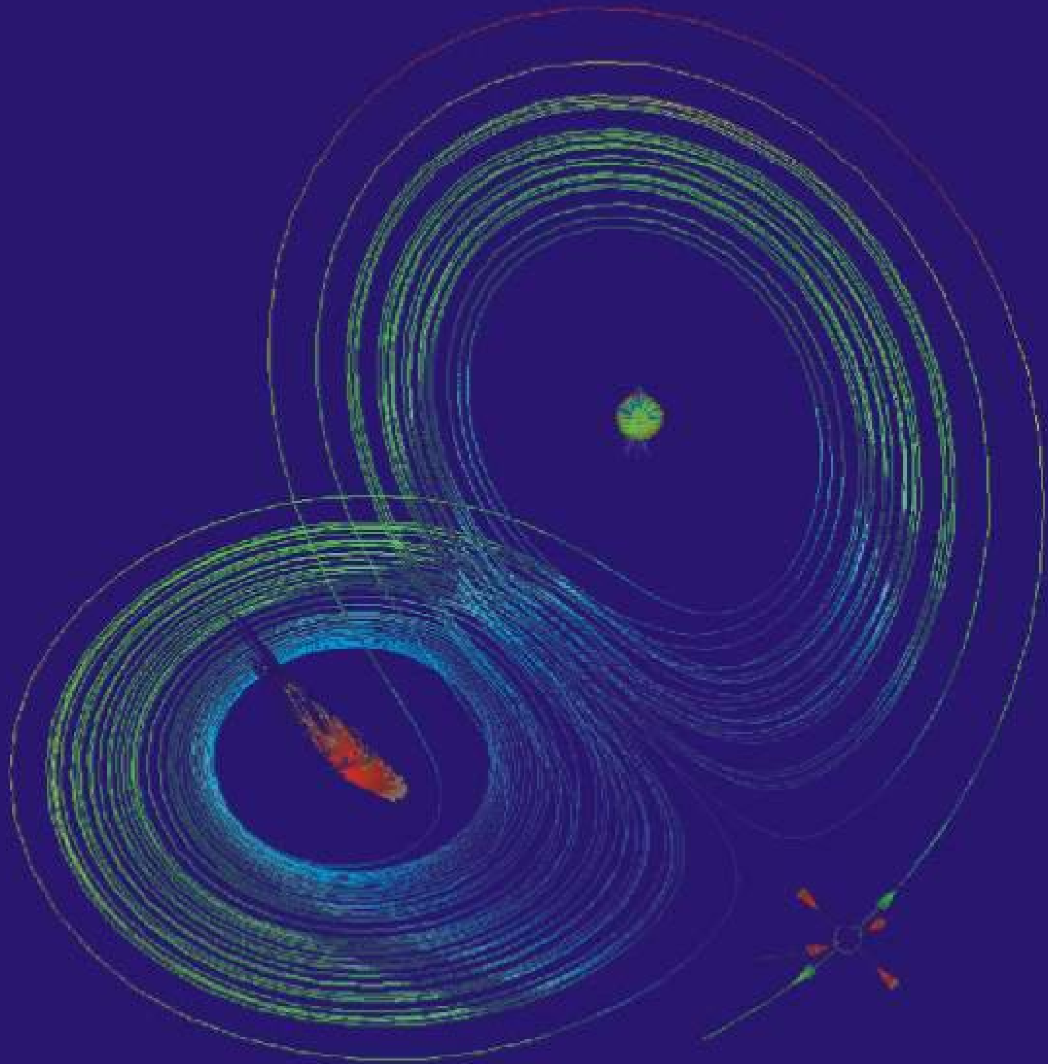


SPIROMETRY

Made Easy

Preface

The last few years have seen a growing interest in the management of asthma. Other pulmonary diseases such as chronic obstructive pulmonary disease (COPD) have also come under the spotlight. It is often difficult to measure the degree of severity of these diseases subjectively. The result is under-estimation of disease severity and hence inadequate treatment and inadequate control of the disease.

Hence, objective measurements such as the lung function tests are very important in diagnosing and monitoring lung disorders just as important blood sugar measurements are in diabetes or blood pressure measurements are in hypertension.

There are several types of lung function tests. The most informative and clinically useful tests are **'spirometry'** and **'peak expiratory flow'** measurements. Simple objective measurements such as peak expiratory flow (PEF) are very effective in the diagnosis and monitoring of asthma. The peak flow meter measures airflow obstruction in the larger airways. With other diseases, such as emphysema, pathological changes occur predominantly in the smaller airways. Here the peak flow meter can give a significant under-representation of the severity of airflow obstruction.

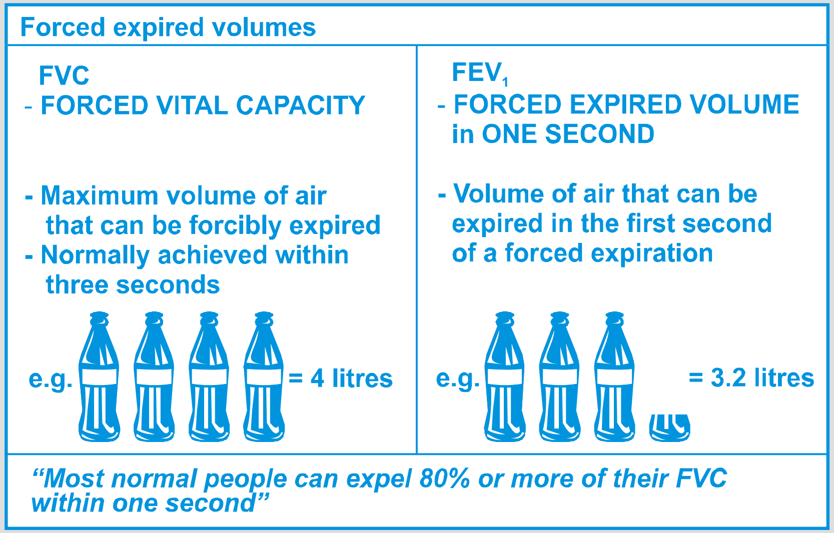
Therefore, one of the most useful instruments is the spirometer invented in 1846 by John Hutchinson, a surgeon. The simple test, called spirometry, measures air-flow in and out of the lungs. A person blows into a tube attached to the spirometer and a computerized sensor calculates and graphs the results. The results demonstrate an individual's air-flow rates and the volume of air that can be forced out of the lungs. This indicates whether or not there is airway obstruction or whether lung capacity is reduced. Spirometry test results are useful in making a diagnosis and grading the severity of various lung disorders. Even more important, yearly spirometric measurements help to detect lung disease at an early stage when lifestyle changes and treatment may help forestall future problems. Today, the spirometer must find its rightful place alongside the sphygmomanometer, the electrocardiograph (ECG), and the ophthalmoscope.

