The Clinical Utility of Lung Function Testing in Respiratory Medicine: A Review.

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INTRODUCTION

The purpose of this review is to outline the range and utility of respiratory physiology tests, which are often referred to as "Lung Function Testing", that are used to assess the respiratory system in health and disease. Most of these tests require the measurement of; flow, volume, pressure or gas concentrations, or a combination of these, but a variety of related tests are included which aren't truly "respiratory" tests (e.g. oximetry, blood gases, etc.) and are fundamental tests for assessing the outcome of respiratory processes and function. Most of the tests are usually only available in secondary care centres where trained workforce (nurses, physiologists, scientists and often physicians) regularly perform the tests to international standards (e.g. ATS/ERS). More recently, there are moves to take more complex testing into primary care using "diagnostic hubs".

Each test will be outlined in terms of what its common uses are in respiratory medicine, particularly around the assessment of the major respiratory disorders. Rather than just listing streams of medical conditions, features of disorders will be described such as "small airway obstruction", "restrictive picture", "parenchymal impairment", etc. Some suggested pathways for use of the tests for each condition will also be outlined for the reader. The review will also act as a good link to useful, up to date resources for respiratory healthcare staff to understand more about lung function testing.

There are some fundamental issues that are relevant to nearly all the tests which needs consideration that include; quality control, technical standards, reference values and interpretation of tests. For clinician's to be able to utilise the results of lung function testing in the clinical picture there needs to be a confidence in the reliability of the measurements being made and two key areas for establishing this confidence are appropriate technical standards and the attainment of quality standards, which can include both quality control of the testing equipment and measurements as well as within-testing quality assurance checks.

QUALITY STANDARDS

Quality control usually refers to the calibration of verification of the signals being used, so for example, in spirometry this requires the checking of volume accuracy with a calibration syringe to make sure it is within the acceptable range. By doing this check at different speeds it is possible to verify the accuracy over a range of flows and thereby have a surrogate assessment of flow function too. A further useful quality assessment is the use of biological controls, where experienced operators who know the usual limits of their own spirometry values (FEV1, FVC) verify that their values are within 5% of their average normal value. In the clinic, this can be a quick and easy way to check whether unexpected low values in a patient are physiological or an equipment problem. Quality control checks, such as calibration, test simulators or biological control can be run on most routine tests including lung volumes, gas transfer, mouth pressures and even oscillometry and airway resistance tests.

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Quality assurance forms a central pillar of the quality testing process so that within-test checks, such as repeatability (e.g. All FEV1 efforts within 150mL), logical cross checks between tests (i.e. alveolar volume (VA) should never be larger than Total Lung Capacity (TLC) can be used to ensure the test performance (both device and patient) have performed correctly and without any errors. This is where the trained operator can recognise abnormal results such as slow starts or sudden stops in spirometry flow-volume loops. This attention to detail ensures that accurate, reliable and trustworthy results can be obtained even in patients who have difficulty performing the test.

TECHNICAL STANDARDS

In addition to quality measures, having global technical standards for (i) the equipment, (ii) the testing process and (iii) defining the test criteria ensures that measurements are standardised and reproducible at different centres, on different devices and even in different countries. Through standardisation technical errors are reduced and savings are made because tests don't have to be repeated when referred to other health sites. The recent ATS/ERS Technical Standards in spirometry[1], lung volumes[2], gas transfer[3], set out the criteria that manufacturers need to achieve when producing global lung function testing equipment. A lot of the detail is complex and highly technical but is important to get right because it is relevant in making many of the assumptions used in the background calculations of many lung function tests.

REFERENCE VALUES

The use of reference values in medicine for biochemistry tests are widely accepted, and with some exceptions, are rarely based on body size, ethnicity or weight, but are often influenced by sex and age. In lung function, historically, reference values are dependent upon age, sex and height but also seem to have an ethnicity component which is a complex interaction of both "nature and nurture". The aim of the reference values is not to compare individuals, but to ascertain if a subject/patient is within their expected range for a specific value (e.g. FEV1, FVC, etc.) or not. However, abnormality can often be present and seen from the shape of the flow-volume curve, the pattern of relative lung volumes of the pattern of reduction in TLCO and KCO together, even when they are within the "normal range" for that reference value.

