Pulmonary Function Testing

Module L

Objectives

• State the indications for pulmonary function testing.
• Describe how each of the following tests are performed:
  • Helium Dilution
  • Nitrogen Washout
  • Body Plethysmography
  • Pre-/Post-bronchodilator Study
  • Flow-Volume Loop
  • Bronchial Provocation
  • Exercise Testing
  • MIP and MEP

Objectives

• Given a set of pulmonary function results, determine
  • Percent predicted
  • Type of defect (e.g. restrictive, obstructive)
  • % improvement (Pre-/Post-) and significance
• Given a flow-volume loop, determine if an obstructive defect is due to a fixed, extrathoracic, or intrathoracic defect.

Objectives

• Describe the key steps in pulmonary function testing
• Describe the process of calibration of pulmonary function equipment.
• Differentiate between volume-displacing spirometers and flow-sensing spirometers.
• Describe how pneumotachs measure volume.
• List the advantages and disadvantages of both volume-displacing and flow-sensing spirometers.

Objectives

• Describe the meaning of the following ATS acceptability criteria:
  • Good start of the test
  • Good Effort
  • No coughing
  • No variable flows
  • No early termination
• Given a spirometry error code, state the cause of the error and the proper corrective measure to be undertaken.
• Given PFT results, determine the severity of an obstructive disorder.

Specialty Examinations

• Certification Examination for Entry Level Pulmonary Function Technologists
  • (CPFT)
• Registry Examination for Advanced Pulmonary Function Technologists
  • (RPFT)
Indications for Pulmonary Function Testing

- Identify the presence or absence of lung dysfunction suggested by history or physical signs/symptoms.
  - Normal, Obstructive, Restrictive
  - Diffusion Defects
  - ATS recommends testing in any patient over 45 years of age with a history of cigarette smoking or under 45 years of age with symptoms.

- Quantify the severity of known lung disease.
- Identify and quantify changes in pulmonary function over time.
  - Is the disease progressing?
  - Is the disease reversible?
  - Is therapy working?

- Assess the potential effects or response to environmental or occupational exposure.
- Assessment of Post-Op Risk
  - Surgical patients (thoracic or abdominal)
- Pulmonary Disability
  - Rehabilitation
  - Legal
  - Military

Pulmonary Function Testing does not diagnose specific pulmonary disease.

PFT Predicted Values

- Based on
  - Age
  - Gender
  - Height
  - Race (?)
  - Weight (?)

- Reference Values
  - Regression Formula (Egan p. 422)
    - Adult: Morris, Crapo, Knudson
    - Pediatrics: Hsu and Polgar

Normal Values

- What is generally “accepted”
  - 80-120% of predicted is considered “normal”.
  - Larger errors with flowrates (FEF25-75%)

- FEV1/FVC of greater than 70% “normal”

- What ATS says should be used
  - 5th percentile of predicted (LLN)
  - Allows for false positives
  - Predicted value - 1.645 x SEE
  - FEV1/FVC “normal” are subject to significant variability and should not be used.
VOLUMES
- Tidal Volume: 500 mL
- Inspiratory Reserve Volume: 3100 mL
- Expiratory Reserve Volume: 1200 mL
- Residual Volume: 1200 mL

CAPACITIES
- Inspiratory Capacity: 3600 mL
- Functional Residual Capacity: 2400 mL
- Vital Capacity: 4800 mL
- Total Lung Capacity: 6000 mL

Normal 20 year old, 70kg male

Lung Volume Measurement
- RV, FRC, TLC cannot be directly measured
- Four Methods
  - Closed Circuit: Helium Dilution
  - Open Circuit: Nitrogen Washout
  - Body Plethysmography
    - Thoracic Gas Volume (TGV) vs. FRC
  - Chest X-ray - TLC
    - Planimeter and ellipse method
- Key Points
  - Tests are begun at the end of a normal exhalation (FRC).
  - Highly reproducible and not effort dependent

HELIXM DILUTION
- Requires the patient to re-breathe a helium gas mixture of a known concentration through a closed circuit from a spirometer of a known volume.
- Helium is inert.
- Re-breathing allows for the equilibration of helium concentration between spirometer and lung.
  - Carbon dioxide scrubber (soda lime) needed.
  - Equilibration time is usually about 3 minutes.

