Pulmonary Function Tests - The Principles, Indications, and Interpretation

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Introduction

The measurement of pulmonary functions is one of the objective methods to provide valuable information for the diagnosis and management of respiratory diseases. Pulmonary functions are evaluated through the measurement of lung volumes, resistance and compliance, spirometry, and diffusing capacity according to the characteristics of the respiratory system. The focus of this chapter is the principles, indications, and interpretation of spirometry. More information about the measurement of lung volumes, resistance, diffusing capacity, and bronchodilator response could be found in ATS/ERS guidelines for pulmonary function testing.[1–5]

Principles of pulmonary function tests

1) Components of lung volumes and capacities

Lung volume is associated with normal physiologic functions. Inspiratory and expiratory lung volumes measured by spirometry are useful for evaluating lung diseases and necessary for a correct diagnosis. Figure 1 shows the components of lung volumes and capacities. Each component is called as “volume”, and “capacity” means a sum of two or more volumes.

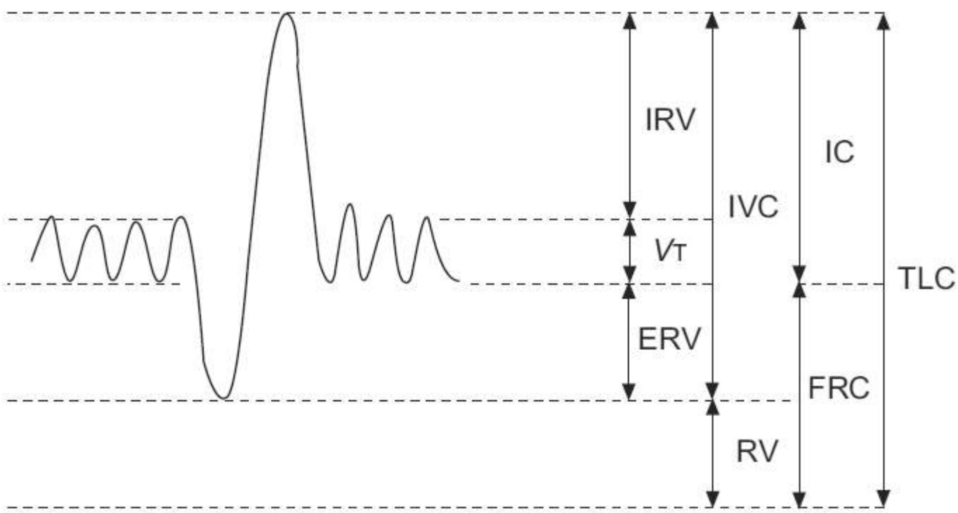


Fig. 1. Static lung volumes and capacities. 5 IVC, inspiratory vital capacity; IRV, inspiratory reserve volume; V_T, tidal volume (TV); ERV, expiratory reserve volume; RV, residual volume; IC, inspiratory capacity; FRC, functional residual capacity; TLC, total lung capacity.

① Tidal volume (TV, V_T): the volume of inhaled or exhaled gas during the respiratory cycle.

② Vital capacity (VC): the volume change at the mouth between the positions of full inspiration and complete expiration.

③ Functional residual capacity (FRC): the volume of gas remained at end expiration during tidal breathing.

④ Residual volume (RV): the volume of gas remaining after a maximal exhalation.

⑤ Total lung capacity (TLC): the volume of gas in the lungs after a maximal inspiration, or the sum of all volume components.

2) Measurement of lung volume

Forced exhalation methods could not measure FRC. By using body plethysmography or gas dilution methods, all components of lung volumes including FRC or RV could be measured. Details are elsewhere.[5]

3) Measurement of resistance and elastance

To measure the airway resistance, body plethysmography, forced oscillation technique (FOT), or interrupter technique could be used. These methods are useful to measure the pulmonary functions of preschool children.

4) Forced expiratory spirometry

This method is the most common of the pulmonary function tests (PFTs). Because it measures the volume and flow of air on forced respiration using a spirometer, the maneuver is highly dependent on patient cooperation and effort. The most important parts of spirometry are the forced vital capacity (FVC) and the forced expiratory volume (FEV) in one second (FEV_1). The results of spirometry can be displayed as graphs, a volume-time curve and a flow-volume loop. FVC and FEV_1 should be measured and recorded as the largest volume from a series of three forced expiratory curves.

① FEVt: FEVt is the maximal volume exhaled by t seconds of a forced expiration from a full inspiration, expressed in liters at body temperature and ambient pressure saturated with water vapor. In the case of very young children, who is not able to produce prolonged expirations, there is increasing evidence of clinical usefulness of forced expiratory times of <1s.[6,7]

② FEV_1/FVC: The FEV_1 for expired volume is generally standardized as a ratio of FEV_1/FVC. In some patients, a slow or unforced VC or IVC may provide more appropriate denominator (FEV_1/VC %).

