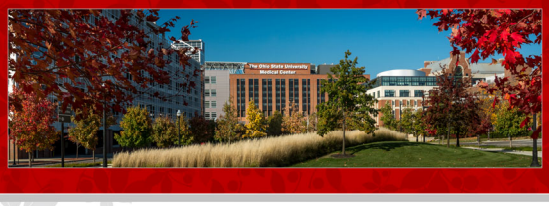

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Pulmonary Function Testing

Jim Allen, MD
October 24, 2019

What do pulmonary function tests tell you?

- Spirometry:
  - Identifies airflow obstruction
- Lung volumes
  - Identifies restriction and hyperinflation
- Diffusing capacity:
  - Measures how well gas exchanges from the air into the blood
- 6 Minute walk test:
  - Measures oxygenation during exercise

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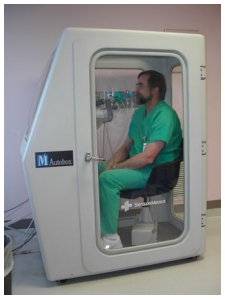
Pulmonary Function Test Lab



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Office Spirometry

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Pulmonary Function Tests: Spirometry

- Measure of airflow
- Forced vital capacity (FVC)
- Forced expiratory volume in 1 sec. ($FEV_{1.0}$)
- Obstruction
  - ↓ $FEV_{1.0}$/FVC ratio (normal ratio is age-dependent)
- Reversible obstruction
  - 12% increase in FVC or $FEV_{1.0}$ with bronchodilator
  - At OSU, we use Combivent (albuterol + ipratropium)

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Indications For Spirometry

- Evaluation of unexplained dyspnea, cough, or wheezing
- Suspected COPD or asthma with no previous spirometry
- Known asthma or COPD with uncertain control
- Known asthma or COPD when assessing response to treatment
- Periodic assessment (every 1-2 years) of asthma to assess for changes in therapy
- Assessment of vital capacity in patients with known neuromuscular disease
- Pre-operative assessment in patients with known or suspected lung disease

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A Spirometry Test Requires 3 Steps To Be Done Correctly

1. Correct demographic information (age, height, gender, race)
2. Correct technique used by the nurse or other provider administering the test
3. Correct interpretation by the physician/NP reading the test

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Computer interpretation of spirometry

- Reasonably good at identifying normal
- The computer cannot interpret flow volume loop patterns
- For patients who are not normal, the computer interpretation is frequently not accurate and can give an incorrect interpretation in more than half of cases, depending on the population of patients being tested

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Entering Demographics

- If demographic values are not entered, the computer cannot calculate the percent predicted values and only the raw numeric results will appear
- If the demographics are entered incorrectly, then the percent predicted values will be incorrect. Always check at the top of a spirometry result to be sure that the age, gender, and height look correct. Decimal point errors or incorrectly entering cm rather than inches are common sources of error

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Incorrect Demographics

Results

Result	Pred	Best	%Prd
FVC (L)	***	0.74	---
FEV1 (L)	***	0.28	---
FEV1/FVC	0.80	¤0.38	47%
FEF25-75% (L/s)	0.23	0.10	43%
PEFR (L/s)	1.29	1.36	106%

In this case, the height was incorrectly entered as 23 inches rather than the correct value of 60 inches for this 57-year old patient. Because there are no normal data sets for 23 inch women who are 57 years old, the predicted values for FVC and FEV1 are left blank. The predicted value for FEV1/FVC ratio is based off of age only and not height, so it is not affected.

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Spirometry Administration

- Each spirometer will have slightly different instructions for preparing the equipment and performing the test. Be sure that your office staff are following the manufacturer's instructions for test performance
- In common to all spirometers, the patient will be required to inhale as deeply as possible and then exhale as hard and fast as they can until they have forced all air out of their lungs
- If the patient does not inhale as deeply as possible or exhale as forcefully or completely as possible, the results will not be valid

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Spirometry Administration

1. Place a nose clip on the patient
2. Have the patient take as deep of a breath as possible
3. When instructed by the spirometer, tell the patient to "blast" their air out as hard and fast as they can
4. The patient should continue exhaling until they have exhaled at least 6 seconds and there is no further flow for at least 1 second. Nearly all patients will complete the exhalation maneuver in less than 15 seconds.

