Pulmonary Function Testing: Concepts and Clinical Applications

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Potential Conflict Of Interest
• Nothing to disclose pertinent to this presentation

Objectives
• Understand common indications for testing
• Review components of PFTs
• Recognize patterns of PFT abnormalities in disease
• Gain familiarity with interpretation strategies

Rationale: Why Test?
• Evaluate symptoms/signs of respiratory disease
• Monitor course of disease and response to therapy
• Prognosticate
• Screen patients at risk
  – pre-operative
  – systemic disease or systemic therapy with known pulmonary effects
  – occupational exposure
• Evaluate disability

Components of Pulmonary Function Testing
• Routine
  – Exhaled volume and flow rates -spirometry
  – Lung volumes-helium dilution or plethysmography
  – Diffusion characteristics -diffusion capacity
  – Airway reactivity-bronchodilator response or methacholine challenge
  – Oxygenation/Ventilation-pulse oximetry or arterial blood gas analysis

Components of Pulmonary Function Testing
• Specialized
  – Respiratory muscle strength-maximal inspiratory and expiratory pressures (MIPs and MEPs)
  – Heart-lung interaction-integrated cardiopulmonary exercise testing
  – Novel assays of exhaled gas
Spirometry

- Most basic and widely used formal pulmonary function test
- Easily performed in the office setting
- Part of the initial evaluation of patients with undiagnosed chest complaints
- Sensitive and specific test for the presence of airflow obstruction as may occur in asthma, COPD, bronchiectasis
- Less specific test for restrictive lung disease

63 y/o Man with Dyspnea

actual % pred.
FVC 1.56 66
FEV₁ 0.66 36
FEV₁/FVC 0.42 56
PEFR 1.56 31
FEF_{25-75} 0.26 16

A. Obstruction due to the reduced FEF_{25-75}
B. Restriction due to the reduced FVC
C. Obstruction due to the reduced FEV₁/FVC
D. Inadequate effort on the basis of marked expiratory coving of the flow-volume loop

Spirometry measures inhaled and exhaled gas volumes and gas flows during a forced vital capacity maneuver

Definitions and Terms

- FEV₁ - forced expiratory volume in the first second
- FVC - forced vital capacity
- FEV₁/FVC-ratio of the FEV₁ to FVC (as a %)
- FEF_{25-75} - average forced expiratory flow during the mid portion of the FVC
- PEFR - peak expiratory flow rate

Definition of Normal Values

- Predicted values are standardized to age, sex, height, and race; measured values are expressed as a percentage of predicted
- Current ATS guidelines suggest that values below the 95% CI be considered abnormal
- This recommendation has not been universally adopted
22 y/o Woman with Wheezing and Chest Tightness

<table>
<thead>
<tr>
<th></th>
<th>actual</th>
<th>% pred</th>
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<tbody>
<tr>
<td>FVC</td>
<td>2.28</td>
<td>75</td>
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<tr>
<td>FEV&lt;sub&gt;1&lt;/sub&gt;</td>
<td>1.40</td>
<td>57</td>
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<tr>
<td>FEV&lt;sub&gt;1&lt;/sub&gt;/FVC</td>
<td>0.62</td>
<td>78</td>
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<tr>
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<td>3.23</td>
<td>56</td>
</tr>
<tr>
<td>FEF&lt;sub&gt;25-75&lt;/sub&gt;</td>
<td>0.74</td>
<td>29</td>
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A. Obstruction due to the reduced PEFR
B. Restriction due to the reduced FVC and FEV<sub>1</sub>
C. Obstruction on the basis of marked expiratory coving of the flow-volume loop
D. Obstruction due to the reduced FEV<sub>1</sub>/FVC

Spirometry- Obstructive pattern

- Limitation to expiratory flow characterized by reduced FEV<sub>1</sub>, relatively preserved FVC, reduced FEV<sub>1</sub>/FVC
- Emphysema
  - loss of elastic recoil
- Chronic bronchitis
  - mucous hypersecretion
  - mucosal thickening
  - bronchospasm
- Asthma
  - smooth muscle contraction
  - airway edema
- Bronchiolitis
  - mucosal inflammation

