Pulmonary Function Tests in Clinical Practice

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Preface

The volume of expelled air is believed to have been first measured by Galen in about 150 AD. However, it was not until the mid-1800s that Hutchinson designed a spirometer, very similar to the ones used today, which allowed routine measurement of exhaled lung volume. Finally, in 1969 Dubois designed the plethysmograph, which allowed a measure of the complete lung volume, which included the residual volume. Nowadays measuring spirometry has become routine with the advent of the pneumotachograph and computers. Although the technology is widely available and not excessive in cost, spirometry or the measurement of exhaled gas volume is still underutilized. To detect disease and assess its severity lung volume measures are extremely useful, indeed one might say mandatory, so the reason for this underutilization remains obscure. We hope that this book, which is aimed at the clinician, helps to explain the basics of lung volume measurement and hence increases its utility. The text also includes an overview of exercise and respiratory sleep diagnostic tests for the clinician.

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Contents

Chapter 1
Spirometry

Spirometry is the most essential part of any pulmonary function study and provides the most information. In spirometry, a machine called a spirometer is used to measure certain lung volumes, called dynamic lung volumes. The two most important dynamic lung volumes measured are the forced vital capacity (FVC) and the forced expiratory volume in the 1st second (FEV_1). This section deals with the definitions of these and other terms.

DEFINITIONS[1, 2]

Forced Vital Capacity

- Is the volume of air in liters that can be forcefully and maximally exhaled after a maximal inspiration. FVC is unique and reproducible for a given subject.
- The *slow vital capacity (SVC)* – also called the *vital capacity (VC)* – is similar to the FVC, but the exhalation is slow rather than being as rapid as possible as in the FVC. In a normal subject, the SVC usually equals the FVC,[3] while in patients with an obstructive lung disorder (see Table 1.1 for definition), the SVC is usually larger than the FVC. The reason for this is that, in obstructive lung disorders, the airways tend to collapse and close prematurely because of the increased positive intrathoracic pressure during a forceful expiration. This increased pressure leads to air trapping. Accordingly, a significantly higher SVC compared with FVC suggests air-trapping; Figure 1.1.
- The *inspiratory vital capacity (IVC)* is the VC measured during inspiration rather than expiration. The IVC should equal the expiratory VC. If it does not, poor effort or an air leak could be

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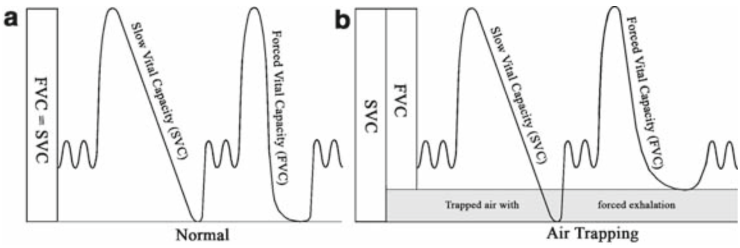


FIGURE 1.1. FVC and SVC are compared with each other in a normal subject (**a**) and in a patient with an obstructive disorder (**b**). In case of airway obstruction, SVC is larger than FVC, indicating air trapping.

responsible. IVC may be larger than the expiratory VC in patients with significant airway obstruction, as in this case the increased negative intrathoracic pressure opens the airways facilitating inspiration, as opposed to the narrowing of airways during exhalation as the intrathoracic pressure becomes positive.[4, 5] Narrowed airways reduce airflow and hence the amount of exhaled air.

Forced Expiratory Volume in the 1st Second

- Is the volume of air in liters that can be forcefully and maximally exhaled in the 1st second after a maximal inspiration. In other words, it is the volume of air that is exhaled in the 1st second of the FVC, and it normally represents ~80% of the FVC.
- FEV_6 is similarly defined as the volume of air exhaled in the first 6 s of the FVC and its only significance is that it can sometimes substitute the FVC in patients who fail to exhale completely.[6]

FEV_1/FVC Ratio

- This ratio is used to differentiate obstructive from restrictive lung disorders; see Table 1.1 for definitions. In obstructive disorders, FEV_1 drops much more significantly than FVC and the ratio will be low, while in restrictive disorders, the ratio is either normal or even increased as the drop in FVC is either proportional to or more marked than the drop in FEV_1.
- Normally, the FEV_1/FVC ratio is greater than 0.7, but it decreases (to values <0.7) with normal aging.[7] In children, however, it is higher and can reach as high as 0.9.[8] The changes in the elderly probably reflect the decrease in elastic recoil of the lungs that occurs with aging.