Contents

1. Common terms used in spirometry

FVC (forced vital capacity)
the maximum volume of air that can be forcibly expired.

FEV_1 (forced expired volume in one second)
the maximum amount of air that can be exhaled in the first second of expiration (measures how fast one can breathe out). Normally, FEV_1 = 70-80% of the FVC.



Ratio of FEV_1 /FVC as percent
the proportion of the total volume of air that can be expired in the first second of expiration.

$FEF_{25-75\%}$ (forced mid expiratory flow rate)
the average rate of airflow during the mid-portion of the forced vital capacity and is regarded as a more sensitive measure of small airways narrowing than FEV_1.

PEFR (peak expiratory flow rate)
the maximal expiratory flow rate achieved and this occurs very early in the forced expiratory manoeuvre.

2. How is spirometry done?

Test Preparation

1. Calibrate the equipment.
2. Enter the patient's name, height, age, weight and gender (these are essential for calculating prediction values for an individual), smoking history (past/present) or occupational exposures.
3. Select prediction equation or correction factor.
4. Make the patient comfortable, loosen clothing and remove loose dentures.
5. Patient can stand or sit but he/she must be in upright posture (in children standing position is recommended).
6. Explain to the patient what the test will analyze and the importance of his involvement for best results.

Test Technique

The patient breathes into the machine using a mouth piece and a noseclip on the nose. The technician instructs the patient on how the breathing manoeuvre is to be carried out.

The patient is asked to breathe normally a few times and then to take in a deep inspiration, as much as he can. Then, he is immediately instructed to blow out as hard and as fast as possible and keep breathing out till he can do so no more. Then, he is asked to breathe in again. (Box 1)

The spirometer calculates the forced vital capacity (FVC) and FEV_1 described earlier along with certain other measurements of how fast one is able to breathe out and displays the values along with the graphs. The FVC and FEV_1 values are the most important measurements.

At least three tests of acceptable effort (Box 2) are performed to ensure reproducibility of results. Select the best trial from the 2 reproducible trials (Box 3) for reporting.

Box 1: Following points to be kept in mind during the test procedure

- Mouth breathing
- Importance of use of diaphragm and respiratory muscles during the test
- Use of noseclip is optional but recommended for better results
- Hold mouthpiece with teeth and seal lips tightly around it
- After instruction, inhale maximally followed by rapid and forced maximum exhalation (approximately 6 seconds) and again rapid maximum inhalation
- Exhalation should be like candle blowing but prolonged

Notes:
- To get the best results encourage the patient by saying "keep blowing", "continue", "do not stop" , "you are doing nicely, keep it up" etc.
- Never discourage a patient or make him/ her feel that he/she cannot perform the test. If the patient cannot perform after repeated trial then ask him to practice and come later for the test. This usually works to get the most authentic results.

Box 2: Acceptable effort

1. Adequate inspiration before starting to expire
2. No hesitation or false start
3. No cough during the early part of forced exhalation
4. No early termination of exhalation*
5. No artifact due to tongue in the mouthpiece or artificial teeth falling in front of mouthpiece

*Exhalation time suggested by ATS is 6 seconds, unless there is no volume change for at least 1 second, or the subject cannot or should not continue to exhale further.
**No manoeuvres should be discarded solely because of early termination. The FEV_1 from such manoeuvres may be an estimate of true FVC, although the FEV_1 / FVC and mild expiratory flows (FEF 25-75% and FEF 50%) may be overestimated. This condition is usually seen in young children or subjects with functional breathlessness.

Box 3: Reproducible trials

Two largest and acceptable forced expiratory manoeuvres should not show a variability of

- more than 5% or 100 ml for FVC and FEV_1, whichever is higher
- more than 10% or 1 litre/sec. for PEF, whichever is lower

3. How to determine test acceptability?

Test acceptability is best determined by examining the two graphs displayed on the computer screen: the flow volume curve and the volume time curve.

A. What is a Flow Volume Curve?

Flow volume curve provides a graphic illustration of a patient's spirometric efforts. Flow is plotted against volume to display a continuous loop from inspiration to expiration. A normal flow volume loop has a rapid peak expiratory flow rate (termed as 'peak of the curve'). The expiratory flow rate then falls and the tracing moves downward to meet the volume axis. It is termed 'the slope of the curve' (Figure 1). The inspiratory portion of the loop is a deep curve plotted on the negative portion of the flow axis.

The overall shape of the flow volume loop is important in interpreting spirometric results. Variable effort can be detected by a flow volume loop that fails to demonstrate the normal early peak, showing that the patient failed to expire maximally when instructed to do so (Figure 2).