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Spirometry Administration

- Be sure there is no air leak around the mouthpiece
- If the patient coughs (especially in the first second), the trial is not valid
- At least 3 trials should be performed
- Trials are considered reliable if the FEV1 and FVC vary by less than 0.15 L between trials
- The computer will generally pick the trial with the largest FVC and FEV1 as the "best" trial and report it first

Defining Normal Values

- The FEV1 and FVC vary depending on:
  1. Age
  2. Gender
  3. Race
  4. Height
- Therefore (for example), the normal FEV1 for a 64 inch tall, 50-year old Caucasian woman will be very different than a 72 inch, 40-year old African American man
- Normal values are determined by doing spirometry on large numbers of people and grouping them by age, gender, race, and height and then creating large databases of normals

Defining obstruction

- Obstruction is present if the FEV1/FVC ratio is reduced
- There are several different ways of defining a low FEV1/FVC ratio. The two most common are:
  1. American Thoracic Society: defines a low FEV1/FVC by comparison to large databases of normal subjects. A low FEV1/FVC is then defined as less than the 5th percentile of normal subjects stratified by age
  2. Global Initiative for Obstructive Lung Disease (GOLD): uses a fixed number for all people regardless of age and defines a low FEV1/FVC as less than 70% for everyone

The FEV1/FVC Ratio Changes With Age

- The FEV1/FVC ratio declines in normal people as they get older
  - An average FEV1/FVC in a 20 year old is 87%
  - An average FEV1/FVC in an 84 year old is 71%
    - The lower limit of normal in an 84 year old is 59%!
- The ATS definition of obstruction takes this age variation into account
- The GOLD definition of obstruction does not
  - Some normal older patients may be mis-classified as being obstructed when using the GOLD criteria

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Spirometry Interpretation

Results

Result	Pred	Best	%Prd		%Prd		%Prd
FVC (L)	3.37	2.97	88%	2.93	87%	2.78	82%
FEV1 (L)	2.60	2.19	84%	2.13	82%	2.08	80%
FEV1/FVC	0.78	0.74	95%	0.73	94%	0.75	96%
FEF25-75% (L/s)	2.32	1.64	70%	1.43	62%	1.59	69%
PEFR (L/s)	6.34	5.00	79%	5.39	85%	4.67	74%
Vext %	—	2.55		3.32		4.92	

Predicted Normal Values

Trial 1 (best)

Trial 1 Percent Of Normal

Trial 2

Trial 2 Percent Of Normal

Trial 3

Trial 3 Percent Of Normal

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Spirometry Interpretation

Results

Result	Pred	Best	%Prd
FVC (L)	3.37	2.97	88%
FEV1 (L)	2.60	2.19	84%
FEV1/FVC	0.78	0.74	95%
FEF25-75% (L/s)	2.32	1.64	70%
PEFR (L/s)	6.34	5.00	79%
Vext %	—	2.55	—

In this case, the FEV1/FVC is within a normal range (0.74 or 74%). Most office spirometers will not display the range of normal (in this case 68%-90%). The computer will flag an abnormally low value by putting an asterisk or square mark to the left of the values

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Important Note:

If the FEV1/FVC ratio is normal, then the patient is NOT obstructed. In this case, the FEV1 can be normal, elevated, or reduced but the patient is still not obstructed

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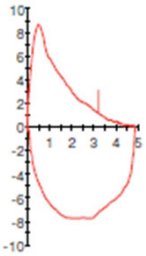
Normal Flow Volume Loop (PFT lab spirometer)



Expiratory limb

Inspiratory limb

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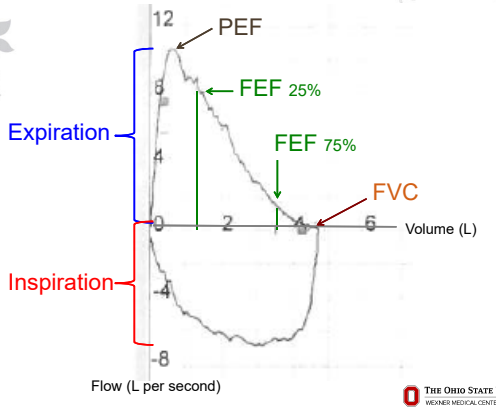