TABLE 1.1. Definitions of obstructive and restrictive disorders

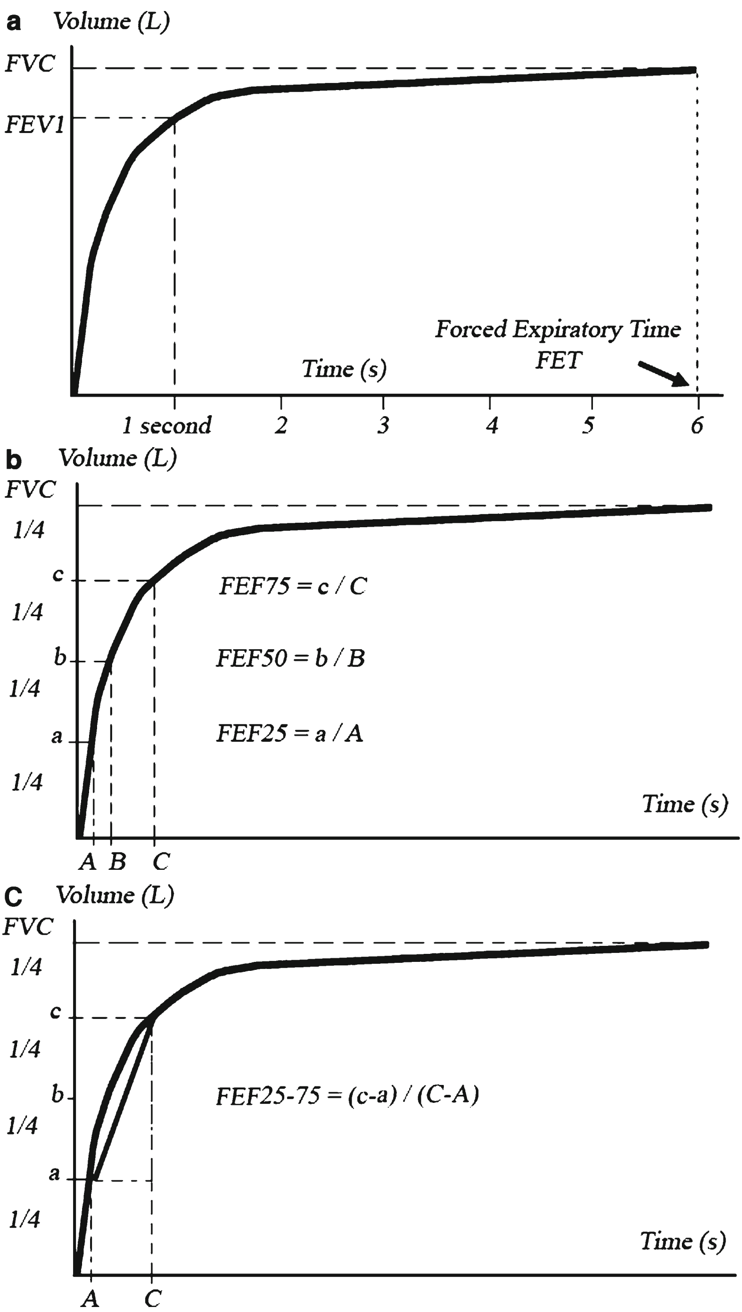
Obstructive disorders
Are characterized by diffuse airway narrowing secondary to different mechanisms [immune related, e.g., bronchial asthma, or environmental, e.g., chronic obstructive pulmonary disease (COPD)]
Restrictive disorders
Are a group of disorders characterized by abnormal reduction of the lung volumes, either because of alteration in the lung parenchyma or because of a disease of the pleura, chest wall or due to muscle weakness

The Instantaneous Forced Expiratory Flow (FEF_{25}, FEF_{50}, FEF_{75}) and the Maximum Mid-Expiratory Flow (MMEF or FEF_{25-75})

- The instantaneous forced expiratory flow (FEF) represents the flow of the exhaled air measured (in liters per second) at different points of the FVC, namely at 25, 50, and 75% of the FVC. They are abbreviated as FEF_{25}, FEF_{50}, and FEF_{75}, respectively; Figure 1.2b. The maximum mid-expiratory flow (MMEF) or FEF_{25-75}, however, is the average flow during the middle half of the FVC (25–75% of FVC); see Figure 1.2c. These variables represent the effort-independent part of the FVC.[9] Collectively, they are considered more sensitive (but non-specific) in detecting early airway obstruction, which tends to take place at lower lung volumes.[10,11] Their usefulness is limited, however, because of the wide range of normal values.[10]

Peak Expiratory Flow

- Is the maximum flow (in liters per second) of air during a forceful exhalation. Normally, it takes place immediately after the start of the exhalation and it is effort-dependent. PEF drops with a poor initial effort and in obstructive and, to a lesser extent, restrictive disorders. PEF measured in the laboratory is similar to the peak expiratory flow (PEF) rate (in liters per minute) that is measured routinely at the bedside to monitor asthmatic patients.


a
Volume (L)
FVC
FEV1
Forced Expiratory Time
FET
Time (s)
1 second
2
3
4
5
6
b
Volume (L)
FVC
1/4
c
1/4
b
1/4
a
1/4
FEF75 = c / C
FEF50 = b / B
FEF25 = a / A
Time (s)
A
B
C
C
Volume (L)
FVC
1/4
c
1/4
b
1/4
a
1/4
FEF25-75 = (c-a) / (C-A)
Time (s)
A
C

SPIROMETRIC CURVES

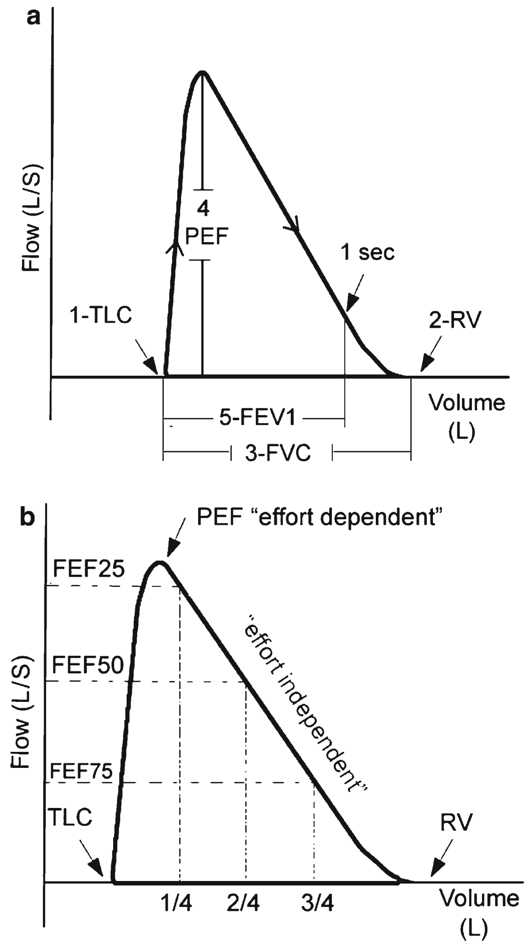
The Volume–Time Curve (The Spirogram)

- Is simply the FVC plotted as volume in liters against time in seconds; Figure 1.2a.
- You can extract from this curve both the FVC and FEV_1. FEV_1/FVC ratio can be estimated by looking at where the FEV_1 stands in relation to the FVC in the volume axis; Figure 1.2a. In addition, the curve's shape helps in determining that ratio: a decreased ratio will necessarily make the curve look flatter and less steep than normal; see Figure 1.16. The FEFs (FEF_{25}, FEF_{50}, FEF_{75}) and MMEF (FEF_{25-75}) can also be roughly estimated from the curve as shown in Figure 1.2b, c.
- This curve also provides an idea about the quality of the spirometry, as it shows the duration of the exhalation [the forced expiratory time (FET)], which needs to be at least 6 s for the study to be clinically reliable. Quality control will be explained in more detail later in this chapter.
- If a postbronchodilator study is done, as in case of suspected bronchial asthma, then there will be two discrete curves. One curve will represent the initial (prebronchodilator) study whereas the second will represent the postbronchodilator study. Looking at how the two curves compare to each other gives an idea about the degree of the response to bronchodilator therapy, if any; Figure 1.16.

