

# Simple Office Spirometry

*for Primary Care Practitioners*

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## Office Spirometry

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In the past, primary care physicians assessed patients with asthma or COPD subjectively by asking about symptom frequency and use of rescue inhalers, sometimes also considering the presence of wheezing upon physical exam. Simple office spirometry provides an objective measure of disease severity.

Spirometry measures *how much* air an individual can blow out and *how fast*. Primary care practitioners will find simple office spirometry useful in the diagnosis and management of obstructive and restrictive lung diseases, particularly to measure and monitor responses to therapy for asthma and chronic obstructive pulmonary disease (COPD). Spirometry is also useful in following the course and prognosis of many other lung diseases. Abnormal spirometry results may indicate an increased risk of morbidity and mortality from asthma, COPD, acute myocardial infarction, lung cancer, and stroke.

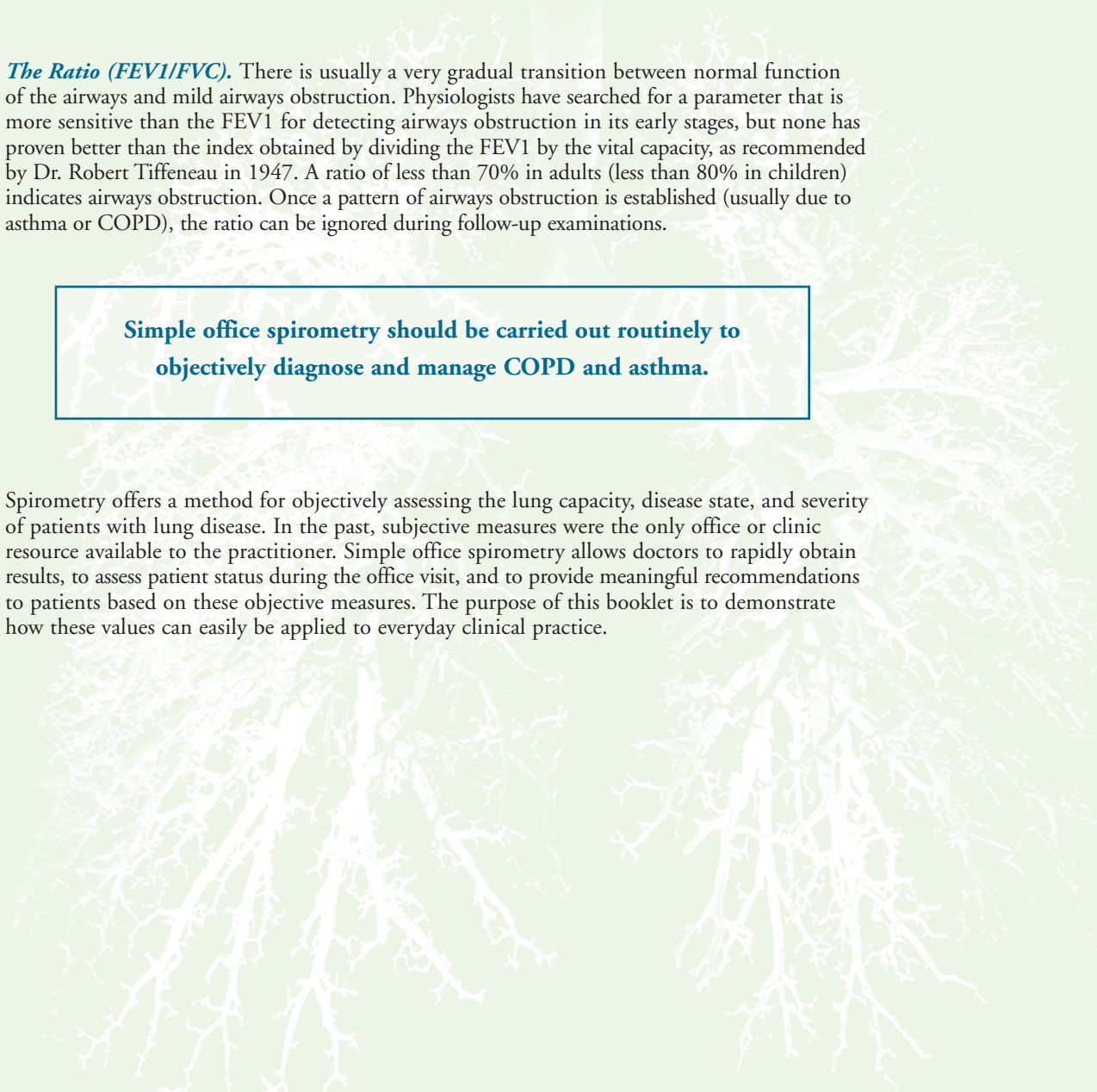
Until recently, inexpensive and user-friendly spirometers were not readily available for office and clinic use. It's now possible for primary care physicians and allied healthcare professionals to obtain a spirometer and easily learn how to perform office spirometry and apply the results for clinical decision making. Spirometry provides two numeric values that are helpful in the assessment and monitoring of patients with compromised lung function: the forced vital capacity (FVC) and forced expiratory volume measured over 1 second (FEV1). Airways obstruction is characterized by a decrease in the FEV1/FVC ratio.

