

Interpretation of Pulmonary Function Tests

University of Kansas Medical School--Ambulatory Internal Medicine Workshop

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Introduction:

Like chest x-rays and EKGs, no one can interpret PFTs any better than the clinician actually taking care of the patient who can interpret the findings in conjunction with the clinical setting. A PFT report does give a wealth of measurements; however, in the final analysis, only a few of these are necessary for you to make a pretty good assessment of the patient's condition.

With that in mind, PFTs can be roughly divided into 5 basic components, spirometry, volumes, diffusing capacity, arterial blood gas, and flow-volume loops.

Abbreviations:

FEV1 forced expiratory volume in the first 1 second of expiration

FVC forced vital capacity

FEF25-75 forced expiratory flow in the middle 1/2 of an expiration

TLC total lung capacity

FRC functional residual capacity

RV residual volume

DLCO diffusing capacity for carbon monoxide

VA alveolar volume (basically the same as the total lung capacity)

DLCO/VA diffusing capacity corrected for alveolar volume

Spirometry:

The first component of a PFT report is spirometry which mainly provides a measure of flow. This defines whether or not the person is obstructed. We define obstruction as an FEV1/FVC ratio of less than the 5th percentile of the values obtained for normals. This value varies according to the age and height of the patient but is generally between 68-77%.

In patients with a low FEV1/FVC ratio, we define the severity of obstruction as the absolute value of the FEV1, the lower the FEV1 (as a percent of predicted), the worse the obstruction. Thus, the American Thoracic Society now recommends that we define severity as follows:

FEV1/FVC < predicted AND FEV1 > 100% of predicted normal variant

FEV1/FVC < predicted AND FEV1 < 100% > 70% of predicted mild obstruction

FEV1/FVC < predicted AND FEV1 < 70% > 60% of predicted moderate obstruction

FEV1/FVC < predicted AND FEV1 < 60% > 50% of predicted moderately severe obstruction

FEV1/FVC < predicted AND FEV1 < 50% > 34% of predicted severe obstruction

FEV1/FVC < predicted AND FEV1 < 34% of predicted very severe obstruction

This definition is not without its pitfalls; for example, if a person is both a little bit obstructed and fairly restricted, the FEV1 may be very low causing you to overestimate the relative role the obstruction is playing in the overall picture of impairment.

We consider obstruction reversible if there is a 12% or greater increase in the FVC or FEV1 after a bronchodilator challenge. We use an albuterol inhaler as our standard but the PFT laboratory will do the challenge test with ipratropium bromide (Atrovent) if requested.

Another value that is given with spirometry is the FEF25-75, or mid-flow rate. This is a measurement of what flow is like during the middle 1/2 of a forced breath. Although often said to be a measurement of small airways obstruction, the FEF25-75 is fairly non-specific and reductions can be seen with a number of non-obstructive diseases. Nevertheless, an isolated reduction in the FEF25-75 serves as an important clue to mild obstructive lung disease when the FEV1/FVC ratio is normal. This occurs, for example, in early COPD and in asthmatics when they are relatively symptom-free. I place less weight on an improvement in the FEF25-75 than on the FEV1 when assessing the response to a bronchodilator challenge.

Lung Volumes

We define restriction (decreased lung volume) as a reduction in the total lung capacity (TLC) to values less than the 5th percentile of the predicted value for normals. For most patients, this is usually about 80% of the predicted TLC. The worse the restriction, the lower the TLC. Thus we grade the severity of restriction as:

TLC < 80% > 70% of predicted mild restriction

TLC < 70% > 60% of predicted moderate restriction

TLC < 60% of predicted severe restriction

If all you ordered on a patient was spirometry, you can make a guess about restriction based on finding a low vital capacity but this is not as accurate an indication as the TLC.

A couple of other measurements worth noting are the functional residual capacity (FRC) and the residual volume (RV). An increase in the FRC indicates hyperinflation. An increase in the RV indicates air trapping.