HELIUM DILUTION
- Oxygen is added to spirometer to account for oxygen depleted by patient (spirometer volume remains constant).
- FRC = (\%He_{initial} - \%He_{final})/\%He_{final} x Volume
- He analyzer (Katharometers)
  - Wheatstone bridge
  - Thermal conductivity

Wheatstone Bridge

![Wheatstone Bridge Diagram]
HELIUM DILUTION CALCULATION

- GIVEN:
  - Initial Helium Percentage: 10%
  - Initial Spirometer Volume: 3 liters
  - Final Helium Percentage: 6%

\[
\text{FRC} = \frac{\% \text{He initial} - \% \text{He final}}{\% \text{He final}} \times \text{Volume Spirometer}
\]

\[
\text{FRC} = \frac{10\% - 6\%}{6\%} \times 3 \text{ liters}
\]

\[
\text{FRC} = 0.6667 \times 3 \text{ liters} = 2 \text{ liters}
\]

MUST CONVERT FROM ATPS to BTPS

\[
\text{FRC} - \text{ERV (from spirometry)} = \text{RV}
\]

\[
\text{FRC} + \text{IC} = \text{TLC}
\]

Problems with He Dilution

- No Leaks can be present from mouth, nose, ears or equipment
  - A ruptured tympanic membrane will result in inaccurate readings

NITROGEN WASHOUT

- The N₂ concentration in the lungs is 75-80%
- Patient breaths 100% O₂ and washes out the nitrogen.
  - The switch to breathing 100% oxygen must come at the end of a normal exhalation (i.e. at FRC).
  - The test continues until the N₂ is less than 1%
  - 3-4 minutes
  - COPD washout time may exceed 7 minutes
- Open circuit (no re-breathing)
- \[
\text{FRC} = \frac{\text{VE} \times \text{FEN}_2}{0.78}
\]
- Once FRC is determined, RV and TLC can be calculated

BODY PLETHYSMOGRAPHY

- Patient breaths normally & at end exhalation (FRC), a shutter is closed and the patient begins to pant
  - Panting Frequency is 1 Hertz (Hz) (one cycle per sec)
  - One-two breaths/sec with glottis open
  - Simplified explanation for a complex formula.
**Thoracic Gas Volume**

- Two pressure changes are measured
  - Drop in mouth pressure as patient attempts to inhale.
  - Increase in chamber pressure as patient’s chest expands.
- Volume change is measured in the body box.
  - TGV ~ FRC
  - Measures ALL gas volume in thorax, even the volume distal to an obstruction.
- Boyles Law \( V_1 P_1 = V_2 P_2 \)
  \[ V_2 = \frac{V_1 P_1}{P_2} \]

**Expiratory Flow Rate Measurements**

- Measures the rate at which gas flows out of the lungs.
- Patency of the airways
- Severity of airway impairment
- Size of the patient’s airways

**Forced Vital Capacity**

- Volume of gas that can be exhaled as forcefully and rapidly as possible after a maximal inspiration.
**Forced Expiratory Flow**

- **200-1200**
  - Maximum expiratory flowrate.
  - Average flow rate between 200 and 1200 mL.
  - First 200 mL is ignored because of:
    - Inertia
    - Response time of spirometer
  - Good index of the patency of large airways

- **25-75%**
  - Maximum midexpiratory flowrate.
  - Average flow rate during middle 50% of FVC.
  - Can be used to assess the middle sized airways.
  - Caution: Use only as a secondary indice.

**Peak Expiratory Flow Rate**

- Peak Flow
- Maximum flow rate that can be achieved.
- Easiest measurement for determining “status” of airways.
- Variable results
  - Life of PF meters
  - Much easier to read from Flow-Volume Loop.

