Pulmonary Function Tests (PFT's)  
“A Practical Approach”  
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Objectives:
- Interpret Spirometry  
- Identify Small Airway Obstruction, Significant Bronchodilator Response, Hyper-reactivity  
- Recognize Upper Airway Obstruction (UAO)  
  - Distinguish fixed from variable intra-thoracic and extra-thoracic UAO  
- Identify Restriction  
  - Know the three main categories of restrictive disease  
  - Recognize the unique pattern of neuromuscular disease  
- Identify Diffusion Defects  
  - Understand the impact of anemia on the interpretation of the DLCO  
- Be able to identify PFT patterns suggestive of:  
  - Asthma, COPD, Upper Airway Obstruction, Interstitial Lung Disease, and Pulmonary Hypertension

PFT's
- Provide information regarding:  
  - Flow Rates  
  - Lung Volumes  
  - Gas Exchange  
- Other:  
  - Airway Resistance  
  - Respiratory Muscle Strength
CC: Dyspnea

- **History:**
  - How bad?
    - With moderate/significant exertion
    - With minimal effort / Activities of Daily Living (ADL’s)
  - When?
    - Always vs Intermittent vs Nocturnal vs Specific Environments/Activities
  - Associated Symptoms?
    - Cough, Hemoptysis, Chest Pain, Wheezing
  - Risk Factors?
    - Cigarettes, Occupational, Environmental

- **Physical Exam**
  - Big Lungs vs Small Lungs
  - Crackles vs Wheezing

- **Labs:**
  - CXR/CT, Exercise Desaturation

- **PFT’s**
  - **Used to answer the Question:**
    - Is there a pulmonary explanation for dyspnea?
    - If so….
      - Is there Obstruction?
      - Is there Restriction?
      - Is there a Diffusion Defect?

- **PFT’s**
  - **Three Main Components:**
    - Spirometry
      - To identify obstruction
    - Lung Volume Determination
      - To identify restriction
    - Diffusion Capacity Measurement
      - To identify a diffusion defect
PFT’s – practically speaking....

- Calculate expected/predicted values:
  - Age
  - Height
  - Sex
  - Race
- Measure patient values
- Compare Measured to Predicted values:
  - "normal" is defined by measured values that are between 80% and 120% of the predicted values
Spirometry

- After a full inspiration, patient blows out as forcefully as possible until all air has been exhaled.
- The volume and rate of air exhaled are measured and reported as both a "Flow-Volume Loop" and "Volume-Time Curve"
**Flow Volume Loop?**

- At High Lung Volumes, both elastic recoil and airway diameter are maximal and thus flow rate is highest.
- As Lung Volumes decrease during the course of exhalation, both elastic recoil and airway diameter are reduced, so flow rate decreases.
- Hence, one can plot Flow at any given Lung Volume graphically resulting in a “Flow Volume Loop”
Spirometry: Volume Time Curve

FEV₁ = Forced Expiratory Volume in 1 Second; FVC = Forced Vital Capacity

Normal Spirometry

Flow-Volume Loop

Volume-Time Curve

Obstruction

Flow-Volume Loop

Volume-Time Curve

FEV₁

PVC

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Spirometry

- Identifies Obstruction if:
  - Reduced \( \text{RATIO} \) of FEV\(_1\) to FVC
    - \( > 0.8 \) age 20-39
    - \( > 0.7 \) age 60-80
    - (not just \( \downarrow \) FEV\(_1\))
  - "Scooping" of the Flow Volume Loop

- **Obstruction**
  - \( \downarrow \) FEV\(_1)/FVC \( \text{RATIO} \) identifies obstruction
  - \( < 0.70 \)

- **Obstruction**
  - FEV\(_1\) percent predicted determines severity
    - \( > 80\% = \) "mild", \( 50-80\% = \) "moderate", \( 30-50\% = \) "severe", \( <30\% = \) "very severe"
    - \( 65-80\% = \) "mild", \( 50-65\% = \) "moderate", \( <50\% = \) "severe"
      - 60-80% = "mild", 40-60% = "moderate", <40% = "severe"
      - No clear consensus
Obstruction

- **Reversibility**
  - Bronchodilator $\rightarrow$ FEV$_1$ INCREASES by 200cc AND 12% 

- **Obstruction**
  - $\downarrow$ FEV$_1$/FVC ratio defines obstruction
  - < 0.70
  - FEV$_1$ percent predicted determines severity
    - 60-80% = "mild", 40-60% = "moderate", <40% = "severe"
    - 50-60% = "mild", 50-45% = "moderate", <50% = "severe"
  - **Reversibility**
    - Bronchodilator $\rightarrow$ FEV$_1$ INCREASES by 200cc AND 12%
  - **Hyper-reactivity**
    - FEV$_1$ DECREASES by 20% in response to methacholine
Other Spirometry Values

| Other values measured in spirometry (FEF 25–75, PEF, FET 100%, etc) are of limited clinical utility |

Obstructive Diseases

**Common:**
- Asthma
- COPD
- Bronchiectasis

**Uncommon:**
- Bronchiolitis
- Lymphangioleiomyomatosis (LAM)
- Toxic Inhalation
- **Upper Airway Obstruction (UAO)**

Lower vs Upper Airway Obstruction?

