Chapter 7 - Static Lung Volumes and Capacities

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Professional Skills

Upon completion of this chapter, the reader will be expected to:

- Define the various static lung volumes and how each can be estimated
- Understand the methods available for estimating static lung volumes by helium dilution, nitrogen washout and body plethysmography
- Understand the need for calibration for the methods above
- Understand the need for routine maintenance and cleaning of equipment
- Understand the differences between the three methods described
- Be able to perform at least one of these methods

7.1 Introduction

The measurement of total lung capacity (TLC) and its subdivisions provide detailed information concerning the functional status of the lung and are determined by the elastic properties of the lung. The results may be used as an aid to diagnosis, for monitoring deterioration or for evaluating the effects of therapy.

Measurement of vital capacity (VC) by spirometry (Chapter 5) gives a useful indication of the ability of the lungs to expand. A reduction in VC may arise because of restriction of the lung caused by intrapulmonary disorders (such as fibrosis of the lungs) or by extrapulmonary factors (such as skeletal or muscular disorders). Total lung capacity (TLC) is also generally reduced in these cases, as lung expansion is restricted. However, a reduction in VC may also arise because of airflow obstruction, with TLC often being increased in these cases, as the lungs are 'floppy' with increased compliance. Measurements of residual volume (RV) and TLC are therefore helpful in distinguishing between the different types of disorder. TLC and related volumes are frequently referred to as static lung volumes. RV and TLC cannot be measured directly and must be measured indirectly by either gas dilution techniques or body plethysmography [1,2].

The relationship between the volumes and capacities that comprise the total lung capacity are shown below in Figure 7.1 with Section 7.2 providing the definitions.

7.3 Gas Dilution Techniques

The residual volume (RV), total lung capacity (TLC) and related volumes cannot be measured directly so special techniques are required to record these volumes. There are several accepted methods for determining these volumes, which are frequently referred to as 'static lung volumes'. These methods include helium dilution, nitrogen washout and body plethysmography.

7.3.1 Helium Dilution Methods

Helium (He) is an inert, poorly soluble gas. The principle in helium dilution methods is that if a gas with known He concentration is breathed in, the He will be diluted by the He-free gas within the lungs. If the expired He concentration is monitored the volume of gas within the lungs can then be calculated from the dilution effect.

7.3.1.1 Steady State Helium Dilution Method

The technique requires a closed circuit spirometer of known volume, prepared with a known concentration of He (between 9 - 14%). The subject is connected to the spirometer at the end of a normal tidal expiration (FRC) and breathes tidally until equilibrium is achieved between the He in the spirometer and in the lungs. To ensure the subject is comfortable and will not hyperventilate, the circuit volume is maintained constant by addition of oxygen and absorption of carbon dioxide. As the subject breathes from the closed system the air contained in the lungs is added to the system and dilutes the initial concentration of helium in direct proportional to the amount of air added. The initial He concentration and the change in the He concentration are used to calculate FRC. Maximal relaxed inspiratory and expiratory manoeuvres are performed so that the subdivisions of TLC can be calculated.

The basic components of a closed circuit He dilution system are shown in Figure 7.2. They include a spirometer or a method utilising a reservoir of gas, chart recorder, circulating pump, He analyser, O_2 source, CO_2 absorber, and a mouthpiece assembly with a two-way tap or flow sensing device to actuate the tap. Equipment can range from a totally manual arrangement to a fully computerised system.

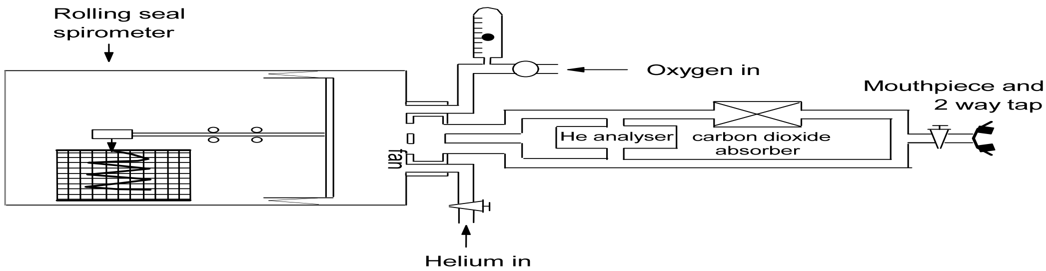

Figure 7.2 Basic Components of a closed circuit system for measuring FRC by steady state He dilution technique.