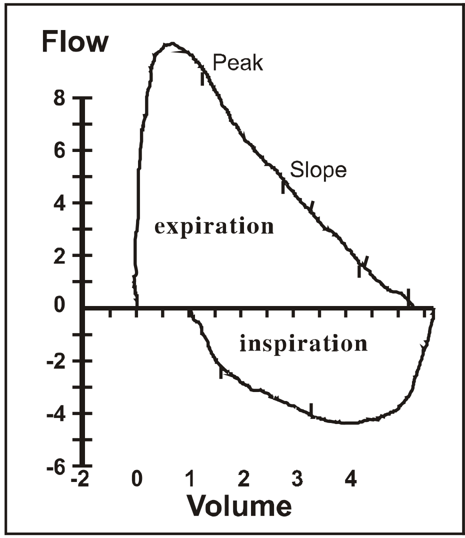


Fig. 1: Flow Volume Curve: Normal

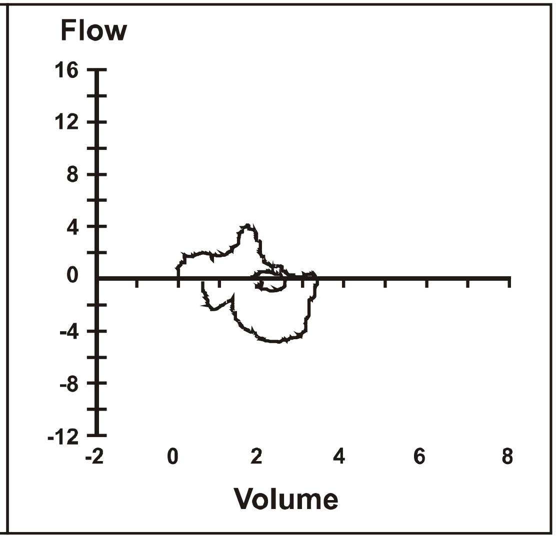


Fig. 2: Variable Effort

a) Abnormal patterns in peak

1) Blunt peak (Sand mound): Such appearance indicates inadequate effort and the test needs to be repeated (Figure 3).

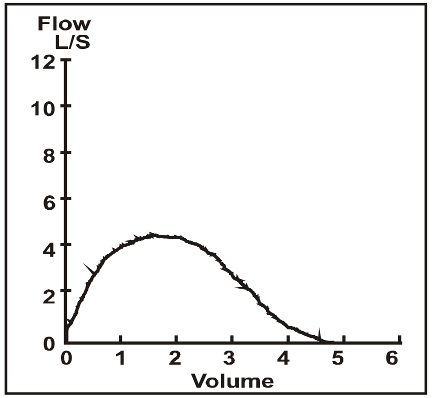


Fig. 3: Blunt peak Test should be repeated.

2) Notch: A notch in the initial part indicates a cough or hesitant start. After the initial flow, the first peak appears and then the glottis is closed, leading to the notch. Flow restarts making a second peak. The test should be repeated (Figure 4).

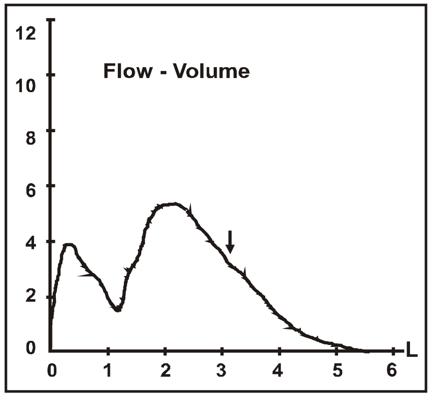


Fig. 4: Notch in initial part Test should be repeated.

3) Delayed peak: Sometimes, the curve starts from zero, but the peak is delayed. This pattern indicates defective start and the test should be repeated (Figure 5).

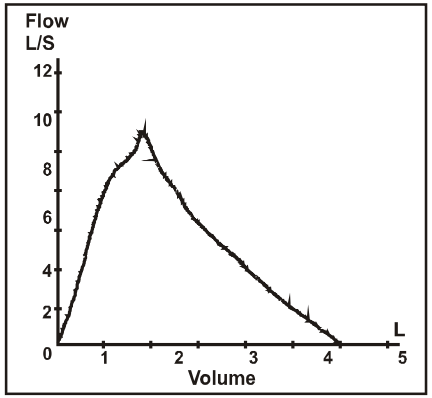


Fig. 5: Delayed peak Test should be repeated.

4) Flat peak: Reduced flow rate along with expiratory plateau indicates upper airway obstruction (Figure 6).

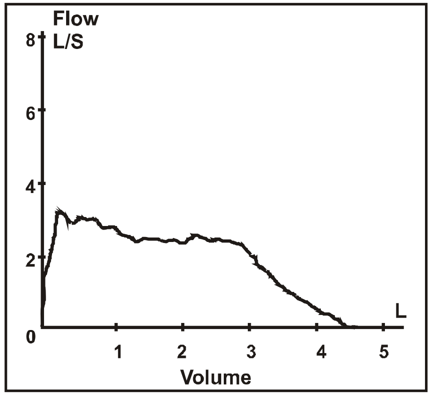


Fig. 6: Flat peak.

b) Abnormal patterns in slope

1) Steep curve: In restrictive lung diseases, such as interstitial lung diseases, the curve is steep and straight (Figure 7).

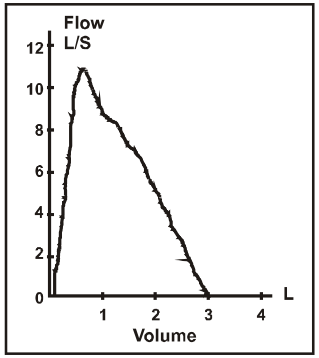


Fig. 7: Steep curve in restrictive disease

2) Rat's tail appearance: In airway obstruction, airflow starts with a sharp peak, but the flow rapidly declines due to airway collapse resulting in shift of upward concavity proximally and a subsequent long plateau. This appearance is described as 'rat's tail' appearance, and is characteristically present in airflow obstruction (Figure 8).