③ FEF25-75% (known as the maximum mid-expiratory flow, MMEF): $FEF_{25-75\%}$ is the mean forced expiratory flow between 25% and 75% of the FVC. $FEF_{25-75\%}$ is highly dependent on the validity of the FVC measurement and the level of expiratory effort. It is useful to evaluate the small airway obstruction.

④ PEF (peak expiratory flow): PEF is the maximum expiratory flow achieved from a maximum forced expiration from the point of maximal inspiration, expressed in L/s. It is often expressed L/min when PEF is measured using a patient-administered portable PEF meter (peak flow meter). The rate of PEF (peak expiratory flow rate, PEFR) is a useful parameter to monitor patients with asthma. PEFR is generally lowest in the morning and maximal in the evening. Diurnal variation of PEFR is calculated as the difference from the maximal to minimal PEFR divided as the mean PEFR. The normal PEFR variability is less than 10%. Asthma should be suspected when the patents have higher than 10% of mean PEFR variability in 2 weeks and can be diagnosed at more than 20% improvement after bronchodilator inhalation or 20% increase of PEFR after 4 weeks of treatment.

⑤ Maximal expiratory flow-volume loops

Figure 2. shows the relationship between the volume-time curve (A) and flow-volume loop (B). Typical examples of commonly encountered flow-volume loop curves are shown in Figure 3 and 4.[3]

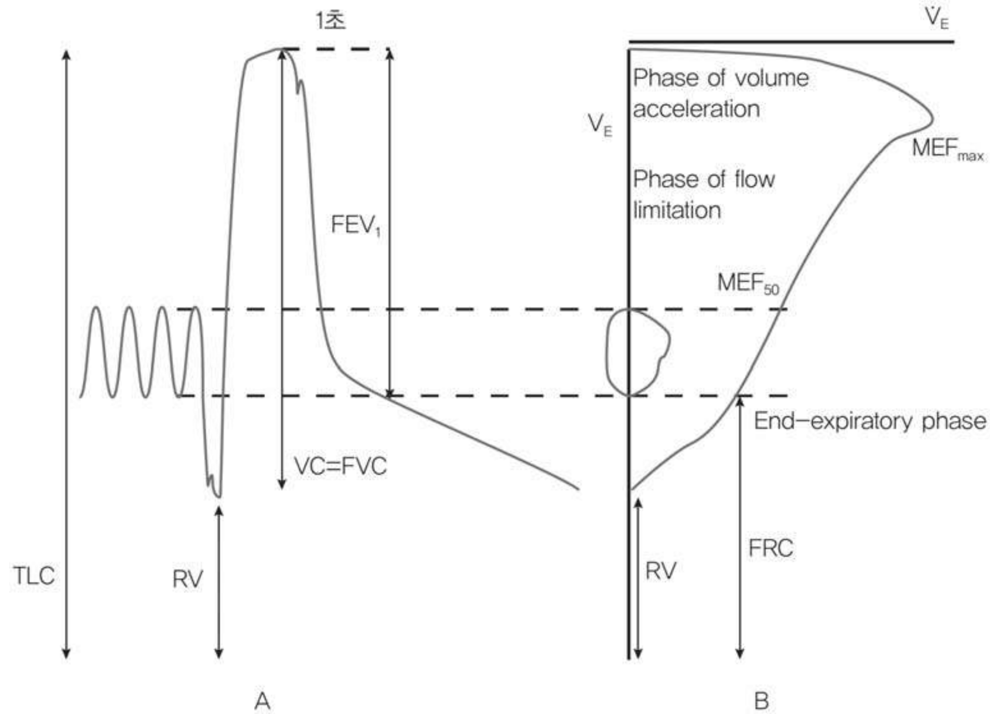


Figure 2. The relationship between volume-time curve (A) and flow-volume loop (B).[8] FEV_1, forced expiratory volume in one second; MEF_{max}, maximal expiratory flow Rate; MEF_{50}, Mid-expiratory flow rate; VE, expiratory flow volume; VE, expiratory flow rate.

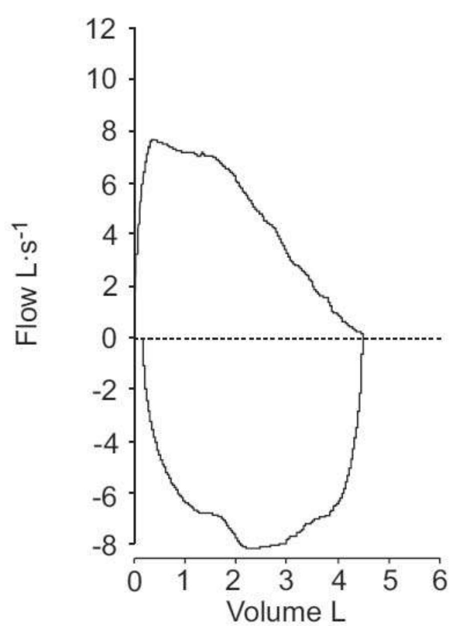


Figure 3. Flow-volume loop of a normal subject.