**Maximum Voluntary Ventilation**

- Largest volume of gas that can be breathed voluntarily in and out of the lungs in one minute.
- Test usually is performed for 12 to 15 seconds.
- Very effort- dependent

**Flow Volume Loops**

- Normal
- Obstructive
- Restrictive
- Fixed
- Variable Extrathoracic
- Variable Intrathoracic
This ratio can be used to determine the type of obstructive defect.

Normally this ratio is 0.8 to 1.0

\[
\frac{\text{FEF}_{50\%}}{\text{FIF}_{50\%}} = 0.8 \text{ to } 1.0
\]

- 6 L/sec
- 6 L/sec
- 6 L/sec
- 7 L/sec

0.85
Criteria

- *Three acceptable flow volume loops should be obtained*
- Sharp rise to PEFR; if not suspect poor effort or large airway obstruction
- F-V loops are used to detect upper airway obstruction
  - Extrathoracic obstruction occurs above the suprasternal notch
  - Intrathoracic obstruction occurs below the suprasternal notch
  - Fixed obstruction can occur either above or below

Variable Extrathoracic Obstruction

- Normal expiratory flows but decreased inspiratory flows
- FEF\textsubscript{50%}/FIF\textsubscript{50%} is greater than 1.0
- Causes
  - Upper airway tumor
  - Edema of epiglottis
  - Vocal cord paralysis
  - Vocal cord adhesions
  - Foreign body in upper airway
Variable Intrathoracic Obstruction

- Tracheomalacia
- Polychondritis
- Tumor near the carina
- Foreign body in trachea
- FEF$_{50}$/FIF$_{50}$% is less than 0.8

Fixed Obstruction

- This results in equally reduced flow rates
- The loop is squared off on both inspiration and expiration
- FEF$_{50}$/FIF$_{50}$% is normal
- Causes
  - Vocal cord stenosis (watch after extubation)
  - Goiter
  - Large foreign body
  - Tumor

Before & After Bronchodilator Studies

- Indication
  - FEV$_1$% < is less than 70%
  - A new medication is being evaluated.
  - Patient is known to have asthma or COPD.
- Medications should be withheld.
  - $\beta_2$ agonist: see CPGs
  - Methylxanthines 12 hours
  - Cromolyn Sodium 8-12 hours
  - Inhaled Steroids: maintain dosage
  - Anticholinergics 8 hours
Before & After Bronchodilator Studies

• Some patients may be unable to withhold medication
  • Document in interpretation section
• After administering the bronchodilator, wait 15 minutes before starting the post test
• If atropine is given, wait 45 - 60 min
• FEV₁ is most commonly used to quantify response

Pre/Post Example

<table>
<thead>
<tr>
<th></th>
<th>PATIENT A</th>
<th></th>
<th></th>
<th>PATIENT B</th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Predicted</td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
<td></td>
</tr>
<tr>
<td>FVC (L)</td>
<td>4.70</td>
<td>2.93 (62)</td>
<td>3.46 (74)</td>
<td>2.93 (62)</td>
<td>2.95 (63)</td>
<td></td>
</tr>
<tr>
<td>FEV₁ (L)</td>
<td>3.56</td>
<td>1.29 (34)</td>
<td>1.59 (45)</td>
<td>2.63 (74)</td>
<td>2.69 (76)</td>
<td></td>
</tr>
<tr>
<td>FEV₁/FVC (%)</td>
<td>76</td>
<td>44</td>
<td>46</td>
<td>90</td>
<td>91</td>
<td></td>
</tr>
</tbody>
</table>

Bronchodilator Mechanics

• Pre- & Post- bronchodilator PFT
  • Some disagreement (ATS, ITS, ACCP)
  • ATS:
    • 12% improvement and 200 mL in FVC
    • 12% improvement and 200 mL in FEV₁
  • % change = \( \frac{\text{Post FEV}_1 - \text{Pre FEV}_1}{\text{Pre FEV}_1} \times 100 \)