FIGURE 1.2. The volume–time curve (spirogram). The following data can be acquired: (**a**) FVC is the highest point in the curve; FEV_1 is plotted in the volume axis opposite to the point in the curve corresponding to 1 s; duration of the study (the forced expiratory time or FET) can be determined from the time axis, 6 s in this curve. (**b**) $FEF_{25,50,75}$ can be roughly determined by dividing the volume axis into four quarters and determining the corresponding time for each quarter from the time axis. Dividing the volumes (a, b, and c) by the corresponding time (A, B, and C) gives the value of each FEF (FEF_{25}, FEF_{50}, FEF_{75}, respectively). Note that this method represents a rough determination of FEFs, as FEFs are actually measured instantaneously by the spirometer and not calculated. (**c**) FEF_{25-75} can be roughly determined by dividing the volume during the middle half of the FVC (c–a) by the corresponding time (C–A). FEF_{25-75} represents the slope of the curve at those two points.

The Expiratory Flow–Volume Curve (FV Curve)

- Is determined by plotting FVC as flow (in liters per second) against volume (in liters); Figure 1.3.* This curve is more informative and easier to interpret, as different diseases produce distinct curve shapes.



*The flow can be measured directly by a pneumotachograph. The volume is obtained by integration of the flow signal. Alternatively, a volume sensing device (spirometer) measures volume and the flow is derived by differentiating the volume signal. Either method allows expression of the flow–volume curve.

- The curve starts at full inspiration (at the *total lung capacity or TLC*: the total amount of air in the lungs at maximal inhalation; Figure 1.3a) with 0 flow (just before the patient starts exhaling), then the flow or speed of the exhaled air increases exponentially and rapidly reaches its maximum, which is the PEF. The curve then starts sloping down in an almost linear way until just before reaching the volume axis when it curves less steeply giving a small upward concavity. The curve then ends in that way at the *residual volume or RV* (the amount of air that remains in the lungs after a maximal exhalation) by touching the volume axis, i.e., a flow of 0 (or within 0.1 L/s)[8] when no more air can be exhaled; Figure 1.3a.
- As you notice, there is no time axis in this curve, and the only way to determine the FEV_1 is by the reading device making a 1st second mark on the curve, which is normally located at ~ 80% of the FVC. See Figure 1.3a.
- Other data can be extracted from this curve including $FEF_{25, 50, 75}$ as shown in Figure 1.3b. $FEF_{25–75}$ cannot be determined from this curve.
- In summary, every part of the curve represents something; Figure 1.3:
  – The leftmost end of the curve represents TLC.
  – The curve's rightmost end represents RV.
  – Its width represents FVC.
  – Its height represents PEF.
  – The distance from TLC to the 1-s mark represents FEV_1.
  – The descending slope reflects the FEFs.
- Remember that we cannot measure RV and hence TLC with spirometry alone, because we cannot measure the air remaining in the lung after a full exhalation with this method. Methods that can measure RV are discussed in the next chapter.
- The morphology of the curve is as important as the other values. It provides information about the quality of the study as well as being able to recognize certain disease states from its shape. These will be explained in detail later in this chapter.

FIGURE 1.3. (**a**) The flow–volume curve: the following data can be extracted: (1) TLC is represented by the leftmost end of the curve (cannot be measured by spirometry); (2) RV is represented by the rightmost end of the curve (cannot be measured by spirometry); (3) FVC is represented by the width of the curve; (4) PEF is represented by the height of the curve; (5) FEV_1 is the distance from TLC to the 1st second mark. (**b**) The flow–volume curve demonstrating the effort-dependent and the effort-independent parts. Instantaneous FEFs are directly determined from the curve by dividing the FVC into four quarters and getting the corresponding flow for the first, second, and third quarters representing $FEF_{25,50,75}$, respectively as shown. The FEFs represent the slope of the FV curve.

- Two curves are often shown in different colors (blue and red) to depict pre- and postbronchodilator studies, respectively, if a postbronchodilator study was done; Figure 1.15b.

The Maximal Flow–Volume Loop

- Combining the expiratory flow–volume curve, discussed earlier, with the inspiratory curve (that measures the IVC) produces the maximal flow–volume loop, with the expiratory curve forming the upper and the inspiratory curve forming the lower parts of that loop; see Figure 1.4.
- This loop is even more informative than the expiratory flow–volume curve alone, as it also provides information about the inspiratory portion of the breathing cycle. For example, extrathoracic upper airway obstruction, which occurs during inspiration, can now be detected.
- This loop commonly includes a tidal flow–volume loop too, shown in the center of the maximal flow–volume loop as a small circle; Figure 1.4. This loop represents quiet breathing. Additional useful data can be acquired from this tidal loop when compared with the maximal flow–volume loop. These useful data include the *expiratory reserve volume (ERV)* and the *inspiratory capacity (IC)*; Figure 1.4b – see next chapter for definitions. The values of ERV and IC estimated from this curve might be slightly different from the lung volume study measurements, where the SVC is measured instead of the FVC as these (FVC and SVC) can be different in some disorders such as obstructive disorders, as was discussed earlier. More details about these measurements will be discussed in the following chapter.

TECHNIQUE OF SPIROMETRY[1]

- The spirometer – the machine used to record spirometry – has to be calibrated every morning to ensure that it records accurate values before it is used. The temperature and barometric pressure are entered into the spirometer every morning, as variation in these measures does affect the final results[†].[12–14]
- The patient must be clinically stable, should sit straight, with head erect, nose clip in place, and holding the mouthpiece tightly between the lips. Initially, he or she should breathe in and

[†]As air in the lungs is at BTPS (body temperature pressure standard) but collected at ATPS (ambient temperature pressure standard), a correction factor has to be applied to obtain the BTPS volumes as these are the reported volumes.