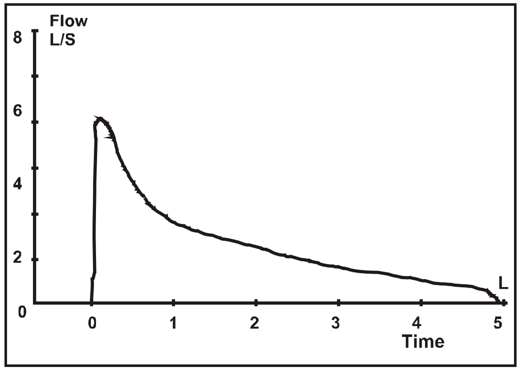


Fig. 8: Rat's tail slope

3) Notches on slope: Sometimes, the descending slope has undulations and these are because of cough Notches in the proximal part indicate a need for repetition of the test, since it can give a falsely reduced FEV_1. Coughing in the later part of the slope does not affect the results (Figure 9).

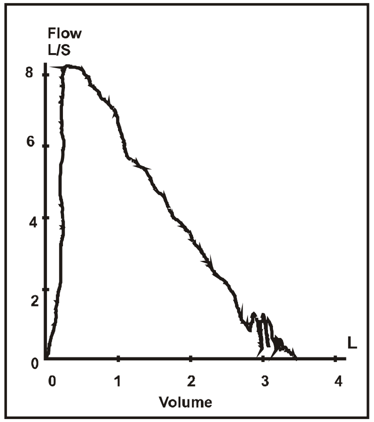


Fig. 9: Late notches due to cough in later part. Test is not required to be repeated.

4) Abrupt termination of the slope: Instead of a slow and smooth pattern, the tracings abruptly fall on the volume axis after the peak. During the test, this pattern appears when the patient stops expiration before complete exhalation. Therefore, the test should be repeated. In such situations, the spirometric parameters will show a typical restrictive defect with FEV_1/FVC ratio as high as 100 percent (Figure 10).

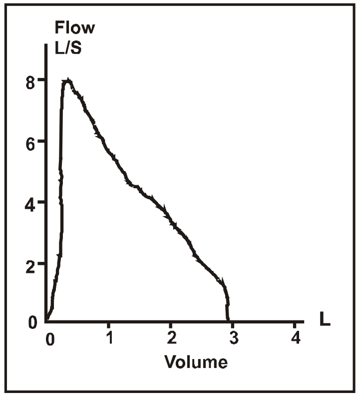


Fig. 10: Abrupt termination of the slope. Test should be repeated.

B) What is the Volume Time Curve?

The volume versus time curve is an alternative way of plotting spirometric results and is another useful illustration of patient performance. Below is an example of a volume-time curve. It shows the amount of air expired from the lungs as a function of time (B of Figure 11). The normal volume time curve has a rapid upslope and approaches a plateau soon after exhalation. The maximum volume attained represents the forced vital capacity (FVC), while the volume attained after one second represents the forced expiratory volume (FEV_1).

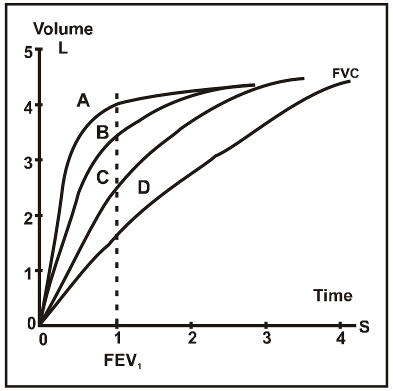


Fig. 11: Volume Time Curve

Abnormal patterns

1) Steep ascent: Restrictive defects. The duration of expiration is reduced. (A of Figure 11)

2) Shallow ascent: In airflow obstruction, instead of being steep, the slope is shallow due to a low flow rate. The duration of expiration is prolonged. (C and D of Figure 11)

3) Ledges on the slope: Because of coughing, the ascending slope shows small ledges. If these appear in the first second, the test should be repeated. Cough in the later part does not affect the results.

4. What is a normal test?

You are familiar with a "normal temperature" or a normal "blood sugar" value. However, in lung function testing, there is no single "normal" value. Each patient has an expected "normal" value that is called a "predicted" value. That means, a person of a particular ethnic origin, sex, age and height should have a particular vital capacity and FEV_1. This is read off from tables compiled after studying hundreds of normal persons. Thus, a native American man of 30 years and a height of 5 ft. 8 inches would have a "predicted" or expected vital capacity quite different from a native Indian man of 5 ft 6 inches.

The measurements made on a patient are called observed values. These are compared with the predicted values to see if there is any difference. As a rule of thumb, values for FVC and FEV_1 that are over 80% of predicted are defined as within the normal range. Of course, the comparison has to be made with predicted values applicable to the local population. The predicted values differ from country to country, from race to race and are different for males and females.

5. What is a "personal best"?

Predicted values are used as general guiding values. But there is always a range of what is considered as normal. For example, there is no single value as a normal height but only a range. Similarly, the predicted values have a range. A person's predicted vital capacity may range from 4 to 4.6 litres. A "personal best" is the value he has when there is no impairment and the disease is fully under control. The "personal best" may be the same as the predicted value or a little above or below it. It can be found out only after spirometry has been carried out repeatedly over several weeks after optimal treatment. For a particular patient, the "personal best" ultimately becomes the goal to be achieved with treatment.