**Forced Vital Capacity (FVC).** The FVC is the total amount of air that can be exhaled following as deep an inhalation as possible. A patient must try to exhale for at least 6 seconds to obtain a useful FVC measure. FVC was defined over 150 years ago by John Hutchinson, an English surgeon who was the inventor of the spirometer. Hutchinson found that when the FVC was large, a patient lived longer than when the FVC was small. Lowered FVC values were often the result of tuberculosis, a common lung condition at that time. Relatively low FVC is still a risk factor for premature death.

Several factors can influence the FVC value, the most important being height. Taller people have larger thoracic cavities and thus larger FVC values. The average adult male has a larger FVC than the average adult female. Disorders that limit the expansion of the chest will reduce inflation of the lungs and therefore reduce the FVC. These include obesity, kyphosis, scoliosis, rib fracture, compression of the spine, and pleural disease. Diaphragm weakness can also reduce a person's ability to take a deep breath.

Pneumonia is associated with a filling of the alveoli with fluid, reducing the amount of air the lungs can hold, and therefore reducing the FVC. Congestive heart failure (CHF) also increases lung fluid and reduces the FVC. Diseases that cause scarring of the lung tissue, such as radiation-induced pulmonary fibrosis, make the lungs stiffer and more difficult to fill, also reducing the FVC. Any disease associated with infiltrates (observed on a chest x-ray) can reduce inflation and lower the FVC; thus, a low FVC is nonspecific.

**Forced Expiratory Volume in 1 Second (FEV1).** The FEV1 measures flow (and volume) during the first second of an FVC maneuver and is often considered the most important spirometry variable. FEV1 declines in direct and linear proportion with worsening of airways obstruction, and FEV1 increases as obstruction is successfully treated. When expressed as a percent of the predicted value, FEV1 is used to determine the degree of obstruction (mild, moderate, or severe). The FEV1 should be used for serial comparisons when following patients with asthma or COPD. Patients should be told their FEV1 percent (%) of predicted.



***The Ratio (FEV1/FVC).*** There is usually a very gradual transition between normal function of the airways and mild airways obstruction. Physiologists have searched for a parameter that is more sensitive than the FEV1 for detecting airways obstruction in its early stages, but none has proven better than the index obtained by dividing the FEV1 by the vital capacity, as recommended by Dr. Robert Tiffeneau in 1947. A ratio of less than 70% in adults (less than 80% in children) indicates airways obstruction. Once a pattern of airways obstruction is established (usually due to asthma or COPD), the ratio can be ignored during follow-up examinations.

**Simple office spirometry should be carried out routinely to objectively diagnose and manage COPD and asthma.**

Spirometry offers a method for objectively assessing the lung capacity, disease state, and severity of patients with lung disease. In the past, subjective measures were the only office or clinic resource available to the practitioner. Simple office spirometry allows doctors to rapidly obtain results, to assess patient status during the office visit, and to provide meaningful recommendations to patients based on these objective measures. The purpose of this booklet is to demonstrate how these values can easily be applied to everyday clinical practice.

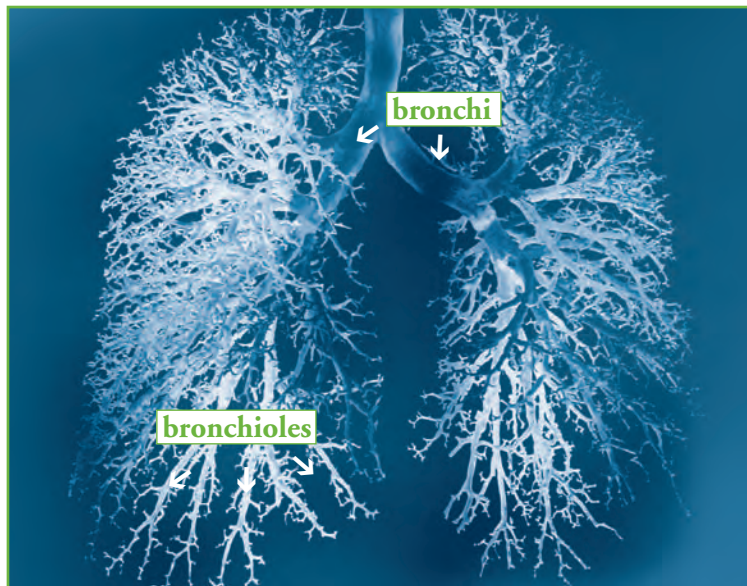
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# The Lungs



