Pulmonary Function Testing

Hawa Edriss MD, Gilbert Berdine MD

The term PFT encompasses three different measures of lung function: spirometry, lung volumes, and diffusion capacity. In this article we will discuss spirometry which is the most commonly performed PFT. It measures the exhaled volume of air against time. Fast and cheap, it takes 15 minutes or less to perform testing.[1]

1. Indications

Spirometry is useful in diagnosing and monitoring respiratory diseases, including asthma, chronic obstructive pulmonary disease (COPD), various diffuse parenchymal lung diseases, and neuromuscular disorders (Table1).[2]

2. Spirometry Measurements

The most important measurements are the forced expiratory volume in 1 second (FEV1) and the forced vital capacity (FVC). The FEV1 measures the amount of air exhaled during the first second of a forced exhalation. The FVC measures the total volume of air forcefully exhaled after a maximal inspiration. All measurements are made at ambient pressure saturated with water vapor and at body temperature (37°C) (BTPS).[1] Both FVC and FEV1 are reported in liters. A decrease in FVC or FEV1 indicates impairment in ventilatory capacity. Eighty percent of predicted is considered to be the lower limit of normal.

Other measurements can be extracted from the FVC maneuvers, including the mean forced expiratory flow between 25% and 75% of the FVC **(FEF 25%–75%)** and the peak expiratory flow **(PEF)**, which is the maximum flow achieved during forced exhalation. Both are measured in liters per second.[2] The FEF 25%-75% is also known as the mid flow. The PEF is helpful to ascertain whether the effort was maximal. A PEF as percentage of predicted should be at least as high as the lesser of the FVC and FEV1 as percentage of predicted. A lower than expected PEF can be due to neuromuscular weakness, central airflow obstruction, or – most commonly – submaximal effort.

Table 1

Evaluate respiratory symptomsor radiographic findings
Assist in diagnosis of respiratory diseases
Monitor respiratory disease progression and response to therapy
Evaluate risk prior to lung surgery
Evaluate the pulmonary effects of occupational, environmental, and toxic exposures
Assess impairment or disability
Assist in determining disease prognosis
Assist in smoking cessation efforts

Changes in FEF 25%–75% reflect changes in small airways; its reduction is associated with small airway dysfunction. However, the FEF 25%–75% is a highly variable test that is dependent on exhalation time and is not specific for small airway disease in individual patients.[3] The PEF reflects the caliber of the large airways and is highly effort dependent. Although PEF can be measured using inexpensive devices, it is a more variable measurement than the FEV1, and the correlation between PEF and FEV1 in patients with airway obstruction is poor.[4] Neither the FEF 25%–75% nor the PEF offers any advantage over FEV1.[4,5]

3. Spirometry Performance

Before performing a PFT, a clear explanation of the test is necessary for optimal patient performance:

- In a sitting position, the thorax should be erect and the head should be in a neutral position (standing will increase FVC).
- The patient should breathe in and out several times with the nose clip in place.Then the patient should insert the mouthpiece. It should be between the teeth and the lips to provide a tight seal around it.
- Smokers should abstain from smoking for at least 1 hour prior to testing.[7]
- The reliability of the spirometer should be checked at least daily with a 3 L syringe. The instrument should **display both flow-volume and volume-time tracings**.[6]

Technique

The best overall result is obtained when the patient gives a maximal effort. After several normal (tidal) breaths, the patient is instructed to take a maximal inspiration to total lung capacity (TLC), and then the patient is instructed to forcefully exhale as hard, as fast, and as long as possible (5- 6 seconds). See Figure 1. In older patients at least 6 seconds may be needed to obtain an adequate result. When the exhalation has been satisfactorily completed, the patient is instructed to forcefully inhale back to TLC in order to complete the maneuver and close the loop.

The test should be repeated three times. A minimum of three and a maximum of eight maneuvers are performed until three acceptable curves are obtained. Two or three maneuvers that have values within a 5% difference of each other indicate reproducibility.