Lung volumes can be measured by three different techniques. (1) Nitrogen washout. Until recently, this was the most commonly used method of lung volume determination. In this technique, 100% oxygen is inhaled briefly and nitrogen in the exhaled gas is measured - this allows calculation of the total amount of gas in the lung originally. (2) Helium dilution. This technique is most commonly performed in conjunction with the diffusing capacity measurement and is commonly reported as the "VA". The patient inhales and exhales from a spirometer of fixed gas volume which contains a known amount of helium. After a period of time, helium equilibrates throughout the lung and measurement of the concentration of helium in the spirometer can be used to calculate the volume of gas within the lung. (3) This is the most commonly used method of measuring lung volumes and the technique used for routine lung volume measurement in the Ohio State University Hospitals Pulmonary Diagnostic Laboratory. Body plethysmography. In this technique, the patient sits in a closed box and the lung volumes are calculated based on the amount of air displaced from the box during ventilation (see discussion below). This technique has several advantages over the other forms of lung volume measurement.

Diffusing Capacity:

In the simplest sense, the diffusing capacity is the ability of gas to cross from the air, across the interstitium, and into the blood. To measure diffusing capacity in the laboratory, we use carbon monoxide and measure the ability of the body to absorb carbon monoxide from a single breath (DLCO). The better the diffusing capacity, the more carbon monoxide will be absorbed from a single, 10 second inhalation.

If the patient is very restricted (ie. has reduced lung volumes), then the amount of absorbed carbon monoxide will be reduced because of a reduced inspired carbon monoxide volume and not because of an inability of carbon monoxide to cross from the alveoli into the blood. We therefore correct the diffusing capacity for the simultaneously measured total lung capacity, in this case referred to as the "alveolar volume" or VA. Because the VA is measured from a single inspiration, it is not as accurate of a measure of restriction as the TLC which is measured a bit differently; nevertheless, the VA is the best correction factor for the diffusing capacity. The corrected value is referred to as the DLCO/VA and a normal value is considered to be 80% or more of the predicted value.

Because carbon monoxide binds quite readily to hemoglobin, the fewer red blood cells in the blood, the less carbon monoxide will be taken up. We therefore correct the diffusing capacity for hematocrit so that an altered diffusing capacity will reflect an altered lung gas transport rather than an altered hemoglobin level. Thus, we report diffusing capacity as Hct-adjusted DLCO/VA.

In summary, if you only had one number to look at to assess the diffusing capacity, look at the Hct-adjusted DLCO/VA.

The Flow-Volume Loop:

The greatest value of the flow-volume loop is to assess for upper airway obstruction (for example, a laryngeal cancer). Examples of flow-volume loops are attached.

Plethysmography:

Plethysmography is an alternative means of measuring lung volume which is performed by having the patient sit in a closed box and measuring the degree of intrathoracic gas compression during inhalation and exhalation plus the amount of air displaced from the box during ventilation. This technique can be performed more rapidly than nitrogen washout lung volume determination and is a better test for lung volumes than nitrogen washout in the marginally cooperative patient. It also has the advantage of giving the most accurate estimation of total thoracic gas volume which can be particularly helpful in patients with air "trapped" within the lung that does not communicate with the airways (for example, bullous lung disease in which the bullae may not be in good communication with the airways and thus may permit "washout" of their contained nitrogen). Using plethysmography, the airway resistance can also be measured. Airway resistance (often abbreviated RAW) can also be measured using plethysmography and is an alternative means of detecting diseases such as asthma which are associated with increased airway tone. Although this measurement may have some theoretic advantages over FEV1 in certain situations, the clinical indications for measuring airway resistance remain uncertain at this time.

Physiologic Shunt Study:

There are times when you will want to know if hypoxemia is due to a pulmonary shunt. This is done non-invasively by having the patient inspire 100% oxygen for 20 minutes. Unlike the patient with hypoxemia from, say, emphysema, the patient with a pulmonary shunt will have an abnormal A-a gradient while breathing 100% oxygen. Using some assumptions, the % physiologic shunt then can be calculated (normal < 8%).

Some Common Diseases:

Asthma. In asthma, the main problem is obstruction. There is no reduction in lung volumes and there is no impairment to gas transport from the alveoli to the blood. Therefore the PFTs in asthma show a low FEV1/FVC ratio, normal (or even increased) TLC, and normal (or even increased) DLCO/VA. The obstruction will typically improve with a bronchodilator challenge.