**Airways Anatomy.** The airways can be divided into the extrathoracic airways, including the mouth, pharynx, vocal cords, and upper trachea (in the neck), and the intrathoracic airways, including the lower trachea (within the chest), the carina, and the branching airways located in the lungs.

Airways can also be classified as either large or small, with the small airways being less than 2 mm in diameter. Traditional thinking has held that airways disease due to cigarette smoking begins in the small airways. It is now known that the chronic airways inflammation associated with smoking, as well as the eosinophilic inflammation associated with asthma, involves the entire length of the airways and extends from the large upper airways (bronchi) to the small peripheral airways (bronchioles).

**Airways Pathology.** Chronic airways inflammation due to asthma or smoking (chronic obstructive bronchitis) is characterized by airways edema and excessive mucus secretion leading to airways narrowing. Narrowing can lead to ventilation disruptions where some airways empty more slowly than others, and airflow is reduced during forced exhalation. This reduction is measured through spirometry testing.

COPD due to smoking develops over several decades in one out of five smokers. The disease is characterized by a dissolution and destruction of the lung parenchyma resulting in a progressive loss of lung elasticity and diminished airways support. The airways become “floppy” and may collapse upon exhalation. Asthma-induced acute bronchospasm narrows airways by contracting smooth muscle resulting in audible wheezing during exhalation. Finally, the upper airways may be narrowed by vocal cord paralysis or dysfunction, or more rarely, by compression due to tumors.

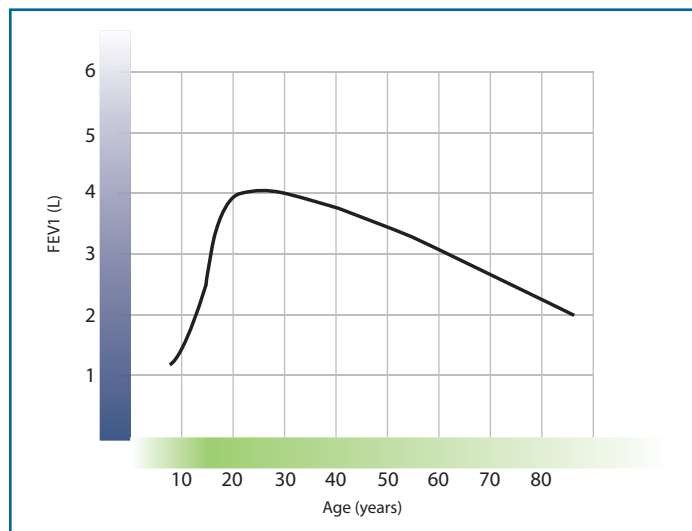


***Growth and Aging of the Lungs.*** Normal lung growth parallels the exponential increase in height observed in children and teenagers, with lung function generally peaking during the 20s or 30s. There is a slow decline in FVC and FEV1 extending throughout adulthood.

Lung growth may be slowed by smoking, cystic fibrosis, repeated pulmonary infections, occupational exposures, or malnutrition. By the age of 25, patients with these risk factors may have an FVC that is 20% to 30% lower than their peers. On the other hand, regular aerobic exercise during the growth years may increase lung volume, so that by age 25, young athletes may have obtained an FVC that is higher than their non-athletic counterparts. After about age 30, the FVC and FEV1 do not increase with exercise, although improvements in cardiovascular fitness and endurance can be achieved.

After about age 30, lung tissue slowly begins to lose its elasticity, airways begin to close prematurely during exhalation, and the FVC decreases by about 0.2 liters (L) per decade, even in healthy individuals who have never smoked. Lung capacity starts out with a large reserve so that, even by age 100, the FVC of a healthy person is usually not the limiting factor in the ability to exercise. Many diseases, however, can cause the FVC to fall more quickly than 0.2 L per decade.