Diffusing Capacity

• Evaluates the ability of a test gas to get across the alveolar-capillary membrane.
• DLCO is a measurement of diffusion in the lungs.
• Predicted based on Height, Age, & Sex or Age, Sex, and BSA. Normal value is 25 ml CO/ min/ mmHg (STPD)
• Multiple methods of testing
  • Single Breath (breath hold) is the most common.
  • Gas diffusion across the A-C membrane is determined by:
    • Diffusion coefficient of the gas used (CO is best)
    • Patient should not have smoked for at least 24 hours.
    • Surface area of the membrane (DL/VA)
    • Thickness of the membrane
    • Blood volume and flow in the pulmonary capillary tree
    • Distribution of the inspired gas/blood flow (body position)
    • Hemoglobin or Hematocrit (correct for Hb level)

DLCO Testing Equipment
**Bronchial Provocation**

- Used to identify and characterize airway hyperresponsiveness.
- Used when patient has symptoms of bronchospasm with normal PFTs or uncertain post-bronchodilator results.
- Several provocative agents used:
  - Methacholine (most common)
  - Histamine
  - Cold air
  - Exercise
  - Nebulizer output and/or use of a dosimeter.
- Response quantified with spirometry (FEV₁, FVC, FEV₁/FVC%).
  - PC₂₀
- Need for increased monitoring secondary to bronchospasm.

**Exercise Testing**

- Allows for evaluation of the heart and lungs under conditions of increased metabolic demand.
- Cardiopulmonary variables (V̇ₑ, V̇ₐ, f, VO₂, VCO₂, ṘER [~RQ], Anaerobic Threshold) are assessed in relation to increasing workload (treadmill or exercise bike).
- Three types of tests:
  - Testing to evaluate the exercise tolerance
  - Testing to evaluate desaturation using oximetry
  - Testing to evaluate exercise-induced bronchospasm.

**Anaerobic Threshold (AT)**

Anaerobic Threshold (Ventilatory Threshold) occurs when the energy demands of the exercising muscles exceed the body’s ability to produce energy by aerobic metabolism.

**Measurement of Respiratory Muscle Strength**

- Maximum Inspiratory Pressure (MIP or NIF)
- Maximum Expiratory Pressure (MEP)
- Forced Vital Capacity
- MVV
MIP or NIF

- This is the lowest pressure developed during a forceful inspiration against an occluded airway.
- It is measured at RV or FRC and recorded as a negative number in cm H2O or mm Hg.
- A small leak is introduced between the occlusion and the patient’s mouth.
  - This eliminates pressures generated by the cheek muscles, but does not significantly affect readings.

- Is used to assess:
  - Response to respiratory muscle training.
  - Muscle strength during weaning from MV.
  - Record at least 3 efforts.
  - Pressure plateau of 1 to 3 seconds.
  - Maximal value should be recorded.
  - Two best efforts should be reproducible within 10% or 10 cm H2O.

MIP or NIF

- Normal values for adult should be greater than -60 cm H2O.
- Measured inspiratory muscle strength.
- Decreased values seen in
  - Neuromuscular diseases
  - Hyperinflation of the lungs
  - Chest wall or spinal deformities (scoliosis)
  - Stroke
- Value below -20 cm H2O is indication for mechanical ventilation.

Maximal Expiratory Pressure

- Highest pressure that can be developed during a forceful expiration against an occluded airway.
  - Usually measured at TLC.
  - It is reported as a positive number in cm H2O or mm Hg.
  - A small leak is introduced between the occlusion and the patient’s mouth.

MIP or NIF

- Healthy adults can generate a MEP over 100 cm H2O
- Is used to assess expiratory muscle strength and the ability of the patient to cough.
- Decreased values seen with:
  - Expiratory muscle weakness
  - Neuromuscular disease
  - High cervical spine fractures
  - Damage to nerves controlling the abdominal and accessory muscles
  - Obstructive lung disease
Obstructive Disease

- An obstructive ventilatory defect may be defined as a disproportionate reduction of maximal airflow from the lung with respect to the maximal volume (VC) that can be displaced from the lung. (ATS)
  - Airflow limitation
  - Airway narrowing during expiration
  - Airway Resistance problem
  - Evaluate the FEV₁, FVC, and FEV₁/FVC.

