Hospital Medicine

Pulmonary Function Tests

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Pulmonary Function Tests

I. Problem/Condition

Indication for Testing

Pulmonary function tests (PFTs) are routinely used in the evaluation of symptomatic complaints such as dyspnea or cough, for predictive assessment prior to surgery or other therapeutic interventions, or to determine changes over time related to disease or an intervention. This term encompasses a family of diagnostic tests, which may include measurement of spirometry, lung volumes, airway reactivity, diffusing capacity, respiratory muscle strength, high altitude simulation, or cardiopulmonary exercise testing. For the purposes of this chapter, we refer primarily to spirometry, plethysmography, and diffusing capacity as the most commonly employed examinations.

II. Diagnostic Approach.

A. What is the differential diagnosis for this problem?

N/A

B. Describe a diagnostic approach/method to the patient with this problem.

Which tests should be ordered?

Typical testing for “routine” PFTs includes spirometry, plethysmography, and diffusing capacity.

Spirometry

Primarily focuses on airflow during both inhalation and exhalation. Results can be broken down into a plethora of measured values, only a few of which are of key importance for “routine” interpretation:

- Forced expiratory volume in 1 second (FEV_1): Measurement of the total volume exhaled in the first 1 second.
- Forced vital capacity (FVC): Total amount of volume exhaled, and exhalation must last over a period of at least of 6 seconds. In patients with severe obstructive lung disease, this may underestimate the total amount of volume that can be expired (i.e., the true vital capacity).
- FEV_1/FVC ratio: This ratio is key to determining whether obstruction is present, defined as a reduction in this ratio. An elevated ratio may only suggest restriction, but not establish it.
- Forced expiratory flow 25-75% (FEF_{25-75}): Mean flow between 25-75% points of FVC. Can be considered a “tie-breaker” in the setting of borderline obstruction. Reflects the concavity of a flow-volume loop in numerical form.

The test is performed with the patient sitting upright in a chair. A nose clip is used to block the nares, and a are rapidly as able, for a minimum of 6 seconds, followed again by a full, rapid inhalation. Multiple attempts can be made, and the “best” values (rather than the average values) are chosen from the set.

Although technical aspects of test administration are not within the scope of this text, a few key points are relevant. Proper spirometry requires acceptability within each maneuver and reproducibility between maneuvers. Acceptability refers to adequacy of patient effort on each individual attempt. This requires maximal effort with adherence to the duration requirements for inhalation and exhalation, because anything short of this can profoundly limit reliable interpretation of results. Care should be taken that language barriers do not impact the results. For this reason, the physician is encouraged to review comments from the technician, which may indicate certain difficulties. In addition, acceptability implies an attempt that is without artifacts, such as coughing, as these may also hinder the reliable interpretation of results.

Reproducibility implies that after at least three acceptable attempts are completed, the two largest values for FEV_1 and FVC are within 0.15 L of each other.

Plethysmography

Also referred to as the “body box,” this is the most common process by which lung volumes are determined. This can be a time-consuming procedure, and requires significant patient understanding and cooperation to ensure accuracy. It is often not routinely ordered by inexperienced practitioners. Plethysmography may not be required for serial PFTs in patients with a known obstructive pulmonary process, but can be key to determining an underlying disorder in a symptomatic patient. Because this maneuver takes place in a sealed box, it can be difficult in patients with decreased hearing. It cannot be reliably performed in the patients with requisite tubing attachments such as supplemental oxygen, chest tubes, or continuous intravenous infusions.

- Total lung capacity (TLC): This refers to the total amount of air in the chest, and is key to diagnosing hyperinflation or restriction.
- Vital capacity (VC): Similar to the FVC as described above, but is measured in the absence of forced exhalation.
- Residual volume (RV): Volume of gas that remains in the chest after full exhalation. Can be elevated in obstructive lung processes with air trapping. Key to differentiating a restrictive lung process secondary to extrapulmonary processes such as obesity, chest wall stiffness, or muscle weakness (normal RV), from those related to intrinsic parenchymal disease such as pulmonary fibrosis (reduced RV).
- RV/TLC ratio: Specifically refers to the proportion of residual gas as a part of total gas in the chest. May provide more information about whether air trapping is present in patients with an abnormal TLC.
- Expiratory reserve volume (ERV): The maximum amount of air that can be exhaled after normal

- Functional reserve capacity (FRC): The total amount of air remaining in the chest after normal exhalation at tidal volume. FRC = RV + ERV.