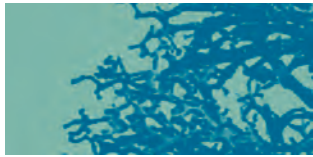
#### **Normal Growth and Subsequent Decline in Lung Function in a Male of Average Height**



***Anthropometric Factors.*** Age, height, and gender are each an independent factor affecting lung function. Taller people have a larger frame size and thoracic cage, leading to larger lung volumes and higher maximal flows, when compared to shorter people. For example, the predicted (expected) mean FVC of a 40-year-old man who is tall (6' 4") is 6.0 L, while that of a short 40-year-old man (5' 4") is only 4.0 L. This means that the accurate measurement of standing height (to the nearest half inch, without shoes) is very important when lung function values are matched against predicted values.

Body weight is much less important than standing height when predicting most pulmonary function (PF) values; thus, weight is not included in spirometry prediction equations. Extremes in weight are associated with lower lung volumes: malnutrition causes reduced diaphragm strength so that the patient cannot take as deep a breath as possible, and truncal obesity restricts complete expansion of the chest cage. When total lung capacity is reduced, the FEV1 is also proportionally reduced. An excellent index of the degree of obesity is the body mass index (BMI) obtained by dividing the weight (in kilograms) by the height (in meters) squared. Mildly reduced lung volumes in patients with a BMI above 30 may be entirely due to their obesity. Changes in body weight result in changes in lung function. For example, some of the improvement in FEV1 due to smoking cessation may be countered by the associated weight gain.

Even when age, gender, and height are taken into consideration, the “normal” range of PF variables for healthy individuals remains wide, often 80% to 120% of the predicted value. This means that large changes with disease progression or therapy can easily occur while the patient’s values remain within the normal range. Therefore, follow-up PF test results in adults should be compared to their own baseline values.



# Spirometry Indications

## Clinical Uses for Diagnostic Spirometry

Spirometry is the most useful test for detecting and managing asthma and COPD. Spirometry is also indicated for use in several other clinical situations commonly encountered by medical practitioners:

- Diagnosing asthma
- Categorizing asthma severity
- Identifying adult smokers who are developing COPD
- Staging the severity of COPD
- Chronic dyspnea workup
- Diagnosing restrictive lung disease
- Detecting bronchial hyper-responsiveness
- Measuring the effectiveness of bronchodilator or corticosteroid therapy
- Evaluating the pulmonary effects of workplace exposure to irritants
- Determining the risk of postoperative pulmonary complications
- Measuring the degree of impairment from respiratory disease



Spirometry maneuvers are obtained by a nurse, respiratory therapist, nurse practitioner, physician's assistant, or in some cases the physician. The following steps may be used by any healthcare provider in the proper performance of a spirometry maneuver.

## Pre-Test Preparations

- Check spirometer accuracy (daily calibration check)
- Measure the patient's height
- Wash your hands
- Ask the patient to sit for the test
- Loosen restrictive clothing
- Place loose dentures in a cup
- Optionally, use noseclips

**Check Spirometer Accuracy.** See the “Daily Spirometer Calibration Checks” section (p. 8) for details.

**Measure Height Accurately.** Predicted FVC and FEV1 values are greatly influenced by height. Standing height should be measured to the nearest half inch (or centimeter) in stocking feet prior to administering the first spirometry test. If the patient has obvious spinal deformities, measure the arm span from fingertip to fingertip with arms outstretched against a wall. Arm span should then be entered into the spirometer in place of standing height.

**Avoid Cross-Contamination.** There have been no documented cases of a patient contracting a respiratory infection from a spirometer contaminated by a previously tested patient. However, to minimize the risk of cross-contamination, always replace the disposable mouthpiece between patients. Routine hand-washing, proper cleaning of permanent flow sensors, and instructing patients not to inhale from the spirometer are equally important precautions.

The technician or nurse is *the* critical factor in achieving good spirometry results since the accuracy of the test depends on proper patient instruction. The patient should always be coached to inhale maximally and then to BLAST out the air upon exhalation.

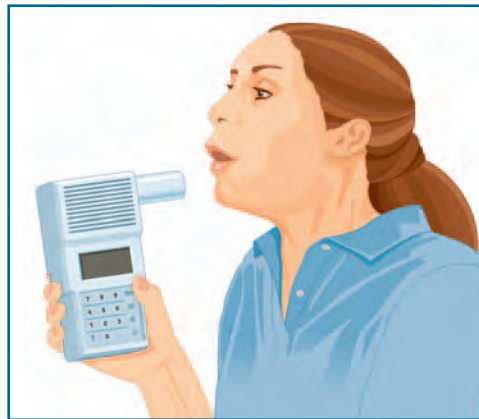
**Explain the Procedure.** Explain to the patient that the purpose of spirometry is to determine how hard and fast air can be exhaled. It should be “like blowing out candles on a birthday cake.” The patient should inhale as deeply as possible and, when the lungs are completely full, quickly seal the lips around the mouthpiece and exhale as hard and fast as possible. Testing should be done in the sitting position. If the patient sniffs air through the nose at the end of the test, use noseclips.