6. How to read a spirometry report?

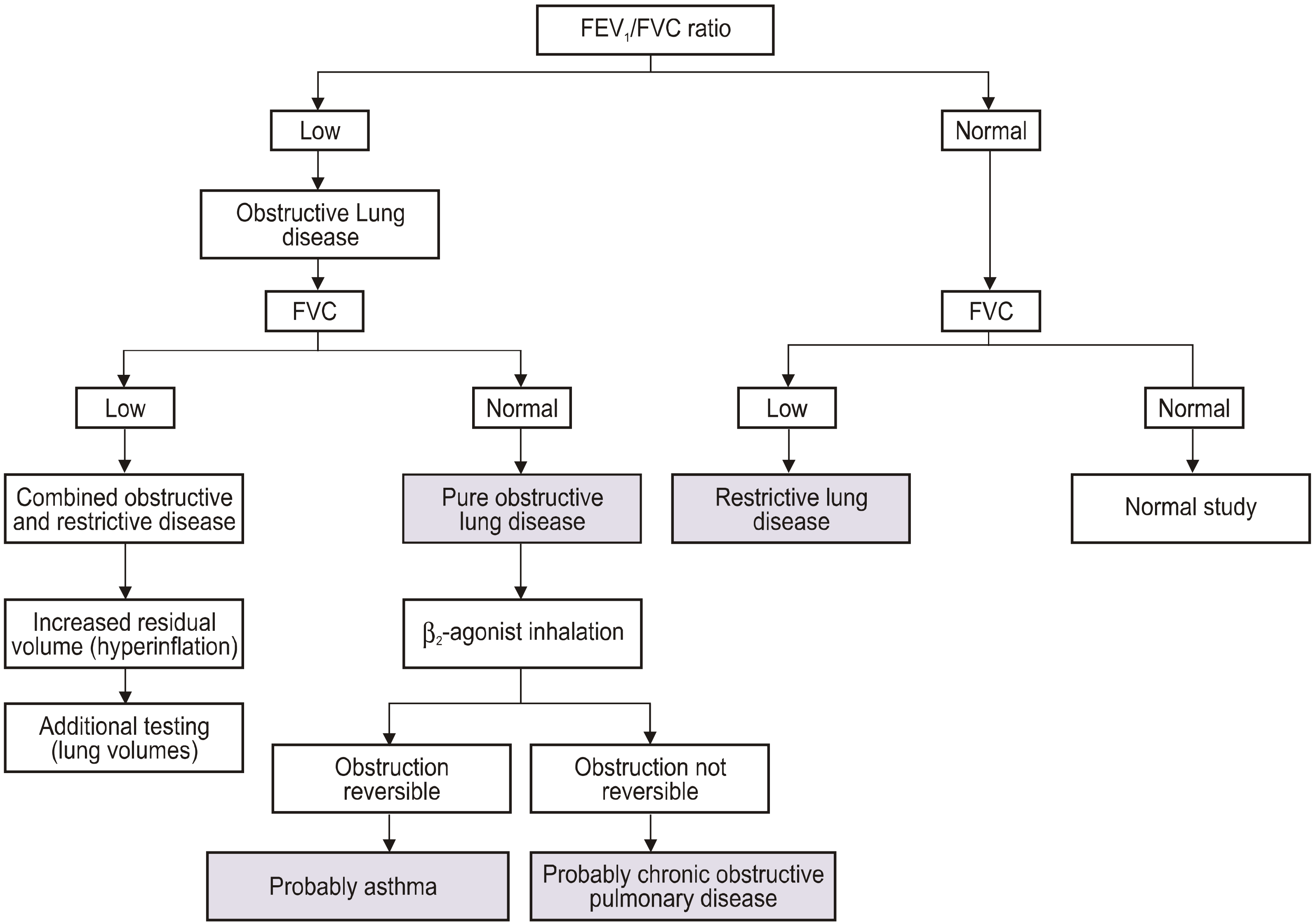
Spirometry can be useful in differentiating between obstructive and restrictive lung disorders (Box 4). In obstructive lung disorders the forced expiratory volume in 1 second (FEV_1) is usually decreased, the forced vital capacity (FVC) is usually normal and the ratio FEV_1 / FVC is decreased. In restrictive disorders the FEV_1 and FVC are both decreased, leaving a normal FEV_1 / FVC.

Box 4 : The two main types of lung didease-obstructive and restrictive

In obstructive lung conditions, the airways are narrowed, usually causing an increase in the time it takes to empty the lungs. Obstructive lung disease can be caused by conditions such as bronchitis, infection (which produces inflammation), and asthma.

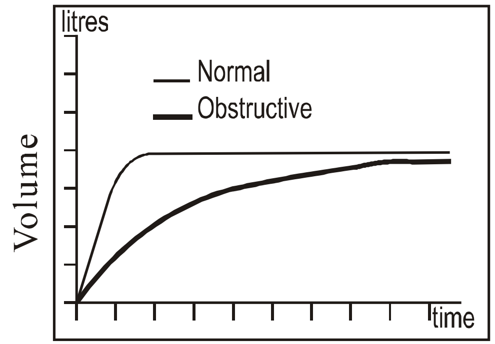
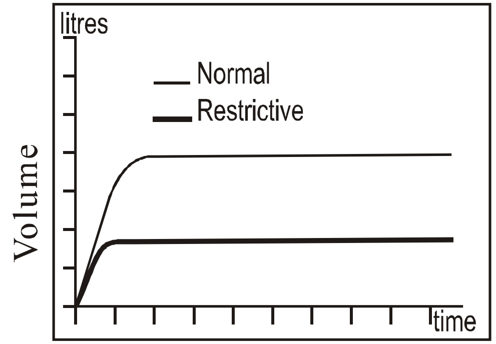
In restrictive lung conditions, there is a loss of lung tissue, a decrease in the lung's ability to expand, or a decrease in the lung's ability to transfer oxygen to the blood (or carbon dioxide out of the blood). In these conditions, the total lung volume and the transfer of oxygen from air to blood may be reduced. Restrictive lung disease can be caused by conditions such as pneumonia, lung cancer, scleroderma and multiple sclerosis. Other restrictive conditions include some chest injuries, being very overweight (obesity), pregnancy and loss of lung tissue due to surgery.