Obstructive Airway Diseases

- Lung Tumors/Neoplasm
- Foreign Bodies
- Goiters
- Vocal Cord Dysfunction
- Croup/Epiglottitis

Differential Diagnosis

- Obstructive Lung Diseases
  - Cystic Fibrosis
  - Bronchiectasis
  - Asthma
  - Chronic Bronchitis
  - Emphysema

Causes of Increased Airway Resistance

- Chronic inflammation and swelling
- Excessive mucus production and accumulation
- Tumor projecting into a bronchus
- Destruction and weakening of the distal airways
- Bronchial smooth muscle constriction
Dynamic Compression

- Effort-dependent portion of FVC
  - First 20-30% of volume exhaled
  - Peak flow
  - Muscular effort of individual
- Effort-independent portion of FVC
  - Last 70-80% of volume exhaled
  - Slope of Flow-Volume loop
  - Limited by dynamic compression of the airways
- Equal Pressure Point

Equal Pressure Point

- Pressure outside the airway equals pressure inside the airway at the EPP.
- When pressure outside exceeds that inside (as occurs during a forced exhalation), the airway collapses and flow stops.

Obstructive Disease Severity

<table>
<thead>
<tr>
<th>VC</th>
<th>FEV1/FVC</th>
<th>% Pred FEV1</th>
<th>Severity</th>
</tr>
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<tbody>
<tr>
<td>N</td>
<td>N</td>
<td>≥ 100%</td>
<td>WNL</td>
</tr>
<tr>
<td>-</td>
<td>L</td>
<td>&lt;100 &amp; ≥ 70%</td>
<td>Physiological Variant</td>
</tr>
<tr>
<td>-</td>
<td>L</td>
<td>&lt;70 &amp; ≥ 60%</td>
<td>“Mild”</td>
</tr>
<tr>
<td>-</td>
<td>L</td>
<td>&lt;60 &amp; ≥ 50%</td>
<td>“Moderate”</td>
</tr>
<tr>
<td>-</td>
<td>L</td>
<td>&lt;50 &amp; ≥ 34%</td>
<td>“Severely”</td>
</tr>
<tr>
<td>-</td>
<td>L</td>
<td>&lt;34%</td>
<td>“Very Severe”</td>
</tr>
</tbody>
</table>

Restrictive Disease

- A restrictive ventilatory defect is characterized physiologically by a reduction in TLC. (ATS)
  - Lung Parenchyma or Thoracic Pump defect
  - Problem getting air in
  - Lung/Thoracic Compliance problem
  - Evaluate lung volumes (TLC, RV, RV/TLC)

Restrictive Lung Diseases

- Interstitial Lung Diseases
  - Pneumoconiosis
  - Sarcoïdosis
  - Idiopathic pulmonary fibrosis
- Diseases of the chest wall and pleura
  - Pleurisy
  - Kyphoscoliosis/ Scoliosis
  - Pleural effusions
  - Obesity
  - Pneumothorax
Restrictive Lungs Diseases

- Neuromuscular Disorders
  - Guillain- Barre
  - Myasthenia Gravis
  - ALS or Lou Gehrig's disease
  - Diaphragmatic paralysis
- CHF/ Pulmonary Edema

American Thoracic Society (ATS)

- Criteria for PFT testing is based on recommendations of the ATS
- Standards have been published
  - 1979 - Snowbird Spirometry Standards
  - 1987 - Revised Standards
  - 1991 - Reference values and Interpretation
  - 1994 - Revised Standards
    - Selection of reference values
    - Spirometry performance
    - Set Quality Assurance Standards and have written a management and department procedure manual
  - 2005 - ATS/ ERS Task Force on Standardization of Testing and Interpretation
  - 2007 - ATS/ ERS Task Force on Spirometry in Children

Steps in PFT Process

Quality Assurance

- QA is a systematic approach to monitoring and evaluating the quality of the test and the test results
### Quality Assurance

