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PULMONARY FUNCTION TESTING

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YOURS, CHAS
(Ms. Charly D. Miller)

Pulmonary Function Testing

I. Purpose of Pulmonary Function Testing

Pulmonary Function Testing has been a major step forward in assessing the functional status of the lungs as it relates to :

1. **How much air volume can be moved in and out of the lungs**
2. **How fast the air in the lungs can be moved in and out**
3. **How stiff are the lungs and chest wall - a question about compliance**
4. **The diffusion characteristics of the membrane through which the gas moves (determined by special tests)**
5. **How the lungs respond to chest physical therapy procedures**

Pulmonary Function Tests are used for the following reasons :

1. **Screening for the presence of obstructive and restrictive diseases**
2. **Evaluating the patient prior to surgery - this is especially true of patients who :**
   - **a. are older than 60-65 years of age**
   - **b. are known to have pulmonary disease**
   - **c. are obese (as in pathologically obese)**
   - **d. have a history of smoking, cough or wheezing**
   - **e. will be under anesthesia for a lengthy period of time**
   - **f. are undergoing an abdominal or a thoracic operation**

   Note : A vital capacity is an important preoperative assessment tool. Significant reductions in vital capacity (less than 20 cc/Kg of ideal body weight) indicates that the patient is at a higher risk for postoperative respiratory complications. This is because vital capacity reflects the patient's ability to take a deep breath, to cough, and to clear the airways of excess secretions.
3. **Evaluating the patient's condition for weaning from a ventilator. If the patient on a ventilator can demonstrate a vital capacity (VC) of 10 - 15 ml/Kg of body weight, it is generally thought that there is enough ventilatory reserve to permit (try) weaning and extubation.**
4. **Documenting the progression of pulmonary disease - restrictive or obstructive**
5. **Documenting the effectiveness of therapeutic intervention**

II. Equipment

The primary instrument used in pulmonary function testing is the spirometer. It is designed to measure changes in volume and can only measure lung volume compartments that exchange gas with the atmosphere. Spirometers with electronic signal outputs (pneumotachs) also measure flow

(volume per unit of time). A device is usually always attached to the spirometer which measures the movement of gas in and out of the chest and is referred to as a spirograph. Sometimes the spirograph is replaced by a printer like the unit used in this laboratory. The resulting tracing is called a spirogram. Many computerized systems have complex spirographs or printouts that show the predicted values next to the observed values (the values actually measured). The unit will have in memory all of the prediction tables for males and females across all age groups. In sophisticated spirometers, there maybe special tables of normal values programmed into the machine for selection when Blacks, children or other groups are being tested who may vary from the normal PFT tables established for caucasian adults.

III. "Normal Values"

Over the last several decades much research has been undertaken to determine what are the normal values for lung volumes and lung capacities. This has made spirometry very useful since now we know that we can compare the patient's PFT results with those measured on thousands and thousands of "normal" adults. By having tables of normal values, it is then easy to compare the severity of the disease process or the rate of recovery taking place in the patient's lungs. There are a few variables such as age, gender and body size which have an impact on the lung function of one individual compared to another.

- Age : As a person ages, the natural elasticity of the lungs decreases. This translates into smaller and smaller lung volumes and capacities as we age. When determining whether or not your patient has normal PFT findings, it would be important to compare the patient with the PFT results of a normal person of the same age and gender.
- Gender : Usually the lung volumes and capacities of males are larger than the lung volumes and capacities of females. Even when males and females are matched for height and weight, males have larger lungs than females. Because of this gender-dependent lung size difference, different normal tables must be used for males and females.
- Body Height & Size : Body size has a tremendous effect on PFT values. A small man will have a smaller PFT result than a man of the same age who is much larger. Normal tables account for this variable by giving predicted PFT data for males or females of a certain age and height. Sometimes as people age they begin to increase their body mass by increasing their body fat to lean body mass ratio. If they become too obese, the abdominal mass prevents the diaphragm from descending as far as it could and the PFT results will demonstrate a smaller measured PFT outcome then expected - i.e. the observed (measured) values are actually smaller than the predicted values (predicted values from the normal tables).
- Race : Race affects PFT values. Blacks, Hispanics and Native Americans have different PFT results compared to Caucasians. Therefore, a clinician must use a race appropriate table to compare the patient's measured pulmonary function against the results of the normal table written for that patient's racial group. Other factors such as environmental factors and altitude may have an affect on PFT results but the degree of effect on PFT is not

clearly understood at this time.