Interpretation of spirometry



7. How to classify the severity of lung abnormality?

Normally, the FVC, FEV_1, FEV_1 / FVC is > 80% (interpreted as "within normal limits") of predicted.

Abnormality/Severity	Percent variation of predicted	
1) Obstructive abnormality	FEV_1 / FVC < 75% of predicted FEV_1 < 80% of predicted	
Mild	≥ 60% and < 80% of predicted	
Moderate	≥ 40% and < 60% of predicted	
Severe	< 40% of predicted	
2) Restrictive abnormality	FVC < 80% of predicted	
Mild	≥ 60% and < 80% of predicted	
Moderate	≥ 40% and < 60% of predicted	
Severe	< 40% of predicted	

8. What are the clinical uses of spirometry?

1. Detect the presence of lung disorders suggested by history or physical signs and symptoms (smoking history, family history of lung disease, cough, breathlessness, wheezing) and / or the presence of other abnormal diagnostic tests (e.g. Chest X-ray, Arterial Blood Gases).

2. Assess the severity and reversibility of airflow obstruction in obstructive lung disease.

3. Assess the change in lung function over time or following the administration of; or change of therapy.

4. Detect subclinical abnormalities in high risk patients (e.g. smokers, occupational exposures, chest wall deformity, etc.).

5. To assess the risk of post-operative complications in high-risk patients who are about to undergo a thoracic or upper abdominal surgery.

9. What is the role of spirometry in asthma?

Spirometry is generally carried out-

- at the time of initial diagnosis of asthma.
- after treatment is initiated and symptoms have stabilized to document attainment of near "normal" airway function.
- at least every 1 to 2 years to assess the maintenance of airway function.

Spirometry measurements are usually done before and after administration of a β_2-agonist. Reversibility with the use of a bronchodilator is defined as an increase in FEV_1 of 12% and 200 ml. (Box 5). Patients with severe asthma may sometimes need a short course of oral steroid therapy before they demonstrate reversibility.

Box 5 : Bronchodilator reversibility test

Step-wise method:

- Determine the baseline FEV_1 using spirometry.
- Two puffs of salbutamol (200 mcg) are administered via a metered dose inhaler and spacer.
- Wait for 15 minutes.
- Spirometry is repeated to determine FEV_1. A positive reversibility test shows an increase in FEV_1 by more than 12 percent and at least by more than 200 ml in comparison to baseline values.

$$\text{Bronchodilator reversibility} = \frac{\text{FEV}_1 \text{ in ml (Post-bronchodilator)} - \text{FEV}_1 \text{ in ml (Pre-bronchodilator)} \times 100}{\text{FEV}_1 \text{ in ml (Pre-bronchodilator)}}$$

Borderline 'normal' values should be interpreted with caution and should be used along with clinical information to decide whether the report is normal or abnormal.

Important Notes :

- This test shows no or partial reversibility in a majority of patients with chronic obstructive pulmonary disease (COPD).
- False negative test may be obtained if the patient has taken bronchodilators in the preceding hours. Therefore, the patients should not take short-acting bronchodilators in the preceding 6 hours and long-acting bronchodilators in the preceding 12 hours of the reversibility test.
- Consumption of cola drinks, tea, coffee & smoking in the hours before and during the investigations should not be permitted.

10. What is the role of spirometry in COPD?

Smokers, bio-fuel users and people exposed to air pollution are at higher risk of developing COPD. Since COPD is a progressive and potentially fatal disease, early detection and treatment is very important. The early symptoms of a patient are cough and sputum formation. Unfortunately, most smokers take these as a normal phenomenon of 'smoker's cough' and do not seek medical consultation. Usually a smoker consults a doctor only when he starts having dyspnea, which is a late symptom of COPD.

Clinical examination is not sensitive and skiagram of chest does not help in early detection of COPD. The best indicator of the onset of COPD is a spirometric test. Demonstration of airflow obstruction in smokers and obstructive and/or restrictive pattern in biofuel users indicates the onset of lung disease. Ideally, the spirometric test should be carried out on every smoker and should be repeated annually in patients with abnormal reports, and every three years in patients with normal reports. Progressive reduction in FEV_1 is the earliest indication of COPD in smokers.

Spirometry-assisted counselling is an excellent tool for encouraging patients to stop smoking with the quit rate as high as 40%.

11. What are the contraindications of spirometry?

Contraindications for spirometry test:

1. Hemoptysis of unknown origin
2. Pneumothorax
3. Unstable cardiovascular status or recent myocardial infraction or pulmonary embloism
4. Thoracic, abdominal or cerebral aneurysm
5. Recent surgery of eye, thorax or abdomen
6. Acute severe asthma

12. What are the complications of spirometry?

Complications during spirometry test:

1. Syncope, dizziness, light headedness
2. Chest pain, muscle cramps
3. Paroxysmal coughing
4. Bronchospasm
5. Oxygen desaturation due to interruption of oxygen therapy

13. What are the factors to consider when choosing a spirometer?

A spirometer must:

- be simple to use
- be safe and effective
- be capable of simple routine calibration checking and have stable calibration which allows adjustments by the operator
- be robust and reliable, with low maintenance requirements and minimum of 5 to 7 years' design life
- provide graphic display of the manoeuvre
- utilise a sensor which is disposable or can be cleaned and disinfected
- be purchased from a reputable supplier who can provide training and servicing/repair
- be provided with a comprehensive manual describing its operation, routine maintenance and calibration
- use relevant normal predicted values
- be reasonably priced

14. Care of a spirometer

Generally, all equipment, if kept with proper care, can function efficiently and effectively for longer periods .