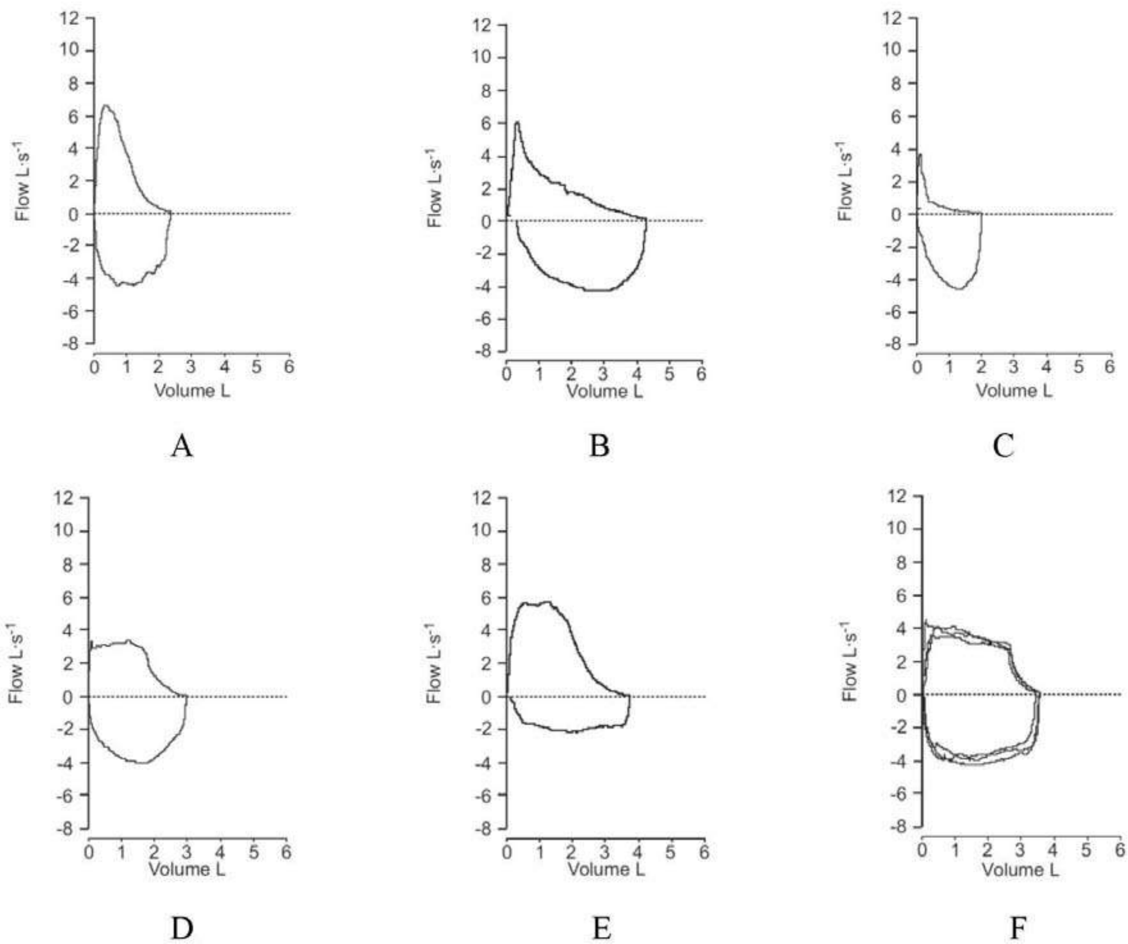


Figure 4. The examples of flow–volume loops. A, a normal subject with end–expiratory curvilinearity, which can be seen with ageing; B, moderate airflow limitation in a subject with asthma; C, severe airflow limitation in a subject with chronic obstructive pulmonary disease; D, variable intra–thoracic upper airway obstruction; E, variable extra–thoracic upper airway obstruction; F, fixed upper airway obstruction shown by three maneuvers.

Indications and contraindications

Clinicians use PFTs to ① evaluate and quantify the mechanical dysfunction of the respiratory system; ② define the characteristics of the dysfunction as restrictive, obstructive, or mixed; ③ diagnose and follow–up respiratory diseases; ④ evaluate the effect of therapeutic interventions; ⑤ evaluate the risk of respiratory complication after surgery; and ⑥ diagnose job–related respiratory disabilities.

Contraindications of the tests are any of the conditions can affect the optimal or repeatable results, including acute respiratory infections, hemoptysis of unproven etiology, pneumothorax, myocardial infarction in the recent 12 months, cerebral or aortic aneurysm, oral or facial pain exacerbated by a mouthpiece, and chest or abdominal pain of any cause.