IV. Terminology and Definitions

FVC - Forced Vital Capacity - after the patient has taken in the deepest possible breath, this is the volume of air which can be forcibly and maximally exhaled out of the lungs until no more can be expired. FVC is usually expressed in units called liters. This PFT value is critically important in the diagnosis of obstructive and restrictive diseases.

FEV1 - Forced Expiratory Volume in One Second - this is the volume of air which can be forcibly exhaled from the lungs in the first second of a forced expiratory manuever. It is expressed as liters. This PFT value is critically important in the diagnosis of obstructive and restrictive diseases.

FEV1/FVC - FEV1 Percent (FEV1%) - This number is the ratio of FEV1 to FVC - it indicates what percentage of the total FVC was expelled from the lungs during the first second of forced exhalation - this number is called FEV1%, %FEV1 or FEV1/FVC ratio. This PFT value is critically important in the diagnosis of obstructive and restrictive diseases.

FEV3 - Forced Expiratory Volume in Three Seconds - this is the volume of air which can be forcibly exhaled in three seconds - measured in Liters - this volume usually is fairly close to the FVC since, in the normal individual, most of the air in the lungs can be forcibly exhaled in three seconds.

FEV3/FVC - FEV3% - This number is the ratio of FEV3 to the FVC - it indicates what percentage of the total FVC was expelled during the first three seconds of forced exhalation. This is called % FEV3 or FEV3%.

PEFR - Peak Expiratory Flow Rate - this is maximum flow rate achieved by the patient during the forced vital capacity maneuver beginning after full inspiration and starting and ending with maximal expiration - it can either be measured in L/sec or L/min - this is a useful measure to see if the treatment is improving obstructive diseases like bronchoconstriction secondary to asthma.

FEF - Forced Expiratory Flow - Forced expiratory Flow is a measure of how much air can be expired from the lungs. It is a flow rate measurement. It is measured as liters/second or liters/ minute. The FVC expiratory curve is divided into quartiles and therefore there is a FEF that exists for each quartile. The quartiles are expressed as FEF25%, FEF50%, and FEF75% of FVC.

FEF25% - This measurement describes the amount of air that was forcibly expelled in the first 25% of the total forced vital capacity test.

FEF50% - This measurement describes the amount of air expelled from the lungs during the first

half (50%) of the forced vital capacity test. This test is useful when looking for obstructive disease. The amount of air that will have been expired in an obstucted patient is smaller than that measured in a normal patient.

FEF25%-75% - This measurement describes the amount of air expelled from the lungs during the middle half of the forced vital capacity test. Many physicians like to look at this value because it is an indicator of obstructive disease.

MVV - Maximal Voluntary Ventilation - this value is determined by having the patient breathe in and out as rapidly and fully as possible for 12 -15 seconds - the total volume of air moved during the test can be expressed as L/sec or L/min - this test parameter reflects the status of the respiratory muscles, compliance of the thorax-lung complex, and airway resistance. Surgeons like this test value because it is a quick and easy way to assess the strength of the patient's pulmonary musculature prior to surgery - a poor performance on this test suggests that the patient may have pulmonary problems postoperatively due to muscle weakness. MVV can therefore be viewed as a measure of respiratory muscle strength. One major cautionary note is that this test is effort dependant and therefore can be a poor predictor of true pulmonary strength and compliance.