**Demonstrate the Maneuver.** Demonstrate the FVC spirometry maneuver with a separate mouthpiece or flow sensor. To emphasize that you are taking a very deep breath, throw back your shoulders, widen your eyes, and stand on your toes. Next, stick out your tongue, place the mouthpiece on top of your tongue, and seal your lips around it. Finally, dramatically BLAST out as hard and as fast as possible for at least 6 seconds. Your vigorous demonstration will prevent time and effort from being wasted on unacceptable maneuvers.

**Coach the Patient.** Ensure that the spirometer is ready to record the FVC maneuver. Coach the patient to take as deep a breath as possible. Watch to ensure that the patient inhales deeply. Encourage the patient to keep the chin up. Once he or she has sealed the lips around the mouthpiece, shout loudly, “BLAST out the air!” Then tell the patient more quietly to, “Keep going, keep going, blow out a little more air.” Some spirometers will help you by indicating with a graph or tone that the patient is continuing to exhale air toward the end of the maneuver.

### Step-by-Step Spirometry

1. Explain the test and demonstrate the maneuver
2. Coach for maximal inhalation, then have the patient BLAST out!
3. Quietly encourage blowing out for at least 6 seconds
4. If necessary, instruct the patient how to correct any problems
5. Obtain three good maneuvers, two of which match closely



Phase 1: Deep inhalation



Phase 2: Blast out

**Recognize Poorly Performed Breathing Maneuvers.** As soon as a poorly performed maneuver is detected (poor inhalation or weak exhalation), tell the patient to stop. Instruct the patient how to perform the test better. Demonstrate the correct maneuver again. Prepare the spirometer to record another maneuver. Tell the patient to repeat the maneuver. The goal is to obtain three acceptable FVC maneuvers with the best two matching closely. If the goal is not reached after eight attempts, end the test session and suggest that spirometry be rescheduled for another day. Repeated test failure is rare. Fewer than 5% of patients are unable to provide meaningful test results (after three test sessions on separate days).

Despite the use of accurate instruments, spirometry results may be misleading due to submaximal breathing efforts. Unlike most other medical tests where the patient remains passive, accurate spirometry results require athletic-like activity. The nurse or technician must coach the patient to perform the breathing maneuvers in three phases: (1) instruct the patient to take as deep a breath as possible; (2) loudly prompt the patient to BLAST out the air into the spirometer; and (3) encourage continued exhalation for at least 6 seconds. Most problems with breathing maneuvers can be detected by watching the patient's body language during these three phases, but resulting spirometry tracings can also show patterns of submaximal effort. Some spirometers provide software that automatically checks each maneuver for acceptability and grades the reproducibility of the FEV1 and FVC values.

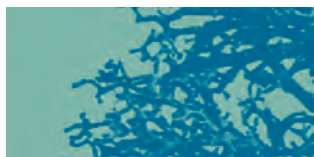
If the patient does not inhale maximally, the FVC and FEV1 will be underestimated, and the result may mimic a restrictive disorder. If the patient doesn't blast out properly, the FEV1 may be underestimated, and the result may mimic airways obstruction (false positive for COPD or asthma). Even when the results from submaximal maneuvers do not lead to misdiagnoses, they can be misleading when compared to results from previous or subsequent testing. For instance, it may appear that the patient with COPD was helped by corticosteroid therapy, when the apparent increase in FEV1 after therapy was actually due to submaximal inhalations during pretreatment spirometry.

### Consequences of Improper Maneuvers

#### Results from two "Ground Zero" 9/11/01 World Trade Center responders demonstrate the effect of improper maneuvers

- 56-year-old woman with a computer-generated report of "normal spirometry"
  - FVC overestimated at 3.0 L
  - Did not wear noseclips and took an extra breath at the end of the maneuver
  - Repeat testing revealed an FVC of 2.0 L, mildly low at 76% of predicted
  - Chest x-ray showed infiltrates
- 46-year-old man with a computer-generated report of "mild restriction"
  - FVC underestimated at 65% of predicted
  - Subsequent deep inhalation revealed his true FVC of 5.0 L (normal)
  - Chest x-ray and methacholine challenge test were normal





# Daily Spirometer Calibration Checks

**Calibration and Accurate Spirometers.** The importance of properly calibrated and accurate spirometers has been repeatedly addressed by the American Thoracic Society (ATS). Several spirometers sold during the 1980s produced errors of more than 20%, but almost all of those manufactured since 1995 are accurate (FEV1 and FVC measurements with less than 3% error). One disadvantage of the new generation of spirometers is that flow sensors can lose accuracy over time. Calibration checks of the flow sensor are needed to verify spirometer accuracy each day it is in use. A 3.0 L calibration syringe should be used for this verification every day the spirometer is to be used.

