Pulmonary Function Tests (PFT)

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Pulmonary function tests (PFT) are a battery of tests that measure lung function and aid in the management of the respiratory disease. They are performed using standardized equipment and can be used for diagnosis, determining prognosis, management, and follow-up for patients with pulmonary pathology. Although PFT may not identify the exact pathology, it broadly classifies respiratory disorders as either obstructive or restrictive. In this article, the role of PFT in the measurement of lung mechanics and diagnosis of various diseases will be discussed in detail.

Definition of PFT

What is PFT?

PFT (pulmonary function tests) can measure lung mechanics (spirometry and lung volumes) or the gas exchange/diffusion function of the respiratory system.

Categories of PFT

There are 3 categories of tests:

Spirometry: FVC and FEV1

- Measures volume of air exhaled as a function of time
- Restrictive lung disease has a reduced volume, i.e. a low FVC
- Obstructive lung disease has a reduced flow, i.e. a low FEV1

Lung volumes: TLC, RV

- The addition of 2 or more volumes comprises a capacity
- Nitrogen washout and helium dilution technique
- Body plethysmography is the standard for measuring lung volumes

Image: Body box with male subject enclosed, by Finchbook01. License: CC BY-SA 3.0

Gas Exchange: DLCO, $AaDO_2$

- Ability to transport gas from alveoli to blood
- Estimates surface area available for gas exchange
- Depends on hemoglobin (Hb) and cardiac output

Indication of PFT

Pulmonary function tests (PFT) are mainly diagnostic/prognostic.

1. Diagnostic: screening of at-risk patients, such as age > 70 years, obese; evaluation of chronic cough; follow-up for patients with chronic lung disease
2. Prognostic: before lung surgery, to evaluate response to drugs, and to assess the degree of disability

Contraindications of PFT

Recent eye surgery, abdominal aneurysms, hemoptysis, pneumothorax, and recent myocardial infarction.

Lung Volumes and Capacities

Volumes

Tidal volume (TV or VT): volume of air inhaled or exhaled during regular respiration at rest; normal value: 500 ml

Inspiratory reserve volume (IRV): volume of air that can be maximally inhaled above and after a normal tidal inspiration; normal value: 3,000 ml

Expiratory reserve volume (ERV): volume of air that can be maximally exhaled after a normal tidal expiration; normal value: 1,500 ml

Residual volume (RV): the amount of air that remains in the lungs after maximal forced exhalation; cannot be measured directly by spirometry but is indirectly calculated as RV = FRC – ERV; normal value: 20–25mL/kg or 1,200 mL.

Capacities (sum of 2 or more volumes)

Total lung capacity (TLC): volume of air present in lungs after maximum deep inspiration; the sum of all volumes: **TLC = IRV + TV + ERV + RV**; normal value: 5,000–6,000 ml

Vital capacity (VC): maximum volume of air exhaled after a maximum deep inspiration: **VC = IRV + TV + ERV or VC = TLC – RV**; normal value: 4,500–5,000 ml

Inspiratory capacity (IC): maximum volume of air inspired after a normal tidal expiration: **IC = TV + IRV**; normal value: 2,400–3,600 ml

Expiratory capacity (EC): maximum volume of air expired after normal tidal inspiration: **EC = TV+ ERV**; normal value: 1,800–2,300 ml

Functional residual capacity (FRC): volume of air remaining in the lungs after normal tidal expiration: **FRC = ERV + RV**. FRC is an important component that maintains a continuous exchange of oxygen and carbon dioxide at the alveolar-capillary membrane. Collapse or atelectasis of the lungs leads to a reduction in FRC, causing hypoxemia and hypercarbia. The normal value is 2,500 ml.