Recently, there has been increasing controversy about the use reference values, ethnicity, racial discrimination and politics, but we need to remember that the goal of the reference value is allow a scientific way to detect the likelihood of respiratory conditions or to show normality in humans irrespective of their backgrounds. Unintended racial bias should be avoided and research is under way to address this issue globally[4].

Currently, it is highly recommended by leading respiratory organisations that GLI values for spirometry, lung volumes and gas transfer,[5-7] are used in most cases even though they are not a perfect fit for all humans. Nevertheless, their strength is in the fact that they contain the largest sample sizes, do consider some ethnic correction and are based on data collected under reasonably standardised conditions. They may be considered to be "good enough for now, better than we've had, but further work needs to be done". They are useful to help determine the initial diagnosis or disease processes, as well as for monitoring disease progression or the effect of interventions, where absolute change or percentage change from a baseline is often clinically more useful.

INTERPRETATION OF TESTS

The interpretation of lung function tests has long been a difficult issue for clinicians, but can be considered to fall into 2 components; (i) the technical interpretation of the physiological tests and (ii) the clinical interpretation of the lung function results in conjunction with other investigations including imaging, bloods, together with signs & symptoms. The respiratory medical literature is full of specific clinical interpretation of diagnostic and imaging results in the large variety of respiratory conditions that have been identified. In this review, only the technical interpretation of the physiological test will be discussed. In fact this is the path taken in the recently published ATS/ERS Task Force on Lung Function Interpretation report.[8]

As stated previously, the physiological interpretation includes the comparison with reference values, specific patterns of the spirometry graphs and the relative values of key parameters taken in the round.

Table 1: Routine tests

Test	Key parameters	Physiological phenomena	Respiratory disorders	Notes
Spirometry	FEV1, FVC, PEF, MEF, MIF, FEF25-75, FEV1/FVC, MEF/MIF, PEF/FEV1 FVC, VC	Upper airways obstruction Peripheral airways obstruction Restrictive patterns	Vocal Cord dysfunction, ILO, etc. Asthma, COPD, sarcoidosis bronchiectasis/CF. Chest wall disorders, Lung fibrosis, Guillan-Barre Syndrome	Flow-volume curves are really helpful. Comparison with reference values helpful, but needs TLC measured to confirm restriction.
Lung volumes	FRC, RV, IC, TLC, VC,	Restrictive patterns Hyperinflation, "gas-trapping"	Chest wall disorders, Lung fibrosis. COPD, Emphysema, Severe asthma, CF, etc.	All measurements made by different techniques are indicated by subscript. (e.g. TLCpleth, TLCHe, TLCN2, etc.) V_A from gas transfer can be used in normal and restrictive subjects as a surrogate for TLC.
Gas transfer	TLCO, VA, KCO	Pulmonary vascular damage. Loss of alveolar surface area Pulmonary haemorrhage	Vasculitis Emphysema Goodpasture's syndrome.	Benefits from correction for Hb, COHb and altitude. TLCO with TLNO test can determine nature of gas exchange impairment.
Mouth pressures	MIP, MEP, SNIP.	Respiratory muscle weakness. Neuromuscular disease	Myotonic dystrophy, muscular dystrophy, etc. Motor neurone disease,	Pdi once set up as a service can be helpful in assessing interventions
Spot oximetry	SpO2 (with known FiO2)	Hypoxaemia	Any respiratory or cardiac condition. Once Sp02 on air is below 92-94%, blood gases should be considered.	Not useful in CO poisoning, or hyperoxia and measurement affected by skin pigment, nail polish, certain medications, etc.
Blood gases (arterial or capillary)	PaO2, PaCO2 and pH (with known FiO2)	Hypoxaemia or hypercapnia	Any respiratory or cardiac condition. Useful to have sequential measures. To follow deterioration/interventions	N.B. Other indices derived from look up tables (e.g. HCO3-, BE, etc.)
Expired breath samples	FeNO, ExpCOHb	Airway inflammation CO levels in smokers	Asthma, COPD, bronchiectasis, UAO. COPD	FeNo better for monitoring rather than as a diagnostic test. Expired CO used for correction of TLCO in smokers or people exposed to indoor cooking.