V. What Can A PFT Be Used For ?

Pulmonary function abnormalities can be grouped into two main categories : obstructive and restrictive defects. This grouping of defects is based on the fact that the routine spirogram measures two basic components - air flow and volume of air out of the lungs. Generally the idea is that if flow is impeded, the defect is obstructive and if volume is reduced, a restrictive defect may be the reason for the pulmonary disorder.

Obstructed Airflow

The patency (dilatation or openness) is estimated by measuring the flow of air as the patient exhales as hard and as fast as possible. Flow through the tubular passageways of the lung can be reduced for a number of reasons:

- narrowing of the airways due to bronchial smooth muscle contraction as is the case in asthma
- narrowing of the airways due to inflammation and swelling of bronchial mucosa and the hypertrophy and hyperplasia of bronchial glands as is the case in bronchitis
- material inside the bronchial passageways physically obstructing the flow of air as is the case in excessive mucus plugging, inhalation of foreign objects or the presence of pushing and invasive tumors
- destruction of lung tissue with the loss of elasticity and hence the loss of the external support of the airways as is the case in emphysema

- **external compression of the airways by tumors and trauma**

Restricted Airflow

"Restriction" in lung disorders always means a decrease in lung volumes. This term can be applied with confidence to patients whose total lung capacity has been measured and found to be significantly reduced. Total lung capacity is the volume of air in the lungs when the patient has taken a full inspiration. You cannot measure TLC by spirometry because air remains in the lungs at the end of a maximal exhalation - i.e. the residual volume or RV. The TLC is therefore the summation of FVC + RV. There are a variety of restrictive disorders which are as follow :

A. Intrinsic Restrictive Lung Disorders

1. **Sarcoidosis**
2. **Tuberculosis**
3. **Pnuemonectomy (loss of lung)**
4. **Pneumonia**

B. Extrinsic Restrictive Lung Disorders

1. **Scoliosis, Kyphosis**
2. **Ankylosing Spondylitis**
3. **Pleural Effusion (fluid in the pleural cavity)**
4. **Pregnancy**
5. **Gross Obesity**
6. **Tumors**
7. **Ascites**
8. **Pain on inspiration - pleurisy, rib fractures**

C. Neuromuscular Restrictive Lung Disorders

1. **Generalized Weakness - malnutrition**
2. **Paralysis of the diaphragm**
3. **Myasthenia Gravis - lack of acetylcholine or too much cholinesterase at the myoneural junction in which the nerve impulses fail to induce normal muscular contraction. These patients suffer from fatigability and muscular weakness.**
4. **Muscular Dystrophy**
5. **Poliomyelitis**
6. **Amyotrophic Lateral Sclerosis - Lou Gerig's Disease**

VI. Criterion for Obstructive and Restrictive Disease

Forced Vital Capacity : Forced Vital Capacity (FVC) is the amount of air that can be maximally and forcibly expelled from the lungs after a maximal inhalation. If the patient has an obstructive disease, the amount of air in the lungs will not be readily exhaled because of physical obstruction and airway collapse during exhalation (loss of elastic recoil of the lungs). FVC is, therefore, an important PFT value to look at when evaluating the presence of obstructive pathology. In obstructive diseases, the lung's air volume will be more slowly expelled and will be a smaller volume over the time course of the FVC test than would be expected in a normal, healthy individual.

In patients with restrictive lung disease, the FVC will be smaller because the amount of air that can be forcefully inhaled or exhaled from the lungs is smaller to start with because of disease. This may be due to the fact that thoracic cage does not have the ability to expand very much. FVC will therefore be smaller due to mechanical limitations. However, since FVC will be smaller in obstructive disorders and in restrictive disorders (usually no one worries about the FVC unless it is 80% - 85% of predicted volumes), FVC alone cannot be used to diagnose obstructive and restrictive disorders all by itself. If the patient demonstrates a reduced FVC, the patient may repeat the test after inhaling a bronchodilator. The bronchodilator dilates the bronchial passages and reduces airflow obstruction. The post-bronchodilator test often shows an improved FVC - often times a 10% - 15% improvement. This simple clinical test strongly suggests that the FVC was low due to obstructive phenomenon. If the FVC did not change, it suggests the FVC was possibly low due to restrictive pathologies.