## How to Use a Calibration Syringe

1. Select “calibration” from the spirometer menu
2. Attach syringe firmly to flow sensor
3. Empty syringe quickly (less than 1 second)
4. Ensure that the reported FVC is within 3% of the syringe size
5. Repeat steps 3 and 4, emptying syringe in about 3 seconds
6. Repeat steps 3 and 4, emptying syringe very slowly (in about 6 seconds)
7. All of the reported FVCs should be between 2.90 to 3.10 L

The syringe will click against the stops with each stroke. Don’t “bang” the plunger too forcefully.

## Storing and Handling the Calibration Syringe

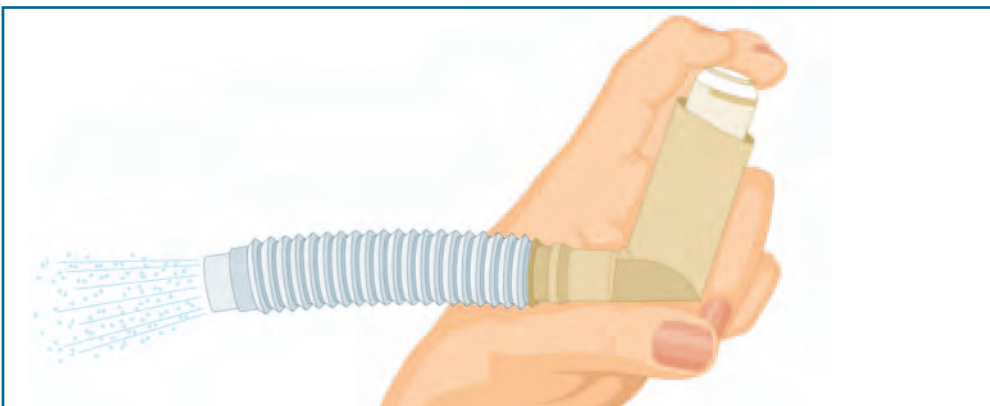


Store the calibration syringe near the spirometer so that the two devices remain at the same temperature. Store the syringe with the plunger pushed all the way in. Take care not to drop the syringe. Don’t loosen the metal rings on the shafts, since this will disrupt the factory calibration. Periodically check the syringe for leaks by filling with air, holding your palm against the outlet snout, and trying to empty the syringe. If any air is expelled with the outlet plugged, the syringe has a leak and must be repaired.

## Common Reasons for Failure to Pass Calibration Checks

1. Clogged permanent flow sensor
2. Tear in disposable flow sensor filter
3. Faulty spirometer electronics
4. Failure to completely fill and/or discharge the syringe
5. Difference in temperature between spirometer and syringe
6. Calibration syringe leak or mechanical failure

## Bronchodilator With Spacer



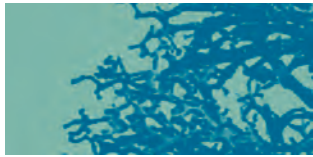
If spirometry indicates airways obstruction, or if asthma is suspected, administration of a bronchodilator (albuterol) followed by post-bronchodilator (BD) spirometry testing is often clinically useful. Comparison of pre-BD and post-BD FEV1s helps determine if bronchodilator therapy would be beneficial to the patient. If the patient has a long history of smoking, consider using both albuterol and ipratropium (a long-acting anticholinergic bronchodilator) prior to retesting. Following administration of the bronchodilator, wait 15 to 30 minutes and repeat spirometry testing.

In a patient with mild-to-moderate airways obstruction, a post-BD FEV1 increase of at least 12% to 15% suggests a meaningful positive response (BD+) and increases the diagnostic probability of asthma. In a patient with severe airways obstruction, a post-BD increase of more than 0.2 L and more than 12% is needed to suggest meaningful positive bronchodilator response. A post-BD improvement of less than 8% to 10% is considered a lack of response (BD-) and is not clinically helpful. Patients may still benefit from therapy for airways obstruction associated with COPD.