Other techniques less commonly employed to measure lung volumes include nitrogen washout and gas dilution methods. Differences between these techniques and plethysmography may affect the accuracy of lung volume measurements in certain situations such as with COPD (see “Interpretation of Results” below).

Diffusing Capacity

Diffusing capacity, also referred to as ‘diffusing capacity of the lung for carbon monoxide’ (D_{LCO}), is a surrogate for the lung’s ability to perform oxygen uptake. Carbon monoxide and oxygen have similar diffusion properties across the alveolar-capillary interface. This value is affected by thickening of this interface, ventilation/perfusion mismatching, total hemoglobin concentration, altitude, pO_2, and carboxyhemoglobin levels. D_{LCO} can be a useful early marker for pulmonary fibrosis, chronic pulmonary vascular disease, and toxicity from drugs such as amiodarone or bleomycin.

Patients performing this maneuver via the single breath method inhale a very low concentration of carbon monoxide (usually about 0.3%). Breath is held for 10 seconds, then exhaled completely. The D_{LCO} maneuver is determined by measuring the concentration of carbon monoxide exhaled in a post-dead space sample of alveolar gas.

- Results may be erroneously elevated in patients who hold their breath longer than instructed.
- D_{LCO} may be underestimated in heavy smokers with an elevated baseline carboxyhemoglobin value.
- All results should be corrected for current hemoglobin concentration, as anemia or polycythemia will underestimate or overestimate D_{LCO}, respectively.

Other testing

For specific scenarios or clinical questions, practitioners may request additional testing.

1. Respiratory muscle strength assessment

Maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) may be measured. The patient is instructed to maximally inhale or exhale against a gated chamber, and pressures in the chamber are measured. Useful in determining the presence or progress of neuromuscular disease, this is routinely ordered in myasthenia gravis crises or amyotrophic lateral sclerosis patients, for example. Clinically significant weakness is not typically seen until measured MIP and MEP values are extremely abnormal. Has a high negative predictive value for ruling out significant respiratory muscle disease.

2. High altitude simulation testing

Oxygen saturation is measured while patients inhale lower-than-normal atmospheric oxygen concentrations. Fifteen percent inhaled oxygen is typically used, equivalent to oxygen concentration at

8,000 ft of elevation. Often used to simulate airplane travel to determine whether a patient might need supplemental oxygen.

3. Cardiopulmonary exercise testing

Cardiopulmonary exercise testing is known as CPET and is also referred to as maximum exercise cardiopulmonary testing. A useful test to determine the etiology of exercise limitation in patients in whom the cause is unclear after routine testing. Patients must demonstrate maximal exertion, often on a stationary bicycle, treadmill, or hand-pedaled ergometer. Expired gases are measured, with frequent determinations of CO_2 (carbon dioxide) and O_2 (oxygen) concentrations, and continuous electrocardiogram (ECG) monitoring. When properly performed and interpreted, this can determine inadequate cardiac response, ventilation limitation, simple deconditioning, or neither as the cause of a patient's symptoms. This test should only be performed in a specialized exercise laboratory with experienced clinicians, as it is prone to misinterpretation.

4. Bronchodilator testing

Spirometry is performed before and after administration of bronchodilators to determine physiologic responsiveness, often when asthma is suspected. Inhaled beta agonists or anticholinergic agents can be used, and an appropriate time delay before repeat testing must be observed. An increase in FEV_1 by 12% and 200 milliliters is considered "positive." False negatives may occur if the patient recently used other bronchodilators prior to testing. It is important to point out that a lack of demonstrable improvement does not necessarily predict a lack of clinical benefit.