22 y/o Woman with Wheezing and Chest Tightness

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- What should be ordered next?
  A. diffusion capacity
  B. post-bronchodilator spirometry
  C. methacholine challenge
  D. ambulatory peak flow monitoring
  E. allergen skin testing

Bronchodilator Testing

- Assessment of lung function (spirometry) pre- and 15 minutes post- administration of a bronchodilator
  - document reversible airflow obstruction
  - asthma diagnosis
  - prognosticate in COPD
  - may imply an increased likelihood of response to CS
  - immediate feedback to patients may increase compliance
  - lack of an acute response does not imply lack of response to long-term therapy
Bronchodilator Testing

- When to test
  - suspected new diagnosis of obstructive lung disease
    - asthma, COPD, emphysema, bronchiolitis, bronchiectasis
  - to assess efficacy of treatment
    - corticosteroids and long-acting bronchodilators (salmeterol) may alter bronchodilator response

Bronchodilator Testing

Positive response:
12% increase in FEV₁ or FVC, and an increase of 200 cc

22 y/o Woman - Bronchodilator Response

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<tr>
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<th>post</th>
<th>% change</th>
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<td>2.45</td>
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<tr>
<td>FEV₁</td>
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<td>57</td>
<td>1.63</td>
<td>16</td>
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<tr>
<td>FEV₁/FVC</td>
<td>0.62</td>
<td>78</td>
<td>0.66</td>
<td>6</td>
</tr>
<tr>
<td>PEF</td>
<td>3.23</td>
<td>56</td>
<td>5.03</td>
<td>55</td>
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<tr>
<td>FEF₂₅₋₇₅</td>
<td>0.74</td>
<td>29</td>
<td>0.94</td>
<td>27</td>
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38 y/o Man with Episodic Cough

- Close friend recently hospitalized with asthma
- Spirometry:
  - actual % pred.
  - FVC: 4.99 98
  - FEV₁: 4.09 97
  - FEV₁/FVC: 0.82 100
  - PEF: 8.45 90
  - FEF₂₅₋₇₅: 3.45 78
- What should be ordered next to r/o asthma?
  - A. diffusion capacity
  - B. post-bronchodilator spirometry
  - C. methacholine challenge
  - D. ambulatory peak flow monitoring
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  - E. allergen skin testing

Bronchial Challenge Testing

- Bronchial challenge testing detects airway hyper-reactivity as may occur in asthma, COPD, and bronchiectasis
- Methacholine is administered by nebulizer in increasing concentrations
  - spirometry is measured at baseline and after each concentration.
  - the degree of airflow obstruction present after any given concentration is a reflection of airway reactivity
  - patients with hyper-reactive airways will bronchoconstrict at lower concentrations

Hyper-reactive

FEV₁ (% baseline)

PC20 = 6.2 mg/ml

Non-reactive

FEV₁ (% baseline)

PC20 = ? mg/ml
Bronchial Challenge Testing

- The concentration required to induce a 20% fall in FEV₁ (PC₂₀) is reported. < 8 mg/ml is hyper-reactive
  - Airway hyper-reactivity may be present in ~15% of normal
  - A negative methacholine challenge excludes asthma in the absence of concurrent therapy with:
    - corticosteroids (6 wks)
    - leukotriene modifiers (48 hours)
    - long-acting bronchodilators (48 hours)
    - theophylline (1 week)
    - cromolyn (1 week)

Indications

- suspicion of asthma with normal spirometry and a negative bronchodilator response
- chronic cough
- nocturnal cough
- episodic chest tightness
- unexplained exercise intolerance
- recurrent “bronchitis”

30 y/o Man with Dyspnea and Cough

Spirometry:

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<td>19</td>
</tr>
<tr>
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<td>1.04</td>
<td>21</td>
</tr>
<tr>
<td>FEV₁/FVC</td>
<td>0.93</td>
<td>115</td>
</tr>
<tr>
<td>PEFR</td>
<td>5.75</td>
<td>72</td>
</tr>
<tr>
<td>FEF₂₅₋₇₅</td>
<td>2.2</td>
<td>48</td>
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A. Suggested obstruction due to the reduced PEFR
B. Restriction due to the increased FEV₁/FVC
C. Obstruction on the basis of the reduced FEV₁
D. Suggested restriction due to the reduced FEV₁ and FVC

