Pulmonary Function Testing

CRC 330 – Cardiorespiratory Assessment Skills
Bill Pruitt, MBA, CPFT, RRT, AE-C
REFERENCES AND SUPPLIES

REQUIRED READING/STUDY:
- Wilkins Assessment Ch 8 (Read first)
- Egan Fundamentals 9th ed Ch 19
- White Competencies Ch 5
- Chang’s 2nd ed Resp Care Calculations
- This handout, lecture, drawings

SUPPLIES: Spirometers, flow sensors, Collins paper, mouthpieces, nose clips, overheads, handouts
What does Pulmonary Function Testing tell us?

- Volume and capacity: how much air can be moved into and out of the lungs
- Flow: how fast the air moves in and out
- Compliance: the stiffness of the lung and chest wall
- Diffusion: characteristics of gas movement across the alveolar-capillary membrane
- Effectiveness of therapy: the lungs response
What affects overall pulmonary function?

1. Condition of conducting airways, gas exchange airways, and the alveolar capillary membrane
2. Gas distribution through the pulmonary tree
What affects overall pulmonary function?

3. Structure and compliance of thorax and the lungs
4. Respiratory muscle strength
5. Neuromuscular control of breathing
6 Uses for Pulmonary Function Testing – Why order a PFT?

1. Support a diagnosis
2. Develop and modify treatment plans
3. Assess for disability (eg. worker’s comp)
4. Pre-op assessment for post-op risks (weaning and recovery issues after surgery)
5. Prevention of disease (esp. asthma)
6. Progression of disease
Test Validity Requirements

- Good patient technique  (Good coaching)
- Patient cooperation   (Good coaching)
- Reproducibility       (Good coaching)

“Tests should be reproducible and reliable”
American Thoracic Society (ATS)

- Sets standards for acceptability for equipment
  - accuracy, calibration, and range of measurement
    - Calibration checks done daily showing $\pm 3\%$ accuracy with a 3 L syringe
  - designates equipment to be either for diagnostics or for monitoring
- Volume spirometers checked for leaks
- Sets standards for accuracy and reproducibility of tests
- The most recent issues of all the PFT standards can be found at www.chestjournal.org
Principles of Measurement

- Most pulmonary function laboratories have three components.
  - Performing spirometry to measure airway mechanics
  - Measuring lung volumes and capacities
  - Measuring diffusion capacity of the lung

- All three components are required when the purpose of the PFT is to identify the presence and degree of pulmonary impairment

- Physician’s offices and clinics only perform spirometry… if anything.
  - Most don’t perform PFT (except pulmonologist office)
Lung Volumes (4)
(estimates for a healthy male 25 yrs old, 6 ft tall, 165 lbs)

- Tidal volume \( V_t = 500 \text{ cc} \)
- Inspiratory Reserve Volume \( IRV = 3100 \text{ cc} \)
- Expiratory Reserve Volume \( ERV = 1200 \text{ cc} \)
- Residual Volume \( RV = 1200 \text{ cc} \)

- Estimate for normal \( V_t = 5 \) to \( 7 \text{ ml/kg} \)
Lung Capacities (4)
Made up from combinations of the 4 volumes

- Total Lung Capacity (IRV + VT + ERV + RV)
  6000 cc
- Vital Capacity (IRV + VT + ERV)
  4800 cc
- Inspiratory Capacity (IRV + VT)
  3600 cc
- Functional Residual Capacity (ERV + RV)
  2400 cc
4 Capacities, 4 volumes
SPIROMETRY
Spirometry

- Measures 3 of the 4 volumes (IRV, VT, ERV)
- Capacities that include RV cannot be determined with simple spirometry (FRC, TLC)
- **Remember**: simple spirometry will not measure RV, FRC, and TLC

Note: Calibration performed daily with 3 L syringe and using varying flow rates to mimic different patients. Must be within ± 3% L to pass calibration (± 90 mL)

Calibration done under ATPS conditions – measurements converted to BTPS (See Chang’s RC Calculations – pg 23)
Devices for Measuring Volume
Volume Displacement Devices

- Water-sealed Spirometers
- Bellows (Wedge) Spirometer
- Dry Rolling Seal Spirometer
- Diaphragm Spirometers

See White’s Lab Competencies Ch 5
Chain Compensated Water-sealed Spirometer
Wedge spirometer
Dry Rolling Seal Spirometer
Flow measurement

- Flow = volume per unit of time
- Usually expressed in liters per second (L/s)
- Disposable PF devices - L/min
- For a PFT lab, volumes are often derived from a flow measurement
Devices for Measuring Flow