5. Airway challenge

Most often performed with inhaled methacholine, the airway challenge tests for airway hyperresponsiveness to inhaled irritants and is often ordered to diagnose or rule out asthma in patients with atypical symptoms (e.g., chronic cough). Increasing concentrations of methacholine are used, with FEV_1 measured repeatedly. A reduction in FEV_1 of 20% from the pre-challenge value is considered positive at methacholine concentrations of 16 milligrams/milliliters or less. Results must be interpreted in light of the clinical scenario. Testing may be negative in an asthma patient without current symptoms, or in patients with exercise-induced asthma who may respond robustly to cool air. It may be positive in 5-15% of otherwise normal individuals. Of note, all inhaled and oral bronchodilator therapies must be held for a pre-specified period of time prior to testing in order for the results to be accurate.

Interpretation of results

Spirometry

1. Review technician comments, including statements pertaining to acceptability and reproducibility of attempts, such as inability to perform the test properly, inability to understand instructions, or submaximal effort. Interpretation of suboptimal testing should be done with great caution.

2. Review flow-volume loops, if available. A concave expiratory limb suggests obstruction. Smaller loops with flat expiratory limbs suggest restriction. Jagged or abrupt changes in flow may represent cough or glottic closure. Familiarize yourself with normal flow-volume loops in order to better recognize those which are abnormal. Some pathologies, such as fixed airway obstructions (e.g., tracheal tumor) may only be appreciated by reviewing the flow-volume loop.

3. Review FEV_1/FVC ratio. If <5th percentile, obstruction is present. If elevated to >95th percentile, restriction is suggested, but cannot be diagnosed unless lung volumes are available for confirmation.

If obstruction is present, a number of criteria (Global Initiative for Chronic Obstructive Lung Disease or American Thoracic Society/European Respiratory Society [ATS/ERS]) can be used to categorize its severity. Most commonly used by pulmonologists are the ATS/ERS guidelines on interpretation of PFTs from 2005:

- If FEV_1/FVC ratio is $<5^{th}$ percentile and FEV_1:

  >70% predicted is defined as mild obstruction.

  60-69% predicted is defined as moderate obstruction.

  50-59% predicted is defined as moderately severe obstruction.

  35-49% predicted is defined as severe obstruction.

  <35% predicted is defined as very severe obstruction.

4. If FEV_1/FVC ratio is borderline low, a decreased $FEF_{25\text{-}75}$ may suggest early obstructive disease.

Plethysmography

1. Review technician comments, including statements such as inability to perform the test properly, inability to understand instructions, or submaximal effort. Any attempt to interpret suboptimal testing should be done with great caution.

2. Review TLC. If elevated >95th percentile, hyperinflation may be present. If reduced <5th percentile, restriction is present.

If restriction is present:

- Reduced VC confirms restrictive lung process.
- Check RV. A reduced residual volume suggests intrinsic lung disease such as pulmonary fibrosis. If normal, an extra-pulmonary pathology such as obesity, chest wall deformity, or neuromuscular weakness may be present.

3. Review RV and RV/TLC ratio. Elevated RV and RV/TLC ratio suggest air trapping with obstructive lung disease.

4. If available, compare TLC as measured by plethysmography with that measured by gas dilution techniques (such as helium dilution or nitrogen washout). Plethysmography measures total compressible gas in the chest, whereas dilution techniques measure communicating (participating in gas-exchange) airspaces only. Thus, larger volumes measured by plethysmography then by dilution suggest the presence of non-communicating (or non-functional) airspace, such as with severe emphysema, pneumothorax, or bullous disease.

Diffusing Capacity

1. Review technician comments, including statements such as inability to perform the test properly, inability to understand instructions, or submaximal effort. Any attempt to interpret suboptimal testing should be done with great caution.

2. Check for recent hemoglobin and carboxyhemoglobin levels. If values are available, be sure to review raw data as well as corrected value.

3. D_{LCO} is normal between 5th and 95th percentiles.

4. D_{LCO} >95th percentile may be seen in polycythemia, alveolar hemorrhage, or severely depressed cardiac output, among other causes.

5. D_{LCO} <5th percentile suggests pulmonary vascular disease, interstitial lung disease, emphysema, or lung resection, among other causes.

If D_{LCO} is reduced:

- D_{LCO} >60% predicted is defined as a mild reduction.
- D_{LCO} 40 – 60% predicted is defined as a moderate reduction.
- D_{LCO} <40% predicted is defined as a severe reduction.

