

EDITORIAL ARTICLE

BASICS OF PULMONARY FUNCTION TESTING

By

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Like chest x - rays and ECGs, no one can interpret PFTs any better than the clinician actually taking care of the patients who can interpret the finding in conjunction with the clinical settings.

The main function of the respiratory system is gasexchange, for completion of this task, four physiologic processes integrate together. They are ventilation, mixing, perfusion and diffusion.

With that in mind, PFTs can be roughly divided into 5 basic components spirometry, flow volume lobe, lung volumes, diffusion, lung mechanics, and arterial blood gases analysis.

However only few of these tests are necessary for you to make a pretty good assessment of the patient's condition.

SPIROMETERY/ FLOW-VOLUME LOOP

Spirometry measures the total volume of air exhaled from a full lung (total lung capacity) to an empty lung (residual volume).

Forced vital capacity (FVC) and forced expiratory volume in the first second (FEV₁) are the most two important parameters measured by spirometry.

When the expiratory and inspiratory flows are

recorded during the forced vital capacity maneuver the test is called the flow - volume loop. The greater value of the flow volume loop over the spirometry, is to assess for upper airway obstruction, assessment of small airway dysfunction, and to give a rapid visual interpretation to differentiate between obstruction and restriction.

Volumes and flows that can be obtained from spirometry / flow volume loop are:-

- Slow vital capacity SVC
- Forced vital capacity FVC
- Forced expiratory volume FEV₁
- FEV₁/FVC ratio
- Peak expiratory flow rate PEF_R
- Mid expiratory flow MEF or FEF₂₅₋₇₅
- Forced expiratory flow at 75 or FEF₇₅
- Peak inspiratory flow

Note that spirometry can not measure (RV) and (TLC).

INDICATIONS

Spirometry is used to establish baseline lung function, evaluate dyspnea, detect pulmonary disease, monitor effect of therapy used to treat respiratory disease, evaluate operative risk, control occupational lung disease, and in sport medicine.

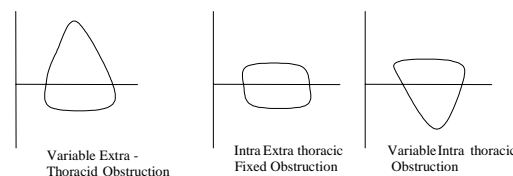
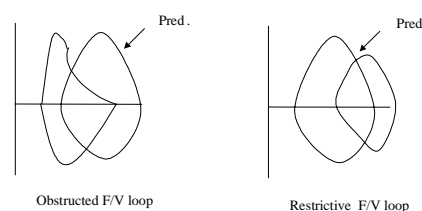
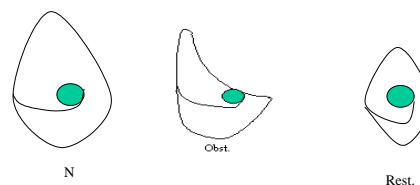
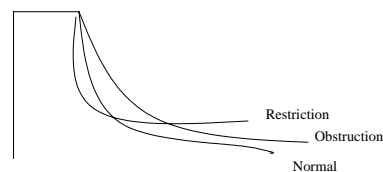
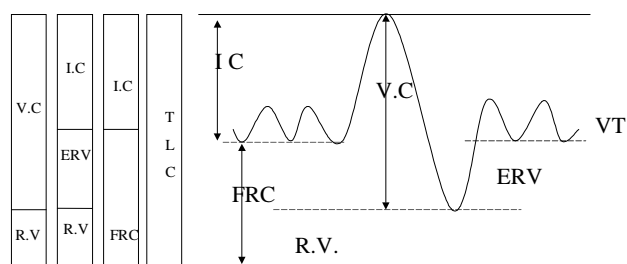
CONTRAINDICATIONS

Relative contraindications for spirometry include haemoptysis, pneumothorax, unstable angina, recent myocardial infarction, aortic aneurysm, cerebral aneurysms, recent eye surgery and patients with syncope associated with forced exhalation.

TEST QUALITY

Failure to meet performance standard can result in unreliable test results. So interpretation of spirometry should begin with assessment of test quality. The American Chest Society (ATS) define acceptable spirometry as an expiratory effort that shows 1-Minimal hesitation at the start of the forced expiration (extrapolated volume < 5% of the FVC or 0.15L) 2- No cough in the first second of forced expiration and 3- Meet 1 of 3 criteria that define a valid end of test (a) Smooth curvilinear rise volume time tracing to a plateau of at least 1-second duration (b) If the test fail to exhibit an expiratory plateau, a forced expiratory time (FET) of 15 sec. or (c) When the patient cannot or should not continue forced exhalation for valid medical reasons.

Additionally the 2 largest values of FVC and FEV₁ should vary by no more than 0.15L (0.1L if FEV₁, FVC is < 1L). This is called test reproducibility.



LUNG VOLUMES DETERMINATION RV, TLC, FRC

Lung volumes are used in evaluation of suspected restrictive lung diseases and in evaluation of hyperinflation and air trapping.

Lung volumes determination depends first on an accurate measurement of volume of gas in the lungs at resting end expiration, known as FRC, which represents the balance of the elastic recoil properties of the lung and the chest wall.

Lung volumes can be measured by 1 of 3

techniques, inert gas dilution N₂ washout test and whole body plethysmography.

a) Helium dilution (closed method).

Based on rebreathing from closed reservoir with known volume (V_1) containing gas mixture composed of helium with known concentration (C_1), 20% O₂ and the rest of gas mixture is Nitrogen. At the end of the test after rebreathing from the closed circuit for few minutes, the helium will be equally distributed between the reservoir and the subjects' lung, a new concentration of diluted helium is obtained at the end of the test (C_2). Using the equation of $C_1 \times V_1 = C_2 \times V_2$, where C_2 is concentration of helium at the end of the test, V_2 is the sum of V_1 (Volume of reservoir) + V_L (Volume of the lung needed to be estimated). This estimated lung volume could be the whole Total Lung Capacity (TLC), the residual volume, or the Functional residual volume depends on at which respiratory phase the subject started the test. Notice that the test is ended when the concentration of Helium in expiration and inspiration remains constant denoting that the Helium is completely distributed between the reservoir and the subjects' lung and the equilibrium point have been reached.

b) Nitrogen washout test. (Open method).

Assuming that nitrogen gas is forming about 80% of the alveolar air contained into lungs. So, if this Nitrogen gas could be washed out of the lung and its volume could be measured, any lung volume (whether RV, TLC, or FRC) could be easily calculated. The washout process can be achieved by rebreathing 100% O₂ for few minutes, with the expired gas being collected in closed reservoir. The test is considered ended when there is no longer Nitrogen coming out with expired air. The volume of washed out nitrogen "which represents 80% of the lung volume" can be easily calculated from knowing the volume of expired gas reservoir and the N₂ concentration in the expired gas.

c) Whole Body Plethysmography.

- The gas volume measured by a plethysmography is known as the Thoracic gas volume (V_{TG}) and in disease states is frequently higher than the value measured by gas dilution.
- The measurement of (V_{TG}) via plethysmography is based on Boyle's law, which states the product of pressure times the volume of the gas in the thorax is constant if the temperature is unchanged ($P_1 \times V_1 = P_2 \times V_2$).
- The subject is seated in the airtight body box with airway occluded; the subject makes inspiratory and expiratory efforts against the occluded airway i.e. causing expansion and compression of gas within the thorax.
- The lung volume can then be calculated, since changes in the volume of the thorax are reflected by changes in the pressure in the box and changes in the thoracic pressure are reflected by changes in the pressure recorded at the mouth.

ADVANTAGES AND DISADVANTAGES

Each technique has its own advantages and disadvantages. In gas dilution techniques (Helium dilution or Nitrogen washout), the test estimates only gas volume present in the areas which are well communicating with the bronchial tree, i.e. excluding air in bad or non communicating airspace e.g. bullae. So in patients with emphysema, or with bullous disease the estimated lung volume with these techniques are usually underestimated.

In contrast, the whole body plethysmography which can estimate the volume of all gas contained inside the thoracic cage including gas in non communicating areas of the lung (bullae) and also any air outside the lung e.g. pneumothorax space, or in GIT as in hiatus or diaphragmatic hernias.

Another advantage of body box technique is that the test can be repeated for several times rapidly

within short time without the need to remain for a recovery time as needed in gas dilution technique.

(To prevent residual Helium or oxygen in the lung remaining from the prior test from affecting the new measurement).

DIFFUSION (DLCO)

The Diffusing Capacity of the lungs (DL) is a measure of ability of gases to diffuse from the alveoli into the pulmonary capillary blood. Carbon Monoxide is the usual test gas since it is not normally present in the lungs or blood and since it is much more soluble in blood than in the lung tissue. When diffusing capacity is measured with carbon monoxide, the test is called Carbon Monoxide Diffusing Capacity DLCO.

To determine DLCO, the amount of CO transferred per unit time and per the average pressure difference of the gas across the alveolar-capillary membrane must be measured. The average normal value for an average subject is approximately 25mL/min/mmHg.

Techniques: The most common method is a single breath DLCO method; other less common methods are steady state, rebreathing method, and intrabreath method.

SINGLE BREATH TEST (DLCO_{SB})

With this method the subject exhales to RV and then inhales fully of a gas mixture containing 0.3% CO, and 10% He and the rest is room air. The subject holds his breath for 10 seconds. And then exhales completely. The first 1200 ml of expired air is discarded then the rest is sampled to get alveolar sample and from CO% of He %, we can calculate the amount of CO diffused through a given alveolar volume (VA). Alveolar Volume (VA) equals to patient's TLC. The helium is used to determine the patient's alveolar volume.

The DLCO/VA ratio is used to differentiate between reduction of DLCO due to reduction of the lung volume from reduced DLCO due to

actual diffusion defect (thickening of alveolocapillary membrane, destructed pulmonary capillary bed, or reduced Hemoglobin).

INTERPRETATION OF PULMONARY FUNCTIONS

Criteria of obstruction:

- FEV₁/FVC is < 70% or less than predicted with normal or mildly reduced FVC and FEV₁ is reduced below 80% predicted.
- In early small airway obstruction the reduction in FEV₁ and FEV₁/FVC may be less evident and the only feature is the reduced FEF₇₅, or FEF₂₅₋₇₅ below 65% predicted.

Criteria of reversible obstruction (reversibility):

- A 12% increase in the FVC or FEV₁ after inhalation of Bronchodilator (Salbutamol 200-400 ug) is considered a criteria of reversibility.
- An increase in FVC or FEV₁ of 0.2L is also considered a sign of reversibility.
- A 35% increase post bronchodilator in FEF₇₅ or FEF₂₅₋₇₅ is needed to consider reversibility if no change is observed in FVC or FEV₁.
- Change in FEV₁/FVC ratio per se is not taken in consideration.
- An increase in normal FVC or FEV₁ by more than 8% may be considered a sign of reversibility in complaining subject with normal spirogram.

– *Criteria of obstruction with Hyperinflation:*

- In addition of obstruction there is an increase in RV, TLC, and RV/TLC with significant reduction in FVC.

– *Criteria of Restriction:*

- Reduced SVC, FVC, and FEV₁ with increased FEV₁/FVC ratio > 90%.

- The IC (inspiratory capacity) is also decreased.
- RV is decreased in most cases, but may be increased in restrictive diseases with air trapping. TLC is reduced below the predicted values (Sure sign).
- RV/TLC is variable; while FEF75 and FEF25-75 are reduced but to some extent they may be preserved.

Criteria of Diffusion Defects:

- Reduced DLCO below 80% of predicted with reduced DLCO/VA ratio.
- DLCO/VA may be preserved in cases of extra pulmonary restrictive diseases e.g. Kyphoscoliosis or lung resection e.g. pneumonectomy.

Quantification of Impairment of Lung Function.

According to reduction in the FVC, FEV₁, TLC and DLCO impairment can be classified into

- Mild → 70-79% of predicted
- Moderate → 60-69% of predicted
- Moderately severe → 50-59% of predicted
- Severe → 35-49% of predicted
- Very Severe → less than 35% predicted

Assessment of operative risk and preoperative assessment.

- While no single test can effectively predict post operative morbidity and mortality from pulmonary complication. The FEV₁ obtained from good quality spirometry is a useful tool. When the FEV₁ is greater than 2L or more than 50% of predicted, major complications are rare.
- In lung resection Surgery a post operative FEV₁> 1L is mandatory to ensure a satisfactory quality of life without being respiratory crippled. This can be reflected roughly on PFT defining that pneumonectomy can not be performed if FEV₁ is less than 2L and lobectomy cannot

be performed if FEV₁ is less than 1.5 L.

- Predicted postoperative FEV₁ can be more accurately estimated by conjunction of spirometry with perfusion lung scan using the equation of Postoperative FEV₁ = Preoperative FEV₁ X Q of the remaining lung

Where Q = Percentage Perfusion.

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