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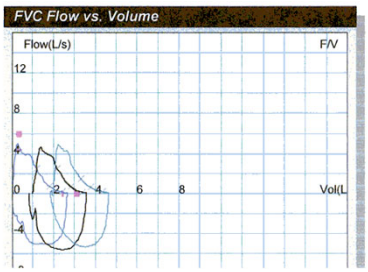
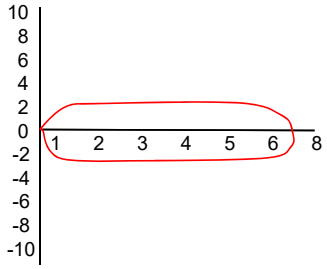
Normal Flow Volume Loop (office spirometer)

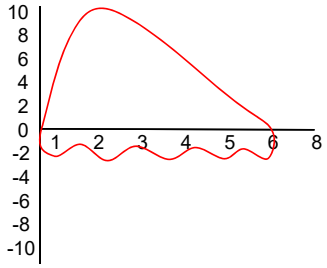


Note that there are 3 separate flow-volume loops all superimposed on one graph. This is typical for office spirometry

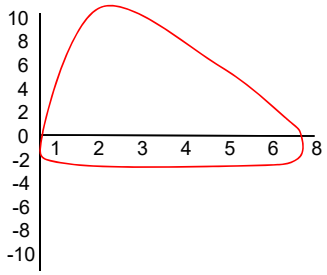
Tracheostenosis



Vocal Cord Dysfunction



Vocal Cord Paralysis



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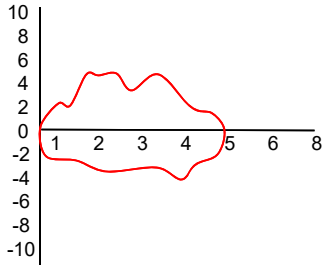
Invalid Test



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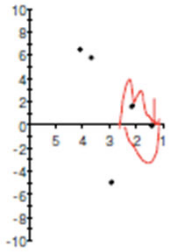
Invalid Test: Patient Coughed During Expiration



Note the “double-humped” pattern on the expiratory limb

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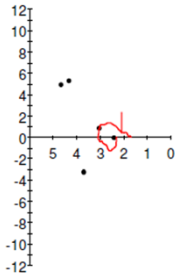
Invalid Test: Poor Effort



Reversible obstruction

- Although more commonly performed in the PFT lab than with office spirometry, a "bronchodilator study" can be performed to determine if there is an improvement in obstruction 15 minutes after a bronchodilator, such as albuterol (or Combivent) is given.
- Reversible obstruction can also be established by repeating spirometry after a 2-3 week treatment trial

Reversible obstruction (continued)

- The most accurate definition of reversible obstruction is an increase in the **FEV1** by > 12% and at least 200 ml.
- An increase in the **FVC** by > 12% and at least 200 ml is also frequently used as a definition of reversibility but it is not as accurate as the FEV1

A note about spirometry and children

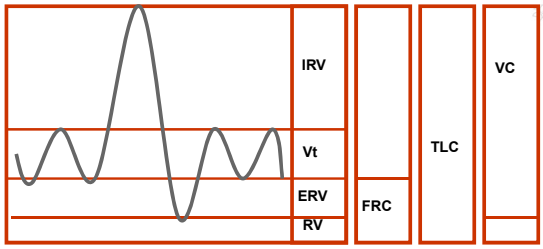
Children

- Office spirometry generally is not possible in children under age 6 years
- A shorter minimal FVC exhalation time of 3 seconds (rather than 6 seconds) is appropriate for children under age 10 years
- Children require more detailed coaching to perform the test
- There must be extra attention to quality measures and reproducibility of trials

Pulmonary Function Tests: Lung Volumes

- Total lung capacity (TLC)
  - Restriction defined as TLC < 80% predicted
  - Hyperinflation defined as TLC > 120% predicted
- Residual volume (RV)
- Functional residual capacity (FRC)
  - Air-trapping defined as FRC or RV > 120% predicted

Derivation of the lung volumes



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Causes Of Restriction

- Interstitial lung disease
- Alveolar filling processes
- Chest wall impairment
- Respiratory muscle weakness

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Diagnosing Restriction Based On Spirometry

