A Stepwise Approach to the Interpretation of Pulmonary Function Tests

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Financial Disclosures

- None
PFT – Why Order Them?

- To identify and quantify changes in pulmonary function
  - Gives a pattern of disease, not a diagnosis
- Assess need for or effectiveness of therapy
  - Decide on treatment, evaluate progression or response to therapy
- Screen for pulmonary involvement
- Preoperative evaluation for complications
  - Rarely performed unless a major thoracic surgery or lung resection surgery is planned
- Disability evaluation
PFT – When NOT To Order

- Unstable patient
- Chest or abdominal pain
- Recent surgery (including eye surgery)
- Nausea/Vomiting
- Acutely/critically ill
- Unable to follow detailed commands
  - Valid and reliable results cannot be expected
PFT – What Do (Can) I Get?

- Conventional PFT
  - Spirometry, lung volumes, DLCO

- Additional tests
  - Bronchodilator challenge
  - Methacholine challenge
  - Mip, Mep, etc

- Cardiopulmonary Exercise Testing (CPET)
  - Exercise oxymetry
  - 6 minute walk test

- Arterial Blood Gases (ABG)
PFT – What Shall I Read?

- Reliability of data (GIGO)
- Normal vs. Abnormal
- Pattern of the abnormality
- Severity of the disease
- Clues to clinical diagnosis
  - “clinical correlation is suggested”
Physiology & Definitions
PFT – Making Sense of The Graphs

[Graphs showing different lung functions and flow rates, labeled with FEV₁ and FVC.]
Troubleshooting

- Good expiratory plateau
- Expiration lasted at least 6 seconds
- Back extrapolation adequate
- No cough interference
- Up to eight spirometry maneuvers done
- Best FEV1 and FVC are reported, even if they come from separate maneuvers
- Technician must evaluate report poor patient effort
Reference Values

- Normal PFT values depend on:
  - Height
  - Age
  - Gender (biological)
  - Race/Ethnicity

- Reference values and formulas to derive it are based on large population-based studies

- “Normally abnormal” vs. “abnormally normal”
Health vs. Disease

![Graph showing distribution of FEV1/FVC ratio for healthy and diseased individuals. The graph compares the overlap between the two distributions, indicating the potential for diagnostics in identifying disease.]
FEV1/FVC – What’s Abnormal?
ULN, LLN and z-Scores

1:10 000 1:1000 1:100 1:20 1:10

Probability that a healthy individual has abnormal results
Let’s Agree to Disagree

**TABLE 3** The 5th percentile values (lower limit of normal (LLN)) for various lung function indices expressed as percent predicted for six individuals

<table>
<thead>
<tr>
<th></th>
<th>Male (age 10 years; height 137 cm)</th>
<th>Female (age 15 years; height 162 cm)</th>
<th>Male (age 25 years; height 175 cm)</th>
<th>Female (age 25 years; height 165 cm)</th>
<th>Male (age 80 years; height 175 cm)</th>
<th>Female (age 80 years; height 165 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV₁</td>
<td>81.3</td>
<td>80.5</td>
<td>80.5</td>
<td>80.2</td>
<td>69.4</td>
<td>70.0</td>
</tr>
<tr>
<td>FVC</td>
<td>81.2</td>
<td>80.4</td>
<td>80.9</td>
<td>79.9</td>
<td>72.0</td>
<td>70.0</td>
</tr>
<tr>
<td>FEV₁/FVC</td>
<td>87.4</td>
<td>87.8</td>
<td>86.9</td>
<td>87.2</td>
<td>80.0</td>
<td>80.5</td>
</tr>
<tr>
<td>TLC</td>
<td>78.0</td>
<td>79.8</td>
<td>80.0</td>
<td>80.4</td>
<td>77.8</td>
<td>77.6</td>
</tr>
<tr>
<td>FRC</td>
<td>70.9</td>
<td>69.9</td>
<td>69.6</td>
<td>72.5</td>
<td>69.8</td>
<td>70.7</td>
</tr>
<tr>
<td>RV</td>
<td>40.6</td>
<td>40.9</td>
<td>49.1</td>
<td>52.5</td>
<td>55.7</td>
<td>57.7</td>
</tr>
<tr>
<td>D_LCO</td>
<td>75.4</td>
<td>77.5</td>
<td>79.0</td>
<td>77.8</td>
<td>72.4</td>
<td>74.5</td>
</tr>
</tbody>
</table>