ROUTINE TESTS

Spirometry

Principal measurements: FEV1, FVC, VC, PEF, MEF, MIF.

Useful indices: FEV1/FVC, MEF/MIF, PEF/FEV1 as Empey Index[9]

Common conditions where useful:

a. All small airways disorders (Asthma, COPD, Bronchiectasis, CF, upper airway disorders (Vocal Cord dysfunction, ILO, etc.)
b. Restrictive disorders (i) Chest wall disorders (respiratory muscle weakness, connective tissue disorders, kyphoscoliosis, chest wall deformity, pleural disorders)
c. Restrictive disorders (ii) Diffuse interstitial lung conditions (Interstitial pulmonary fibrosis, sarcoidosis, extrinsic allergic alveolitis)
d. Pre-operative assessment in cancer, orthopaedic surgery, cardio-thoracic surgery, etc.

Spirometry is the fundamental respiratory physiological test which can help triage patients into normal or abnormal, but then if abnormal, into the patterns of obstructive or restrictive lung disorders. In airways diseases (Asthma, COPD) it is useful to capture the response to inhaled bronchodilators, but a negative response does not rule out asthma or rule in COPD. In fact, multiple daily peak-flow measurements are a better way to assess asthma rather than a one-off measurement in an out-patient clinic[10].

More recently, patient self-monitoring with "home" spirometry is becoming more widespread in monitoring deterioration in disease (e.g. ILD) or response to treatment (e.g. asthma, COPD) as technology allows data sharing "in the cloud" and smartphone Apps linking to health professionals coaching the patients via video link to perform the tests to acceptable quality standards.

Spirometry is used during a variety of specialist tests including airway challenge tests, CPET (ergospirometry) and is often necessary to assess the ability of patients to be fit or able to conduct other lung function tests such as lung volume and gas transfer measurement.

The patterns of the flow-volume loop (inspiration and expiration) can be helpful in diagnosing the site of airway obstruction when compared with a normal loop (Fig 1a). In small airways obstruction, the reduction in PEF and the concavity of the mid expiratory flows are characteristic of small airways obstruction (Fig. 1b). In the most severe obstruction the "church-steeple" pattern (Fig. 1c) can be seen and this is almost diagnostic for emphysema.

For normal flow volume loops (and in restrictive lung disorders), the ratio of the mid expiratory flow to mid-inspiratory flow should always be one (i.e. inspired and expired flows are the same). However in obstructive patterns this can vary, especially in large airway obstruction (Figs 1d, 1e and 1f) dependent upon the site of the obstruction (e.g. intrathoracic compared to extra thoracic) or even the nature of the obstruction (fixed or variable) and exceptionally can indicate bi-phasic filling such as in the case of a bronchial obstruction (Fig. 1g)

Lung Volumes

Lung volume measurement is most useful for the confirmation of a restrictive defect or the presence of hyperinflation and gas-trapping (as seen in severe COPD. Values and patterns are dependent of the technique used to measure lung volumes. Body plethysmography (body box) measures all the ventilated and not ventilated gas in the thorax (and abdomen!), whereas gas dilution techniques (helium dilution, nitrogen washout) can only measure the ventilated parts of the lung. This is why sometimes in severe COPD for example, measuring by both techniques can confirm the approximate amount of non-ventilated lung. One useful check, if gas transfer is being performed at the same appointment is to compare the TLC by helium dilution with the alveolar volume (VA) from the single breath dilution. Usually VA is 90% of the TLC when no airway obstruction is present. This means the test can act as a good surrogate for TLC and confirming restriction without the need for another tests. However, in the presence of airways obstruction, TLC should be measured separately, but the VA / TLC ratio can help determining the levels of poor mixing and gas-trapping. It can also be used to confirm consistent good quality in test performance since they should be similar in value. If VA is larger than TLC, this suggests a serious error in one or both tests.