- **Pre-testing**
  - Demographics, History, Medications, Pre-test instructions, appropriate order, calibration of equip.
  - Competency of PFT personnel/ Training
  - Instrumentation/ Equipment

- **Testing**
  - Patient comprehension of instructions and expectations
  - Technologists instructions & training
  - Reference equations
  - Patient performance

- **Post-Testing**
  - Maneuver selection
  - Interpretation/ comments; Report Review

### Spirometers

- **Volume Displacing Spirometers**
- **Flow Sensing Spirometers**
  - Pneumotachometers

### Volume Displacing Spirometers

- **Water Seal Spirometer (Collins or Stead- Wells)**
  - “Gold Standard” - most accurate
  - Uses a Kymograph as a recording device
  - Best system to check accuracy of other PFT equipment
- **Dry Rolling Seal**
- **Bellows Type**
- **Diaphragm**

### Volume Displacing Spirometers

- **Advantages**
  - Directly measure volume
  - Low cost
  - Ease of operation
- **Disadvantages**
  - LEAKS
  - Large and bulky (little portability)
  - Water in water seal needs changing
  - Without a microprocessor/computer, manual calculations are needed

### QA for Water Seal Spirometers

- Water level checked daily
- Paper tracing speed checked daily
  - Paper speed 32, 160 & 1920 mm/ min
- Leak test & calibration checked daily
- Water changed weekly
SPIROMETER LEAK TEST

Flow Sensing Spirometers

- Use of various physical principles to produce a signal proportional to gas flow
- Integration is a process in which flow \((V/T)\) is divided into a large number of small intervals of time and volume is calculated
  
  \[
  \text{Flow} = \frac{\text{Volume}}{\text{Time}} \quad \text{Volume} = \text{Flow} \times \text{Time}
  \]
Uses of Flow Sensing Spirometers

- Respirometers
- Mechanical Ventilators
- Incentive Spirometers
- PFT equipment
- Exercise Equipment
- Metabolic Measurement Carts (Indirect Calorimetry)

Types of Flow Sensing Spirometers

- Pneumotachometers
- Turbine or Turbinometers
- Heated Wire Flow Sensors
- Sonic Devices (Sound waves)
  - Ultrasonic
  - Vortex

Flow Sensing Spirometers

- Pneumotachometers
  - Pressure Differential Flow Sensors
  - Uses a pressure change caused by a resistive element to calculate flow
  - Flow = Δ Pressure (any change in P will affect flow)
  - Resistance (keep resistance the same)

Types of Pneumotachs

- Fleisch Type (bundle of capillary tubes)
- Screen Type (fiber or metal)
- Ceramic Type
- Variable & Fixed Orifice
**Turbine Device: Wright Respirometer**

- Bladed rotating vane
- Inspiratory measurement port
- Expiratory measurement port

**Advantages**
- Smaller and usually more portable
- Computerized; no manual calculations
- Bidirectional devices provide flow volume loop capabilities
- Can be used to continuously measure minute ventilation

**Flow Sensing Spirometers**

**Disadvantages**
- More knowledge needed to operate
- Frequent calibration
- Moisture/secretions can affect results
- Gas composition can affect results
- May not be accurate at very high or low flowrates
Flow Sensing Peak Flow Meters

- More important to be precise than accurate
- Repeated measurements should be reproducible (valid) within 5% or 10 L/min whichever is greater
- Tend to underestimate flowrate as altitude increases

Spirometer Calibration

- Spirometers should be calibrated every day
- Volume Spirometers should be leak tested
- A Super Syringe is used to calibrate spirometers.
  - +/- 3% accuracy or 0.05L whichever is larger (diagnostic spirometer)
  - Use three flowrates 1 sec, 6 sec and between 1-6 sec
  - If using a 3 L super syringe, the volume measured by the device should be between 2.91 and 3.09 L

Spirometric Technique

Patient Preparation

- Explain which medications to stop taking before testing
- Instruct if physician wants patient to stop smoking before the test (DLCO)
- Explain to the patient the length of time
- Do not eat a full meal