FEV₁: forced expiratory volume in 1 s; FVC: forced vital capacity; TLC: total lung capacity; FRC: functional residual capacity; RV: residual volume; D_LCO: diffusing capacity of the lung for carbon monoxide. Global Lung Function Initiative reference equations were used for all indices [10–12]. The table demonstrates that the equivalent percent predicted value at the LLN varies considerably for individuals of different ages and for each pulmonary function index, and highlights the potential bias introduced when using percent predicted thresholds for defining normal limits.
PFT

- Basic Evaluation:
  - FEV1
  - VC (usually FVC)
  - FEV1/VC
  - TLC
  - RV/TLC
  - ERV
  - DLCO
  - Flow-volume loop (FVL)

- Additional Test:
  - Bronchoprovocation test
  - Bronchodilator response
  - FEF 25-75%
  - MIP, MEP
  - Pseudorestriction
  - Pseudo-pseudorestriction
Patterns of Disease

- **Normal**
- **Obstructive**
  - FEV1/VC is low
  - FVC is normal or low
- **Restrictive**
  - FEV1/VC is normal
  - FVC is low
- **Mixed**
  - FEV1/VC is low
  - FVC is usually low
### Spirometry Interpretation

#### TABLE 5 Classification of ventilatory impairments defined by spirometry (reduced or elevated results are defined by the lower and upper limits of normal, respectively)

<table>
<thead>
<tr>
<th></th>
<th>FEV&lt;sub&gt;1&lt;/sub&gt;</th>
<th>FVC</th>
<th>FEV&lt;sub&gt;1&lt;/sub&gt;/FVC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obstructive impairments</td>
<td>Normal/↓</td>
<td>Normal</td>
<td>↓</td>
<td>TLC reduced to confirm</td>
</tr>
<tr>
<td>Restrictive impairments</td>
<td>↓</td>
<td>↓</td>
<td>Normal/↑</td>
<td>TLC normal (additional testing may be helpful, e.g. bronchodilator response, R&lt;sub&gt;aw&lt;/sub&gt;); when TLC is not available, this pattern has been described in population-based studies as preserved ratio impaired spirometry (PRISm) in current and former smokers [122]</td>
</tr>
<tr>
<td>Non-specific pattern [121]</td>
<td>↓</td>
<td>↓</td>
<td>Normal</td>
<td></td>
</tr>
<tr>
<td>Muscle weakness</td>
<td>↓</td>
<td>↓</td>
<td>Normal</td>
<td>Lack of sharp PEF</td>
</tr>
<tr>
<td>Suboptimal effort</td>
<td>↓</td>
<td>↓</td>
<td>Normal</td>
<td>Lack of sharp PEF</td>
</tr>
<tr>
<td>Mixed disorder</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>Need lung volumes to confirm</td>
</tr>
<tr>
<td>Dysanapsis [118]</td>
<td>Normal</td>
<td>Normal/↑</td>
<td>↓</td>
<td>May be normal variant</td>
</tr>
</tbody>
</table>

FEV<sub>1</sub>: forced expiratory volume in 1 s; FVC: forced vital capacity; TLC: total lung capacity; R<sub>aw</sub>: airway resistance; PEF: peak expiratory flow.
Spirometry Interpretation

1. **FEV₁/FVC >5th percentile?**
   - **Yes**
     - **FVC >5th percentile?**
       - **Yes**
         - Normal spirometry
       - **No**
         - Possible restriction or non-specific pattern
   - **No**
     - **FVC >5th percentile?**
       - **Yes**
         - Airflow obstruction
       - **No**
         - Possible mixed disorder