Gas Transfer

The single breath gas transfer for carbon monoxide (CO) test (often known as TLCO in Europe or DLCO in North America) is the only true routine test of lung "function", as it estimates the lungs ability to exchange gases. The basic premise of the measurement is to measure the rate of disappearance (uptake) of the marker gas (CO) during a ten second breathold manouvre. The CO combines with haemoglobin in the alveolar capillary blood and effectively disappears, so analysing the exhaled sample shows the uptake of CO over the 10 seconds.

Gas transfer can be lower or higher than predicted values, and is also dependent on a number of physical/physiological properties like altitude, ambient oxygen levels, haemoglobin levels, background blood CO levels and haemoglobin species.

It can also be measured with NO in the gas mix and the TLCO/ TLNO ratios and values can tell much about impairments in either the alveolar-capillary membrane or capillary blood components of the transfer test.

The test is better understood if the Krogh coefficient (Kco) and the transfer factor (TLco) are interpreted together as there are specific patterns dependent upon the respiratory impairment. Table XX summarises the key pattern is disease;

Table XX: Interpretation of gas transfer tests

Condition	Kco	TLco	Notes
Intrapulmonary impairment/damage	**Reduced**	**Reduced**	**Disorders of the lung parenchyma, airways, alveoli, pulmonary blood vessels**
Interstitial pulmonary fibrosis	Reduced	Reduced	Loss of volume leads to loss of surface area and gas exchange
Emphysema	Reduced	Reduced	Loss of volume leads to loss of surface area and pulmonary vasculature and therefore gas exchange
Asthma	Normal or slightly raised	Reduced but can be raised	Early asthma has relative inflammatory process that increase pulmonary vasculature. Severe asthma leads to loss of volume and reduction in TLCO.
Pulmonary vascular disease (Vasculitis)	Reduced (modest)	Reduced (modest)	Altered V/Q mismatching leads to impaired gas exchange.
Alveolitis (Farmer's Lung)	Reduced	Reduced	Gas diffusion reduction caused by the reduction in lung volume, maldistribution of inspired gas and damage to pulmonary capillaries.
Sarcoidosis	Reduced (mild or none)	Reduced	Minority get reduced TLCO. Thickening of alveolar-capillary membrane and obliteration of alveolar architecture are the main mechanisms for reduction.
Collagen diseases (Rheumatoid arthritis, systemic sclerosis, SLE)	Reduced	Reduced	RA shows only a mild or no reduction in KCO. However, it depends on whether pleural involvement and/or alveolar fibrosis occurs.

Extrapulmonary impairment/damage	**Normal or relatively raised**	**Reduced**	**Disorders of the chest wall, respiratory muscles or**
Respiratory muscle weakness	Normal or relatively raised	Reduced	The reduction in lung volume produces the reduction in surface area, but also increases the relative pulmonary blood volume per alveoli and hence the raised KCO.
Connective tissue diseases	Normal or relatively raised	Reduced	The reduction in lung volume produces the reduction in surface area, but also increases the relative pulmonary blood volume per alveoli and hence the raised KCO. In SLE there may also be respiratory muscle weakness too.
Pleural disease	Normal or relatively raised	Reduced	The pleural involvement in asbestosis/mesothelioma is often very evident with this gas transfer pattern
Other disorders			
Pulmonary haemorrhage	Raised greatly	Raised greatly	Occult blood in the airways mean CO combines easily and mimics a increased gas transfer. This can be exploited in Goodpasture's syndrome to monitor pulmonary haemorrhage.
Cardiac disease (Cardiac failure, valve disease, R-L shunts)	Reduced	Reduced	R-L shunts decrease TLCO and KCO. (N.B. L-R shunts increase TLCO and KCO) Most cardiac disorders lead to reduction in gas transfer despite the pulmonary blood congestion.

The physiological mechanisms that lead to reductions in gas transfer at the alveolar level can be summarised into several basic processes but are essentially impairment of the alveolar-capillary membranes or the impairment of the pulmonary blood volume.

Membrane impairment can mainly be as the result of impairment of the alveolar membrane or the capillary membrane or the seven layers of tissue from the alveolar space to the combination with haemoglobin.