The recommendations for minimum equipment requirements include a spirometer with at least an 8 litre volume displacement (tolerance +2% or +50ml whichever is the greater) with a 25ml resolution. The driving pressure should be less than 0.03kPa and ideally, the spirometer should have the capability of measuring temperature inside the instrument to allow accurate BTPS (Body Temperature, Pressure, Saturated with water vapour) corrections to be made (see chapter1).

Measurement of FRC: The FRC calculation and measurement of circuit dead space is given in Appendix 7.1 The manual technique for measuring FRC is as follows, based on the ARTP /BTS Guidelines for the Measurement of Respiratory Function (1994).

1. Sufficient time should be allowed for the equipment to warm up. Absorber condition should be assessed prior to the start of each test. The closed circuit is prepared according to the manufacturer's instructions with the appropriate volumes of air, O_2 and He, these volumes being marked on the chart recorder if performing a manual test. The circuit volume is V_1 and comprises the dead space (see Appendix 7.1 for definition and method of measurement) plus the total volume of gases added to the spirometer. The gases are mixed within the circuit by the circulation pump and the He concentration (He_1) recorded at equilibrium.
2. The purpose and nature of the test are explained, the subject is seated by the equipment and the height of the mouthpiece assembly adjusted as appropriate. The subject should be encouraged to sit upright, the arms should rest by the side or along the arm of the chair and both feet should be positioned on the floor directly in front of the seat. Tight clothing should be loosened. The subject should not be able to view the chart recording or display unit while performing the test. The subject, wearing a nose clip, starts to breathe via the mouthpiece; at this stage the circuit is closed and the subject is breathing room air. The chart recorder is switched on. After observing the subjects, tidal breathing movements, the mouthpiece tap is turned so that the subject is connected to the spirometer circuit at the end of a normal tidal expiration, i.e. at FRC.
3. The He concentration is recorded every 30 seconds until it is stable, i.e. when two consecutive readings are within + 0.02% (absolute) of each other (fig. 7.3), or within + 0.025 litres if FRC is displayed directly. At this point the final reading is noted. Throughout the test the recorder trace is observed and the volume of gas in the circuit kept constant by adding O_2 as it is consumed by the subject, while CO_2 is automatically removed by means of the absorber. If final stability of He concentration is not achieved within 10 minutes then the final reading at this time should be taken and the fact that stability was not reached should be recorded.
4. The subject is then asked to perform relaxed ERV and / or VC manoeuvres. In the presence of chronic obstructive lung disease, the FRC may change during these manoeuvres due to the effect of air trapping consequent from airway collapse. Sufficient time should be allowed between manoeuvres to enable the subject to return to normal breathing at a stable FRC level. Other manoeuvres may be used to measure ERV e.g. from a position of full inspiration. However, this is not recommended because of the effect of effort induced bronchoconstriction/airway collapse in chronic obstructive airways disease. The ERV and VC are read from the chart recorder trace (see Figure 7.3).

   The manoeuvres for ERV, IVC and the EVC can be carried out in one sequence, or, ERV and IVC recorded with a rest before EVC is performed. The highest value from a stable baseline should be taken. The manoeuvres for ERV and VC should be performed at the end of the FRC measurement as in figure 7.3.

Some systems allow the performance of these manoeuvres earlier in the test but this is not recommended, as these may induce changes in lung volume (see above).

5. The FRC is calculated from the helium concentration as follows:

$$FRC = V_1 \times (He_1 - He_2)/He_2$$

Where: V_1 is the circuit volume, including mouthpiece and filter deadspace
He_1 is the initial helium concentration
He_2 is the final helium concentration
(The derivation is given in appendix 7.1).