2. **FVC >5th percentile?**
   - **Yes**
     - Normal spirometry
   - **No**
     - Need lung volumes
Flow Volume Loop
FVL – Patterns of Poor Quality Test

- Normal
- Cough
- Glottis closure
- Suboptimal effort
- Hesitation at start
Interpreting FVL
Interpreting FVL
Interpreting FVL
Interpreting FVL
Interpreting FVL
Interpreting FVL
Interpreting FVL
Lung Volumes – Tale of Two Tests

- **Helium Dilution**
  - Inaccurate
  - May miss air trapping
  - Widely available

- **Plethysmography**
  - More accurate
  - Not routinely available
### TABLE 7 Classification of ventilatory impairments defined by lung volumes

<table>
<thead>
<tr>
<th></th>
<th>TLC</th>
<th>FRC</th>
<th>RV</th>
<th>FRC/TLC</th>
<th>RV/TLC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large lungs</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal variant above ULN</td>
</tr>
<tr>
<td>Obstruction</td>
<td>Normal/↑</td>
<td>Normal/↑</td>
<td>↑</td>
<td>Normal/↑</td>
<td>↑</td>
<td>Hyperinflation if FRC/TLC and RV/TLC elevated; gas trapping if only RV/TLC elevated (e.g. COPD)</td>
</tr>
<tr>
<td>Simple restriction</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>Normal</td>
<td>Normal</td>
<td>e.g. ILD</td>
</tr>
<tr>
<td>Complex restriction [156]</td>
<td>↓</td>
<td>↓</td>
<td>Normal/↑</td>
<td>Normal</td>
<td>↑</td>
<td>When FEV₁/FVC is normal, complex refers to the process contributing to a restrictive process that disproportionally reduces FVC relative to TLC (e.g. small airway disease with gas trapping and obesity)</td>
</tr>
<tr>
<td>Mixed disorder</td>
<td>↓</td>
<td>Normal/↓</td>
<td>Normal/↑</td>
<td>Normal/↑</td>
<td>Normal/↑</td>
<td>Typically, FEV₁/FVC is reduced (e.g. combined ILD and COPD)</td>
</tr>
<tr>
<td>Muscle weakness</td>
<td>↓</td>
<td>Normal/↓</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>When effort appears sufficient; TLC is reduced especially with diaphragm weakness; RV is increased especially with expiratory muscle weakness</td>
</tr>
<tr>
<td>Suboptimal effort</td>
<td>↓</td>
<td>Normal/↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>Especially when effort appears insufficient</td>
</tr>
<tr>
<td>Obesity</td>
<td>Normal/↓</td>
<td>↓</td>
<td>Normal/↑</td>
<td>Normal/↓</td>
<td>Normal/↑</td>
<td>ERV low; reduced TLC at very high BMI (&gt;40 kg·m⁻²) [37]</td>
</tr>
</tbody>
</table>

TLC: total lung capacity; FRC: functional residual capacity; RV: residual volume; ULN: upper limit of normal; COPD: chronic obstructive pulmonary disease; ILD: interstitial lung disease; ERV: expiratory reserve volume; BMI: body mass index.
Lung Volumes – Interpretation

- **TLC <5th percentile?**
  - Yes → **Restriction**
  - No → **TLC > 95th percentile?**
    - Yes → **FRC/TLC or RV/TLC > 95th percentile?**
      - Yes → **Hyperinflation**
      - No → **Normal lung volumes**
    - No → **FRC/TLC or RV/TLC >95th percentile?**
      - Yes → **Complex restriction**
      - No → **Simple restriction**
  - No → **Possible hyperinflation**
    - Yes → **Hyperinflation**
    - No → **Large lungs**
The DLCO Puzzle

- DLCO depends on:
  - Size of the breath (VA)
  - Area of the capillary bed
  - Thickness of the capillary basement membrane
  - Blood’s capacity to take up CO (hemoglobin, cardiac output)
The DLCO Puzzle

- Normal DLCO
  - Asthma/Chronic bronchitis
  - Obesity
  - Neuromuscular and chest wall diseases