- The spirometers directly fitted to the regular electricity supply should be ensured a supply with minimal voltage fluctuations.
- The spirometer should be cleaned and should be kept in a dust-free atmosphere.
- Water, tea and edibles should not be kept over the spirometer because spilling can spoil the software.
- Proper cleaning of mouthpiece and tubing should be carried out.
- Use disposable cardboard mouthpieces to avoid chances of cross-infection.
- Regular calibration should be carried out to get accurate readings.

15. Sample spirograms

The sample spirograms shown are from actual individuals and represent a few illustrations of acceptable and unacceptable manoeuvres. It is imperative that the technician administering the test be capable of recognizing these anomalies and take appropriate correction action.

Figures A1a and A1b are volume-time and corresponding flow-volume samples that are acceptable spirograms.

Figures A2a and A2b illustrate an unacceptable spirogram due to a cough during the first second of exhalation. Notice that the cough, which occurs at approximately 3.0 to 3.5 L, is very apparent in the flow-volume curve but is more difficult to detect in the volume-time curve.

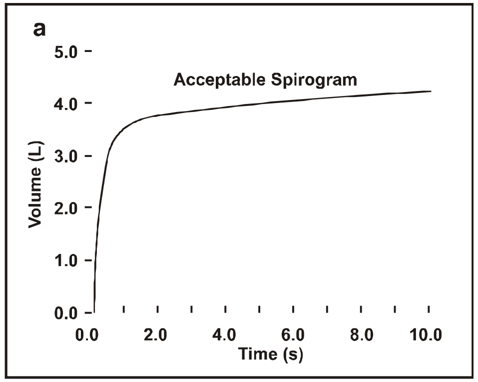


Figure A1a: Acceptable volume-time spirogram

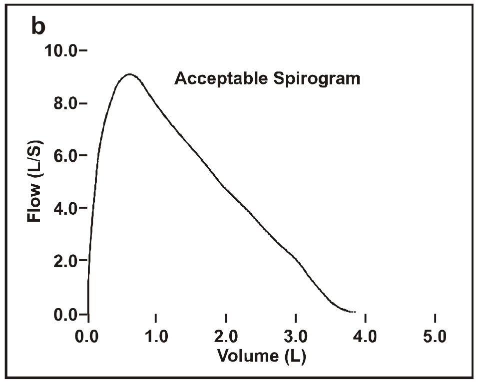


Figure A1b: Acceptable flow-volume spirogram

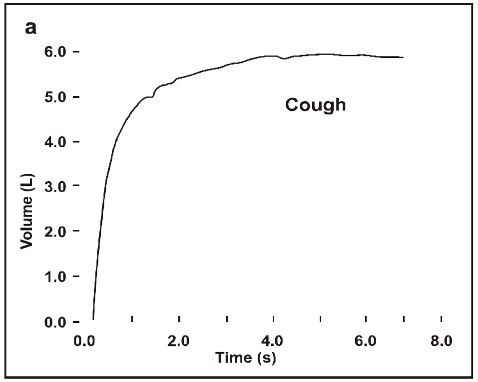


Figure A2a: Volume-time spirogram with a cough during the first second of exhalation

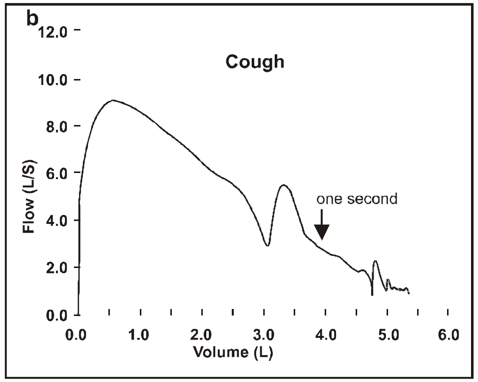


Figure A2b: Flow-volume spirogram with a cough during the first second of exhalation

Figures A3a and A3b illustrate an unacceptable spirogram due to a variable effort or cough during the first second of exhalation and early termination of the manoeuvre. The anomaly observed at 1 L of exhalation is apparent on both the volume-time and flow-volume curves.

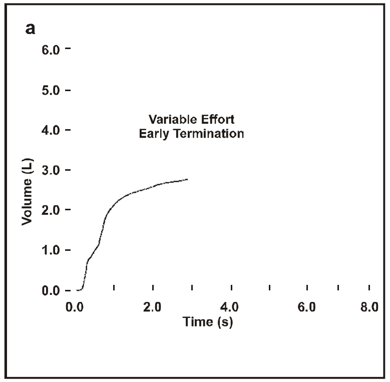


Figure A3a: Unacceptable volume-time spirogram due to variable effort and early termination

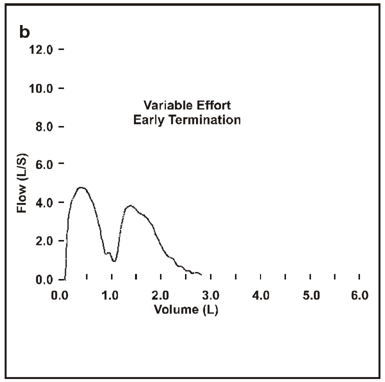


Figure A3b: Unacceptable flow-volume spirogram due to variable effort and early termination