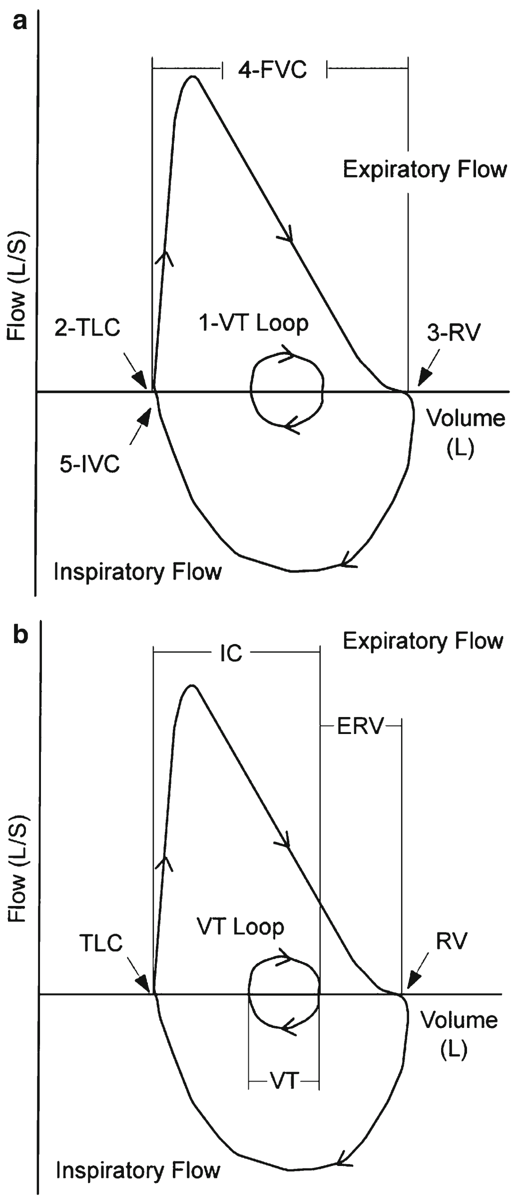


FIGURE 1.4. (**a**) Represents the steps in data measurement during spirometry. (**b**) Demonstrates the ERV and IC in relation to the tidal flow–volume loop (V_T stands for tidal volume).

out at the tidal volume (V_T: normal quiet breathing) to record the tidal flow–volume loop; Figure 1.4a, No. 1. Then, when the patient is ready, the technician instructs him/her to inhale maximally to TLC (Figure 1.4a, No. 2), and then exhale as fast and as completely as possible to record the FVC (Figure 1.4a, No. 4). The point at which no more air can be exhaled is the RV (Figure 1.4a, No. 3). The patient is then instructed to inhale fully to TLC again in order to record the IVC (Figure 1.4a, No. 5). This test is then repeated to ensure reproducibility in order to meet quality control criteria (American Thoracic Society or ATS criteria); see next section.
- If a bronchodilator study is needed, then the test is repeated in the same way 10 min after giving the patient a short-acting β_2 agonist (usually 2–4 puffs of salbutamol through a spacer chamber). The ATS criteria should be met in the postbronchodilator study too.
- The spirometer will produce the volume as absolute numbers and as curves.
- The technician should make a note to the interpreting doctor of any technical difficulty that may have influenced the quality of the study. Technician's comments are important as are the ATS criteria in the final report.

THE ATS GUIDELINES[1,2]

The ATS criteria are easy to remember. They include both acceptability and reproducibility criteria. This means that each individual study should meet certain criteria to be accepted, and the accepted studies should not vary more than predefined limits to ensure reproducibility. If either of the criteria are not met, then the study is rejected as it may give a false impression of either normal or abnormal lung function. Of course, bedside tests or field testing, e.g., in the emergency department, do not, in many instances, meet the ATS criteria that are required for measures in an accredited laboratory.

Acceptability[1,2]

The ATS mandates three acceptable maneuvers. The number of trials that can be performed on an individual should not exceed 8. An acceptable trial should have a good start, a good end, and absence of artifacts.

1. Good start of the test:
   - If the study needs back extrapolation, the extrapolation volume should not exceed 5% of FVC or 150 ml, whichever is larger. See Figure 1.5.[1,2,15–19]

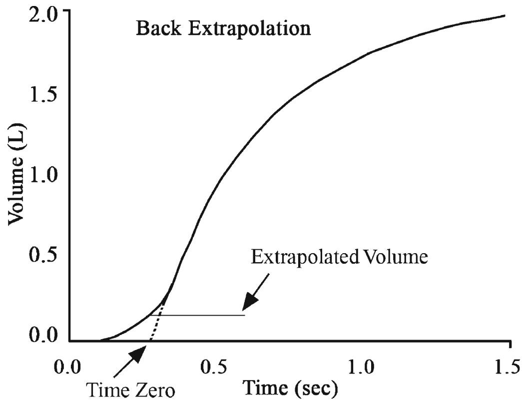


FIGURE 1.5. Extrapolation volume of 150 ml or 5% of FVC (whichever is larger) (with permission from American Thoracic Society[2]).

Note: Back extrapolation applies to the VT curve and means that if the start of the test is not optimal, correction can be made by shifting the time axis forward, provided that the extrapolation volume is within either one of the limits mentioned earlier. To simplify this, consider that a patient's FVC is 2 L and the study requires a back extrapolation correction, and 5% of the FVC (2 L) is 100 ml. Because 150 ml is larger than 5% of the patient's FVC (100 ml), 150 ml should be used as the upper limit of extrapolated volume. Then, if the measured extrapolated volume is greater than 150 ml, the result cannot be accepted.

Note: A good start of the study can be identified qualitatively on the FV curve as a rapid rise of flow to PEF from the baseline (0 point), with the PEF being sharp and rounded. The FEV_1 can be over- or underestimated with submaximal effort, which may mimic lung disorders such as those due to airway obstruction or lung restriction; see later.[2,20]

2. Smooth flow–volume (FV) curve, free of artifacts[1,2]:

These artifacts will show in both volume–time (VT) and FV curves but will be more pronounced in the FV curve. These artifacts include the following:

(a) *Cough during the 1st second of exhalation* may significantly affect FEV_1. The FV curve is sensitive in detecting this artifact; Figure 1.6. Coughing after the 1st second is less likely to make a significant difference in the FVC and so it is accepted provided that it does not distort the shape of the FV curve (judged by the technician).[1]

(b) Variable effort; Figure 1.7.
(c) Glottis closure; Figure 1.8.
(d) Early termination of effort.