- Decreased DLCO
  - Emphysema
  - ILD (fibrosis, etc)
  - Pulmonary vascular diseases

- Increased DLCO
  - Pulmonary hemorrhage
  - Heart failure (could go either way)
DLCO Interpretation

- $D_{LCO}$
  - $<\text{LLN (5th percentile)}$: Abnormally low
  - $>\text{ULN (95th percentile)}$: Abnormally high

- $V_A$
  - Low
  - Normal

- $K_{CO}$
  - Low/normal
  - High

- Pulmonary vascular abnormality
  - (e.g., pulmonary hypertension, pulmonary embolism, vasculitis)
  - Emphysema with preserved lung volume (e.g., early ILD)
  - Anaemia

- Increased blood flow (e.g., left-to-right shunt, asthma, obesity)
  - Erythrocytosis
  - Alveolar haemorrhage

- Loss of alveolar capillary structure with loss of lung volume (e.g., emphysema, ILD)

- Localised loss of lung volume (e.g., pneumonectomy)
  - Incomplete lung expansion (e.g., failure to take deep breath, neuromuscular dysfunction)
VC = Best of SVC, FVC, IVC maneuvers; PV = Pulmonary vascular; LLN = Lower limit of normal; CW = Chest wall; CB = Chronic bronchitis

Eur Respir J 2005; 26: 948–968
# PFT: Severity Assessment

<table>
<thead>
<tr>
<th>Degree of Severity</th>
<th>FEV1 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>&gt;70</td>
</tr>
<tr>
<td>Moderate</td>
<td>60-69</td>
</tr>
<tr>
<td>Moderately Severe</td>
<td>50-59</td>
</tr>
<tr>
<td>Severe</td>
<td>35-49</td>
</tr>
<tr>
<td>Very Severe</td>
<td>&lt;35</td>
</tr>
</tbody>
</table>

- **Caveats:**
  - Extremes
  - DLCO
  - Upper airway obstruction

<table>
<thead>
<tr>
<th>Degree of Severity</th>
<th>DLCO (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>&gt;60</td>
</tr>
<tr>
<td>Moderate</td>
<td>40-59</td>
</tr>
<tr>
<td>Severe</td>
<td>&lt;40</td>
</tr>
</tbody>
</table>

*Eur Respir J 2005; 26: 948–968*
Bronchoprovocation

- Indications:
  - H&P suggestive of asthma
  - PFT not diagnostic

- Contraindications:
  - Absolute
    - Severe airflow obstruction (FEV1 <50% or <1L)
    - MI or stroke within 3 months
    - Uncontrolled BP/ Aortic aneurism
    - Poor patient effort during spirometry
  - Relative
    - Moderate airflow obstruction (various definitions)
    - Pregnant/nursing mother
    - Myasthenia Gravis diagnosis/treatment
Bronchoprovocation

- Sensitive, but not specific
- $\text{PC}_{20}$ reported
- False Negatives:
  - Inactive disease
- False Positives:
  - CHF
  - COPD
  - Rhinitis
  - Sarcoidosis
Bronchodilator Response

Does it really matter?
### TABLE 9
Summary of the procedures relating to bronchodilator response

- Procedures suggested to minimise differences within and between laboratories
  - Assess lung function at baseline
  - Administer salbutamol in four separate doses of 100 μg through a spacer
  - Re-assess lung function after 15 min. If you want to assess the potential benefits of a different bronchodilator, use the same dose and the same route as used in clinical practice. The wait time may be increased for some bronchodilators
  - An increase in FEV1 and/or FVC ≥12% of control and ≥200 mL constitutes a positive bronchodilator response
  - In the absence of a significant increase in FEV1 and/or FVC, an improvement in lung function parameters within the tidal breathing range, such as increased partial flows and decrease of lung hyperinflation, may explain a decrease in dyspnoea
  - The lack of a bronchodilator response in the laboratory does not preclude a clinical response to bronchodilator therapy