### How to Administer Albuterol: Step-by-Step

1. Shake the metered-dose inhaler (MDI) to ensure drug delivery
2. If the patient has never used an MDI or if the device has not been used in over 4 weeks, prime the MDI by activating it once or twice
3. Attach a spacer to the mouthpiece
4. Instruct patient to exhale completely and then place spacer in mouth
5. Instruct patient to take a *very slow*, deep breath
6. At beginning of inhalation, have the patient squeeze the MDI to deliver drug and continue inhaling to maximum
7. Tell patient to hold breath for at least 10 seconds or amount of time that is comfortable
8. After 30 seconds of quiet breathing, repeat steps 4 through 7
9. Wait 15 minutes before repeating spirometry (30 minutes or more if ipratropium is used)

A 6- to 8-week therapeutic trial period using bronchodilators, inhaled corticosteroids, and/or prednisone should be considered, even if there is no appreciable post-BD response during this first spirometry session. Symptoms and lung function may show improvement after several weeks of therapy.



# How to Interpret Spirometry Results

Once it has been determined that the patient's maneuvers were acceptable and reproducible (the largest two FEV1s match within 0.2 L), observe the shape of the flow-volume curves or spirograms for the pattern of airways obstruction, confirmed by a low ratio ( $FEV1/FVC < 70\%$  in adults).

Modern office spirometers process numeric results automatically and print out a report that includes data from each maneuver and a graph corresponding to those data points. Spirometer interpretations are based on widely recognized clinical practice guidelines and assume an accurate spirometer and good patient maneuver quality. Incorrect results or misleading interpretations may result if these conditions are not met. The degree of bronchodilator response may also be misinterpreted if either the baseline (pre-BD) or post-BD maneuver was of poor quality.

In order to determine the severity of lung function impairment, the FEV1 is expressed as a percent of the predicted value. The predicted FEV1 for an average height 50-year-old man is about 4.0 L, while that for an average 50-year-old woman is about 3.0 L. In general, patients with severe COPD usually have an FEV1 of 0.5 to 1.0 L, while patients with moderate COPD have an FEV1 of 1.0 to 1.5 L.

Some physiologic values, such as pH, are tightly controlled by the body and are not significantly different in healthy men versus healthy women, tall versus short people, or children versus the elderly. On the other hand, most spirometry variables vary widely, sometimes by as much as 20%, even in patients of the same age, height, and gender. Interpretation of initial numeric spirometry results must take these factors into consideration. Spirometry reference equations from the Third National Health and Nutrition Examination Study (NHANES III) are now recommended for use throughout the United States. This study included thousands of healthy men, women, and children, including African Americans and Hispanic Americans.



### *How to Recognize Normal and Abnormal Patterns*

**Normal Pattern (N).** There are two ways to graph FVC maneuvers: the flow-volume (F-V) curve and the traditional volume-time (V-T) graph. Both are shown on the following page and in the examples which follow. The flow-volume curve was developed during the 1960s by Drs. Hyatt and Fry and became popular due to the ease with which patterns of poor expiratory effort and airways obstruction were quickly recognized. Note how flow quickly rises to a peak (in the normal F-V graph) and then descends at a 45-degree angle until the FVC is reached at the bottom right corner (like the sail on a boat).

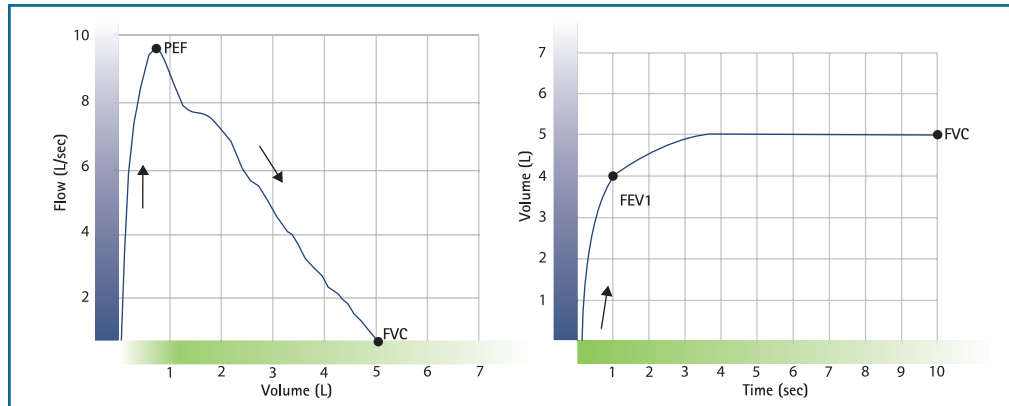
The V-T graph was developed during the 1950s by Drs. Stead and Wells in Minneapolis. The volume-time graph allows important measurement of the volume of air which was exhaled 1 second after the beginning of the maneuver (FEV1). Note how the curve then reaches a flat plateau within 6 seconds, ending in the FVC.