- The only confident way to diagnose restriction is by full lung volume measurements with measurement of the total lung capacity (TLC).
- You can suspect restriction if the FVC is low on spirometry but this can be fraught with error.
  - Many patients with COPD will have a low FVC
  - The FVC is often low even when the TLC is normal
- If the FVC is low and you suspect restriction, you should order lung volumes in the PFT lab to confirm restriction

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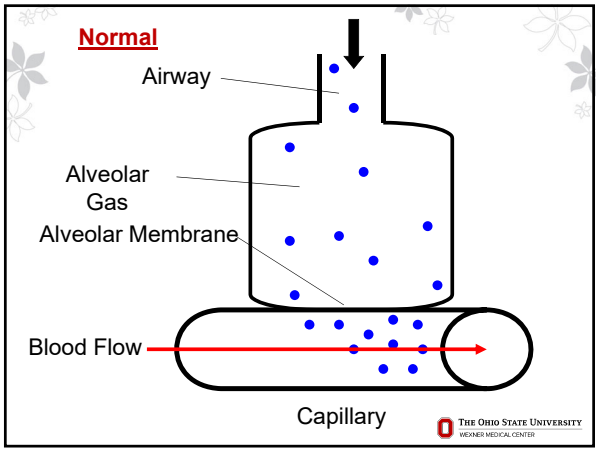
Diagnosing Restriction Based On Spirometry (continued)

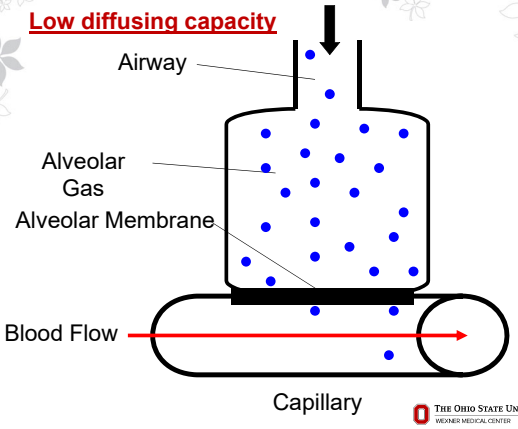
- However, in some diseases, following the FVC serially can be a good marker of lung capacity and respiratory muscle strength
  - Patients with interstitial lung disease
  - Patients with neuromuscular weakness
- When using the FVC to follow these patients for disease progression, it is important that the test be done with consistent technique, preferably by the same individual(s). Often, this is best accomplished in the PFT lab or in clinics that regularly care for neuromuscular patients.

Pulmonary Function Tests: Diffusing Capacity

- Measure of gas exchange across the alveolar/capillary membrane
- Dependent on surface area, gas solubility, membrane thickness, and transit time
- Affected by age, body size, gender, hemoglobin, and lung volume
- Measured by carbon monoxide uptake



Low diffusing capacity



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Decreased Diffusing Capacity

- Anemia
- Right-left intracardiac shunt
- Poor inspiration
- Interstitial lung disease
- Emphysema
- Pulmonary vascular disease

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Correcting The Diffusing Capacity

- DLco
- Hematocrit-adjusted DLco
- DLco/VA
- Hematocrit-adjusted DLco/VA

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4 Questions Of PFT Interpretation

1. Is the patient obstructed?
   - Is FEV1/FVC reduced?
2. If obstructed, is obstruction reversible?
   - Use 12% improvement in FEV1 OR FVC
3. Is the patient restricted?
   - Is the TLC reduced?
4. Is the diffusing capacity reduced?
   - DLCO vs. DLCO/VA

PFT Patterns in Lung Disease

	Asthma	Emphysema	Interstitial Lung Disease
FVC	Nl or ↓	↓	↓↓
$FEV_{1.0}$	↓↓	↓↓	↓
$FEV_{1.0}$/FVC	↓	↓	Nl
TLC	Nl or ↑	↑	↓
DLCO	Nl	↓	↓

What else can the pulmonary lab do for you?