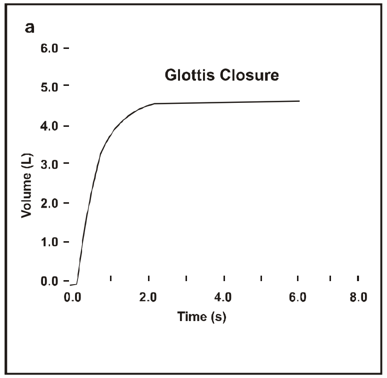


Figure A4a: Unacceptable volume-time spirogram due to possible glottis closure

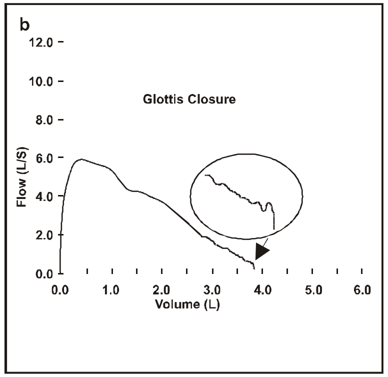


Figure A4b: Unacceptable flow-volume spirogram due to possible glottis closure

Figures A4a and A4b illustrate unacceptable sample spirograms due to an abrupt termination of flow at the end of the manoeuvre, possibly the result of the individual closing his/her glottis.

In addition to requiring three acceptable manoeuvres, the reproducibility criteria for FVC and FEV_1 should be met as a goal during test performance. Figure A5a illustrates the volume-time curve and Figure A5b the corresponding flow-volume curve for a 22-year-old healthy female. In these figures, the subject did not meet the minimum reproducibility criteria for both the FVC and FEV_1 despite performing three acceptable manoeuvres.

The most likely cause of this pattern (non-reproducible tracings but good initial effort) is a failure to achieve a maximal inhalation before performing the FVC manoeuvre.

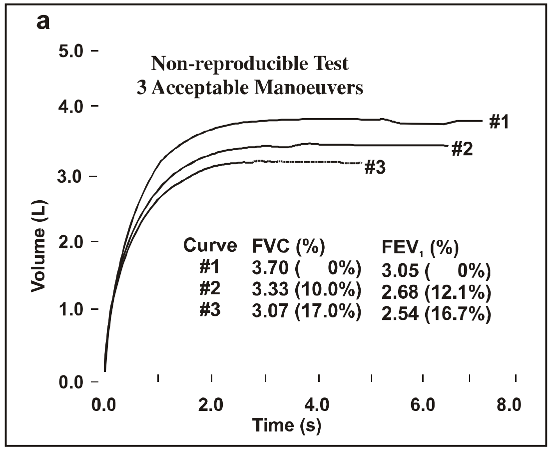


Figure A5a: Non-reproducible test with three acceptable volume-time curves. Percents are difference from largest value

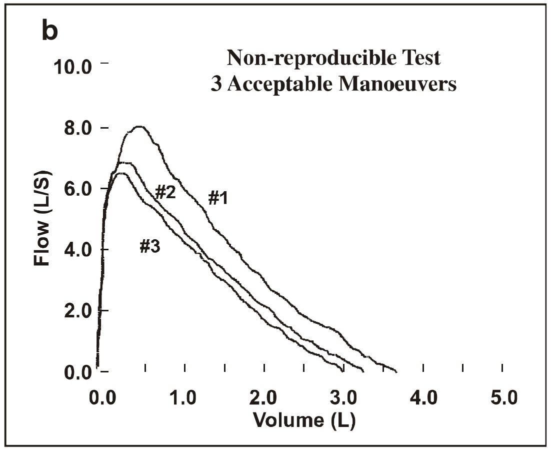


Figure A5b: Non-reproducible test with three acceptable flow-volume curves

Figures A6a and A6b illustrate a reproducible test with three acceptable manoeuvres.

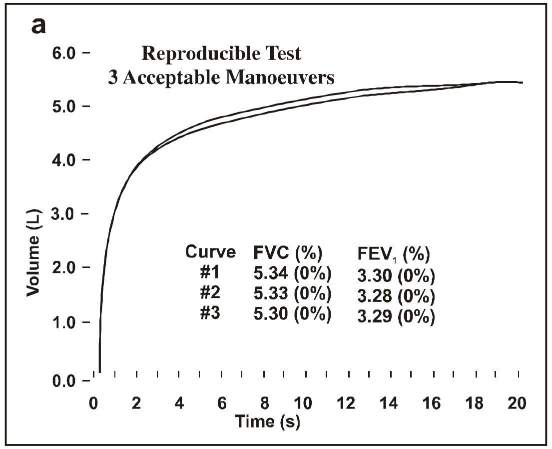


Figure A6a: Reproducible test with three acceptable volume-time curves. Percents are difference from largest value

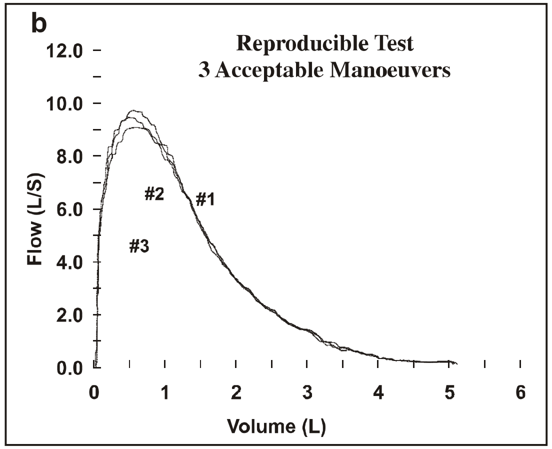


Figure A6b: Reproducible test with three acceptable flow-volume curves

References
1. American Thoracic Society. 1995. Standardization of Spirometry. Am Rev Respir Dis. 152:1107-1136.
2. Measurement of Ventilatory Function. In: Pierce R and Johns D editors. Spirometry - The measurement and interpretation of ventilatory function in clinical practice. 1995:6-7.
3. Interpretation of Spirometry. In: Virendra Singh editor. Pulmonary Function Testing for Clinicians. 1999:10-40.
4. British Thoracic Society Guidelines. Thorax, Dec 1997; 52:Suppl 5