6. The ERV and VC are read from a stable baseline on the chart recorder trace (see fig. 7.3). The largest values should be reported (from both IVC and EVC) and RV and TLC calculated as follows:

$$RV = FRC - ERV$$

$$TLC = RV + VC \text{ or } TLC = FRC + IC$$

7. Provided one technically acceptable result has been achieved, this result is quoted. If a duplicate measurement is to be carried out, then the delay between repeated measurements by the steady state helium dilution method must be at least the same as the time taken for the initial test to be completed.

8. The ambient temperature and barometric pressure are recorded. The lung volumes are then corrected to BTPS. If available the spirometer temperature should be used as this gives a more accurate correction.

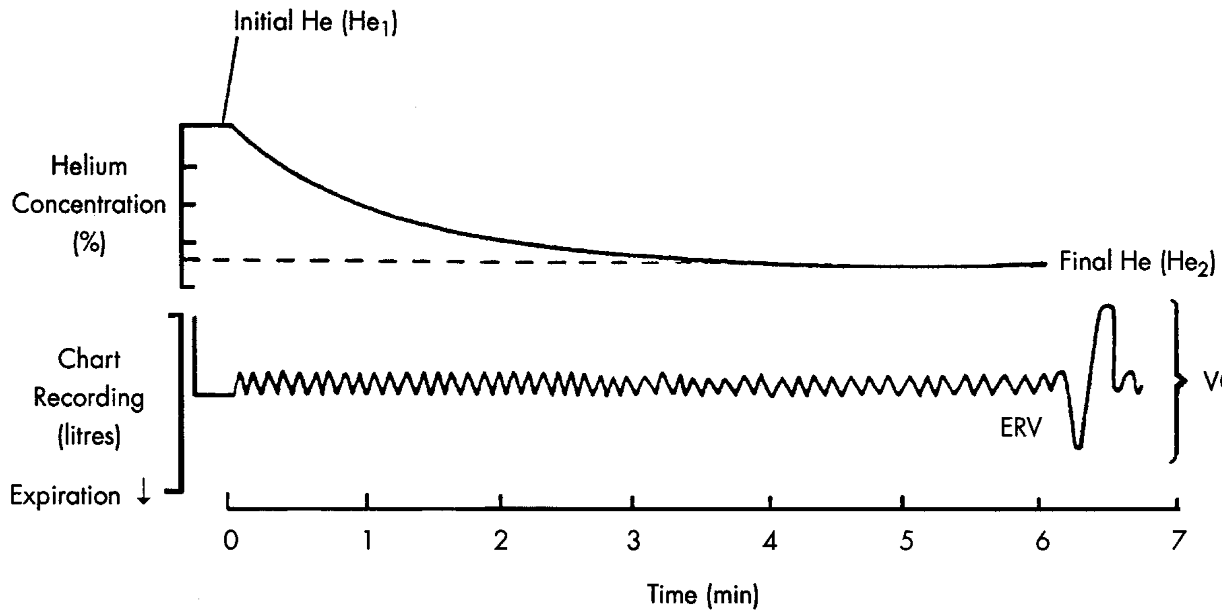

Figure 7.3 Diagram of helium and volume changes when recording FRC by steady state helium dilution

Sources of Error

Position of FRC: The subject should be connected into the circuit at FRC by observing chest or abdominal movement and by turning the mouthpiece tap swiftly at the end of a tidal expiration. Occasionally a subject will breathe erratically or the breathing pattern can be misjudged and the tap is not turned exactly at FRC. Corrections can be made to compensate for small errors of this type (Figure 7.4). The O_2 flow should not be altered at this point to correct the position of the chart recorder trace as this may alter the He concentration both by dilution and by the direct effect of O_2 on the He analyser. If a switch in error of more than 500 ml has occurred the subject should be taken off the mouthpiece and allowed to breathe room air for 2-3 minutes before the test is attempted again.