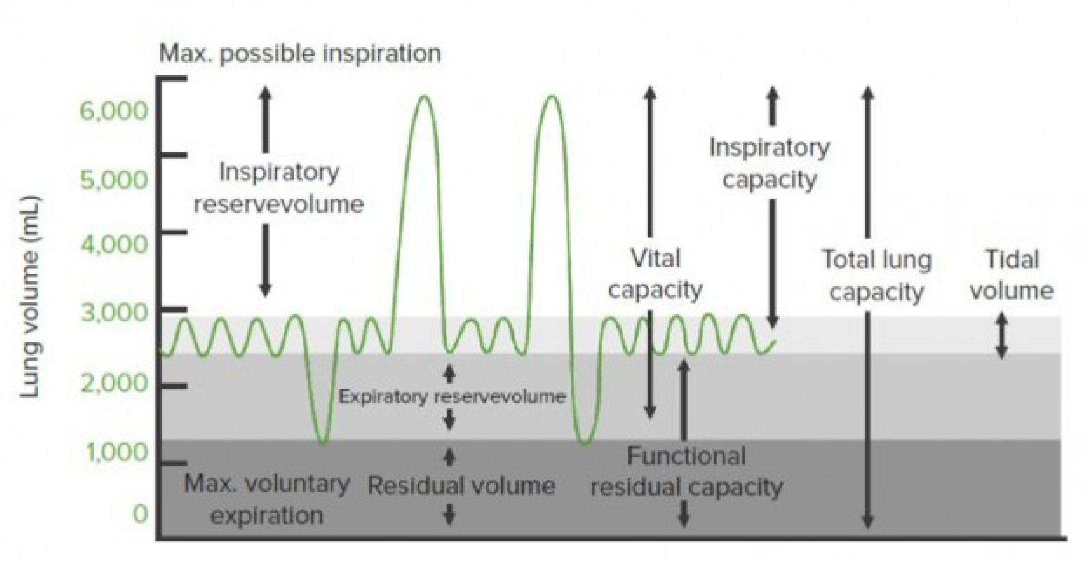


Image: Functional residual capacity

Spirometry

Image: Doing a spirometry, by Jmarchn. License: CC BY-SA 3.0

Spirometry is the most frequently used measure of pulmonary function. It measures the volume of air inhaled or exhaled by the patient as a function of time. The patient is asked to take a deep inspiration and then to forcefully expel air, as quickly and as long as possible. The results of the test include:

- **Forced vital capacity (FVC):** maximum volume of air forcefully exhaled after a maximal inspiration. This is usually reduced in restrictive lung disease; however, an obstructive lung disease with significant hyperinflation can also cause reduced FVC.

- **FEV1:** volume of air exhaled during the initial second of the FVC maneuver.
- **The ratio of FEV1/FVC:** Normal value is > 75%. The value is decreased in obstructive lung disease. Values < 50% suggests a severe obstruction.
- **FEF 25–75% (forced mid-expiratory flow):** maximum flow rate during mid-expiratory part of the FVC maneuver. Expressed in L/min, it represents the status of small airways. Normal value is 300 L/min.
- **PEFR (peak expiratory flow rate):** Maximal flow rate during the FVC maneuver occurs in the initial 0.1 seconds. It gives a crude estimate of larger airway function. Normal value is 400–700 L/min.

Important: Spirometry does not measure volumes such as FRC, TC, and RV.

Two patterns of results are identified: obstructive and restrictive diseases.

In **obstructive diseases**, a reduction in flow is predominant, leading to low FEV1; however, FVC may be normal or low. Hence, the FEV1/FVC ratio is usually < 0.7.

Reversibility: An increase in FEV1 by 12–15% on repeat spirometry after administration of a bronchodilator (salbutamol) is characteristic of asthma.

In **restrictive diseases**, a reduction in lung volume is predominant, which leads to low FVC; however, FEV1 may be normal or low. Hence, FEV1/FVC ratio is > 0.7 (and may be > 1.0).

This needs confirmation, as RV cannot be measured by spirometry (low RV is the hallmark of restrictive lung disease).