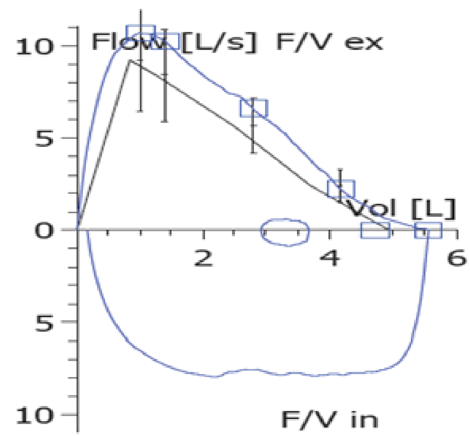

Figure 1A: Normal flow-volume loop (clinical files-G Berdine MD)

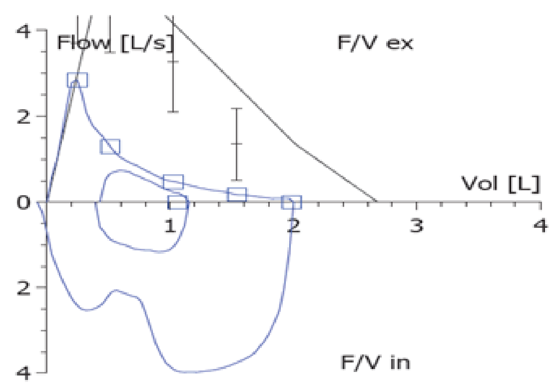

Figure 1B: Flow-volume loop in a patient with COPD (clinical files-G Berdine MD)

Cooresponding Author : Hawa Edriss MD
Author Contact Information: hawa.edriss@ttuhsc.edu
DOI: 10.12746/swrccc2014.0206.081

4. PFT INTERPRETATION

Assessment of test acceptability, reproducibility, repeatability, and integration with the patient's presentation are essential for PFT interpretation. The American Thoracic Society/European Respiratory Society (ATS/ERS) Task Force on Standardization of Lung Function Testing provides clear guidelines for assessing test acceptability and repeatability.[6] Criteria are listed below.

The test should be started with a sharp take-off with no hesitation with an extrapolated volume < 5% or 0.15 L. A question that needs to be answered during testing is:
Are the two largest values of FVC and FEV1 within 0.15 L of each other?

Good test criteria are a complete exhalation to RV, plateau on volume-time curve, and exhalation time ≥ 6 seconds (3 sec for children), and **no artifacts**, such as coughing, glottis closure, hesitation, and obstructed mouthpiece.

If the above criteria are not met, continue testing until criteria are met, a maximum of eight tests have been performed, or the patient is fatigued.

Interpretation of spirometry using the FVC, FEV1, and FEV1/FVC ratio can be categorized into three common patterns: normal, airflow obstruction, or a suggestion of restriction. While obstruction is defined based on spirometry alone, restriction requires lung volume measurements by helium dilution or body plethysmography for diagnosis.

Interpretation should begin with the shape of the flow volume loop. A normal loop (Figure 1-A) looks like a child's drawing of a sailboat. The expiratory limb is the triangular sail and should have a sharp peak and near straight line descent. The inspiratory limb is the rounded hull with maximal flow in the middle of inspiration.

Airflow ***obstruction*** is defined as a reduction in FEV1 out of proportion to the reduction in FVC. This can be determined graphically as a "sagging sail" in the flow volume loop (Figure 1-B) or numerically as a reduced FEV1/FVC. Note that FEV1/FVC is a ratio and has no units. Although a reduced FEV1/FVC defines obstruction, the severity of the obstruction is based on the degree of impairment in FEV1.

The term reduced or low FEV1/FVC is not used consistently. The ATS/ERS defines an obstructive ventilatory defect as a FEV1/FVC ratio below the 5th percentile of the predicted value, a statistically defined lower limit of normal (LLN).[8] The Global Initiative for Chronic Obstructive Lung Disease (GOLD) defines airway obstruction as a post-bronchodilator FEV1/FVC ratio less than 70%.[9] Both approaches use the FEV1 percent predicted to grade the severity of airway obstruction (Table 2).