Spirometry: Restrictive pattern

- Reduction in gas volume of the chest characterized by symmetric reduction in FEV₁ and FVC; FEV₁/FVC is preserved
  - reduced chest wall compliance
  - loss of parenchyma (i.e. s/p resection)
  - increased parenchymal stiffness
  - respiratory muscle weakness
- Spirometry can measure only exhaled gas, not the total gas in the chest; it can only suggest a diagnosis of restriction

Absolute Lung Volumes

- After complete exhalation, residual air remains in the lung (RV)
- Without quantification of the RV, the total volume of gas in the chest (TLC) cannot be determined
- Direct measurement of lung volumes is necessary for the formal diagnosis of restriction
Measurement of the residual volume (RV)

Helium dilution

Plethysmography

Significance of the TLC and RV

- A reduction in TLC defines restriction which may have only been suggested by a reduced FVC.
- A normal TLC excludes restriction which may have been suggested by a reduced FVC measured by spirometry.
- An elevated RV indicates gas trapping as can be seen in severe obstructive lung disease.

30 y/o Man with Dyspnea and Cough

Spirometry:

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<td>48</td>
</tr>
<tr>
<td>TLC</td>
<td>2.09</td>
<td>28</td>
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Suggested restriction due to the reduced FEV₁ and FVC

Confirmed restriction due to the reduced TLC

Diffusing Capacity (D<sub>L</sub>) quantifies the transfer of oxygen from alveolar gas to the red cell

- The quantity and rate of oxygen transfer depends on:
  - Area (A) of the alveolar-capillary membrane
  - Thickness (T)
  - Driving pressure (ΔPo<sub>2</sub>)

\[
D_L = \frac{A \times \Delta P_{O_2}}{T}
\]

Abnormalities in D<sub>L</sub>-CO

- Increased D<sub>L</sub>-CO
  - supine position
  - polycythemia
  - alveolar hemorrhage
  - left-to-right shunt
  - early CHF
  - asthma

- Decreased D<sub>L</sub>-CO
  - decreased area
    - emphysema, a/p resection, pulmonary emboli, HTN
    - anemia
  - increased thickness
    - pulmonary fibrosis, pneumoconiosis, sarcoid, drug-induced lung disease, CHF
  - increased CO back-pressure
    - cigarette smoking

Abnormalities in TLC/D<sub>L</sub>-CO

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</tr>
<tr>
<td>D&lt;sub&gt;L&lt;/sub&gt;-CO/V&lt;sub&gt;L&lt;/sub&gt;</td>
<td>15 (43%)</td>
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A. Emphysema
B. Interstitial lung disease
C. Diaphragmatic dysfunction
D. Primary pulmonary hypertension
### Abnormalities in TLC/D_LCO

- **FVC:** 1.12 (19%)
- **FEV₁:** 1.04 (21%)
- **FEV₁/FVC:** .93 (100%)
- **TLC:** 2.10 (28%)
- **D_LCO/V_A:** 15 (43%)

A. Emphysema  
B. Interstitial lung disease  
C. Diaphragmatic dysfunction  
D. Primary pulmonary hypertension

#### Neuro-muscular weakness  
or  
Thoracic deformity

### Interpretation Algorithm

#### Acceptable Spirogram

- ? FEV₁/FVC ratio low
- Obstruction  
  - Yes  
  - No
  - No Obstruction

- ? FVC low  
  - Yes  
  - No
  - No  
  - Yes

- Hyperinflation vs. Pure obstruction  
  - Further testing*
    - Yes
    - No
    - No

- ? Reversible with β-agonist/Incr NO
  - Yes
  - No

#### Prob. Restriction Normal

- **FEV₁/FVC:** .86 (100%)
- **D_LCO/V_A:** 24 (110%)

**Neuro-muscular weakness or Thoracic deformity**

### Summary

- Pulmonary function testing is an essential component of the evaluation of patients with respiratory complaints.
- Spirometry can document obstruction (through the FEV₁/FVC ratio) and suggest restriction.
- Novel measures of exhaled gas may assist in the diagnosis of asthma.
- Lung volumes and D_LCO are indicated to diagnose and differentiate restrictive and vascular abnormalities.