- Pneumotachometers – many measure a pressure differential created by breathing through a known resistance
  - Fleisch (brass capillary tube)
  - Metal screen (Hans Rudolph, Servo 900 ventilator)
- Thermistors (heated wire - measures heat loss)
  - Commonly used in PFT equipment
More Devices for Measuring Flow

- **Respirometers** (vanes connected to precision gears) “Wrights”, “Haloscale”
  - Avoid high flows… operate at < 300 L/min
- **Flow interrupters** - rotating vanes “chop” a light beam
- **Fiber screen** (exhalation only)
More Devices for Measuring Flow

- Sonic devices
  - Vortex - uses a strut to cause gas swirls (turbulence or vortices) which interrupt an ultrasonic beam. Pulses in beam are counted.
  - Ultrasonic - sends sound waves through a tube, speed increases with flow, decreases against flow (Easy One)
Devices for Measuring Flow

- Peak flow meters
  - Thorpe-type
    - Tapered body - gravity / ball / indicator
  - Spring tension
    - Straight body / spring / indicator
  - Flexible vane
    - Curved body / cut metal / indicator
Key Determinants of Predicted Values

- **Age** - values decrease with age
- **Height** - values increase with height
- **Sex** - females have smaller lungs = less volume
  - Race/Ethnicity carries weight too

Reports given with Measured, Predicted, and Percent predicted. Example:

- FVC Meas = 4.71 Pred = 5.28, % Pred = 89

Note – use arm span if height is not measurable
Other Factors

- **Weight** (ideal body weight vs actual weight)
- Environment
- Smoking
  - See nomograms for males/females on page 92 in White’s Lab Competencies. Also Wilkins pg. 144
Figuring Percent Predicted

% Predicted = \frac{\text{Measured value}}{\text{Predicted value}} \text{ (based on age, ht, sex)}

Example: Measured FVC = 3.52
Predicted FVC = 4.30

% Predicted = \frac{3.52}{4.30} = 81.8\% \text{ predicted}
Figuring Percent Change

(Used to measure effect of bronchodilators or challenges)

% change = \frac{\text{Post measurement} - \text{Pre measurement}}{\text{Pre number}} \times 100

Example - Peak flow before bronchodilator = 8.63 L/s
Peak flow post bronchodilator = 9.75 L/s

% change = \frac{9.75 - 8.63}{8.63} \times 100 = 12.97\% change

Think: you expect the post tx to be bigger than the pre tx values
Forced Vital Capacity

- Inhale fully then exhale as forcefully as possible for as long as possible to reach zero flow (Usual goal minimum 6 sec. May go 15+ seconds)
- Need three acceptable measurements
  - The 2 largest $FVC \leq 150$ ml, and the 2 largest $FEV1 \leq 150$ ml of each other
  - **Start of test:** Back-extrapolated volume is $< 5\%$ of $FVC$ or less than 150 cc (whichever is greater)
  - **End of test:** Flow reaches a plateau or patient cannot/should not exhale any longer (avoid syncope)
- Deep breath in, then BLAST IT OUT and keep blowing!
Forced Vital Capacity

- Do at least 3 and usually no more than 8 FVC maneuvers
- Rest between maneuvers if needed
- No cough, no leaks, give maximum effort (no “sighs”)

See Chang’s RC Calculations pg 95 for FVC, FEV$_T$
Assessing the start of the test: BEV
Start of test: BACK - EXTRAPOLATION
Start of test: BACK - EXTRAPOLATION

- A horizontal line is drawn at peak inspiration “A”
- A tangent is drawn at the steepest part of the expiratory curve “B” which intersects line A
- A vertical line is placed at the intersection of A and B = line C
- The intersection of A, B, and C is the time zero point whereby the timed values are measured (FEV₁ etc.)
Start of test: BACK - EXTRAPOLATION

- The extrapolated volume is difference between the beginning volume at the start of exhalation and the point on the expiratory curve where the time zero line (C) intersects.
- Computer software does this measurement and warns the RCP if out of ATS standards.
- Error code gives warning for “Start of exhalation too slow”
Measurements from FVC

- *Forced Vital Capacity (FVC) expressed in liters
- *Forced Expiratory Volume in 1 second (FEV₁) expressed in liters/sec
- *FEV₁ /FVC (aka FEV₁ %)

- = These 3 are KEY measurements for interpretation and COPD/Asthma guidelines
- Note use of FEV₆ instead of FVC
Measurements from FVC