Loop spirometry

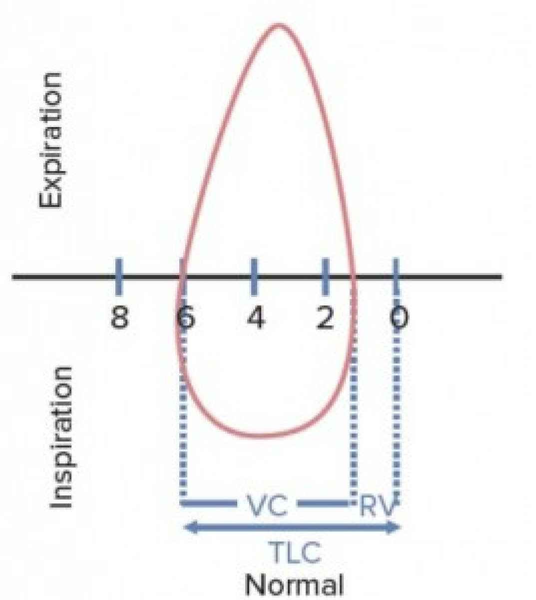


Image: Loop spirometry

Flow volume loops are formed when a patient performs the spirometry maneuver, and a graph is plotted with the volume on the x-axis and the flow on the y-axis. The expiratory limb is usually represented as positive. The initial one-third of the expiratory flow is effort dependant; the latter part is effort independent; hence the shape. The inspiratory limb is entirely effort dependent, and the curve is smooth (useful for identifying the phase of respiration if not labeled).

In the obstructive pattern of the flow-volume loop, there is a decrease in the height of the y-axis, which represents decreased air flow. The volume remains normal or **high (hyper-inflation)**. In the restrictive pattern, there is predominantly reduced volume, which is more prominent than the decrease in flow.

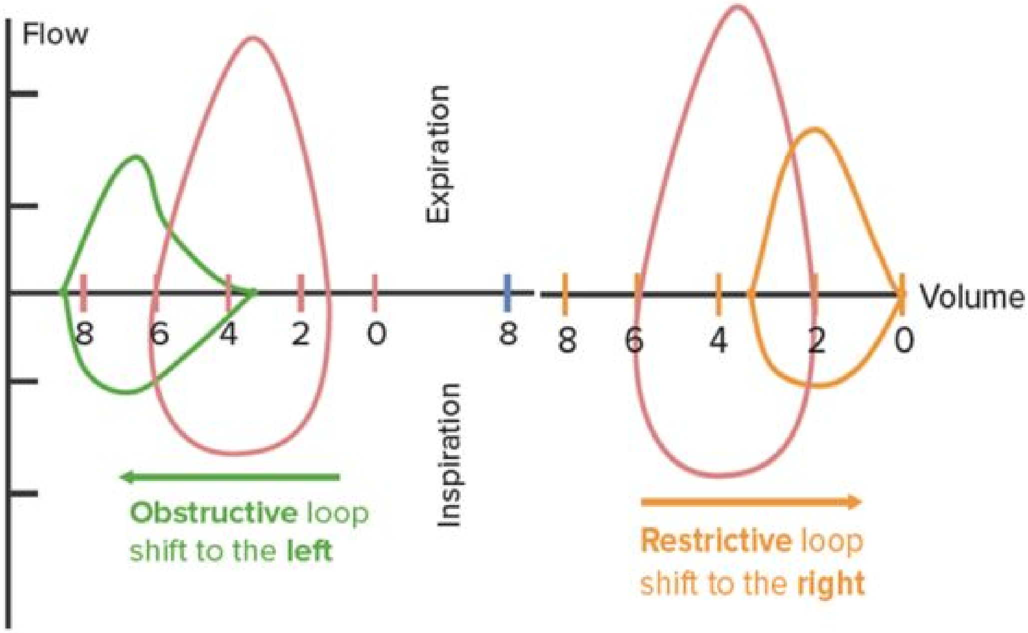


Image: Loop spirometry

Limitation of spirometry

Spirometry cannot measure RV or TLC. It is important to differentiate the cause of decreased VC in a patient suffering from **chronic obstructive pulmonary disease (COPD)**. In COPD, VC can be reduced in two scenarios:

- The patient has a superimposed **restrictive lung disease**.
- The patient has significant **hyper-inflation**.

These can be differentiated using lung volume measurement. The former will have a reduced TLC, while hyper-inflation will show increased TLC. Hence, a confirmation by lung volume studies is necessary.