Another strategy that can help you decide if the low FVC is due to obstructive or restrictive processes is to have the patient perform a Slow Vital Capacity (SVC) Test. This test is performed by having the patient slowly and completely blow out all of the air from their lungs. The SVC test eliminates the strong bronchoconstriction that usually accompanies a strong forced exhalatory effort. Hence, the vital capacity of the patient may well be much larger after a SVC test because there is little or no airway collapse during a controlled and slow exhalatory effort. If the vital capacity improves after a SVC test, then it can be assumed that the original small FVC was caused by airway collapse and does not indicate the presence of restrictive disease. If the vital capacity does not improve either with the inhalation of a bronchodilator or does not improve with the administration of a SVC test, then restrictive pathologies must be considered as a possible cause for the small vital capacity results.

Forced Expiratory Volume in One Second : Forced Expiratory Volume in One Second (FEV1) is the amount of air that is forcefully exhaled in the first second of the FVC test. In general, it is common in healthy individuals to be able to expell 75% - 80 % of their vital capacity in the first second of the FVC test. Hence, FEV1 is a pulmonary function value that is highly diagnostic of obstructive disease - i.e. - if an individual's FEV1 is low compared to the predicted FEV1 in the normal population, the individual may have an obstructive lung disease. FEV1 is also expressed as a ratio or a percentage of the FVC and is written as %FEV1 or as FEV1/FVC. If the individual being tested displays a low FEV1 and the FEV1% is low, then the clinician should suspect the presence of obstructive pathologies.

In patients with restrictive lung disease, the FEV1 will be lower than predicted normal values and so will the FVC. Since both of these values may equally be effected in restrictive disease, the % FEV1 may well be calculated to be between 85% - 100% of normal. Hence, in restrictive disease look closely at %FEV1 when FEV1 and FVC are low and if the %FEV1 is 85% or greater, then you should suspect the patient has a restrictive pathology.

Forced Expiratory Flow 25 % to 75 % : Forced Expiratory Flow 25% - 75% (FEF25%- 75%) is a measure of the flow rate in liters per second of the middle half of a FVC test. This test is a sensitive test for the presence of obstructive airway disease. The value of looking at the middle half becomes clear when you realize that the first quarter of the FVC test is in part effected by the patient's effort in overcoming the inertial forces which resist thoracic wall expansion. Additionally, the expiratory effort in the last quarter of a FVC test is polluted by the patient's diminishing physical effort, the instigation of bronchospasm during forced expiration and the breathlessness associated with the terminal completion of a FVC test. Hence, the FEF25%-75% (middle 50% of a PFT) is the most representative of true expiratory patency and is therefore a very sensitive test for the presence of obstructive disease.

Peak Expiratory Flow Rate : Peak Expiratory Flow Rate (PEFR) is a measure of the highest expiratory flow rate during the PFT test. It is measured in liters of air expired per second or liters of air expired per minute. Since it is a measure of the peak or maximum flow of expired air, it becomes a sensitive test for the presence of obstructive disease. Patients with a low PEFR would have to be further evaluated for obstructive pathologies.

VII. How Do You Tell If The Patient Is Normal or Has Mild, Moderate or Severe Pulmonary Disease ?

There are a number of systems which physicians use to determine the severity of disease. Here is just one way that is very commonly used :

- Normal PFT Outcomes - > 85 % of predicted values
- Mild Disease - > 65 % but < 85 % of predicted values
- Moderate Disease - > 50 % but < 65 % of predicted values
- Severe Disease - < 50 % of predicted values

In most good spirometers on the market today, there is a set of normal tables (sometimes multiple sets of tables) which can be chosen as you perform the PFT. Also, there are interpretive microchips in the PFT machines which will tell you what the diagnosis is for a particular patient. These two features make it easy for the clinician to immediately see what the predicted values (normal table values) are for a specific patient and whether or not the PFT has a normal observed outcome. The PFT data are examined by the computerized spirometer and a diagnosis of obstructive or restrictive disease is made.