- Forced Expiratory Flow between 200 and 1200 ml (FEF<sub>200-1200</sub>) expressed in L/sec
  - Early in exhalation… reflects larger airways
  - To calculate – see Chang’s RC Calculations pg 102

- Forced Expiratory Flow between 25% and 75% of vital capacity (FEF<sub>25-75%</sub>) expressed in L/sec
  - Later in exhalation… reflects medium to small airways
  - To calculate – see Chang’s RC Calculations pg 110

- Peak Flow (PEFR, PEF, PF) expressed in L/sec
FVC
(Forced Vital Capacity)

- May be recorded in a volume/time curve or flow/volume loop
- PFTs are measured at ATPS but must be reported at BTPS. See Egan, pg 394 (computer system will convert ATPS to BTPS)
- Usually FVC = SVC (± 200 cc)
- If SVC > FVC, indicates COPD (due to airway closure and air trapping)
SPIROMETRY

- Practice drawing and labeling spirometry results
- Normal versus obstructive versus restrictive patterns
  - Flow/volume loop
  - Volume/time curve
  - “Boxes”
VOLUME-TIME CURVES

Note CHANGES due to LUNG DISEASE
FLOW - VOLUME LOOPS

Expiration

Inspiration

Volume (liters)

FVC

PIF

FEF<sub>25%</sub>

FEF<sub>50%</sub>

FEF<sub>75%</sub>

PEF
Significance of FVC Measurements

- FVC: < predicted indicates probable abnormality
- FVC < SVC: may be seen in obstruction
- FEV$_1$ used for guidelines in treating asthma and COPD
  - NAEPP – National Asthma Education and Prevention PRogram
  - GOLD – Global Initiative for Chronic Obstructive Lung Disease
- FEV$_1$/FVC (FEV$_1$ %): <70% = DEFINES obstruction
Significance of FVC Measurements

- **FEV$_1$:** decreased in restriction (small lungs) or obstruction (decreased flows in large airways)
- **FEF$_{200-1200}$**: if abnormal (low) reflects problems in the large airways
- **FEF$_{25-75\%}$**: if low reflects problems in the medium to small airways
- **PEF**: indicator of patient effort
Interpretation of PFT

- **Normal vs abnormal**: abnormal usually anything < 80% of predicted values, except FEV₁/FVC

- **Obstruction**: air trapping, decreased flows, big lungs (in relative terms) FEV₁/FVC < 70%
  - Determined with spirometry, confirmed with lung volumes test

- **Restriction**: reduced total lung capacity (small lungs), often increased flows (when corrected for size of lungs) FEV₁/FVC is normal
  - Hint shows up in spirometry (small FVC).
  - Determined by measuring lung volumes
FEF\textsubscript{200-1200} (Forced expiratory flow between 200 –1200 ccs)

- Measured between 200 and 1200 cc of the FVC
- First 200 cc disregarded (beyond inertia, measuring error)
- Measures the effort dependent portion of the FVC
- Good indicator of large airway integrity (after first 200 cc, standardized measure of 1st liter exhaled)
- Decreases with age and obstructive disease

To calculate – see Chang’s RC Calculations pg 102
FEF 25-75%

(Forced expiratory flow between 25% and 75% of the FVC)

- Measures airflow between 25 and 75% of FVC
- Good indicator for medium to small airways
- Decreases with age and obstructive disease
- May be sensitive for early detection of COPD (10 pack years)

- To calculate – see Chang’s RC Calculations pg 110
PEF
(Peak expiratory flow)

- Measured by peak flow meter or taken from FVC measurement
  - Normal range for young & healthy =7.5 to 10 lps
  - Decreases with age and obstructive disease
  - May be used for pre & post response to bronchodilator treatments at the bedside
- Asthma guidelines use this to gauge severity of disease and titrate therapy/doses
- Assessed from an established “usual best” (3 zones)
  - > 80% (green) / 50 - 80% (yellow) / <50% (red)
Withholding Medications

Before performing spirometry, withhold:

- Short acting $\beta_2$-agonists for 6 hours
- Long acting $\beta_2$-agonists for 12 hours
- Anticholinergics
  - Ipratropium for 6 hours
  - Tiotropium for 24 hours

Optimally, subjects should avoid caffeine and cigarette smoking for 30 minutes before performing spirometry
Spirometry Quality Control – 6 points

At least 3 tests and:

1. Acceptable tests have no hesitation …BEV < 5% of FVC (this is the start of test)
2. Acceptable tests have 6 seconds for exhalation (this is the middle of test)
3. Acceptable tests reach a plateau (this is the end of test)
4. The 2 best tests FVC values ± 150 ml
5. The 2 best FEV$_1$ values ± 150 ml
6. The best 2 acceptable tests PEF ± 10%
Spirometry - Possible Side Effects

- Feeling light-headed
- Headache
- Getting red in the face
- Fainting: reduced venous return or vasovagal attack (reflex)
- Transient urinary incontinence

Spirometry should be avoided after recent heart attack or stroke
Before and After Bronchodilator Therapy (Pre & post bronchodilator)

- Indication: FEV$_1$% is less than predicted
- Patient should hold meds that could “blunt” the spirometry
  - Hold quick-acting bronchodilators at least 4 hours prior to testing (if possible), long lasting at least 12 hours
- Record baseline (pre) F/V loops and lung volumes (lung subdivisions) before giving bronchodilator.
- Give tx and wait 15 minutes before retesting F/V loops
Before and After Bronchodilator Therapy (Pre & post bronchodilator)

- To be called “Significant response to bronchodilator”
  - (+) 12% change and 200 cc increase in \( FEV_1 \)
  - This is the most “favored” change

- \( \text{\% Change} = \left( \frac{\text{Post} - \text{Pre}}{\text{Pre}} \right) \times 100 \)
  - Expectation is for increased FVC and \( FEV_1 \) post tx
    - Note: Decreased volume (FVC) in post measurements could be related to fatigue
This photo courtesy of the American Association for Respiratory Care

This photo courtesy of my boss
Pre-post F/V loops and V/T curves
## PULMONARY FUNCTION ANALYSIS

### Spirometry

<table>
<thead>
<tr>
<th>Measure</th>
<th>Unit</th>
<th>Ref Value</th>
<th>Pre Meas</th>
<th>Pre % Ref</th>
<th>Post Meas</th>
<th>Post % Ref</th>
<th>Post % Chg</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC</td>
<td>Liters</td>
<td>5.74</td>
<td>(4.14)</td>
<td>(72)</td>
<td>4.79</td>
<td>83</td>
<td>16</td>
</tr>
<tr>
<td>FEV1</td>
<td>Liters</td>
<td>4.77</td>
<td>(2.81)</td>
<td>(59)</td>
<td>3.64</td>
<td>76</td>
<td>29</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>%</td>
<td>84</td>
<td>(68)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEF25-75%</td>
<td>L/sec</td>
<td>5.00</td>
<td>(1.88)</td>
<td>(38)</td>
<td>2.96</td>
<td>(59)</td>
<td>58</td>
</tr>
<tr>
<td>FEF200-1200</td>
<td>L/sec</td>
<td>8.76</td>
<td>(4.72)</td>
<td>(54)</td>
<td>7.76</td>
<td>89</td>
<td>64</td>
</tr>
<tr>
<td>PEF</td>
<td>L/sec</td>
<td>10.30</td>
<td>(5.02)</td>
<td>(49)</td>
<td>8.34</td>
<td>81</td>
<td>66</td>
</tr>
<tr>
<td>FET100%</td>
<td>Sec</td>
<td>10.08</td>
<td>8.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FIVC</td>
<td>Liters</td>
<td>5.74</td>
<td>(3.98)</td>
<td>(69)</td>
<td>1.53</td>
<td>(27)</td>
<td>-19</td>
</tr>
<tr>
<td>MVV</td>
<td>L/min</td>
<td>193</td>
<td>(98)</td>
<td>(51)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>BPM</td>
<td>55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
MVV
(Maximum voluntary ventilation)

- Measures deep and rapid breathing over 12 to 15 seconds
- Rate > 60 (one breath per second)
- Goal is to reach or exceed best $\text{FEV}_1 \times 40$ for indication of patient effort (some use 35)
- Marked reduction reflects higher post-op risks for abdominal and thoracic surgery patients
MVV Recording
Volume \times rate

Amount of air moved in 12 seconds
<table>
<thead>
<tr>
<th></th>
<th>Ref</th>
<th>Best</th>
<th>% Ref</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVV</td>
<td>159</td>
<td>93</td>
<td>58</td>
<td>93</td>
</tr>
<tr>
<td>f</td>
<td></td>
<td>85</td>
<td></td>
<td>85</td>
</tr>
<tr>
<td>MVV 6</td>
<td></td>
<td>147</td>
<td></td>
<td>147</td>
</tr>
</tbody>
</table>

![Graph](image)
Methods of Measuring Lung Volumes (Lung subdivisions or $V_{TG}$)