Table 2

Definition of obstruction and classification of severity by spirometry

ATS/ERS	GOLD
FEV1/FVC<LLN	**FEV1/FVC<0.70**
FEV1% predicted	**FEV1%predicted**
>70 Mild	Stage I: Mild >80
60-69 Moderate	Stage II: Moderate <80
50-59 Moderately severe	Stage III: Severe <50
35-49 Severe	Stage IV: Very severe <30
<35 Very severe	

- In asthma with airway obstruction (FEV1/FVC ratio < 80%), repeat testing after an inhaled bronchodilator should increase the FEV1>200 mL or >12% from baseline. In general, FEV1/FVC ratio is a better measure of asthma severity than FEV1.
- Patients with COPD have less improvement after receiving bronchodilator challenges and the FEV1/FVC ratio <70%, and the FEV1 <80% of

normal remain abnormal.

Some individuals have FEV1/FVC ratio reduced but preserved FEV1 (i.e., greater than 100% of predicted). Patients with this pattern have been identified as obstructed or a "normal" physiologic variant.[8] Clinical correlation here is important. In healthy individuals this may represent unequal growth of the airways. However, in people with symptoms this result may indicate obstruction.

Aging and loss of elastic recoil lead to reduction in FEV1 more rapidly than FVC, resulting in a progressive reduction in the FEV1/FVC ratio. The GOLD uses a fixed ratio for FEV1/FVC for simplicity of inclusion criteria into studies. However, this may result in the over diagnosis of COPD in the elderly and the under diagnosis of COPD in the young.

A restrictive ventilatory defect is defined as a total lung capacity (TLC) below the 5th percentile of the predicted value. The best methods to measure lung volumes include plethysmography, inert gas, or nitrogen washout methods.

However, restrictive defects are suggested by a reduction in FVC with a normal value for FEV1/FVC. Patients with interstitial lung disease have stiff lungs and often demonstrate higher than normal values for FEV1/FVC. In extreme cases, the exhalation will be complete in less than 1 second and the FEV1 and FVC will be identical. Spirometry can exclude restrictive defects with accuracy greater than 95% if the FVC is normal.[9] Patients who have spirometry suggestive of restriction should have lung volumes measured to confirm the restriction.

Many patients do not fall neatly into any of the categories. These patients have ventilatory impairment based on reduced FVC and/or FEV1, but they do not meet the criteria for either obstruction or restriction. Some patients meet criteria for both obstruction and restriction. Mixed defects with apical emphysema and basilar fibrosis should be considered in these cases. Chest wall problems due to skeletal abnormalities or obesity should also be considered.

The following factors should be considered during PFT interpretation

- Factors that affect the PFTs testing include the formula used to predict the normal values, smoking status, height, age, weight, sex, ethnicity, and effort.
- In addition, several observations regarding PFT are important
  1. Males have larger PFT values than females. Taller people have larger volumes and higher maximal flow rates.
  2. The FEV1 decreases by about 30 ml/year.
  3. The residual volume (RV) increases, the vital capacity (VC) decreases with aging, and the TLC remains unchanged.
  4. African-Americans have lower values than Caucasians of the same height, age, and gender. Caucasians' FEV1 should be corrected by 0.88 for African- Americans. FEV1/FVC ratio should not be race corrected.

5. NormalUS reference values

Equations for predicted (normal) values have been developed for FVC and FEV1. The equations were originally obtained by linear regression of measured values for FVC and FEV1 against age and height in normal healthy subjects.[9] The general form of the equation is:

*Lung function parameter = a + b*height + c*age.*

The regressions were valid only for adults. The coefficient for height (b) is a positive number since FVC and FEV1 increase in larger subjects, and the coefficient for age (c) is a negative number since FVC and FEV1 decrease with age. Different coefficients were obtained for men and women. Subsequent efforts separated subjects by race.