- Impaired pulmonary vasculature (thickened vessels, loss of vessels)
- Alveolar fibrosis, (thickened alveolar wall)

Loss of lung volume (and subsequently alveolar surface area) can result from several mechanisms including;

- Restrictive disorders (both intra and extra pulmonary)
- Loss of alveolar units and surface area (e.g. emphysema)

The gas transfer test is sensitive to a wide variety of pathological processes, but is poorly specific to individual diseases and thus warrants careful interpretation to understand the results of the test.

There are the added complications of impaired airflow to the alveoli either because of airway disease, infection or poor ventilation that adds to these basic mechanisms by altering ventilation and perfusion matching.

Assessment of Respiratory Muscles

The assessment of respiratory muscles when muscle weakness is suspected is an important basic measurement[11] which whilst relatively simple, can be difficult for patients to master. Basic mouth pressures measuring maximum expiratory pressure (MEP) and maximum inspiratory pressure (MIP) can give a global assessment of muscle weakness or fatigue, but reference values are generally poor and often using a cut off value (e.g. MEP +40 cm H2O; or MIP -40 cm H2O) can be clinically more useful to define weakness.

Diaphragmatic weakness can be better assess using nasal sniff inspiratory pressures (SNIP) which whilst simple in concept, does take significant patient training to get reliable results[12]. Respiratory muscle assessment as an addition to spirometry, lung volumes and gas transfer, which indicate an extrapulmonary restrictive picture can usually seal a diagnosis of respiratory muscle weakness. Using the drop in vital capacity (VC) between sitting and supine spirometry of greater than 15% is a good screening tool for muscle weakness if only spirometry is available.

Blood Gas Assessment

The ultimate physiological consequence of any respiratory disorder can be respiratory failure where the body's homeostatic mechanisms are unable to sustain normal oxygen and/or carbon dioxide levels. Whilst this is often used in acute medicine, it shouldn't be forgotten that long-term monitoring of blood gases aids prognosis and timely interventions such as additional oxygen on non-invasive ventilation (NIV).

Spot check pulse oximetry

The simplest way to monitor blood oxygen levels is to use simple pulse oximetry. Devices are now relatively cheap and widely available but caution must be used when interpreting results given the issues around false and inaccurate readings due to systemic medications, skin pigmentation, poor perfusion and inaccurate devices. The use of storage oximetry for monitoring oxygen levels during field exercise tests or overnight are specific uses of the basic technique. Using a cut-off value whilst breathing room air of 92% (or 94% in patients with pigmented skin), can act as a good screen for performing a blood gas test.

Blood gases

Traditionally arterial stabs are the gold standard methodology for assessing blood gases, but arterialised capillary blood gas (ABG) and venous blood gas samples can also be used if appropriate. Whilst arterial punctures for ABG analyses are safe procedures, the main complication rate is 0.14% (CI 0.13 – 0.15), and patients on antithrombotic medication carry an increased risk of developing major complications[13]. In these cases, arterialised techniques are less risky and painful for the patient but all techniques require good training and competence to be reliable.

Assessment of shunt

This is a relatively simple test, but requires meticulous attention to the correct technique to get meaningful results. The principle is to get the patient to breath 100% oxygen for at least 10 minutes (so cannot be used in patients who retain CO2!) and then measure an arterial gas perfectly. The oxygen breathing requires a tight-fitting mask with a Hans-Rudolf one-way valve with an anaesthetic reservoir bag in the circuit to allow tidal breathing of oxygen comfortably. An arterial stab is performed (without air bubbles, clotting.) and requires immediate analysis on a calibrated blood gas analyser. The values obtained are used to calculate the shunt on reliable reference tables/graphs[14].

Specialised Tests

Outside of routine lung function testing services there are a number of more advanced/complex techniques (see Table YY) which have often been developed from research institutes into useful clinical tools. Initially they are of interest to the specialist services and research teams, but often are the subject of "disruptive technology" and become cheaper, more widely available and clinically useful. Indeed, as technology advances in this digital age, it is likely that more and more new innovations will emerge that will provide rapid, simple to use diagnostic tests that can be used outside specialist centres and perhaps move into more remote rural settings (e.g. in Nepal) with virtual support and interpretation being possible remotely. If we look at the trends over recent decades in respiratory physiology techniques (e.g. oscillometry, sleep study measurements, portable blood gas machines, etc.) devices have become smaller, portable, more reliable and robust for use in primary care or in remote situations.