Two methods used to measure lung volumes:

1. Gas analysis methods
   - Closed circuit (multiple breath helium dilution)
   - Open circuit (multiple breath nitrogen washout)
   - Single breath helium dilution
   - Single breath nitrogen washout

2. Body plethysmography

BOTH methods MEASURE FRC (subtract ERV to get RV)
Multiple Breath Nitrogen Washout Test - Open Circuit

Technique

- Test starts with subject at resting end-expiratory level (FRC)
- Subject begins breathing 100% O₂ to wash out N₂
- Volume of each breath is measured with a pneumotachometer and N₂ measured with a rapid N₂ gas analyzer (Geisler tube type analyzer)
- Test halted when N₂ % is ~ 1%. Maximum time allowed is approximately 7 minutes
Nitrogen Washout Test

Assumptions

- $N_2$ in the lungs is assumed to be 78%
- Each minute of $O_2$ breathing 30 - 40 ml are washed out from blood and tissues

$$FRC \times N_2\% \text{ start} = \text{Expired volume} \times N_2\% \text{ end}$$
  - Solve for $FRC$

$$FRC - ERV = RV$$
Nitrogen Washout Recording
Nitrogen Washout Test

- **Current Method**
  - rapid N₂ Analyzer with spirometer
  - breath-by-breath graphic display of %N₂ vs accumulated volume

- MUST MEASURE N₂ AND ACCUMULATED VOLUME TO GET FRC

- Discuss the bath tub illustration
Helium Dilution Test

- **Technique**
  - Test starts with subject at resting end-expiratory level (at FRC)… just like the N\textsubscript{2} washout
  - Subject breathes from a spirometer system containing \textasciitilde 10\% He (closed circuit)
  - The subject rebreaths air but water and CO\textsubscript{2} are absorbed and O\textsubscript{2} is added as it is being consumed.
  - Test halted when He \% is constant (plateau at \textpm 0.02\% for 30 seconds); 2 to 5 minutes if healthy, longer if COPD
Helium Dilution Test

Assumptions
- He does not readily cross the A/C membrane
- 100 ml is usually subtracted from the determined FRC

Old way
- Bolus method: large volume of $O_2$ added at beginning of test
- Problem: $O_2$ might be consumed before equilibrium reached
Helium Dilution Measurement
Helium Dilution

Test halted when He % is constant (plateau at ± 0.02% for 30 seconds);
Gas Analysis Methods

- Helium dilution and Nitrogen washout have certain errors and problems
  - Leaks make the measurements worthless … stop the test
  - Good measurement depends on all parts of lung being well ventilated
  - Underestimates FRC in severe obstruction due to poor gas communication with the trapped gas (if you don’t measure it, you don’t know its there –eh?)
Body Plethysmography

Fig. 7–8 Measurement of airway resistance (Raw) by body plethysmograph. $\dot{V} =$ ventilation; $P_A =$ airway pressure; $P_F =$ pressure. (From Scanlon CL, Spearman CB, and Sheldon RL: Egan's fundamentals of respiratory therapy, ed 5, St L. Mosby-Year Book.)
Body Plethysmography

**Technique**

- Test starts with subject at resting end-expiratory level (FRC) Shutter closes at zero flow.
- Subject pants against a closed shutter at rate of 1 Hz.
- Changes in pressure reflect changes in volume in the thorax and the box. (Boyle’s Law)
- Subject holds hands against cheeks to prevent pressure changes in the mouth due to flaccidity.
  - Body Box also gives measurement of resistance and conductance
Body Plethysmography

- Relies on Boyle’s gas law which states that volume and pressure vary inversely if temperature is held constant.

\[ V_1 \times P_1 = V_2 \times P_2 \]

\[ V_1 = \frac{V_2 \times P_2}{P_1} \]
Body Plethysmography

- Measures Thoracic Gas Volume ($V_{TG}$)
- $V_{TG}$ may be larger than FRC if there is gas trapped in the body (pneumothorax, abdominal gas) but this is rare!
- FRC should match $V_{TG}$ for reliable start of test (shutter should close at end of exhalation or at FRC)
- More accurate than $N_2$ washout or Helium dilution…. Measures all the volume trapped in the lungs during the panting maneuver
Carbon Monoxide Diffusing Capacity

- Measures how quickly gases move across the alveolar-capillary (a-c) membrane
- Sometimes called “Transfer factor”
- Abbreviation – DLCO_{SB} referring to “diffusion in the lung of carbon monoxide in a single breath”
- Interpretation uses DLCO/VA where VA = alveolar volume (measured by tracer gas – usually methane)
Carbon Monoxide Diffusing Capacity