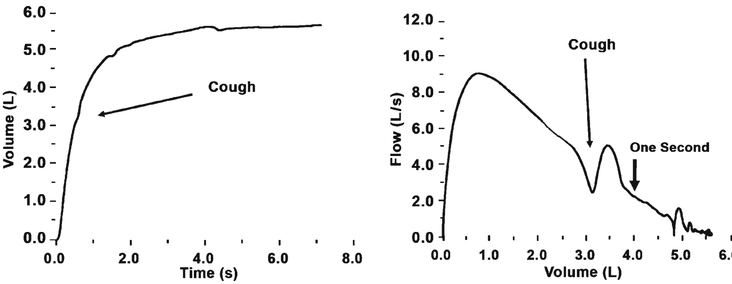


FIGURE 1.6. Cough in the 1st second. It is much clearer in the FV curve than in the VT curve as indicated by the *arrows* (with permission from American Thoracic Society[2]).

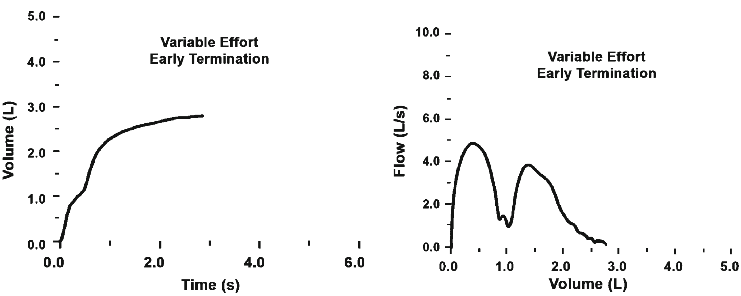


FIGURE 1.7. Variable effort: any study with a variable effort is rejected (with permission from American Thoracic Society[2]).

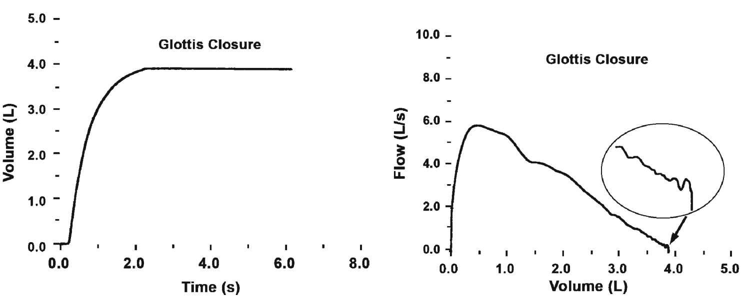


FIGURE 1.8. Glottis closure (with permission from American Thoracic Society[2]).

(e) Obstructed mouthpiece, by applying the tongue through the mouthpiece or biting it with the teeth.
(f) *Air leak*[1,2,16,21]:
- The air leak source could be due to loose tube connections or, more commonly, because the patient weakly applies lips around the mouthpiece. Air leak can be detected from the FV loop; Figure 1.11e.

3. Good end of the test (demonstrated in the VT curve):

(a) Plateau of VT curve of at least 1 s, i.e., volume is not changing much with time indicating that the patient is approaching the residual volume (RV).[1,2]

OR

(b) Reasonable duration of effort (FET)[1,2]:
- Six seconds is the minimum accepted duration (3 s for children[1]).
- Ten seconds is the optimal.[22]
- FET of >15 s is unlikely to change the clinical decision and may result in the patient's exhaustion.[1] Patients with obstructive disorders can exhale for more than 40 s before reaching their RV, i.e., before reaching a plateau in the VT curve; Figure 1.9. Normal individuals, however, can empty their lung (i.e., reach a plateau) within 4 s.

OR

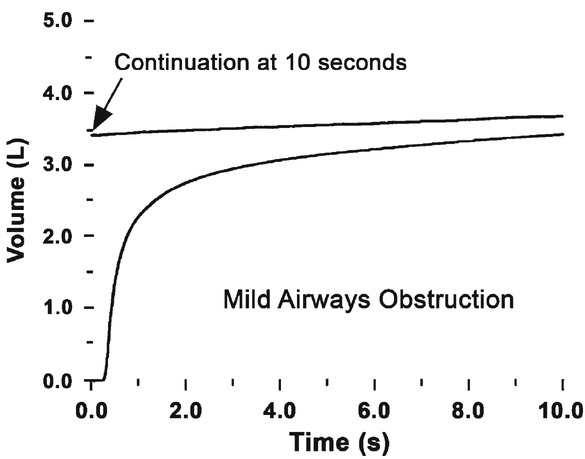


FIGURE 1.9. Mild airway obstruction, with prolonged duration of exhalation (20 s). Notice that, when the curve exceeds the limit of the time axis, the continuation of the curve will be plotted from the beginning of the time axis (with permission from American Thoracic Society[2]).

(c) The patient cannot or should not continue to exhale.[1,2]

Note: A good end of the study can be shown in the FV curve as an upward concavity at the end of the curve. A downward concavity, however, indicates that the patient either stopped exhaling (prematurely) or started inhaling before reaching the RV; Figure 1.10. This poor technique may result in underestimation of the FVC.[10]

- Figure 1.11 shows the morphology of FV curve in acceptable and unacceptable maneuvers.

Reproducibility[1,2]

- After obtaining three acceptable maneuvers, the following reproducibility criteria should be applied:
  - The two largest values of FVC must be within 150 ml of each other.
  - The two largest values of FEV_1 must be within 150 ml of each other.
- If the studies are not reproducible, then the studies should be repeated until the ATS criteria are met or a total of eight trials are completed or the patient either cannot or should not continue testing.[1,2]

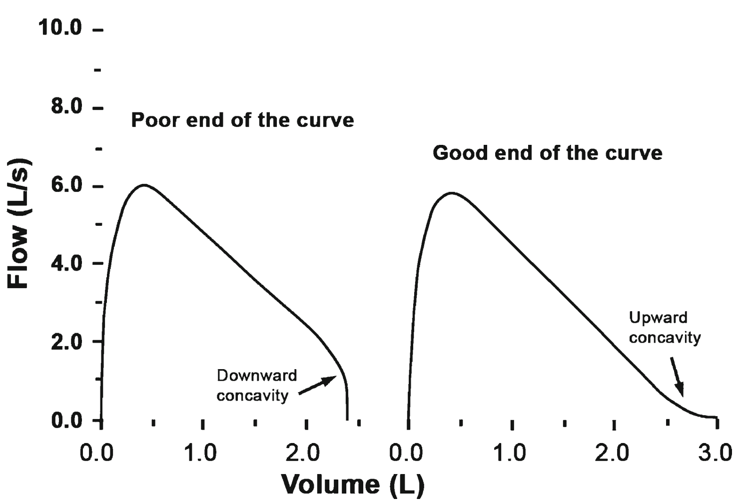


FIGURE 1.10. Poor end in comparison to good end (small upward concavity) of FV curve. A poor end (downward concavity) indicates premature termination of exhalation (before 0 flow).