From a logistical point view, in the clinical setting, very often the routine lung function tests can be enough to indicate the broad direction of a patient's diagnosis into obstructive, restrictive, airway diseases, parenchymal disease. However, other more specific tests can be used to assess the severity of a disorder (e.g. oscillometry or airways resistance/conductance in airways disease), or in the case where patients cannot perform standardised manouevres required for routine tests, more "passive " measurements may be utilised instead. Taking the airways disease example, portable oscillometry devices can be used to measure quiet breathing and assess

Table YY: Specialised Tests

Test	Key parameters	Physiological phenomenon	Respiratory disorders	Notes
Airway resistance	Raw, SGaw	Small airways obstruction	Asthma, COPD, sarcoidosis bronchiectasis/CF.	Required "panting" action & use of a body box.
Oscillometry	R5-R20, X5-X20, RF	Small & large airways obstruction	Vocal Cord dysfunction, ILO, etc.	Doesn't require more than tidal breathing.
Airway challenges	PD20, PC20	Airway hyper reactivity	Asthma	Can be used to check adverse reactions to nebulised drugs.
Assessment of shunt	% Shunt	Abnormal gas exchange	Pulmonary embolism, V/Q mismatch	Requires 100% oxygen and arterial gas sample.
Structured Light Plethysmography (SLP)[18,19]	RTC, IE50, RR, Duty Cycle	Abnormal breathing patterns	Unexplained dyspnoea,	Just requires quiet breathing. New reference values available.
Overnight oximetry	Mean SpO2, Time <90%,	Nocturnal hypoxaemia, OSAH	Respiratory failure or a sleep breathing disorder.	Not useful in mild/ normal sleep breathing disorders
Multichannel sleep studies	AHI, ODI,	Nocturnal hypoxaemia, Sleep disordered breathing	OSAH/S, CSA,	Can be done in the patient's home and not in hospital.
Transcutaneous CO2/O2 monitoring	Tc'O2, Tc'CO2	Nocturnal hypoxaemia and/or hypercapnia.	Respiratory failure (Type I and Type II) Nocturnal oxygen titration.	Oxygen probe site needs relocating after about 6 hours.
CPET	Peak VO2, HR RER, VeMax. HRmax, Ventilatory threshold, Ventilatory equivalents for O2 and CO2.	Pre-operative assessment	Cardiothoracic surgery assessment, assessment of anyone with respiratory condition	Distinctive patterns help determine cardiac or respiratory conditions. Threshold values used pre-surgery.

Airways resistance

Airways resistance usually needs the use of a body plethysmograph ("body box") which are expensive and can be sensitive to fluctuations in atmospheric pressure and temperature, although "hand held "interrupter" devices are available and can be used especially in children. Airways resistance measurements can be more sensitive than spirometry in detecting early changes in small airway calibre and can be used in bronchial challenge testing.[15]

Oscillometry[16,17]

Another method of assessing the airway which is becoming more widely available is the use of oscillometry devices. Whilst the techniques has been used for nearly 70 years, the standardisation of the measurement and better reference values means it has greater uses and can be used instead of airways resistance. Devices are more portable

Airway challenges

SLP[18,19]

Sleep/Overnight studies

Whilst this article is principally about respiratory physiology (i.e. lung function testing) it is now well established that assessing nocturnal ventilation makes up large part of modern respiratory medicine. Most of this work use sleep studies to detect obstructive and central sleep apnoea (OSA), but here the main aim is to use techniques to assess nocturnal ventilation using non-invasive techniques.

To detect OSA it is necessary as a basic to measure a respiratory signal and an arousal signal. So for oximetry 4% oxygen desaturations and heart rate arousals can detect any potential apnoea. However, the technique has poor specificity and sensitivity in borderline normal/mild subjects. Using multichannel studies it is possible to have more accurate identification of respiratory events by airflow and chest wall/abdomen signals, and then add further information about snoring, body position, sleep stage, and arousals.