Gas exchange measurement is effected by:
- diffusion coefficient of the gas used in testing
- surface area of the a-c membrane
- thickness of the a-c membrane
- blood volume in the pulmonary capillaries
- distribution of inspired gas
- hemoglobin (results are adjusted for anemia)
Carbon Monoxide Diffusing Capacity

- Average normal DLCO is 25 ml CO/min/mmHg.
- Emphysema destroys alveoli and thus reduces surface area and distribution of gas = decreased DLCO
- Restrictive diseases [ie interstitial diseases (“osis”)] reduce lung volume= decreased DLCO
Carbon Monoxide Diffusing Capacity

- Low capillary blood volume (or PE), low hemoglobin, and increased COHb reduce the diffusion. (Correcting for low hemoglobin and/or COHb will increase the DLCO)

- Bronchitis doesn’t typically affect alveoli structures or volumes, so DLCO will be normal unless there is a markedly abnormal V/Q
Top line at the split – methane (CH4), bottom line carbon monoxide (CO)
Technique for DLCO\textsubscript{SB}

- If possible… measure hemoglobin to get results corrected for Hb issues (polycythemia or anemia)
- Subject takes a single breath in of the gas source (CO and tracer gas)
- Inspired volume should be 90% of best FVC
- Holds breath to 9-11 seconds then exhales
- Measures CO and tracer gas after first 750 cc (tracer can be helium or methane)…discard volume
<table>
<thead>
<tr>
<th></th>
<th>Ref</th>
<th>Best</th>
<th>% Ref</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLCO</td>
<td>24.7</td>
<td>23.2</td>
<td>94</td>
<td>23.1</td>
<td>23.3</td>
</tr>
<tr>
<td>DL Adj</td>
<td>24.7</td>
<td>23.2</td>
<td>94</td>
<td>23.1</td>
<td>23.3</td>
</tr>
<tr>
<td>DLCO/VA</td>
<td>4.38</td>
<td>5.15</td>
<td>118</td>
<td>5.54</td>
<td>4.82</td>
</tr>
<tr>
<td>VA</td>
<td>4.50</td>
<td></td>
<td></td>
<td>4.16</td>
<td>4.85</td>
</tr>
<tr>
<td>IVC</td>
<td>2.02</td>
<td></td>
<td></td>
<td>1.45</td>
<td>2.58</td>
</tr>
<tr>
<td>DLCO ECode</td>
<td>0010</td>
<td>010</td>
<td></td>
<td>010</td>
<td>010</td>
</tr>
<tr>
<td>FI CH4</td>
<td>0.300</td>
<td></td>
<td></td>
<td>0.300</td>
<td>0.300</td>
</tr>
<tr>
<td>FE CH4</td>
<td>0.113</td>
<td></td>
<td></td>
<td>0.084</td>
<td>0.142</td>
</tr>
<tr>
<td>FI CO</td>
<td>0.300</td>
<td></td>
<td></td>
<td>0.300</td>
<td>0.300</td>
</tr>
<tr>
<td>FE CO</td>
<td>0.056</td>
<td></td>
<td></td>
<td>0.038</td>
<td>0.073</td>
</tr>
<tr>
<td>BHT</td>
<td>9.80</td>
<td></td>
<td></td>
<td>9.88</td>
<td>9.72</td>
</tr>
<tr>
<td>DLCO Time</td>
<td>13:59</td>
<td></td>
<td></td>
<td>13:59</td>
<td>14:03</td>
</tr>
<tr>
<td>DLCO Date</td>
<td>11/03</td>
<td></td>
<td></td>
<td>11/03</td>
<td>11/03</td>
</tr>
</tbody>
</table>
DLCO$_{SB}$

Tips and points to consider

- What happens with breath hold of 14 seconds?
- What happens with valsalva maneuver?
- What if the patient just smoked a cigarette?
- How does exercise affect DLCO$_{SB}$?
Sequence for the “Complete PFT”
(usual order of tests)

- ABG on room air (if ordered)
- Flow/volume loops (Spirometry)
- Maximum Voluntary Ventilation (MVV)
- Lung subdivisions by gas analysis or body box
- $DLCO_{SB}$ (Diffusion)
- Response to bronchodilator (if indicated)
## Severity of Abnormality