Emphysema. In emphysema, not only is there obstruction, but there is also hyperinflation and air trapping with an impairment in gas transport from the air to the blood. Therefore, the PFTs in emphysema show a low FEV1/FVC ratio, an elevated TLC and a reduced DLCO/VA. The obstruction is not reversible in pure emphysema, however, most patients with COPD have some bronchial hyper-reactivity as a component of their overall disease. Although obstruction will dominate in the majority of patients with emphysema, a small subgroup of patients will have an isolated low diffusing capacity with no evidence of obstructive ventilatory defects; in this situation, further studies (such as high resolution chest CT) may be helpful to discriminate between emphysema and other causes of an isolated low diffusing capacity.

Interstitial lung disease. In interstitial lung disease, there is no obstruction but the lungs get progressively less compliant (and consequently have progressively smaller lung volumes) and develop a progressive impediment to gas transport. Therefore, the PFTs in interstitial disease show a normal FEV1/FVC ratio, a low TLC and a low DLCO/VA. Depending on the type of interstitial disease, either the TLC or the DLCO/VA may be the first abnormality noted early in the disease.

Chest bellows diseases. In disorders which affect the chest wall and muscles (for example, kyphoscoliosis or muscular dystrophy), the lungs are normal but there is a limit to how much they can be inflated. Therefore, the FEV1/FVC ratio and DLCO/VA are normal but the TLC is reduced.

Questions:

Patient	FVC	FEV1	FEV1/FVC	FEF 25-75	TLC	DLCO/VA
1	3.1 L (73%)	0.7 L (23%)	25%	0.2 LPS (6%)	9.7 L (150%)	0.9 (19%)
2	1.9 L (62%)	1.1 L (42%)	56%	0.4 LPS (11%)	3.0 L (64%)	1.5 (29%)
3	1.2 L (31%)	1.0 L (33%)	85%	1.2 LPS (29%)	2.7 L (50%)	8.2 (144%)
4	1.1 L (36%)	0.8 L (29%)	78%	0.7 LPS (22%)	2.1 L (54%)	7.0 (120%)
5	2.9 L (83%)	1.8 L (60%)	61%	0.9 LPS (23%)	4.9 L (100%)	6.8 (122%)
6	1.7 L (51%)	1.4 L (49%)	78%	1.3 LPS (35%)	2.7 L (52%)	2.6 (51%)
7	3.4 L (86%)	2.5 L (81%)	75%	1.3 LPS (34%)	6.1 L (97%)	4.6 (98%)
8	3.5 L (95%)	2.8 L (95%)	80%	2.0 LPS (55%)	6.3 L (99%)	1.9 (44%)

- 60 year old man with a 60 pack/year smoking history and dyspnea on exertion. An arterial blood gas demonstrates a $pO_2 = 56$ and a $pCO_2 = 44$.
- 50 year old man with a 65 pack/year smoking history and a cough. His chest x-ray shows a diffuse reticulonodular pattern.
- 36 year old man with muscular dystrophy. He is presently wheelchair bound and an arterial blood gas demonstrates a $pO_2 = 60$ and a $pCO_2 = 52$.
- 17 year old girl with cerebral palsy and severe kyphoscoliosis referred for pre-op evaluation. Arterial blood gas demonstrates a $pO_2 = 62$ and a $pCO_2 = 48$.
- 22 year old woman with dyspnea on exertion. She also notes dyspnea when exposed to cats. On physical exam, she is wheezing.
- 43 year old woman with progressive dyspnea on exertion. Chest x-ray shows bilateral reticular infiltrates, especially in the lung bases.
- 30 year old non-smoking man with a chronic cough. An arterial blood gas demonstrates a $pO_2 = 94$ and a $pCO_2 = 32$.
- 55 year old woman with dyspnea on exertion. The chest x-ray is normal. While breathing room air, her pO_2 is 48. While breathing 100% oxygen, her calculated physiologic shunt is 18%. On physical exam, there are cutaneous spider angiomas.

References:

1. Lung Function Testing: Selection of Reference Values and Interpretative Strategies. Am. Rev. Resp. Dis. 144: 1202-18, 1991.
2. Pulmonary Function Testing. Clin. Chest Med. vol. 10, June 1989.
3. Textbook of Respiratory Medicine, Murray JF & Nadel JA eds. 1994, pgs 798-893.