Special Considerations

- GOLD vs. ATS/ERS Guidelines: GOLD guidelines for the interpretation of spirometry values differ considerably from the ATS/ERS guidelines. Therefore, it is important to note which guidelines are used routinely at your institution in order to avoid confusion.
- Air trapping vs. hyperinflation: Air trapping and hyperinflation are not synonymous. Air trapping tends to precede hyperinflation and refers to an elevated RV in the setting of a normal TLC. When TLC is also elevated above the upper limit of normal, then hyperinflation is present.
- Obesity: There is some speculation and discrepant opinion regarding how obesity affects pulmonary function tests, but there is general consensus on the following:

  Spirometry – Data suggest that increasing BMI does increase airway resistance which may lead to diminished, if at all, and the FEV_1/FVC ratio is preserved. Flow rates may appear reduced (owing to diminished lung volumes, see below) but are within normal range when adjusted for actual and not predicted lung volumes.

Lung volumes – Recent data show that, though FRC and ERV can be significantly decreased in overweight (BMI 25-29.9 kilograms/meters^2 [kg/m^2]) and obese (BMI ≥30 kg/m^2) patients, TLC may only decrease slightly, even in morbidly obese (BMI ≥ 35-40 kg/m^2) patients. RV is also well-maintained in severe obesity. *Keep this in mind before attributing unexpected restrictive lung physiology to obesity. Also keep in mind that the distribution of fat in an obese patient matters – abdominal and thoracic fat contribute more to changes in lung volumes than lower body fat which should not affect lung volumes at all.

D_{LCO} – Increases slightly with increasing BMI but remains within normal range. Therefore, D_{LCO} is not significantly affected by obesity.

Overall, obesity may exaggerate symptoms and PFT abnormalities in a patient with pre-existing lung disease.

- Pregnancy: The diaphragm may rise approximately 4 centimeters above normal at full-term, but the lower rib cage and supporting muscles will also undergo compensatory changes in order to maintain diaphragmatic excursion. Airway resistance is also maintained.

  Spirometry – NOT significantly affected during pregnancy.

  Lung volumes – Expect a progressive decline in ERV, RV, and FRC throughout pregnancy (partly due to diaphragmatic elevation). TLC, however, may only decrease slightly at full-term.

  D_{LCO} – May increase in the first trimester but will likely decrease toward baseline values thereafter, owing to changes in pulmonary blood flow and other mechanisms that are not well-understood.

- Other:

  FEV_1 % predicted (contrary to intuition) does not invariably correlate with patient symptoms and may not be a good predictor of clinical severity or prognosis in individual patients. In other words, a patient with a higher FEV_1 may present with worse symptoms and more frequent exacerbations than a patient with a lower FEV_1.

  All measurements are compared with predicted or "reference" values that are obtained based on age, height, race, and sex. Therefore, an error or variation in any one of these data can affect the accuracy of the % predicted (and thus, the interpretation of the results). Furthermore, as flows and volumes are based on height – a patient who has a relatively short or long torso for his/her height may show values that are falsely low or falsely high, respectively.

Summary

Pulmonary function testing encompasses a broad range of maneuvers, measuring airflow, lung volumes, gas cardiopulmonary ability. Choosing the correct tests for the questions to be answered is key. PFT's can be reliably interpreted in most cases, assuming appropriate patient cooperation, understanding, and effort. While a "by the numbers" approach to interpreting results is often employed to enhance consistency across tests, knowledge of the clinical scenario and pretest probability ensures optimal and accurate interpretation for the individual patient.

1. Historical information important in the diagnosis of this problem.

N/A

2. Physical Examination maneuvers that are likely to be useful in diagnosing the cause of this problem.

N/A

3. Laboratory, radiographic and other tests that are likely to be useful in diagnosing the cause of this problem.

N/A

C. Criteria for Diagnosing Each Diagnosis in the Method Above.

N/A

D. Over-utilized or 'wasted' diagnostic tests associated with the evaluation of this problem.

N/A

III. Management while the Diagnostic Process is Proceeding.

A. Management of Clinical Problem.

N/A

B. Common Pitfalls and Side-Effects of Management of this Clinical Problem.

N/A

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Back to Top