It is well known that both FVC and FEV1 decrease faster with age in older patients. Hankinson *et al* modelled FVC and FEV1 to a 2^{nd} order polynomial in order to capture this curvature.[10] They recorded spirometric reference values in 1999 for 7,429 asymptomatic, nonsmoking Caucasians, African-Americans, and Mexican-Americans, eight to 80 years of age in the third National Health and Nutrition Examination Survey (NHANES III). These spirometry examinations followed the 1987 American Thoracic Society recommendations.

The general form of the reference equation is:

$$\textit{Lung function parameter} = b_0 + b_1 * age + b_2 * age^2 + b_3 * height^2$$

They concluded that both male and female Mexican-Americans and African-Americans have lower FEV1 values than do Caucasians for all age groups. When adjusted for height, only the African-Americans have lower FEV1 values. The lower FEV1 values observed in Mexican-Americans were due to their shorter heights compared with Caucasian participants of similar age.

African-Americans have FEV1 values lower than both Caucasians and Mexican-Americans even though they have similar heights for age. These differences may be due to a difference in body build; African-Americans in general have a smaller trunk: leg ratio.[10]

Examples

1. 25-year-old Caucasian man 6 feet tall (183 cm)

$$FVC= (-)\ 0.1933+0.00064 * 25 + (-)\ 0.000269 * 25^2 + 0.00018642 * 183^2 = 6.04\ L$$

2. 25-year-old Caucasian woman 5 feet 2 inches tall (157.5 cm)

$$FVC= (-)\ 0.3560 + 0.01870 * 25 + (-)\ 0.000382 * 25^2 + 0.00014815 * 157.3^2 = 3.54\ L$$

Author Affiliation: Hawa Edriss is a resident in Internal Medicine at TTUHSC in Lubbock, TX. Gilbert Berdine is a pulmonary physician in the Department of Internal Medicine at TTUHSC in Lubbock, TX.
Received: 03/12/2014
Accepted: 04/11/2014
Reviewers: Kenneth Nugent MD
Published electronically: 04/15/2014
Conflict of Interest Disclosures: None

References

1. Marciniuk DD. ACCP Pulmonary Medicine Board Review: 26th edition.
2. Mason RJ, Broaddus VC, *et al*. Murray and Nadel's Textbook of Respiratory Medicine, Fifth Edition. Chapter 24, 522-553.
3. McFadden ER, Linden DA. A reduction in maximum mid-expiratory flow rate. A spirographic manifestation of small airway disease. *Am J Med* 1972; 52: 725-73.
4. Brusasco V, Crapo R, Viegi G, et al. Coming together: The ATS/ERS consensus on clinical pulmonary function testing. *Eur Respir J* 2005; 26: 1-2.
5. Hegewald MJ, Lefor MJ, Jensen RL, *et al*. Peak expiratory flow is not a quality indicator for spirometry: Peak expiratory flow variability and FEV 1 are poorly correlated in an elderly population. *Chest* 2007; 131: 1494-1499.
6. Miller MR, Hankinson J, Brusasco V, *et al*.Standardization of spirometry. *Eur Respir J* 2005; 26: 319-338.
7. Pfenninger JL, Fowler GC. Pfenninger and Fowler's Procedures for Primary Care, Third Edition, chapter 91, 599-605© 2011, 2003, 1994 by Mosby, Inc, an affiliate of Elsevier Inc.
8. Pellegrino R, Viegi G, Brusasco V, *et al*. Interpretative strategies for lung function tests. *Eur Respir J*. 2005 Nov; 26:948-68.
9. http://www.hopkinsmedicine.org/pftlab/predeqns.html

10. Hankinson JL, Odencrantz JR, Fedan KB. Spirometric reference values from a sample of the general U.S. population. *Am J Respir Crit Care Med* 1999; 159:179-87.