Answers:

1. This patient has emphysema. His FEV1/FVC ratio is $< 70\%$ which indicates obstruction. His FEV1 is $< 34\%$ of predicted which indicates very severe obstruction. His TLC is elevated and his diffusing capacity is very low. Emphysema can be defined from a radiographic standpoint, a pathologic standpoint, or a physiologic standpoint. For the purpose of the latter, we consider PFTs consistent with emphysema if there is (1) non-reversible obstruction, (2) elevated lung volumes, (3) low diffusing capacity, and (4) an adequate smoking history.

2. This patient is a bit more complex. First, he is obstructed because the FEV1/FVC ratio is $< 72\%$. Second, he is restricted since the TLC is $< 80\%$. Third, he has a low diffusing capacity. The differential diagnosis of combined restrictive & obstructive defects includes cystic fibrosis, bronchiectasis, lymphangioleiomyomatosis, eosinophilic granuloma, and interstitial disease + COPD. This patient has eosinophilic granuloma.

3. This patient has ventilatory muscle failure with a chest bellows-type restrictive defect. His FEV1/FVC ratio is normal so he is not obstructed. His TLC is low so he is restricted. His corrected diffusing capacity is normal (actually quite high) so there is no impairment to gas transport. This type of pattern is often seen in neuromuscular disease, kyphoscoliosis, severe ascites, and immediately post-cardiothoracic surgery.

4. Like the previous patient, this patient has a chest bellow type restriction. In assessing her pre-op risk, she would be a high risk patient from a pulmonary standpoint. Although different authors use different PFT cut-offs for surgical risk assessment, I usually find it convenient to look primarily at two values, the FEV1 and the pCO₂. The lower the FEV1, the higher the risk for pulmonary complications of surgery. Once the patient gets below 0.8 or 1.0 liters, they get into the high risk category. Similarly, if the patient is being evaluated for lung resection, you like them to end up with an FEV1 > 0.8 or 1.0 liters. Therefore, a patient with an FEV1 of 1.2 liters would be very high risk for a pneumonectomy (predicted post-op FEV1 = 0.6 L) but only moderate risk for a lobectomy (predicted post-op FEV1 = 1.0 L). The pCO₂ is also valuable; carbon dioxide retention > 45 indicates increased risk of pulmonary complications of surgery.

5. This is pretty typical for asthma. The FEV1/FVC ratio is $< 75\%$ so she is obstructed. The FEV1 puts her in the moderate obstruction category. She is not restricted and the diffusing capacity is increased. The reason why the diffusing capacity is increased in asthma is not fully known but it has been suggested that there is increased pulmonary blood flow, allowing increased carbon monoxide extraction from the carbon monoxide inhalation.

6. This is characteristic for interstitial lung disease. The FEV1/FVC ratio is $> 73\%$ so she is not obstructed. The TLC is 35% of predicted so she falls in the severe restriction category. The diffusing capacity is low indicating impairment to gas transport.

7. This patient presents a common problem in the outpatient clinic, the chronic cough in a non-smoker. In this case, the FEV1/FVC ratio is normal indicating an absence of obstruction (at least at the time of testing and of great enough severity to be measurable). The TLC and DLCO are normal indicating an absence of restriction and an absence of impairment to gas transport. There is an isolated reduction in the FEF25-75, however. Although the differential diagnosis is fairly long, most of these patients will have asthma, post-nasal drip, or GE reflux. In this age group, it is also worth considering chronic infection with either *Chlamydia pneumoniae* or *Bordetella pertussis*. The finding of an isolated low FEF25-75 can be an important clue to asthma, especially if it improves by more than 25% after bronchodilator challenge. If there is still some question of the diagnosis, you can either treat the patient empirically with a course of inhaled steroids (which I usually do) or order a methacholine challenge test. This test will cause the FEV1 to fall and is indicative of bronchial hyper-reactivity.

8. This patient has normal spirometry and normal lung volumes. However, there is a dramatic isolated reduction in the diffusing capacity. The differential diagnosis of this finding includes early interstitial lung disease, pulmonary vascular disease, or (less commonly) variant emphysema. In the category of pulmonary vascular disease, you should consider pulmonary thromboembolic disease, pulmonary vasculitis, pulmonary hypertension, and right to left shunts. This patient had cirrhosis-associated hypoxemia (small vessel arterio-venous malformations).