**Lower (i.e. small) Airway Obstruction**
- Obstruction worsens during exhalation as lung volume decreases
  - Bronchioles lack cartilage
  - During exhalation, small airway diameter gradually decreases
  - Results in gradually decreasing airflow

**Upper (i.e., large) Airway Obstruction**
- Airflow is reduced even at high lung volumes
  - Where bronchioles should be maximally open
Lower vs Upper Airway Obstruction?

- Lower (i.e., small) Airway Obstruction
  - Flow Volume Loop: Relatively normal flow at high lung volumes. Obstruction gradually worsens during expiration.
- Upper (i.e., large) Airway Obstruction
  - Flow Volume Loop: Reduced flow even at high lung volumes.

Upper Airway Obstruction (3 types)

- Fixed
  - Intra-thoracic pressure changes do NOT affect the degree of obstruction:
    - Both Inspiratory and Expiratory limbs of the FVL are affected
    - Obstruction may be located either intra- or extra-thoracic
- Variable
  - Intra-thoracic pressure changes DO affect the degree of obstruction:
    - Inspiratory limb affected = Extra-thoracic obstruction (a)
    - Expiratory limb affected = Intra-thoracic obstruction (b)

“Fixed” Upper Airway Obstruction

- Both Inspiratory and Expiratory limbs affected.
- Site of obstruction may be either intra- or extra-thoracic.

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Variable Upper Airway Obstruction

- **Intrathoracic obstruction**
  - Only the Expiratory limb is affected.
  - Site of obstruction is Intra-thoracic.
  - i.e., tracheomalacia

- **Extrathoracic obstruction**
  - Only the Inspiratory limb is affected.
  - Site of obstruction is Extra-thoracic.
  - i.e., vocal cord dysfunction

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**“Variable” Intrathoracic UAO**

- Only the Expiratory limb is affected.
- Site of obstruction is Intra-thoracic.
  - i.e., tracheomalacia

**“Variable” Extrathoracic UAO**

- Only the Inspiratory limb is affected.
- Site of obstruction is Extra-thoracic.
  - i.e., vocal cord dysfunction
Spirometry Identifies Obstruction

- Why not Restriction?
  - No defined upper limit of normal for FEV₁/FVC ratio, and
  - "Loops" of normal and restriction look similar

<table>
<thead>
<tr>
<th>Normal</th>
<th>Restrictive</th>
<th>Mixed</th>
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<tbody>
<tr>
<td>[Diagram]</td>
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Restrictive Lung Disease

- Requires measurement of lung volumes:
  - Helium Dilution
  - Body Box Plethysmography
Three Main Lung Volumes

Total Lung Capacity (TLC):
Determined by Lung Elastic Recoil

Functional Residual Capacity (FRC):
Determined by the balance between Elastic Recoil of the Lung (in) vs Chest Wall (out)
Residual Volume (RV): the volume of gas trapped due to airway closure

Why do we care about lung volumes?

If LOW:
- Decreased TLC = a RESTRICTIVE process
  - Interstitial Lung Disease
  - Chest Wall Disease
  - Neuromuscular Disease

If HIGH:
- Increased TLC = Hyperinflation:
  - Loss of lung elastic recoil
  - Emphysema
- Increased RV = Gas Trapping
  - Any obstructive process

Restrictive Lung Disease = Reduced TLC (< 80% Predicted)
Restrictive Lung Disease = Reduced TLC (<80% Predicted)

- Three Categories of Restriction
  - Interstitial Lung Disease (↑ Lung Elastic Recoil)

Interstitial Lung Diseases

- Sarcoid
- Hypersensitivity Pneumonitis (chronic)
- Idiopathic Inflammatory Pneumonitis / Idiopathic Pulmonary Fibrosis (IPF)
- Tumor / TB (scarring)
- Failure / Fungal (granulomata)
- Aspiration/Asbestosis
- Connective Tissue Diseases
- Environmental
- Drugs

Restrictive Lung Disease

- Restriction = ↓ TLC
- Three Categories
  - Interstitial Lung Disease (↑ Lung Elastic Recoil)
  - Chest Wall Disease (↓ Chest Wall Elastic Recoil)
    - Kyphoscoliosis, Ascites, Pleural Effusions, Obesity, etc
Obesity:
CW Recoil (out) is reduced

Severe Obesity may even reduce TLC.

Mild Obesity results in a reduced FRC.

Restrictive Lung Disease

Restriction = ↓ TLC

Three Categories

- Interstitial Lung Disease (↑ Lung ER)
- Chest Wall Disease (↓ Chest Wall ER)
  - Kyphoscoliosis, Obesity, Ascites, ...
- Neuromuscular Disease
  - Amyotrophic Lateral Sclerosis (ALS),
    Muscular Dystrophy (MD), Myopathies, ...