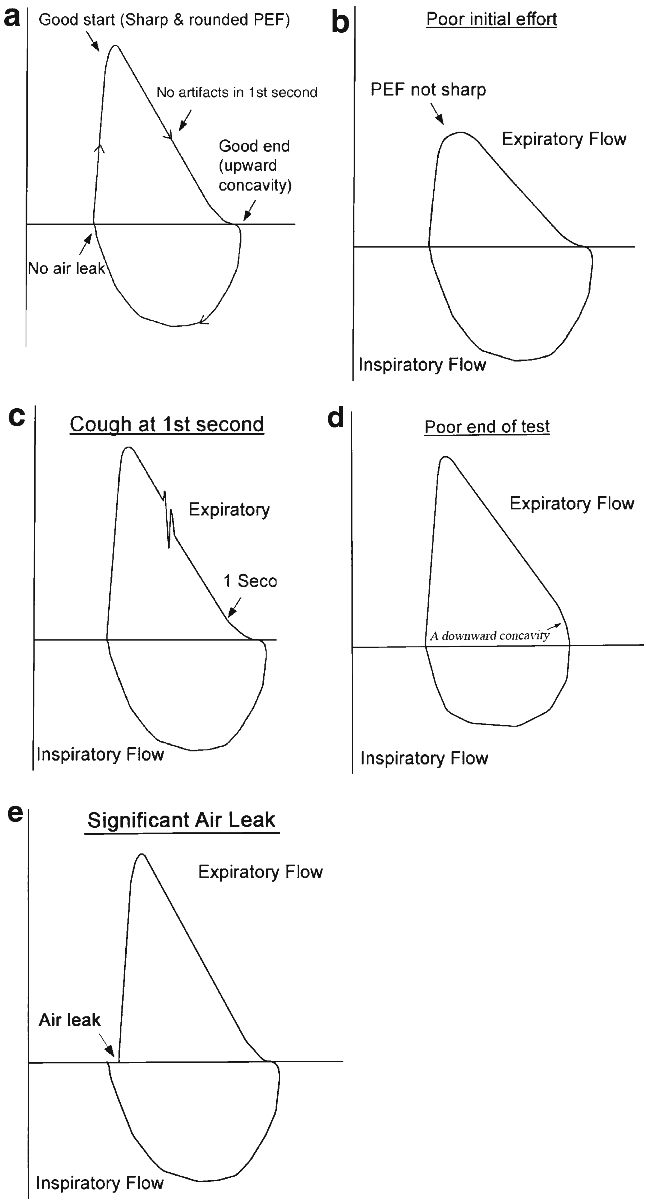


FIGURE 1.11. (**a**) An acceptable FV curve, with good start, good end, and free from artifacts. (**b**) Shows a poor start. (**c**) Shows a cough in the 1st second. (**d**) Shows a poor end. (**e**) Shows air leak.

- The final values should be chosen based on the following[1,2]:
  - FEV$_1$ and FVC should be reported as the highest values from any acceptable/reproducible trial (not necessarily from the same trial).
  - The other flow parameters should be taken from the best test curve (which is the curve with the highest sum of FVC + FEV$_1$).
  - If reproducibility cannot be achieved after eight trials, the best test curve (the highest acceptable trial) should be reported. The technician should comment on this deviation from protocol so that the interpreting physician understands that the results may not be accurate.
- Finally, acceptable trials are not necessarily reproducible, because the patient may not produce maximum effort in all trials. Figures 1.12 and 1.13 give some useful examples.[2]

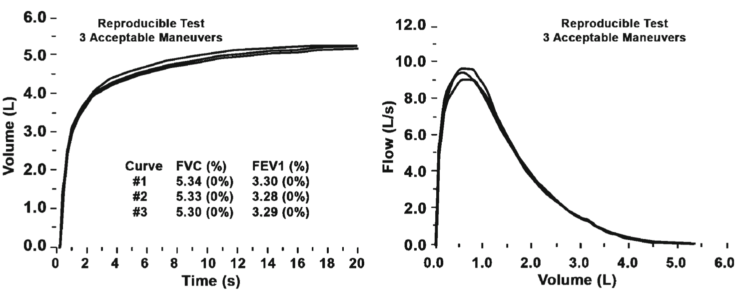


FIGURE 1.12. Acceptable and reproducible trials (with permission from American Thoracic Society[2]).

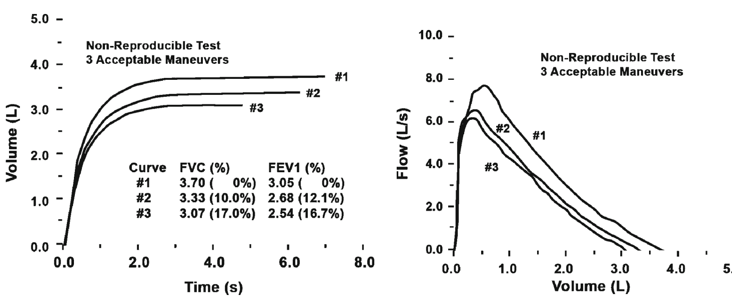


FIGURE 1.13. Acceptable but not reproducible trials (With permission from: American Thoracic Society[2]).

TABLE 1.2. Features of the ideal FV and VT curves
The ideal FV curve should have the following features; Figure 1.11a: Good start with sharp and rounded PEF Smooth continuous decline free from artifacts Good end with a small upward concavity at or near the 0 flow
The ideal VT curve should either have a plateau for 1 s *or* show an effort of at least 6 s

- Now, by looking at any FV curve, you should be able to tell whether or not it reflects an acceptable study. Table 1.2 summarizes the features of the ideal FV and VT curves. Keep in mind that the lack of any of these features may indicate a lung disorder rather than a poor study.