*Eur Respir J 2005; 26: 948–968*
RV/TLC Ratio

- $RV = TLC - VC$
- $RV/TLC = 1 - VC/TLC$
  - VC could be decreased due to dynamic airway collapse
  - RV/TLC elevation is another sign of obstruction
MIP & MEP

- MIP = Maximum inspiratory pressure
- MEP = Maximum expiratory pressure
  - Used to assess respiratory muscle strength
  - Technician and patient-dependent
  - Normal values debatable
  - <50% predicted to indicates abnormality
  - >25% change is considered significant

Not a terribly valuable test
Summary

- Evaluate the quality of the test
- Scan for abnormal values
- FEV1/FVC reduced $\rightarrow$ obstruction
  - Check RV/TLC to confirm
  - Check FVL to look for additional problems
- TLC reduced $\rightarrow$ restriction
- DLCO reduced $\rightarrow$ destruction of pulmonary parenchyma or capillary bed
- Finally, correlate the PFT findings with symptoms and physical findings
Critical Understandings in Pulmonary Function Tests

Practice Section
Warm-Up Questions
Which of the following is equal to RV?

A. FRC – IRV
B. TLC – VC
C. VC – IRV
D. IC – IRV

https://www.respiratorytherapyzone.com/pft-final-exam/
Which of the following is equal to IC?

A. TLC – RV
B. VC – ERV
C. TLC – IRV
D. VT + ERV
A patient has a VC of 4200 ml, an FRC of 3300 ml, and ERV of 1500 ml. What is the patient’s RV?

A. 2700 ml  
B. 3700 ml  
C. 1500 ml  
D. 1800 ml

https://www.respiratorytherapyzone.com/pft-final-exam/
Results of a pulmonary function study on a patient indicate a VC of 3600 ml, an FRC of 2000 ml, and an RV of 1000 ml. What is the TLC?

A. 5500 ml  
B. 7000 ml  
C. 4600 ml  
D. 8600 ml  

https://www.respiratorytherapyzone.com/pft-final-exam/
If VT is 650 ml, ERV is 1100 ml, and RV is 1150 ml; FRC would be equal to:

A. 3650 ml
B. 4750 ml
C. 2250 ml
D. 2900 ml
1. The following measurements were obtained during routine pulmonary testing:

<table>
<thead>
<tr>
<th>Measure</th>
<th>Measured</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vital Capacity (VC)</td>
<td>3 Liters</td>
<td>3.5-4.5 Liters</td>
</tr>
<tr>
<td>Expiratory Reserve Volume (ERV)</td>
<td>1 Liter</td>
<td>1.5-2 Liters</td>
</tr>
<tr>
<td>Functional Residual Capacity (FRC)</td>
<td>5 Liters</td>
<td>3-4 Liters</td>
</tr>
</tbody>
</table>

a. Calculate TLC
b. Discuss which, if any, respiratory disease these results would suggest
c. Which other measurement(s) would you like to obtain to support your diagnosis?

a. TLC = VC + RV = VC + (FRC − ERV) = 7L
b. Obstructive lung disease. TLC is high, FRC is elevated, and RV seems also very elevated (reference values not given)
c. Obtain FEV1, FVC, FEV1/FVC ratio, RV/TLC ratio
FVC 80% predicted
FEV1 50% predicted
FEV1/FVC% 55
FEF 25-75% 40% predicted

What’s the most likely diagnosis?
A. Silicosis
B. Kyphoscoliosis
C. Pneumothorax
D. Chronic bronchitis

https://www.respiratorytherapyzone.com/pft-final-exam/
The FRC measured by body plethysmography is 30% larger than that measured by Helium dilution. This difference is best explained by an increase in which of the following?