VIII. The PFT Before and After Aerosol Bronchodilators

Patients are almost always tested twice - once before bronchodilators are given and once after one is administered. This is a nice way to evaluate the amount of bronchoconstriction that was present and how responsive the patient was to a bronchodilator medication. This assesses the degree of reversibility of the airway obstruction. The drug that is nearly always used is a Beta-2 selective sympathomimetic because it is a drug that causes bronchodilation but which does not stimulate the heart to any great degree. After the drug has been administered, the PFT is repeated. If two out of three measurements (FVC, FEV1 and FEF25% - 75%) improve, then it can be said that the patient has a reversible airway obstruction that is responsive to medication. The amount of improvement is variable between clinics but some standards are presented below:

1. **FVC : an increase of 10% or more**
2. **FEV1 : an increase of 200 ml or 15% of the baseline FEV1**
3. **FEF25%-75% : an increase of 20% or more**

Pulmonary Function Tests - A Systematic Way To Interpretation

There is a systematic way to read the PFT and be able to evaluate it for the presence of obstructive or restrictive disease. The following steps will be helpful.

1. **Step 1. Look at the forced vital capacity (FVC) to see if it is within normal limits.**
2. **Step 2. Look at the forced expiratory volume in one second (FEV1) and determine if it is within normal limits.**
3. **Step 3. If both FVC and FEV1 are normal, then you do not have to go any further - the patient has a normal PFT test.**
4. **Step 4. If FVC and/or FEV1 are low, then the presence of disease is highly likely.**
5. **Step 5. If Step 4 indicates that there is disese then you need to go to the %predicted for FEV1/FVC. If the %predicted for FEV1/FVC is 88%-90% or higher, then the patient has a restricted lung disease. If the %predicted for FEV1/FVC is 69% or lower, then the patient has an obstructed lung disease.**

Examples:

Case # 1.

	Predicted Values	Measured Values	% Predicted
FVC	6.00 liters	4.00 liters	67 %
FEV1	5.00 liters	2.00 liters	40 %
FEV1/FVC	83 %	50 %	60 %

Decision : This person is obstructed

Case # 2.

	Predicted Values	Measured Values	% Predicted
FVC	5.68 liters	4.43 liters	78 %
FEV1	4.90 liters	3.52 liters	72 %
FEV1/FVC	84 %	79 %	94 %

Decision : This person is restricted

Case # 3.

	Predicted Values	Measured Values	% Predicted
FVC	5.04 liters	5.98 liters	119 %
FEV1	4.11 liters	4.58 liters	111 %
FEV1/FVC	82 %	77 %	94 %

Decision : This person is normal. This person is normal because the FVC and FEV1 are normal. It is irrelevant that the %Predicted for FEV1/FVC is 94% when FVC & FEV1 are normal. The % predicted values for FEV1/FVC are only relevant when the FVC and the FEV1 are abnormal.

Case # 4.

	Predicted Values	Measured Values	% Predicted
FVC	3.20 liters	2.48 liters	77 %
FEV1	2.51 liters	2.19 liters	87 %
FEV1/FVC	78 %	88 %	115 %

Decision : Case 5.

	Predicted Values	Measured Values	% Predicted
FVC	3.20 liters	3.01 liters	94 %
FEV1	2.51 liters	1.19 liters	47 %
FEV1/FVC	78 %	39 %	50 %

Decision : Case 6.

	Predicted Values	Measured Values	% Predicted
FVC	4.80 liters	4.10 liters	85 %
FEV1	3.65 liters	3.10 liters	85 %
FEV1/FVC	76 %	76 %	100 %

Decision :