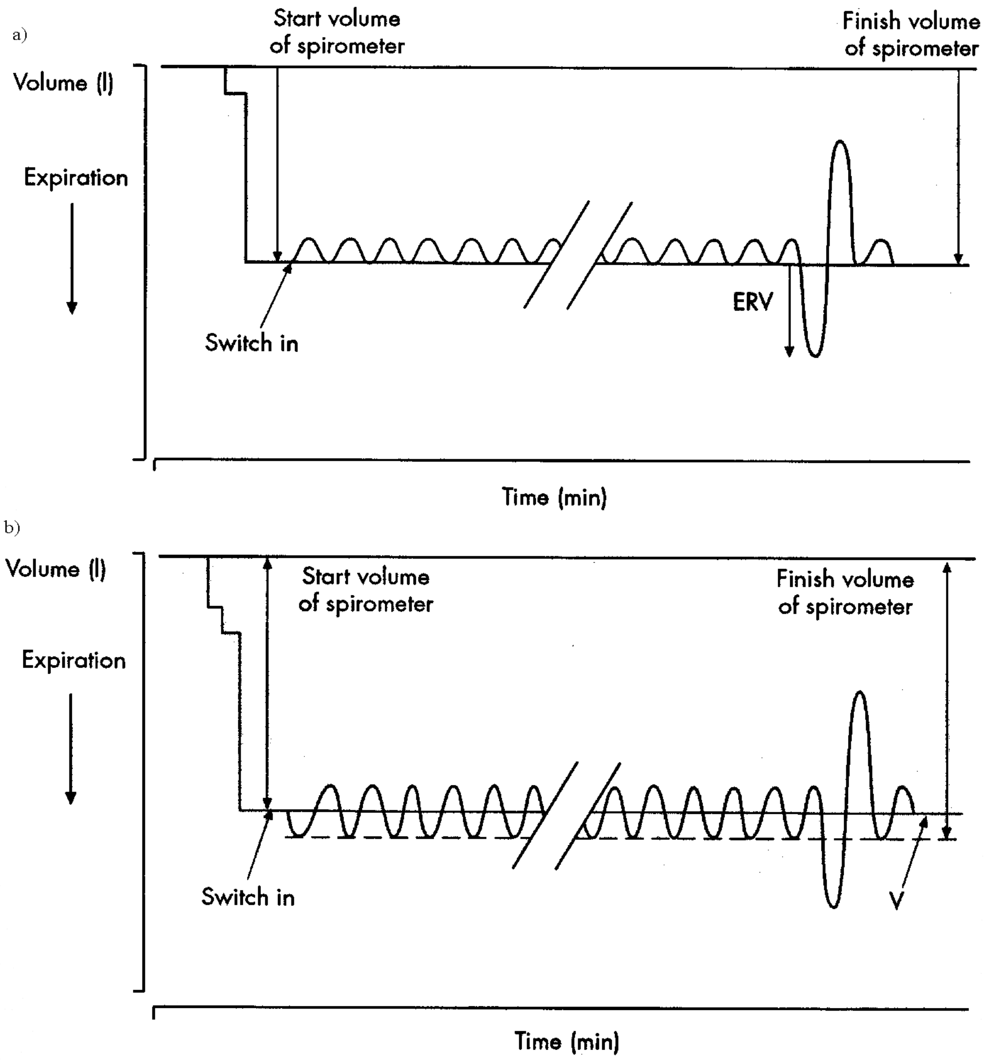

Figure 7.4 Steady state Helium dilution method: diagram illustrating correct and incorrect 'switch-in' methods. (a) Correct connection of subject to circuit at the end of a tidal expiration, i.e. at FRC. (b) Incorrect connection of subject to circuit during tidal breathing. The tracing should be kept at the same level throughout the test and the true FRC determined by subtracting the small volume error (ΔV) from the calculated FRC.

O_2 Addition: The O_2 consumption of each subject is different and O_2 consumption may even vary during FRC measurement. The amount of O_2 added to the circuit must therefore be adjusted as required. The flow of O_2 should be adjusted to keep the trace within 200ml of the starting circuit volume.