<table>
<thead>
<tr>
<th>Level</th>
<th>Percentage Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&gt;80% predicted *</td>
</tr>
<tr>
<td>Mild</td>
<td>65 - 80% predicted</td>
</tr>
<tr>
<td>Moderate</td>
<td>55 - 65% predicted</td>
</tr>
<tr>
<td>Severe</td>
<td>35 - 55% predicted</td>
</tr>
<tr>
<td>Very severe</td>
<td>&lt; 35% predicted</td>
</tr>
</tbody>
</table>

* * except for FEV$_1$/FVC (>70%)
General Interpretation for Complete PFT Exam

- Spirometry – Key is the FEV₁%
  - FEV₁% below predicted = Obstruction
  - Pre and post bronchodilator is indicated
    - Note distinction of FEV₁% versus FEV₁% predicted

- FEF₂₅₋₇₅% below predicted - small airways (not held in high favor)
- FEF₂₀₀₋₁₂₀₀ below predicted - medium/ large airways
General Interpretation for Complete PFT Exam

Lung subdivisions

A. TLC < 80% predicted and all other volumes reduced proportionally = restriction
B. TLC > 95% predicted = probable hyperinflation
C. RV, FRC, and RV/FRC increased = air trapping
General Interpretation for Complete PFT Exam

- Diffusion (DLCO) results should be examined with spirometry in mind
- DLCO/$V_A$ used for interpretation (alveolar volume)
  
  A. DLCO/$V_A$ low + obstruction = emphysema
  B. DLCO/$V_A$ low + restriction = fibrosis
  C. DLCO/$V_A$ normal + obstruction = bronchitis
  D. DLCO/$V_A$ low + no lung obstruction / restriction = low hemoglobin, decreased blood flow
 Bronchial Provocation

- No bronchodilators, antihistamines, coffee, tea, chocolate (methylxanthines and theobromines)
- Do a complete PFT - must be free of air flow obstruction (AFO)
- Bland aerosol to start to check for reaction F/V loop at 30 seconds and 90 seconds.
Bronchial Provocation

- Low dose of *methacholine (provacholine) inhaled. Start at 0.025mg/ml, then 0.25 mg, 2.5mg, 10mg, up to 25mg. Positive response is a 20% decrease in FEV₁.

- Finish with a bronchodilator - FEV₁ must be within 5% of baseline to go home.

  *Histamine has also been used.

New test coming out using Mannitol (Aridol)

- DPI, no mixing, takes less time to get negative or positive.
Bronchial Provocation

- The absence of airways obstruction does not rule out asthma.
  - (Normal spirometry?)
- A negative response to bronchial provocation does.
- OR – if you have asthma, you have “twitchy” airways that will react to provocation. No response? no asthma.
Quality Assurance

- **Spirometry – 6 standards**
  - Minimum 3 spirograms recorded
  - 2 of the 3 have $\pm$ 150 ml in FVC and FEV1, $\pm$10% in PEF
  - Start of test is acceptable ($BEV < 5\%$ of FVC)
  - 6 second exhalation
  - End of test criteria met (plateau)

- **MVV – 2 standards**
  - 1 breath/second or total rate 60 to 75 breaths/minute
  - Goal = $FEV_1 \times 40$ (or 35 based on textbook)
Quality Assurance

- **Lung Subdivisions**
  - Gas analysis… machine is in good calibration, no leaks
  - Gas reaches acceptable level
    - N2 - stop after 7 minutes if not at ~ 1%
    - He % is constant (plateau at ± 0.02% for 30 seconds)

- **Plethysmography**
  - Shutter closes to measure VTG at FRC level
  - Panting at about 60/min (1 Hz)
  - Two recordings have to be within ±10% in all measured values to be acceptable
Quality Assurance

- DLCO
  - Inspired volume is > 90% of best FVC
  - Breath hold time 9 – 11 seconds, no leaks
  - Discard first 750 ml before analyzing
  - Tracer gas and CO calibration is good
  - Two tests needed that are within ± 10% or 3 ml CO (using the raw DLCO number)
Case study

**History**

The patient is a 73-year-old black woman with a previous history of COPD. She denies cough or sputum production. She states that any activity results in breathlessness. She has a 50 pack-year smoking history but quit 4 years ago. She had repeated bouts of pneumonia as a child, but has no other occupational or exposure history. She currently takes Advair and uses albuterol as a rescue inhaler. She has not used either medication this morning.