Restrictive Lung Disease

- Neuromuscular Disease
  - ALS, MD, Myopathies, ...
  - ↓ TLC, ↑ RV, normal FRC

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Restrictive Lung Disease

- Restriction =  TLC
- Three Categories
  - Interstitial Lung Disease ( Lung ER)
  - Chest Wall Disease ( Chest Wall ER)
  - KS, Obesity, Ascites, …
- Neuromuscular Disease
- Prove by measuring strength:
  - Negative Inspiratory Force (NIF)
  - Positive Expiratory Force (PEF)

95% Diffusion Capacity

Assesses Alveolar-Capillary Surface Area available for gas exchange.
Diffusion Capacity
(DLCO = Diffusion capacity of the Lung for Carbon Monoxide)

Carbon Monoxide easily diffuses across alveolar and capillary membranes
- Easily binds with Hgb

\[ \text{DLCO} = [\text{CO}]_{\text{inhaled}} - [\text{CO}]_{\text{exhaled}} \]
**Diffusion Capacity**

- DL\(_{CO}\) = \([\text{CO}]_{\text{inhaled}} - [\text{CO}]_{\text{exhaled}}\)
  - Normal is 25 mL/min/mmHg
- DL\(_{CO}\) corrected\(^*\) = \(DL_{CO} \times (15/\text{Hgb})\)
  - Corrects for patient's Hgb
  - In anemia, DL\(_{CO}\) is low but DL\(_{CO}\) corrected is normal
- DL/VA = \(DL_{CO}\) corrected / Alveolar Volume
  - Corrects for patient's lung volume
  - Post-resection, DL\(_{CO}\) is low but DL/VA is normal
- Which value to use?
  - No consensus.

\(^*\)DL\(_{CO}\) corrected sometimes called "DL\(_{CO}\) adjusted" or "DL Adj"

**Abnormal DL\(_{CO}\)?**

- Reduced DL\(_{CO}\):
  - Loss of alveoli
    - Both Emphysema and Interstitial Lung Disease
  - Loss of blood flow to the alveoli
  - I.e., Pulmonary Hypertension
  - Anemia
- Increased DL\(_{CO}\):
  - Alveolar Hemorrhage
  - Congestive Heart Failure
  - Polycythemia

**DL\(_{CO}\) Summary**

- Expected DL\(_{CO}\) to be low in any disease with loss of either alveoli or capillaries
  - Can occur in both obstruction (emphysema) and restriction (pulmonary fibrosis)
- Suspect Pulmonary Hypertension when DL\(_{CO}\) is low but spirometry, lung volumes, and hemoglobin are all normal
  - I.e., "Isolated Low DL\(_{CO}\)"
PFT’s: A Practical Approach

- **FEV₁/FVC** Obstruction
- **TLC** Restriction
- **DLCO** Diffusion Defect

- Asthma
- COPD
- Bronchiectasis
- Interstitial Disease
- Chest Wall Disease
- Neuromuscular Disease
- Associated with COPD and/or Interstitial Lung Disease
- If “isolated” consider Pulmonary HTN

3-Step Pulmonary Function Test Interpretation Overview

1. **FEV₁/FVC Ratio** < 0.70 → YES → Obstructive Defect (Asthma, COPD, Bronchiectasis, etc)
2. **TLC** < 80% Predicted → YES → Restrictive Defect (ILD, CWD, NMD)
3. **DLCO** < 80% Predicted → YES → Diffusion Defect (If “isolated” Mild Pulmonary Hypertension)

No to all questions → Normal PFT’s (Eliminate “Isolated” Mixed Defects)

PFT Examples (and expectations)

- **Normal**
- **Obstructive Lung Disease**
  - Asthma
  - COPD
- **Upper Airway Obstruction**
  - Fixed
  - Variable
  - Intra-thoracic
  - Extra-thoracic
- **Restrictive Lung Disease**
  - ILD
  - Obesity
  - Neuromuscular Disease
- **Decreased Diffusion Capacity**
  - Associated with either Emphysema or ILD
  - Isolated suggesting Pulmonary Hypertension
Group Interpretation

Restriction

Normal
Asthma

“Hyper-reactivity”

Variable Extrathoracic Upper Airway Obstruction
### COPD

**Max Hyperinflation / Gas Trapping / Low DLCO**

<table>
<thead>
<tr>
<th>COPD</th>
<th>Obstructed (NO Bronchodilator Response)</th>
<th>Hyperinflation / Gas Trapping / Low DLCO</th>
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<tbody>
<tr>
<td>FEV1</td>
<td>2.16</td>
<td>2.08</td>
</tr>
<tr>
<td>FVC</td>
<td>2.88</td>
<td>2.83</td>
</tr>
<tr>
<td>MMEF</td>
<td>4.56</td>
<td>4.48</td>
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### Restriction

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### Preliminary Pulmonary Function Report

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<tr>
<th>Long Volumes</th>
<th>Diffusion</th>
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<tbody>
<tr>
<td>NVIC Unit:</td>
<td></td>
</tr>
<tr>
<td>DLCO, V01</td>
<td>10.93</td>
</tr>
<tr>
<td>TICOQ, V01</td>
<td>2.65</td>
</tr>
<tr>
<td>DLCO, V02</td>
<td>10.93</td>
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<tr>
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