Detection of upper airway obstruction–other spirometry patterns

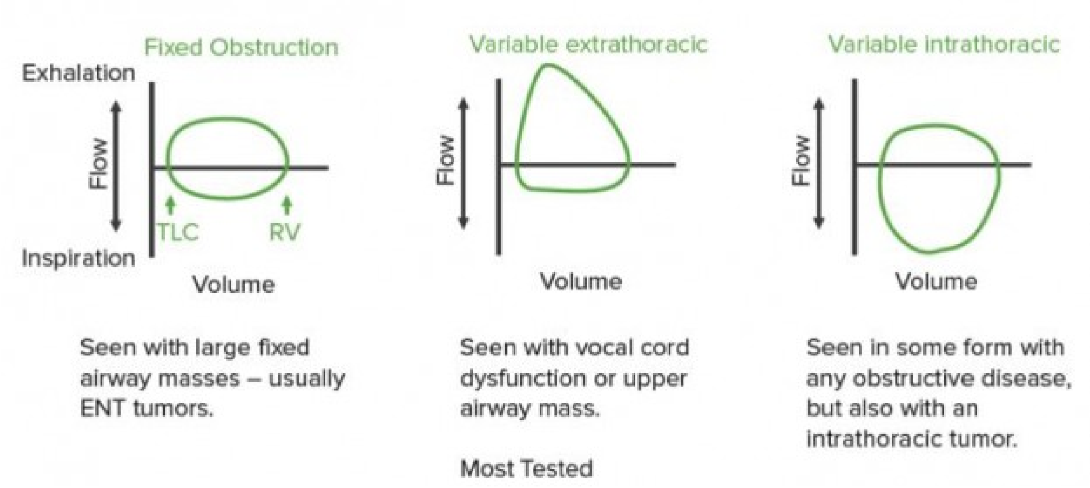


Image: Detection of upper airway obstruction

- **Fixed airway obstruction: constant limitation of flow during inspiration and expiration; for example: stricture, goiter, or stenosis**
- **Variable extrathoracic obstruction:** Reduction in flow is greater during inspiration (airways tend to collapse during inspiration due to negative transmural pressure). Positive pressure in airway during expiration decreases obstruction. For example: vocal cord palsy, obstructive sleep apnea
- **Variable intrathoracic obstruction:** Reduction inflow is greater during expiration (high pleural pressure decreases airway diameter). During inspiration, lower pleural pressure around the airway tends to decrease obstruction. For example: tracheomalacia, tumor of bronchus

Lung Volumes – RV, FRC, TLC

Gas dilution technique

N2 washout: Patient breathes 100% oxygen, so that all nitrogen in the lungs is washed out. The difference in nitrogen volume at initial exhaled concentration and final concentration gives the value of FRC.

He dilution: Patient breathes from a reservoir containing a known volume of gas with a trace of helium. The inhaled helium gets diluted in the gas present in lungs. The concentration of helium in the exhaled gas is expressed as a percentage, giving the lung volume. For example, if the patient breathes 50 mL of helium, and its concentration in the exhaled gas is 1%, the volume of the lung is 5 L.

Plethysmography

The patient sits inside an airtight body box with a known volume. The patient pants with an open glottis against a closed shutter. The increase in chest volume reduces the relative box volume and increases the box pressure. Measurements are done during expiration, and hence FRC is measured. The principal behind plethysmography is Boyle’s law (P x V = K).

Important: Lung volumes, such as RV, FRC, and TLC, cannot be measured by spirometry.

Applications of volume testing

- Measures RV, FRC, and TLC (which spirometry cannot measure)
- Spirometry only measures FVC, which can be misleading when used alone.
- Reduced RV, FRC, and TLC is seen in restrictive diseases like interstitial lung disease, sarcoidosis, or fibrosis.
- Increased RV, FRC, and TLC is seen in obstructive lung diseases like asthma, COPD, and cystic fibrosis.

Gas Exchange Function – DLCO, $AaDO_2$

DLCO (Diffusion capacity of Carbon Monoxide)

The patient inspires a diluted mixture of CO and is told to hold their breath for 10 seconds. The amount of CO taken up is then measured by infrared analysis.