A. Airway resistance  
B. Diffusing capacity  
C. Residual volume  
D. Lung compliance
The largest volume of gas that can be expired from a resting end-expiratory level is known as the:

A. Expiratory reserve volume
B. Inspiratory reserve volume
C. Residual volume
D. Vital capacity

https://www.respiratorytherapyzone.com/pft-final-exam/
The total amount of gas in the lungs following a maximum inspiration is described as the:

A. Total lung capacity
B. Vital capacity
C. Inspiratory reserve volume
D. Tidal volume
The volume of gas in the lungs that can be exhaled from end-inspiratory level during normal or tidal breathing is the:

A. Expiratory reserve volume  
B. Functional residual capacity  
C. Residual volume  
D. Total lung capacity

https://www.respiratorytherapyzone.com/pft-final-exam/
The volume of gas which remains in the lung at the end of a maximum expiration is known as:

A. Residual Volume  
B. Expiratory Reserve Volume  
C. Functional Residual Capacity  
D. Vital capacity

https://www.respiratorytherapyzone.com/pft-final-exam/
FVL Reading
This is a schematic representation of a FVL. Each hash mark is represents 1L, A is lung “at rest” and 0 represents an arbitrary point where lung is void of all air. Represent/calculate as many PFT parameters as possible.
RV = 2L
VC = 5L
TLC = 7L
FRC = 2L
TV = 1L
ERV = 1.5L
IRV = 2.5L
PFT Reading
<table>
<thead>
<tr>
<th>FEV1/VC</th>
<th>FEV1%</th>
<th>VC%</th>
<th>TLC%</th>
<th>DLCO%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.42</td>
<td>20</td>
<td>24</td>
<td>150</td>
<td>21</td>
</tr>
</tbody>
</table>

• **Reading:**
  – Very severe obstructive lung disease with air trapping and decreased gas transfer

• **Diagnosis:**
  – Severe COPD with large bullae
<table>
<thead>
<tr>
<th>FEV1/VC</th>
<th>FEV1%</th>
<th>VC%</th>
<th>TLC%</th>
<th>DLCO%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>69</td>
<td>83</td>
<td>85</td>
<td>112</td>
</tr>
</tbody>
</table>

• **Reading:**
  – Moderate obstructive lung disease with normal gas transfer

• **Diagnosis:**
  – Asthma
<table>
<thead>
<tr>
<th>FEV1/VC</th>
<th>FEV1%</th>
<th>VC%</th>
<th>TLC%</th>
<th>DLCO%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.88</td>
<td>58</td>
<td>51</td>
<td>55</td>
<td>23</td>
</tr>
</tbody>
</table>

- **Reading:**
  - Moderately severe restrictive lung disease with severely decreased gas transfer

- **Diagnosis:**
  - Hypersensitivity pneumonitis
**Reading:**
- Moderate restrictive lung disease with moderate decrease in gas transfer

**Diagnosis:**
- Sarcoidosis
<table>
<thead>
<tr>
<th>FEV1/VC</th>
<th>FEV1%</th>
<th>VC%</th>
<th>TLC%</th>
<th>DLCO%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.55</td>
<td>52</td>
<td>65</td>
<td>62</td>
<td>20</td>
</tr>
</tbody>
</table>

- **Reading:**
  - Moderately severe mixed lung disease with severely reduced gas transfer

- **Diagnosis:**
  - COPD with IPF
• Reading:
  – Severe restrictive lung disease with moderately decreased gas transfer

• Diagnosis:
  – SLE (with alveolar hemorrhage)
<table>
<thead>
<tr>
<th>FEV1/VC</th>
<th>FEV1%</th>
<th>VC%</th>
<th>TLC%</th>
<th>DLCO%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.85</td>
<td>60</td>
<td>60</td>
<td>63</td>
<td>75</td>
</tr>
</tbody>
</table>

- **Reading:**
  - Moderate restrictive lung disease with normal gas transfer

- **Diagnosis:**
  - Neuromuscular disease
Further (Extensive) Reading

  - ERS/ATS technical standard on interpretive strategies for routine lung function tests.
  - Eur Respir J 2022; 60: 2101499

- European Respiratory Journal 2005; 26
  - Page 153-161  General Considerations
  - Page 319-338  Standardization of Spirometry
  - Page 511-522  Standardization of Lung Volumes
  - Page 720-735  Standardization of DLCO
  - Page 948-968  Interpretation