- 66.5 inches tall, 230 lbs
- African-American
- Hb 12.21 g/dl
<table>
<thead>
<tr>
<th>Spirometry</th>
<th>Predicted</th>
<th>Measured Pre-tx</th>
<th>% Predicted</th>
<th>Measured Post-tx</th>
<th>% Predicted</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC (L)</td>
<td>2.56</td>
<td>1.73</td>
<td>67</td>
<td>2.04</td>
<td>80</td>
<td>18</td>
</tr>
<tr>
<td>FEV₁ (L)</td>
<td>1.98</td>
<td>0.65</td>
<td>33</td>
<td>0.84</td>
<td>42</td>
<td>28</td>
</tr>
<tr>
<td>FEV₁/FVC (%)</td>
<td>77</td>
<td>38</td>
<td>41</td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>FEF₂₅%-₇₅% (L/sec)</td>
<td>1.76</td>
<td>0.18</td>
<td>10</td>
<td>0.33</td>
<td>19</td>
<td>81</td>
</tr>
<tr>
<td>FEF max (L/sec)</td>
<td>5.00</td>
<td>2.87</td>
<td>57</td>
<td>2.80</td>
<td>56</td>
<td>-2</td>
</tr>
<tr>
<td>MVV (L/min)</td>
<td>87</td>
<td>24</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lung volumes</th>
<th>Predicted</th>
<th>Measured Pre-tx</th>
<th>% Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVC (L)</td>
<td>2.56</td>
<td>2.25</td>
<td>88</td>
</tr>
<tr>
<td>TLCpl (L)</td>
<td>4.38</td>
<td>5.98</td>
<td>136</td>
</tr>
<tr>
<td>RVpl (L)</td>
<td>1.82</td>
<td>3.73</td>
<td>205</td>
</tr>
<tr>
<td>VTG (L)</td>
<td>2.60</td>
<td>4.40</td>
<td>169</td>
</tr>
<tr>
<td>RV/TLC (%)</td>
<td>42</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Diffusion</td>
<td>Pred</td>
<td>Actual</td>
<td>%Pred</td>
</tr>
<tr>
<td>----------------------</td>
<td>------</td>
<td>--------</td>
<td>-------</td>
</tr>
<tr>
<td>$DL_{CO}$ (ml/min/mm HG)</td>
<td>18.1</td>
<td>8.8</td>
<td>49</td>
</tr>
<tr>
<td>$DL_{CO}^{cor}$ (ml/min/mm HG)</td>
<td>18.1</td>
<td>9.3</td>
<td>51</td>
</tr>
<tr>
<td>$D_L/V_A$</td>
<td>4.31</td>
<td>2.79</td>
<td>55</td>
</tr>
<tr>
<td>$V_A$ (L)</td>
<td>4.38</td>
<td>3.32</td>
<td>76</td>
</tr>
</tbody>
</table>
Interpretation

- Good example of a common pattern of pulmonary pathology associated with COPD. PFT shows severe airway obstruction seen in the FEV$_1$ and FEV$_1$/FVC ratio. Lung volumes show air trapping (increased RV and RV/TLC ratio) and hyperinflation (increased TLC). The slow VC is significantly larger than even the post-bronchodilator FVC. All of these findings suggest an emphysematous pattern. Rather unexpected is the patient’s response to inhaled bronchodilator, which suggests some reversibility of the obstruction (Asthma too?). Her DL$_{CO}$ shows a severe reduction in diffusion suggestive of the types of changes accompanying emphysema (e.g., loss of alveolar surface area, destruction of capillaries, and increased diffusion distance from the terminal airways).
Spirometry

- FEV1/FVC < 70%
- Normal Lung Volumes
  - Normal
  - FVC < 80% Predicted
- FRC, RV, RV/TLC
  - Air trapping
  - TLC > 95%
- Hyperinflation

- All volumes reduced
  - Confirms Restriction
  - TLC > 95%
DLCO

Decreased - Obstructive  Normal  Decreased - Restrictive
Stuff to do:

- Determine measurements, predicteds, and % predicted for Collins Spirometer recording. Complete paperwork and turn in. See lecture notes for steps.
- Perform spirometry with Easy One and print results
- Calibrate device then perform spirometry with KoKo and print results
- Review examples of PFT results… interpret
Hand calculations

- **FVC** – measure volume at plateau (L)
- **FEV1** – measure from 1 second mark up to curve and figure the volume (L/sec)
- **FEF\textsubscript{25-75%}**
  - Mark dots on the curve at 25% FVC and 75% FVC
  - Draw a line connecting the two dots, extend the line to cross a full second
  - Determine the base (using 1 second) and measure the height of the right triangle – (L/sec)
- **FEF\textsubscript{200-1200}**
  - follow the pattern above, using dots at 200 and 1200 ml
Collins spirometer tracing: