Pulmonary Function Tests

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Spirometry

Spirometry is a physiological test used to measure how an individual inhales or exhales volumes of air as a function of time. Lung Function is generally assessed by measuring maximum flows and volumes during forced expiratory and inspiratory manoeuvres (Flow Volume loops). With the shape of the loop indicating disease patterns, obstructive, restrictive and mixed. ***ATS/ERS 2019 technical standard for spirometry***

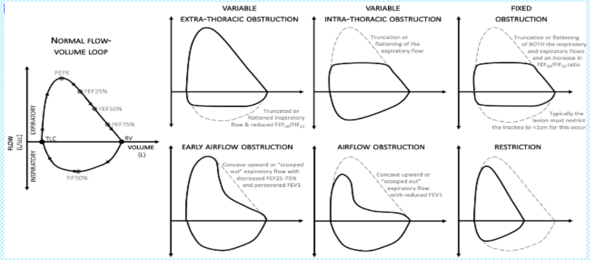


Fig 1: Note volume time curves are also recorded but not presented here

The most important indices include:
FEV1: *(Forced Expiratory Volume in 1 sec) is the maximum volume of gas that can be expired from the lungs in the 1st second of a forced expiration from a position of full inspiration measured in Litres.*
FVC: *(Forced Vital Capacity) is the maximal volume of gas that can be expired from the lungs during a forced and complete expiration from a position of full inspiration measured in Litres.*
PEF: *(Peak Expiratory Flow) is the maximal flow from a forced expiration from a Position of full inspiration measured in Litres/sec.*

Spirometry is used to: aid diagnosis, evaluate respiratory symptoms, monitor disease effect on pulmonary function, screen individuals at risk, pre-operatively risk assessment, monitor disease progression and for therapeutic intervention.
Changes in FEV1 are used in Asthma to assess bronchodilator response with a significant response seen as 200mls and 12% change in FEV1 and / or FVC. FEV1 is also used in COPD to grade disease severity using the GOLD guidelines.

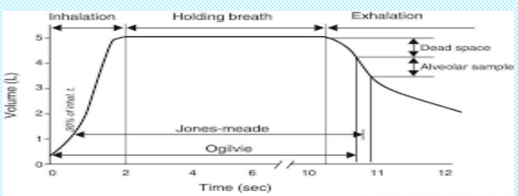
Absolute Contraindications to Performing PFT's:

Due to increases in myocardial demand or changes in blood pressure Acute myocardial infarction within 1 week ***For List of Relative Contraindications refer to ERS/ATS Standardisation of Spirometry 2019 Update.***
The majority of contraindications are relative and depend on balancing any possible complications with the clinical need for the results. Adhere to local recommendations for infectious patients with TB, COVID-19 etc.

Diffusing Capacity DLCO or TLCO

Diffusing Capacity for carbon monoxide (CO) usually called transfer factor, measures the surface area of the lung available for gas exchange. Primary role of the lung is gas exchange between the atmosphere and the pulmonary circulation. Any structural or functional abnormalities of the lungs can affect gas exchange e.g. lung volume, membrane thickness, surface area, Hb concentration. CO is an appropriate gas to use to measure diffusing capacity due to its high affinity to Hb. It is safe to breath at low concentrations and easy to measure using infrared / electrochemical analysis. The method used involves breath-holding at maximum inspiration for 10 +/- 2 secs.

Fig 2



Important measurements include:

- ***DLco:*** *Diffusing Capacity or transfer factor is the product of Kco and V_A.*
- ***Kco***: *transfer coefficient, the rate of transfer of gas between the alveoli and the erythrocytes into the alveolar capillaries.*
- *V_A: alveolar volume, the volume of the lungs during the measurement of gas transfer.*
- *V_{IN}: volume inspired is the volume of test gas inhaled during the measurement of gas transfer.*

Following breath-hold during exhalation the initial portion of breath is discarded or washed out as this contains gas from both the anatomical deadspace and deadspace of the equipment (approx. 750mls). Then a sample volume of gas is collected (approx. 750mls) and analysed. In patients with a small VC (less than 1.5L) this value can be reduced to allow smaller sample volume, however it must be considered that this will lead to some contamination of sample gas with dead space gas, ultimately reducing the measured transfer factor.

A low DLCO supports a diagnosis of fibrosis, emphysema or pulmonary vascular disease.

A high DLCO indicates possible polycythaemia.

ATS/ERS 2017 technical standard for diffusing capacity test

Lung Volumes Methods by Helium dilution, Nitrogen Washout, or Body Plethysmography

This involves the measurement of Lung volumes indirectly using both functional residual capacity (FRC) and Vital capacity (VC) to yield Total Lung Capacity TLC and Residual Volume (RV) :

(1) ***Helium (He) dilution*** where He is an inert and poorly soluble gas. It works on the principle that if a known concentration of He is inhaled it will be diluted with the He free gas in the lungs. Then if the He concentration is monitored the volume of gas within the lungs can be calculated.

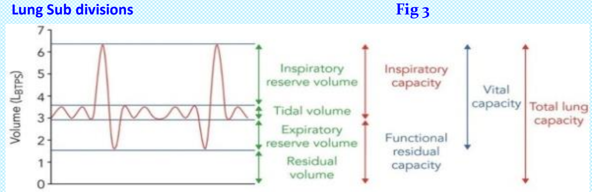
(2) ***Nitrogen (N2) washout*** works on the principle that the patient inhales 100% oxygen (O_2). The concentration of exhaled O_2 and CO_2 is continuously monitored as a surrogate for decreasing N_2. This N_2 subtraction method is used to calculate the total volume of gas within the lungs.

(3) ***Whole Body Plethysmography***. Generally accepted as the gold standard method. This involves using a constant volume box based on Boyles Law which states at constant temperature and in an enclosed space changes in absolute pressure (P) and Volume (V) are inversely related P1V1=P2V2

The patient is enclosed completely in an airtight box. Airflow is measured at the mouth using a pneumotachograph and a shutter is used to occlude the airway when required. Changes in pressure within the box and at the mouth are measured using two pressure transducers. The change in the box pressure is inversely proportional to the volume change then the change in Vol of box =change in lung volume.

There should be no significant difference between the different techniques however in obstructed patients with gas trapping, volumes measured using body plethysmography are generally higher that those measured using gas methods due to the measurement of the unventilated gas trapped areas of the lungs.

Lung Sub divisions **Fig 3**



TLC *: Is the volume of gas in the lungs and airways at full inspiration measured in Litres.*
RV: *is the volume of gas in the lungs and airways at full expiration also measured in Litres.*
FRC: *is the volume of gas in the lungs at the end of tidal expiration, in Litres.*

TLC = RV+VC or **TLC=FRC+IC**

ATS/ERS 2005 technical standard for lung volumes (new standard due in 2022)

Interpretation of Lung function Results

Historically interpretation of pulmonary function tests are based on a comparison of patient results with predicted values. The predicted reference equations are based on data from healthy individuals matched for age, gender, ethnic origin and height. This assumes the lower limit of normal (LLN) to be 80% predicted, with the upper limit of normal (ULN) as 120% predicted. The problem with this assumption is that lung function declines with age and using this form of interpretation may lead to over/under estimation of disease in the older and younger populations.
More recently interpretation has been updated to include standard residuals (SR's or Z-scores). An SR is a dimensionless number which states how many standard deviation (SD) the subject's value is from predicted and this is identical to a z-score. A negative SR means the result is below predicted. An SR value of 0 means the result is identical to the predicted value. So a SR of −1.645 puts the result on the fifth percentile and is at the LLN. SR's correct for age and gender bias.
Global Lung Initiative (GLI) is a network set up to establish standardised lung function reference values for all ages, both sexes and ethnic backgrounds. GLI reference values are now available for all tests, Spirometry (2012), DLCO (2017)*, Lung Volumes (2021)*. * European ancestry only

Classification of Disease Severity using LLN/ ULN / z-scores

Parameter	Obstructive	Restrictive	Mixed
FVC	N or ↓LLN	↓LLN	↓LLN
FEV1	↓ LLN	N or ↓LLN	↓LLN
PEF	↓ LLN	N or ↑ULN*	↓LLN
FEV1/FVC	↓ LLN	N or ↑ULN	↓ LLN
TLC	N or ↑ULN	↓LLN	↓LLN
RV	N or ↑ ULN	↓LLN	↓LLN
DLCO	N or ↓ LLN	↓LLN	N or ↓LLN
		*early dx	

Z Scores (SR) using FEV1	
-1.64	Mild
-2	Moderate
-2.5	Mod severe
-3	Severe
-4	Very severe

Additional Lung function tests:

FeNO or fractional exhaled nitric oxide: Used to measure the amount of exhaled nitric oxide when breathing out. It is a marker of allergic or eosinophilic airway inflammation. Used to aid the diagnosis of Asthma, determine steroid responsiveness, optimise dose of inhaled corticosteroids and identify asthmatics as candidates for treatment with biologics. *caution in smokers, vegan/high plant based diets impact on NO readings

Skin Prick Allergy Testing: Test used to identify allergies to pollens, grasses, house dust mites, animal dander's, foods etc. Usually performed on the forearm of adults and tested against positive (Histamine) and negative (glycerol) controls. With a positive reaction seen as a wheal on the surface of the skin. The wheal size indicates the level of reaction

Muscle Strength tests: Maximal Inspiratory Pressure tests (MIPS), Maximal Expiratory Pressure (MEPS) and Sniff Nasal Inspiratory Pressure (SNIP): Series of tests that measure the pressure generating capacity of the respiratory muscles when muscle weakness is suspected.

Supine Spirometry:. Spirometry is performed both upright and in the supine position where a reduction in FVC of 20% or more is indicative for diaphragmatic muscle weakness.

Bronchial Challenge tests: Methacholine, Mannitol, Exercise, Eucapnic Hyperventilation: Used to identify airway hyper responsiveness by provoking airway changes

Oscillometry: Test used to measure total lung impedance (resistance and reactance) during passive tidal breathing. Used to distinguish increased resistance in the peripheral airways from central airways and give an overview of stiffness of the lung tissue.

References: Fig. 1 https://www.grepmed.com/images/9976/pulmonary-diagnosis-pfts-loops-patterns
Fig.2 https://www.analesdepediatria.org/en-measurement-co-diffusion-capacity-ii--articulo-resumen-S234128791500126X
Fig. 3 https://doi.org/10.1136/bmjresp-2020-000575