REFERENCE VALUES[10,23–27]

- The reference values for the PFT have a wide range of normal as the lung size varies considerably in the normal subjects. These values depend on certain variables:
  - Sex (Men have bigger lungs than women.)
  - Age (The spirometric values drop with age.)
  - Height (Tall people have bigger lungs. If it is difficult to measure the height, as in kyphoscoliosis, then the arm span can be measured instead.[14,28])
  - A fourth important variable is race (Caucasians have bigger lungs than Africans and Asians), related to differing body proportions (legs to torso)
- Spirometric measurements from a group of healthy subjects with a given sex, age, height, and race usually exhibit a normal distribution curve; Figure 1.14. The 5th percentile (1.65 standard deviations) is, then, used to define the lower limit of the reference range for that given sex, age, height, and race; Figure 1.14.[10,27]
- The available reference values apply only to Caucasians on whom the original studies were performed. Blacks are well studied too, and they generally have lower predicted values than the Caucasians, although they are usually taller, because blacks have higher leg length to torso length ratios, i.e., smaller lungs. So, while interpreting the lung functions of a black American, you need to make race-specific corrections to the standard predicted values; Table 1.3.[10,27]
- Asians also have lower values than the standard predicted values. An adjustment factor of 0.94 is recommended for Asian Americans.[29,30]

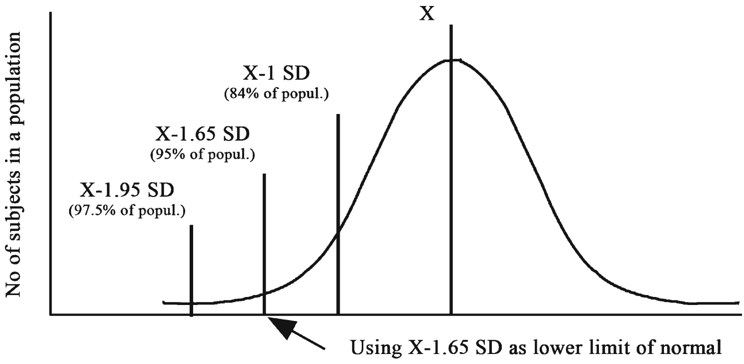


Figure 1.14. The predicted values for a group of normal subjects at a given height, age, and sex form a normal distribution curve. Applying 1.65 standard deviations (the 5th percentile) to define the lower limit of normal will include 95% of that population.

TABLE 1.3. Correction factors for the PFT of Black Americans

Variable	Correction factor
FEV_1, FVC, TLC	0.88
RV, DL_{CO}	0.93
FEV_1/FVC ratio	1 (i.e., no correction needed)

Blacks have smaller lungs than Caucasians and their lung function values need to be adjusted by multiplying these correction factors by the reference values acquired from Caucasian studies.[10,27]

- The standard normal values roughly range from 80 to 120% of the predicted values that are derived from Caucasian studies.‡ When you interpret a PFT, you should always look at the patient's results as percentage of the predicted values for that particular patient (written in the report as % pred.). If the patient is normal, then his/her values should roughly lie within 80–120% of predicted values.*

‡Using a fixed value of the lower limit of normal (80%) may be accepted in children but may lead to some errors in adults.[27]

*As can be seen in figure 1.14 the 95% confidence limit may be used for normality as well. Values outside this range are then below the limit of normal (LLN). Many software programs for lung function testing can display the LLN and interpreting physicians may use this to determine normality. The predicted values used (reference equations) should be representative of the population being tested.

- The absolute value for each variable has some significance. As an example, FVC equals roughly 5 L in an average young adult. This number could vary significantly among normal individuals, but if somebody tells you that your patient's FVC is 1 L, you will know that this is far below the expected for an average young adult and will warrant some attention.

GRADING OF SEVERITY

- Different variables and values were used to grade severity of different pulmonary disorders[10,27,31–33];
- Recently, FEV_1 has been selected to grade severity of any spirometric abnormality (obstructive, restrictive, or mixed); Table 1.4.[10] The traditional way of grading severity of obstructive and restrictive disorders involve the following:
  - In obstructive disorders, the FEV_1/FVC ratio should be <0.7, and the value of FEV_1 is used to determine severity[27]; Table 1.4.
  - In restrictive disorders, however, FEV_1/FVC ratio is normal and the TLC is less than 80% predicted. The ATS suggested using the TLC to grade the severity of restrictive disorders, which cannot be measured in simple spirometry.[27] Where only spirometry is available, FVC may be used to make that grading.[27] The TLC, however, should be known before confidently diagnosing a restrictive disorder[27,34,35]; Table 1.4.

BRONCHODILATOR RESPONSE

- Bronchodilators can be used in selected patients following the initial spirometry. Response to bronchodilators suggests asthma, but other obstructive lung disorders can respond to bronchodilators as well, i.e., chronic obstructive pulmonary disease (COPD). Normal subjects can also respond to bronchodilators by as much as 8% increase in FVC and FEV_1, but this change is not considered significant.[36,37] The bronchodilator of choice is salbutamol delivered by metered dose inhaler (MDI), through a spacer.[§38–45]
- For the test to be accurate, patients are advised to stop taking any short-acting β_2 agonists or anticholinergic agents within 4 h of testing.[1] Long-acting β_2 agonists (like formoterol and salmeterol) and oral aminophylline should be stopped at least 12 h before the test.[1] Smoking should be avoided for ≥1 h prior to testing

[§] A spacer is an attachment to the MDI, which optimizes the delivery of salbutamol.