Interpretation

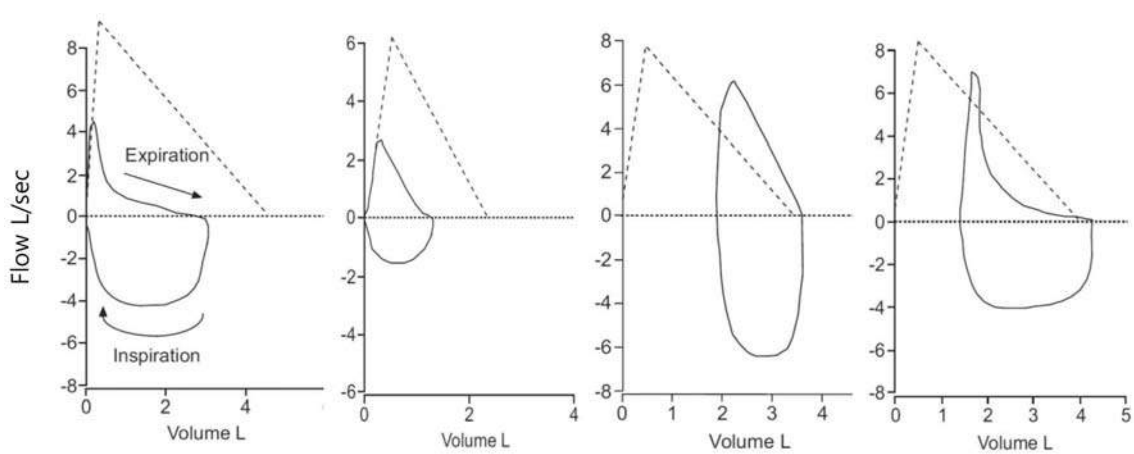
Before the interpretation of PFTs, it needs to be evaluated whether the tests are appropriate. Interpretation is usually based on comparisons of the test results in a patient or subject with reference values. If pulmonary dysfunction is found, its classification and degree of disability are evaluated. Predicted (reference) values or equations can be obtained from “normal” or “healthy” subjects with the same sex, age, and height in a general population. Height and weight should be measured for each patient at the time of testing. To differ the dysfunctions, almost results of spirometry are shown as a percentage of predicted values. The normal values of FVC or FEV1 and FEF25%–75% are considered as higher than 80% and 50%–60% of the predicted values, respectively.

1) Types of pulmonary dysfunctions

Abnormal lung functions are divided as obstructive, restrictive, and mixed type.

An obstructive abnormality is characterized as a reduction of maximal airflow from the lung, that implies airway narrowing during expiration. It is defined as a reduction of FEV1/FVC ratio below the 5th percentile of the predicted value. Typical examples are shown in Figure 5A and 5B. Obstructive patterns are commonly observed in patients with asthma, COPD, emphysema, or bronchiectasis.[4]

A restrictive dysfunction is characterized as a reduction of TLC below the 5th percentile of the predicted value, and normal FEV1/FVC. The examples of restrictive dysfunctions are shown in 5C. Chest wall deformities like scoliosis, disease of respiratory muscles, interstitial pneumonitis, pulmonary fibrosis, and congenital cysts are typical restrictive pulmonary diseases. Mixed type is shown in Figure 5D.



A B C D

Figure 5. The examples of pulmonary dysfunctions. A, obstructive pattern with a low FEV_1/VC; B, obstructive pattern with normal FEV_1/VC; C, a typical restrictive defect; D, mixed defect with a low TLC and a low FEV_1/VC ratio.

2) Degree of pulmonary dysfunctions

The degree of pulmonary dysfunctions should be interpreted with clinical experience. The severity of spirometric abnormality based on FEV1 is classified as follows: mild, >70% of predicted value; moderate, 60%–69%; moderately severe, 50%–59%; severe, 35%–49%; very severe, < 35%. The severity of restrictive dysfunctions can be evaluated with a predicted value of FVC or TLC with the same criteria as above.[3]

According to the progression of obstructive diseases FVC, FEV_1, and $FEF_{25\%-75\%}$ are decreased with a different proportion. $FEF_{25\%-75\%}$ is generally considered as an early parameter of airway obstruction and FVC is usually decreased in a later period of the disease. Because the reduction of FEV_1 is linearly associated with a disease progression, it is suitable for long term evaluation of the degree of obstruction.

Conclusion

PFTs are critical tools for the diagnosis, evaluation of treatment response, and prediction of progression of the pulmonary disease. For the exact and right application of PFTs, comprehension of test principles, appropriate pretest preparation, quality control of device, precise measurement under the standardized protocol, and detailed interpretation based on clinical characteristics are essential.

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