DLCO = CO (ml/min/mm Hg) ÷ PACO – PcCO

CO is the ideal gas for this study, as it has a very high affinity for Hb and very low plasma/lung concentration. It demonstrates the ability of the lung to transport inhaled gas from the alveoli to the blood. Normal value is 20–30 ml/min/mm Hg.

DLCO values depend on three factors:

- Thickness and permeability of alveolar-capillary membrane (increased in pulmonary bleeding, interstitial lung disease)
- Hemoglobin concentration
- Cardiac output

Factors altering DLCO

Decrease DLCO (< 80%)	Increase DLCO (> 120%)
Anemia	Polycythemia
Emphysema	Exercise
Fibrosis	Congestive heart failure

Alveolar to arterial oxygen tension gradient (AaDO2)

- Detects the difference between alveolar oxygen (PaO_2) and arterial oxygen tension (PaO_2)
- Needs arterial blood gas analysis for PaO_2
- Normal values are below 10 mm Hg, and values above 100 mm Hg indicate significant impairment in gas exchange.

Cardiopulmonary reserve/exercise testing

- The stair-climbing test and 6-minute walk test measure changes in SaO_2/SpO_2, HR, and oxygen utilization (VaO_2).
- These tests analyze the individual’s ability to cope with increased metabolic demands during exercise.
- They give a clear picture of the functional improvement of a patient during follow-up.

Summary

Parameter	Obstructive lung disease	Restrictive lung disease
TLC	High/normal	Very low
VC or FVC	Low/normal	Very low
RV	High	Low
FRC	High	Low
FEV1	Very Low	Normal/low
FEV1/FVC	Low	Normal/high
Peak flow	Low	Low
Examples	COPD, asthma	Interstitial lung disease, fibrosis

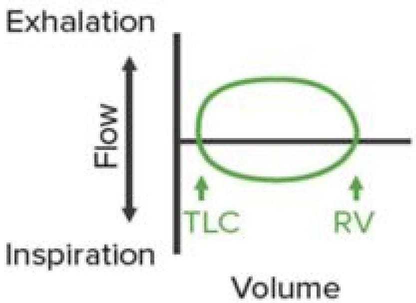
Review Questions

The correct answers can be found below the references.

1. Which of the following is not true regarding a patient with obstructive lung disease?

A. History of chronic smoking may be present. TLC, RV, and FVC are all high.
B. TLC and RV are high, but FVC is low.
C. FEV1, FVC, and PEFR are all low.
D. Repeat spirometry after 15 minutes of bronchodilator therapy may show a 12–15% improvement in FEV1.

2. A 40-year-old man presents to the outpatient department with complaints of dyspnea and wheezing. He has a history of tracheostomy and prolonged ventilation two years ago due to acute respiratory distress syndrome. His tracheostomy was removed after four months. His flow-volume loop is as follows:



What is the most appropriate interpretation of the flow-volume loop?

A. Restriction of flow is predominantly during expiration.
B. Bronchodilator use is likely to produce a 15% improvement in obstruction.
C. Flow volume loop shows variable intrathoracic obstruction.
D. Flow volume loop suggests fixed upper airway obstruction.
E. DLCO would be significantly affected in this patient.

3. A 28-year-old woman presents to your clinic for evaluation of dyspnea on exertion. She has noticed her symptoms for the past two months and feels that dyspnea is slowly increasing. She is a non-smoker and has no prior history of

asthma. She has a history of intermittent rash and joint pain. She has many parakeets at home. Her pulmonary function test results are as follows:

Parameters	Actual	Predicted
FVC (L)	1.84	4.54
FEV1 (L)	1.52	3.65
FEV1/FVC %	82.6	80.3
RV (L)	1.21	1.99
DLCO	6.23	33.21

Which of the following statements best describes this patient?

A. Decreased FVC in this condition is due to obstructive lung disease.
B. DLCO reduction is characteristic of restrictive lung disease.
C. Flow volume loop will show a shift to left with increased volume.
D. Low RV in this patient clinches the diagnosis of restrictive lung disease.
E. Volume studies are expensive and unnecessary in such situations.

References

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Diffusing capacity for carbon monoxide via uptodate.com

Correct answers: 1B, 2D, 3D

Notes