TABLE 1.4. Methods of grading the severity of obstructive and restrictive disorders

(A) Grading of severity of any spirometric abnormality based on FEV_1[10]	
After determining the pattern to be obstructive, restrictive, or mixed, FEV_1 is used to grade severity:	
Mild	FEV_1 > 70 (% pred.)
Moderate	60–69
Moderately Severe	50–59
Severe	35–49
Very severe	<35
(B) Traditional method of grading the severity of obstructive and restrictive disorders*,[27]	
• Obstructive disorder (based on FEV_1) – Ratio < 0.7	
May be a physiologic variant	FEV_1 ≥100 (% pred.)
Mild	70–100
Moderate	60–69
Moderately severe	50–59
Severe	35–49
Very severe	<35
• Restrictive disorder (based on TLC, preferred)	
Mild	TLC > 70 (% pred.)
Moderate	60–69
Severe	<60
• Restrictive disorder (based on FVC, in case no lung volume study is available)	
Mild	FVC > 70 (% pred.)
Moderate	60–69
Moderately severe	50–59
Severe	35–49
Very severe	<35

*This is a widely used grading system but different organizations use different systems of grading.

and throughout the procedure.[1,14] Caffeine-containing substances should be avoided the day of testing. Inhaled or systemic steroids do not interfere with the test results, and so, they do not need to be stopped.[8] The technicians' comment should indicate if a patient has just had a bronchodilator prior to the study.

- The definition of a significant response to bronchodilators according to ATS & ERS (European Respiratory Society) is increase in FEV_1 or FVC by >12% and >200 ml in the postbronchodilator study.[¶10,46]

COMPONENTS OF SPIROMETRY

- Table 1.5 summarizes the causes of abnormal spirometric components. In any spirometry report, you may see multiple other parameters that are not discussed here and have little or even no clinical usefulness. For the purpose of completeness, these components are also shown in this table.
- Table 1.6 summarizes the effects of different lung disorders on every component of spirometry.

SPIROMETRIC PATTERN OF COMMON DISORDERS

In this section, we will discuss the PFT pattern of some common disorders.

Obstructive Disorders

- The two major obstructive disorders are bronchial asthma and COPD; Table 1.7. The key to the diagnosis of these disorders is the drop in FEV_1/FVC ratio.[10] FEV_1 may be reduced too and is used to define the severity of obstruction; see Table 1.4. FVC may be reduced in obstructive disorders but usually not to the same degree as FEV_1.
- The features of obstructive disorders are summarized in Table 1.6.
- The flow–volume curve can be used alone to confidently make the diagnosis of obstructive disorders, as it has a distinct shape in such disorders; Figure 1.15. These features include the following:
  - The height of the curve (PEF) is much less than predicted.
  - The descending limb is concave (scooped), with the outward concavity being more pronounced with more severe obstruction. The slope of the descending limb that represents MMEF and FEFs is reduced due to airflow limitation at low lung volumes.

¶Increments of as high as 8% or 150 ml in FEV_1 or FVC are likely to be within the variability of the measurement.[36,56]

TABLE 1.5. Causes of abnormal spirometric components

FVC
- Increased in acromegaly[8]
- Decreased in restrictive disorders (most important) and obstructive disorders; Table 1.6

FEV_1
- Decreased in obstructive and, to a lesser extent, restrictive disorders

FEV_1/FVC ratio
- Increased in interstitial lung diseases (ILD) such as pulmonary fibrosis (because of increased elastic recoil that results in a relatively preserved FEV_1)
- Decreased in obstructive disorders (asthma and COPD)

PEF
- May be increased in pulmonary fibrosis (because of increased elastic recoil)
- Decreased in the following:
  - Obstructive disorders (COPD, asthma)
  - Intrathoracic or fixed upper airway obstruction[10,46,47] (associated with flattening of the expiratory curve of the flow–volume loop)
  - Restrictive disorders other than pulmonary fibrosis

$FEF_{(25,\ 50,\ 75,\ 25–75)}$
- Decreased in obstructive and restrictive disorders
- Decreased also in variable extrathoracic or fixed upper airway obstruction
- Reduction in FEF_{75} and/or $FEF_{25–75}$ may be the earliest sign of airflow obstruction in small airways.[10,48–50] This sign, however, is not specific for small airway disease.[11]

FET (forced expiratory time)
- May be increased in obstructive disorders

PIF (peak inspiratory flow)
- Decreased in variable extrathoracic or fixed upper airway obstruction

FIF_{50} (forced inspiratory flow at 50% of FIVC)
- Decreased in variable extrathoracic or fixed upper airway obstruction

FIVC (forced inspiratory vital capacity)
- Its main use is to check for the quality of the study (for air leak)

FIF_{50}/FEF_{50}
- Increased in variable intrathoracic upper airway obstruction (>1)[10]
- Decreased in variable extrathoracic upper airway obstruction (<1), see also Table 1.9.[10]

TABLE 1.6. Features of obstructive and restrictive disorders

Features of obstructive disorders
- Diagnostic features: ↓ FEV_1/FVC ratio
- Other features:
  - ↓ FEV_1
  - ↓ FVC (can be normal)
  - ↓ FEFs and MMEF (FEF_{25}, FEF_{50}, FEF_{75}, FEF_{25-75})
  - ↓ PEF
  - ↓ FET
  - Significant bronchodilator response
  - Scooped (concave) descending limb of FV curve

Features of restrictive disorders
- Most important features: ↓ FVC and normal or ↑ FEV_1/FVC ratio
- Other features:
  - ↓ FEV_1 (proportional to FVC), but it can be normal
  - ↓ MMEF
  - PEF: normal, increased, or decreased
  - Steep descending limb of FV curve

TABLE 1.7. Causes of obstructive and restrictive disorders

Causes of obstructive disorders
- Bronchial asthma (usually responsive to bronchodilators)
- COPD

Causes of restrictive disorders
- Parenchymal disease as pulmonary fibrosis and other interstitial lung diseases (ILD)
- Pleural disease as pleural fibrosis (uncommon)
- Chest wall restriction:
  - Musculoskeletal disorders (MSD), e.g. severe kyphoscoliosis
  - Neuromuscular disorders (NMD), e.g. muscular dystrophy, amyotrophic lateral sclerosis (ALS), old poliomyelitis, paralyzed diaphragm; see Table 5.1 for more detail.
  - Diaphragmatic distention (pregnancy, ascites, obesity)
  - Obesity (restricting chest wall movement)
- Loss of air spaces:
  - Resection (lobectomy, pneumonectomy)
  - Atelectasis
  - Tumors (filling or compressing alveolar spaces)
  - Pulmonary edema (alveolar spaces become filled with fluid)
  - Pleural cavity disease (pleural effusion, extensive cardiomegaly, large pleural tumor)