Monitoring nocturnal breathing using oximetry or transcutaneous O2/CO2 sensors enables analysis of trends such as REM sleep desaturation/hypoventilation, or the effectiveness of NIV or oxygen therapy. The common methods to measure sleep breathing disorders include; overnight oximetry[20], multichannel sleep studies[21] and transcutaneous O2/CO2 measurements[22] have been discussed elsewhere.[23]

Cardiopulmonary exercise testing (CPET)

Cardiopulmonary exercise testing is a complex and large area of physiological interpretation which warrants its own detailed review and will not be considered here. It is recommended that CPET should be performed when full lung function testing has been completed and some cardiology investigations have ruled out any cardiovascular causes. It is increasingly popular as a test for preoperative assessment in cardiothoracic, vascular and hepatic surgery.

Lung function testing in the post-Covid19 era

Finally, the recent Covid19 pandemic saw the reduction and cessation in lung function testing in lung function departments and clinical practices across the world, as the lung function process (not the tests performed through a bacterial-viral filter but the coughing into the room afterwards) was deemed to be like an aerosol generating procedure. It is now evident [24, 25] that lung function testing requires a risk assessment approach and the introduction of precautions such as UV air scrubbers, improved air-changes in testing rooms and the use of "fallow" periods between patients to decrease the spread of respiratory-borne infections. Nevertheless, lung function remains an important set of weapons in the fight against lung disease and must be utilised to assess patient's diagnosis and subsequent interventions.

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(N.B. See figures below on next page)

FIGURES 1 a to 1g: Flow volume loops.

Figure 1a: Normal Flow Volume Loop

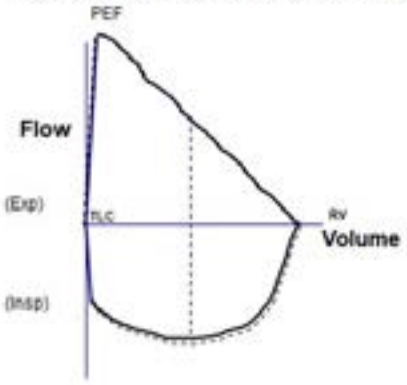


Figure 1b: Mild COPD Flow Volume Loop

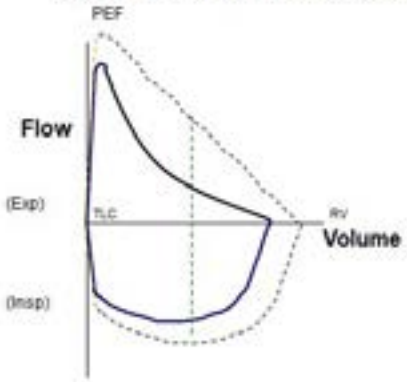
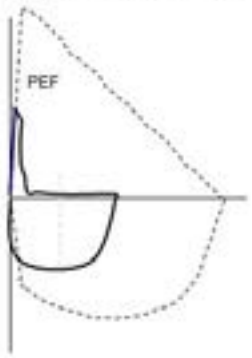


Figure 1c: Flow Volume Loop in Emphysema



Figures 1d - 1f. Flow Volume Loops in UAO

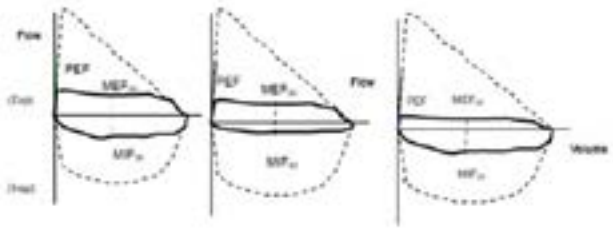


Fig 1d
Fixed UAO
MEF50/IF = 1.0

Fig 1e
Variable extrathoracic UAO
MEF/MIF >1.0

Fig 1f
Variable intrathoracic UAO
MEF/MIF = <1.0

Figure 1g: Bronchial obstruction