6 Minute Walk

- Oxygen saturation
- Distance walked
- Heart rate
- Dyspnea scale (Borg scale)

Special Studies:
Six Minute Walk O2 LPM: FIO2%: 21

	REST	MAX
SpO2	100	91
Heart Rate	96	128
Blood Pressure	139/88	149/97
Dyspnea BORG Scale	1	3
Leg Fatigue BORG Scale	0	2

Distance:	366 Meters	1200 Feet	Saturation Monitor Location: forehead
Predicted distance:	591 Meters	1939 Feet	
LLN Distance:	452 Meters	1483 Feet	
Pt required rest period	NA Times		Ambulatory Assistance Required Type: NA

Post-Test Comments: Patient identified and procedures explained. Patients history and drug reconciliation completed and drug interaction reviewed. Hemoglobin obtained from labs.. The best of plethysmogrpahy were chosen, though ATS criteria was not met. The best of DLCO were chosen, though ATS criteria was not met. The results of these tests appear to be valid, although the ATS standard for acceptable maneuvers was not met.

Oxygen Titration Study (oxygen qualification)

- Oxygen saturation at rest on room air
- Oxygen saturation walking on room air
- Titrate oxygen flow to determine the flow rate necessary to maintain O2% > 89%

This is required by insurance for oxygen prescription

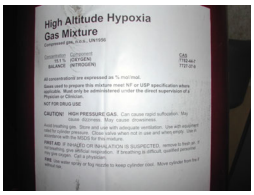
OXYGEN TITRATION
Lowest SpO2 % Resting on Room Air: 94%
Lowest SpO2% during Exercise on Room Air: 87%
Was Oxygen SpO2 less than or equal to 88% during any phase of the test: yes
The oxygen required to maintain oxygen saturation greater than or equal to 90% during exercise was: 2 LPM
Lowest SpO2 with supplemental oxygen was:95 %

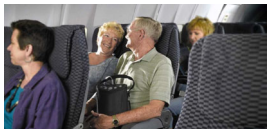
High Altitude Hypoxia Simulation Test

- Simulates to 8,000 ft elevation
  - 15% FiO2
  - Cabin pressure for most commercial aircraft
- Arterial blood gas or oximetry measurement:
  - If PO2 < 50 or O2% < 89% at rest, oxygen needed in flight
  - If O2% < 89% with exertion, then oxygen needed at high altitude travel destination
- Used for pulmonary patients planning:
  - Air flight
  - Travel to altitude

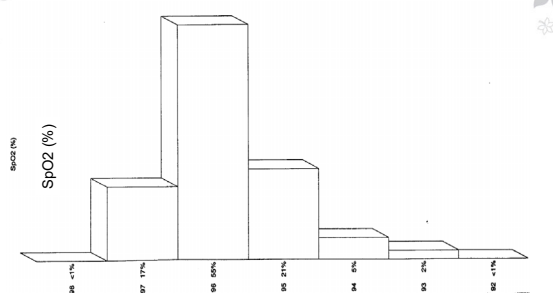
High Altitude Hypoxia Simulation Test - Exercise

- Place face mask & nasal cannula on patient
- Measure oxygen saturation breathing 15% O2 by mask at rest
- Measure oxygen saturation breathing 15% O2 by mask riding a stationary bike
- Titrate nasal cannula oxygen for O2% > 89%
- Used for patients traveling to high altitude travel destinations





Normal Overnight Oximetry



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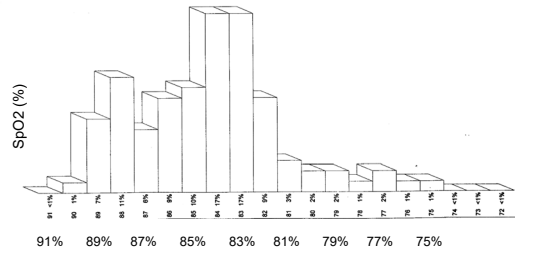
Nocturnal Hypoxemia



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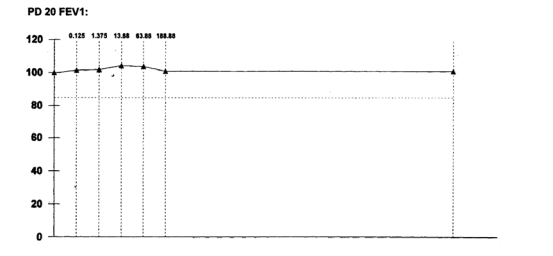
Normal Methacholine Challenge



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Abnormal Methacholine Challenge