Instructions

Breathing at resting baseline, the subject is instructed to inhale completely and exhale as hard and as long as possible. This procedure should be repeated at least twice. Breathing maneuvers need to be instructed clearly; especially the forced exhalation should be supported by incentive commands. For evaluation, maximum forced flow rates (FEFs) are picked from the recording. Either best values are taken from all forced traces or the trace with the

highest sum of FVC and FEV1 is considered for analysis.

Predicted Values

Evaluation of spirometry testing is carried out by comparing measured data with predicted norms or reference data, derived from body weight, height, age, and gender. Predictions are calculated from equations published and recommended by scientific societies. When comparing measured with predicted values, the standard deviation, an indicator of the variation of the tested parameter in a healthy population, needs to be taken into consideration.

The determination of the residual *R*

$$R = \frac{M - S}{\text{SD}}$$

is recommended, where *M* is the measured value, *S* is the predicted value, and SD is the standard deviation, allowing comparison with a distribution in the reference population and detection of significant deviations[9].

Flow Volume Curves

Flow volume curves are produced when a patient performs a maximal inspiratory manoeuvre which is then followed by a maximal expiratory effort. A graph is produced with a positive expiratory limb and a negative inspiratory limb. The maximal flow rate during expiration can also be measured (peak expiratory flow rate PEFR). With knowledge of the expected appearance of the flow volume loop in a normal patient, important information can be obtained from the morphology of the curve in patients with suspected respiratory disease. Patients with obstructive lung diseases with reduced expiratory flow in the peripheral airways typically have a concave appearance to the descending portion of the expiratory limb rather than a straight line (Figure No.1 and 2)[1].

Lung Volumes

Static lung volumes are measured with the use of whole body plethysmography in an airtight body box. Other techniques that can be used to measure static lung volumes included nitrogen washout or helium dilution. They cannot be measured by spirometry. A body plethysmograph, also called a whole-body plethysmograph or body box, consists of an airtight chamber, similar to a sealed phone booth, in which the patient is seated (Fig. 8.8). The thoracic movements created by the patient's breathing are transferred into volume and pressure swings inside the enclosure, which are measured and evaluated. Measurements are based on Boyle's law which states that at constant temperature the volume of a given mass of gas varies inversely with pressure. Therefore the increase in their chest volume slightly reduces the box volume (the non-person volume of the box) and thus slightly increases the pressure in the box. Static lung volumes can be obtained either by measuring the changes in pressure in a constant volume box or volume in a constant pressure box[5].

Diffusion Capacity

The measurement of diffusion capacity (DLCO also known as transfer factor) gives important information regarding the integrity and size of the alveolar blood membrane. It measures the diffusion of gas across the alveolar membrane which is determined by the surface area and integrity of the alveolar membrane and the pulmonary vascular bed. Normally the value is corrected for the patient's haemoglobin (DLCOc). DLCOc is measured using carbon monoxide gas, which is soluble and binds to haemoglobin with its uptake limited by diffusion only. It is measured by a single breath technique where 10% helium and 0.3% carbon monoxide are rapidly inspired, held for 10 seconds and then expired with the measurement of the remaining carbon monoxide. Comparison of the inspired and expired CO fractions allows calculation of DLCO[4].

Arterial blood gases

Arterial blood gas sampling provides important information on gas exchange and oxygen delivery to the tissues. Type 1 respiratory failure is defined as a partial pressure of oxygen (PaO2) < 8 kPa with normal partial pressure of carbon dioxide (PaCO2). Causes of type 1 respiratory failure include pneumonia and pulmonary embolism. Type 2 respiratory failure occurs when hypoxia is accompanied by hypercapnia (PaCO2 > 6.5 kPa). This is seen in ventilatory failure and examples of causes include respiratory muscle weakness and COPD[1].

Ergospirometry

Ergospirometry serves as the most prominent method to determine ventilation and gas exchange under physical exercise, in the English-speaking world often referred to as cardiopulmonary stress testing. A complete instrument consists of:

• A device producing a defined level of physical stress (ergometer)
• A transducer for measurement of ventilation
• Gas analyzers for O2 and CO2
• A computer for online processing of measured data, as well as
• A multichannel electrocardiograph (ECG).

For physical exercise, usually a bicycle or treadmill ergometer will be employed.[9]

Cardiopulmonary exercise testing (CPET) involves patients exercising on a treadmill or cycle ergometer with measurements of variables such ventilation, heart rate, oxygen uptake (V'O2) and cardiac output. This allows causes for a reduced exercise tolerance to be identified, which may be due to ventilatory abnormalities in those with chronic lung disease or impaired cardiac output in patients with cardiac disease. It may be useful in patients who complain of excessive breathlessness and in whom investigations such as echocardiogram and pulmonary functions tests are normal. A V'O2 peak standardized by body mass below 80% predicted is considered to be abnormal[12].

Table No.1: Indications for Pulmonary Function Tests

1. Investigation of patients with symptoms/signs/ investigations that suggest pulmonary disease e.g. • Cough • Wheeze • Breathlessness • Crackles • Abnormal chest x-ray
2. Monitoring patients with known pulmonary disease for progression and response to treatment e.g. • Interstitial fibrosis • COPD • Asthma • Pulmonary vascular disease
3. Investigation of patients with disease that may have a respiratory complications e.g. • Connective tissue disorders • Neuromuscular diseases
4. Preoperative evaluation prior to e.g. • Lung resection • Abdominal surgery • Cardiothoracic surgery
5. Evaluation patients a risk of lung diseases e.g. • Exposure to pulmonary toxins such a radiation, medication, or environmental or occupational exposure
6. Surveillance following lung transplantation to assess for • Acute rejection • Infection • Obliterative bronchiolitis

Contraindications to pulmonary function test

Myocardial infarction within the last month
Unstable angina
Recent thoraco-abdominal surgery
Recent ophthalmic surgery
Thoracic or abdominal aneurysm
Current pneumothorax

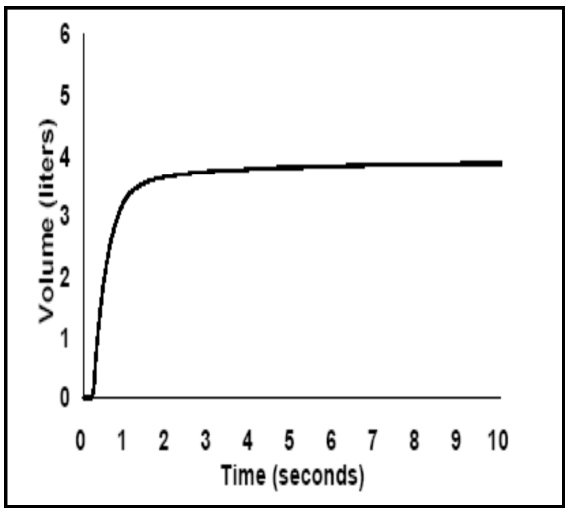

Figure No.1: Normal volume-time curve

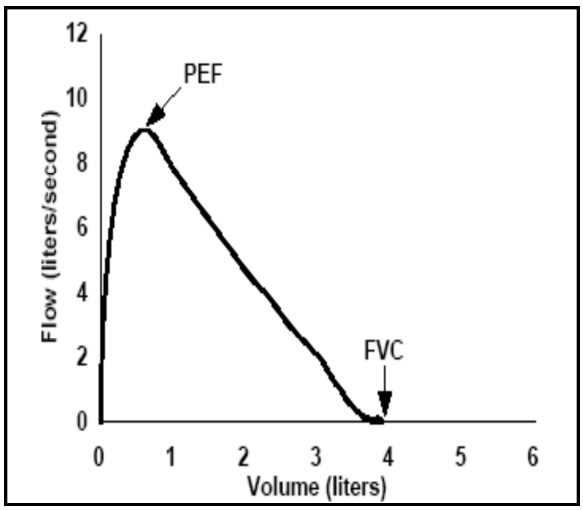

Figure No.2: Normal flow-volume curve

CONCLUSION

This article describes the working principles of major tests including spirometry, peak flowmetry, body plethysmography, arterial blood gases measurement and ergospirometry.

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CONFLICT OF INTEREST

None declared.

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