Recommended Times for Withholding Bronchodilators

- Salmeterol 12 hours
- Ipratropium 6 hours
- Terbutaline 4-8 hours
- Albuterol 4-6 hours
- Metaproterenol 4 hours
- Isoetharine 3 hours

Patient Preparation

- Pulmonary history/physical assessment
  - Height, Weight, Age, Race, Sex
  - Patients who cannot stand use arm span to determine height
  - Height should be measured without shoes
- Predicted normal values are based on
  - Height
  - Age
  - Sex
  - Race (?)
**Patient Preparation**

- Determine any relative contraindications
  - Hemoptysis
  - Pneumothorax
  - Unstable cardiovascular status
  - Thoracic/abdominal or cerebral aneurysms
  - Recent eye surgery
  - Acute symptoms (vomiting, nausea, dizziness)
  - Recent surgery of thorax or abdomen
  - Should not do after a full meal

- Keep explanations simple
- Explain that the test does not hurt but requires “lots of effort”
- Explain that each test may require a number of efforts
- Position the patient
  - Chin up, feet flat on the floor, loosen clothing

- Explain & demonstrate the maneuver
  - Explain the procedure and what you expect from the patient
  - Stop oxygen just for test maneuvers
  - Demonstrate the maneuver
  - Coach the patient throughout the maneuver
- Evaluate for proper performance and carefully inspect the graphs

**ATS Standards**

- **3 Acceptable FVC Maneuvers**
  - If an acceptable maneuver cannot be obtained after 8 attempts, testing may be discontinued
- **2 Trials that are reproducible (valid)**
  - The two largest FVC from acceptable trials should not vary by more than 0.15 L
  - The two largest FEV₁ from acceptable trials should not vary by more than 0.15 L
  
  Can be 100 mL if the FVC is less than or equal to 1.0 L

**Acceptability Criteria**

- **Good start of the test**
  - No hesitation.
  - An extrapolated volume of ≤ 5% of the FVC or 150 mL, whichever is greater.
- **Good Effort**
  - No coughing (especially during the 1st sec)
  - No variable flows
  - Minimum exhalation of 6 seconds unless there is a plateau
Extrapolated Volume

Every test shows deteriorating flowrates

All tests must be reported at BTPS
All predicted values are based on
  - Age
  - Height
  - Sex
  - Race (?)
Weight is reported, but not used in prediction

Office/Bedside Spirometry

FEV₆ can replace FVC as an end of test criteria
- Shortens the testing session
- Avoids overexertion while attempting a FVC
- Airway obstruction will be detected when FEV₆/FEV₅ are below the lower limit of normal
### APPENDIX 4: Selected Adult Reference Populations, Methods, and Regression Equations for Spirometry and Lung Volumes

#### Table A4.1 PVC (L)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Year</th>
<th>Race</th>
<th>Age Range</th>
<th>No.</th>
<th>Sex</th>
<th>Method</th>
<th>Site</th>
<th>Regression Equation</th>
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<td>Abernathy</td>
<td>2006</td>
<td>B</td>
<td>20-44</td>
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<td>W</td>
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#### Table 2 - Classification of Severity*

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<th>Characteristics</th>
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<td>FEV&lt;sub&gt;1&lt;/sub&gt;/FVC &lt; 70%</td>
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<td>FEV&lt;sub&gt;1&lt;/sub&gt;/FVC &lt; 50%</td>
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<td>5</td>
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<tr>
<td>7</td>
<td>FEV&lt;sub&gt;1&lt;/sub&gt;/FVC &lt; 70%</td>
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<tr>
<td>8</td>
<td>FEV&lt;sub&gt;1&lt;/sub&gt;/FVC &lt; 50%</td>
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<td>9</td>
<td>FEV&lt;sub&gt;1&lt;/sub&gt; &lt; 30% predicted</td>
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*Note: The classification criteria are based on percent predicted values for FEV<sub>1</sub> and FVC.