Pulmonary function tests (PFT) are a battery of tests that measure lung function and aid in the management of patients with respiratory disease. They are performed using standardized equipment and can be used for diagnosis, prognostication, management and follow-up of 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 gas exchange/diffusion function of the respiratory system.
Categories of PFT

There are three 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., low FVC
- Obstructive lung disease has a reduced flow, i.e., low FEV1

**Lung volumes: TLC, RV**

- Volumes and capacities; addition of two or more volumes comprise a capacity
- Nitrogen washout and helium dilution technique
- Body plethysmography (body box) - gold standard for measuring lung volumes

**Gas Exchange: DLCO, AaDO2**

- Ability to transport gas from alveoli to **blood**
- Estimates surface area available for gas exchange
- Depends on Hb and cardiac output
Indication of PFT

An indication of pulmonary function tests (PFT) is mainly diagnostic/prognostic.

1. **Diagnostic:** Screening of at-risk patients like age > 70 years, obesity, evaluation of a chronic cough, follow-up of patients with chronic lung disease
2. **Prognostic:** Before lung surgery, response to drugs, and assess 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: 3000 mL

**Expiratory Reserve Volume (ERV):** Volume of air that can be maximally exhaled after a normal tidal expiration. Normal value: 1500 mL

**Residual Volume (RV):** Amount of air that remains in lungs after maximal forced exhalation. It cannot be measured directly by spirometry, but is indirectly calculated as RV = FRC - ERV. Normal value: 20–25mL/kg or 1200 mL

Capacities (Sum of Two or More Volumes)

**Total Lung Capacity (TLC):** Volume of air present in lungs after maximum deep inspiration. It is the sum of all volumes; TLC = IRV + TV + ERV + RV. Normal value: 5000–6000 mL

**Vital Capacity (VC):** Maximum volume of air exhaled out after a maximum deep inspiration; VC = IRV + TV + ERV or VC = TLC − RV. Normal value: 4500–5000 mL

**Inspiratory Capacity (IC):** Maximum volume of air inspired after a normal tidal expiration. IC = TV + IRV. Normal value: 2400–3600 mL

**Expiratory Capacity (EC):** Maximum volume of air expired after normal tidal inspiration. EC = TV + ERV. Normal value: 1800–2300 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 lungs leads to the reduction in FRC causing hypoxemia and hypercarbia. Normal value: 2500 mL
Spirometry

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 out after a maximal inspiration. This is classically reduced in **restrictive lung disease**; however, an obstructive lung disease with significant **hyperinflation**
- **FEV1**: Volume of air exhaled during the initial second of the FVC maneuver.
- **The ratio of FEV1/FVC**: Normal value is > 75%. 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 sec. 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.

**Obstructive diseases**, where a reduction in flow is predominant leading to low FEV1; however, FVC may be normal or low. Hence FEV1/FVC ratio is usually < 0.7 (less than 0.7).

Reversibility: Increase in FEV1 by 12-15% on repeat spirometry, after administration of a bronchodilator (salbutamol) is a characteristic of asthma.

**Restrictive diseases**, where 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 (may be > 1).

However, this needs confirmation as RV can’t be measured by spirometry (low RV is the hallmark of restrictive lung disease).

**Loop Spirometry**

Flow volume loops are formed when a patient performs the spirometry maneuver, and a graph is plotted with the volume on x-axis and flow on the y-axis. The expiratory limb is usually represented as positive. 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 to identify 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.

Limitation of Spirometry

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

- If the patient has a superimposed restrictive lung disease
- If 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
Detection of Upper Airway Obstruction

- **Fixed airway obstruction:** Constant limitation of flow during inspiration and expiration. Example: Stricture, goitre, stenosis
- **Variable extrathoracic obstruction:** Reduction in flow is more during inspiration (airways tend to collapse during inspiration due to negative transmural pressure). Positive pressure in airway during expiration decreases obstruction to flow. Example: Vocal cord palsy, obstructive sleep apnea
- **Variable intrathoracic obstruction:** Reduction in flow is more during expiration (high pleural pressure decreases airway diameter). During inspiration, lower pleural pressure around the airway tends to decrease obstruction. Example: Tracheomalacia, tumor of bronchus

Lung Volumes - RV, FRC, TLC

Gas dilution technique

**N2 washout:** Patient breathes 100% oxygen so that all nitrogen in 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 exhaled gas expressed in percentage, gives the lung volume. Example: the patient breathes 50 mL of helium and its concentration in exhaled gas is 1%, the volume of the lung is 5 litres.

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 can’t 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, AaDO2

DLCO (Diffusion capacity of Carbon Monoxide)

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

\[ DLCO = \frac{CO (\text{mL/min/mmHg})}{PACO - PcCO} \]

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

DLCO values depend upon three factors:

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

Factors altering DLCO

<table>
<thead>
<tr>
<th>Decrease DLCO (&lt; 80%)</th>
<th>Increase DLCO (&gt; 120%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anemia</td>
<td>Polycythemia</td>
</tr>
<tr>
<td>Emphysema</td>
<td>Exercise</td>
</tr>
<tr>
<td>Fibrosis</td>
<td>Congestive heart failure</td>
</tr>
</tbody>
</table>

Alveolar to arterial oxygen tension gradient (AaDO2)

- Detects the difference between alveolar oxygen (PAO2) and arterial oxygen tension (PaO2)
- Needs arterial blood gas analysis for PaO2
- Normal values are below 10 mmHg, and values above 100 mmHg, indicate significant impairment in gas exchange

Cardiopulmonary reserve/exercise testing

- Stair climbing test, 6-min walk test – measure change in SaO2/SpO2, HR, oxygen utilization (VaO2)
- Tests the individual’s ability to cope with increased metabolic demands during exercise
- It gives a clear picture regarding the functional improvement of a patient on follow up
Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Obstructive lung disease</th>
<th>Restrictive lung disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLC</td>
<td>High/normal</td>
<td>Very low</td>
</tr>
<tr>
<td>VC or FVC</td>
<td>Low/normal</td>
<td>Very low</td>
</tr>
<tr>
<td>RV</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>FRC</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>FEV1</td>
<td>Very Low</td>
<td>Normal/low</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>Low</td>
<td>Normal/high</td>
</tr>
<tr>
<td>Peak flow</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Examples</td>
<td>COPD, asthma</td>
<td>Interstitial lung disease, fibrosis</td>
</tr>
</tbody>
</table>

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?

   History of chronic smoking may be present.

   A. 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 comes to the outpatient department with complaints of dyspnea and wheezing. He has a history of tracheostomy and prolonged ventilation two years back due to ARDS. His tracheostomy was removed after four months of discharge from the hospital. 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 female comes to your clinic for evaluation of dyspnea on exertion. She has noticed her symptoms since 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 some rash and joint paints which are waxing and waning. She has many parakeets at home. Her pulmonary function test results are as follows:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Actual</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC (L)</td>
<td>1.84</td>
<td>4.54</td>
</tr>
<tr>
<td>FEV1 (L)</td>
<td>1.52</td>
<td>3.65</td>
</tr>
<tr>
<td>FEV1/FVC %</td>
<td>82.6</td>
<td>80.3</td>
</tr>
<tr>
<td>RV (L)</td>
<td>1.21</td>
<td>1.99</td>
</tr>
<tr>
<td>DLCO</td>
<td>6.23</td>
<td>33.21</td>
</tr>
</tbody>
</table>

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


Diffusing capacity for carbon monoxide via uptodate.com

Correct answers: 1B, 2D, 3D

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