Basic Lung Function Tests for the Radiologist

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Learning objectives

In this poster we aim to provide an overview of the various different pulmonary function tests available and a basic guide to their interpretation.
Background

The radiologist is an essential member of the multi-disciplinary chest team - on hand to provide both specialist interpretation of imaging and recommendations as to how imaging can best be used to monitor disease progress and plan interventions. Imaging, however, forms only one facet of patient assessment. Lung function testing provides important information which can both aid in diagnosis and track disease progression. In this poster we aim to provide an overview of the various different tests available and a basic guide to their interpretation.
Lung volumes

An understanding of changes in static gas volume within the lungs during the respiratory cycle provides a useful context to understanding the dynamic tests used in clinical practice. Absolute lung volumes vary depending on body size, with standing height being the most important correlating variable. (1) These are best illustrated by the trace from a spirometer - which at its most basic consists of a bell jar suspended over a vat of liquid, the gas within which is in continuity with a mouthpiece. The jar rises and falls as the volume of gas within it changes as a subject breathes in and out through the mouthpiece. A pen connected to the jar can be used to plot the change in volume within the jar, and thus the lungs, on a moving paper tape, providing a trace as in figure 1.

The trace shows two "quiet" breaths in and out, before a maximal inspiration and maximal expiration. Whilst the spirometer is able to give measurements of inspired and expired gas volumes (table 1), more advanced techniques such as body plethysmography are needed to measure the functional residual capacity, total lung capacity and residual volume.

Forced expiration manoeuvre

One of the most useful and simple pulmonary function tests is the forced expiration manoeuvre. The subject is asked to inspire maximally, then exhale as forcefully and as completely as possible through a spirometer. Two values are then derived from the resulting volume-time curve: the volume of gas exhaled in the first second (the forced expiratory volume or FEV\(_{1.0}\)), and the total volume expired (the forced vital capacity, FVC). These are then compared against predicted values based on factors such as age, sex, height and ethnicity (the exact variables depend on the equation used). The quotient of the two values, the FEV\(_{1.0}/\text{FVC}\) ratio, is also calculated - this is approximately 0.80 in health. (3)

Two disease patterns can be distinguished (table 2). In restrictive lung disease such as pulmonary fibrosis inspiration is limited by reduced compliance of the lung or chest wall - thus the FEV\(_{1.0}\) and FVC will both be proportionally lower than predicted, leaving the FEV\(_{1.0}/\text{FVC}\) ratio preserved or in some cases increased. (3) In obstructive lung diseases such as asthma expiration ends prematurely, despite an abnormally large total lung capacity, because of an increase in airways resistance or a decrease in elastic recoil of the lung. Here the FEV\(_{1.0}\) tends to be disproportionally lower than predicted compared to the FVC, resulting in a FEV\(_{1.0}/\text{FVC}\) ratio that is below the fifth percentile of the predicted value. (2) A mixed picture may also be seen. The severity of airflow obstruction is graded...
by the quotient of the FEV$_{1.0}$ and the predicted FEV$_{1.0}$ - the FEV$_{1\%}$. This ranges from mild at > 70% to severe at < 35% (1).

A further value that is can be derived from the forced expiration manoeuvre is the average flow rate over the middle half of the expiration - the *forced expiratory flow rate* (FEF$_{25-75\%}$). This may be reduced in early small airways disease before the FEV$_{1.0}$, however this is not specific for individual patients.

Whilst an FEV$_{1.0}$/FVC ratio below the fifth percentile of predicted is diagnostic of obstructive airways disease, a low FVC alone cannot definitively diagnose a restrictive defect and thus TLC must be measured and shown to be below the fifth percentile of predicted. TLC can also be useful in obstructive disease - assisting in the diagnosis of emphysema, bronchial asthma and chronic bronchitis as well as assessing the degree of lung hyperinflation. (1)

Following an abnormal forced expiration result, patients may then be challenged with a bronchodilator and then tested again to assess for improvement. Signs of reversibility in the ventilatory defect can help to guide medical management.

**Flow-volume loops**

A more detailed picture of the respiratory cycle can be obtained by plotting a flow-volume loop. The subject is asked to take a maximal inspiration, then perform a forced expiration manoeuvre through a spirometer immediately followed by a further maximal inspiration. (4) A graph of flow against volume is plotted, the area above the x-axis representing expiration and the area below inspiration. The flow-volume pattern is characteristic in certain disease states (figure 2).

**Single breath carbon monoxide uptake**

Whilst the tests thus far have focussed on mechanical defects in ventilation, lung disease is often associated with dysfunction of the alveolar-capillary interface. Carbon monoxide binds avidly to haemoglobin and as such provides an ideal factor to help assess the efficiency of gas exchange at this juncture.

Nose-clips and a mouthpiece are attached to the subject, who then makes a maximal (but not forced) expiration to RV. The mouthpiece is then attached to a source of test gas with a known concentration of carbon monoxide (usually 0.3%), and a tracer gas to help measure alveolar volume (e.g. 10% helium). The patient is asked to take a rapid inspiration to TLC, and then hold in inspiration for around 10 seconds, before exhaling again to RV through a rapid gas analyser. (5) The CO uptake by the lung ($K_{CO}$) is calculated as a measure per unit time per unit CO driving pressure. This is then multiplied by the alveolar volume ($V_A$) - determined by measurement of the tracer gas.
The resulting value is known as the transfer factor of the lung for CO (Europe) or as $D_{L,CO}$, the diffusing capacity of the lung for CO (North America). (3) This will be reduced in diseases that interfere with the alveolar membrane conductivity or haemoglobin binding, and vice versa.
Fig. 1: Figure 1: Example spirometer tracing

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### Table 1: Definitions of lung volumes and capacities (2)


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<tr>
<th>Lung Volume</th>
<th>Definition</th>
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<tr>
<td>Tidal volume (TV)</td>
<td>The volume of gas inhaled or exhaled during tidal (&quot;quiet&quot;) breathing - i.e. at rest.</td>
</tr>
<tr>
<td>Inspiratory capacity (IC)</td>
<td>The maximal volume of gas that can be inspired above FRC</td>
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<tr>
<td>Total lung capacity (TLC)</td>
<td>The volume of gas within the lungs after a maximal inspiration</td>
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<tr>
<td>Expiratory reserve volume (ERV)</td>
<td>The maximum volume of gas that can be exhaled after end-expiration during tidal breathing</td>
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### Table 2: Diagnosis of ventilatory defect using forced expiration spirometry and total lung capacity (2)

Fig. 2: Example flow-volume loops showing the characteristic patterns of various lung diseases

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Conclusion

Confluence

As we have shown there are many tests that can help diagnose respiratory illness, however each alone is not specific to any particular problem. To simplify this, the American Thoracic Society & European Respiratory Society joint Task Force for the Standardisation of Lung Function Testing produced an algorithm combining these tests to aid in the diagnosis of respiratory disease (figure 5).

Whilst lung function tests may seem daunting to the uninitiated, we hope that we have shown them to be (at a basic level) relatively easy to understand and integrate into our MDT practice.
Fig. 3: Flow-chart to assist in interpretation of lung-function tests. Adapted from (1).

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