Peak expiratory flow (PEF), as measured by mechanical meters used for home monitoring, can be seen at the top of each F-V curve. The PEF measured by a spirometer is usually expressed in liters per second, while the PEF measured by a mechanical meter is expressed in liters per minute (10 L/s=600 LPM). Peak flow may be reduced in both obstructive and restrictive lung diseases. PEF is less specific, less sensitive, and less accurate for detecting and following lung diseases when compared to the FEV1 and FVC.

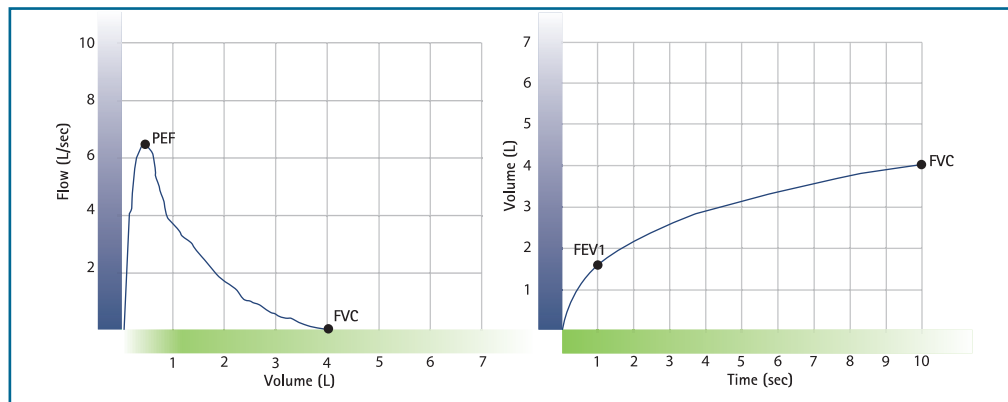
**Obstructive Pattern (Obs).** It's easy to recognize the bowl-shaped pattern of airways obstruction on the flow-volume curve. Flow quickly reaches a peak (within two tenths of a second, as in healthy persons), but then it scoops or droops downward, so that subsequent flow is depressed, and becomes very low as it reaches the FVC (4.0 L in this example). In severe airways obstruction (usually due to COPD), the F-V curve is shaped like a rat's tail. The difference between a normal spirometry tracing and airways obstruction is more subtle on the volume-time graph. It takes more time to exhale the air, so a flat plateau is often not obtained, even after 10 seconds.

**Restrictive Pattern (Reduced Inflation, No Obstruction [RINO]).** Patients with one of the many conditions that restrict lung volumes have a low FVC. The shape of their flow-volume curve may resemble the Transamerica building or the tip of a missile: after the sharp peak, the curve has a steeper decline than normal, as the air is exhaled quickly. The FVC is only about 3.0 L in this example. The volume-time curve shows that a flat plateau is rapidly obtained—often within 1 or 2 seconds—but the plateau is lower than normal.

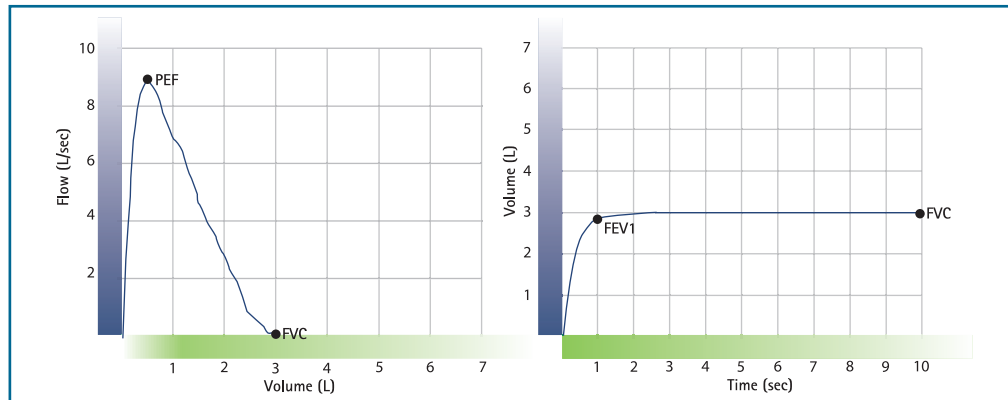
### *Normal Pattern: N*

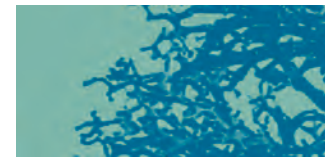


### *Obstructive Pattern: Obs*



### *Restrictive Pattern: RINO (Reduced Inflation, No Obstruction)*



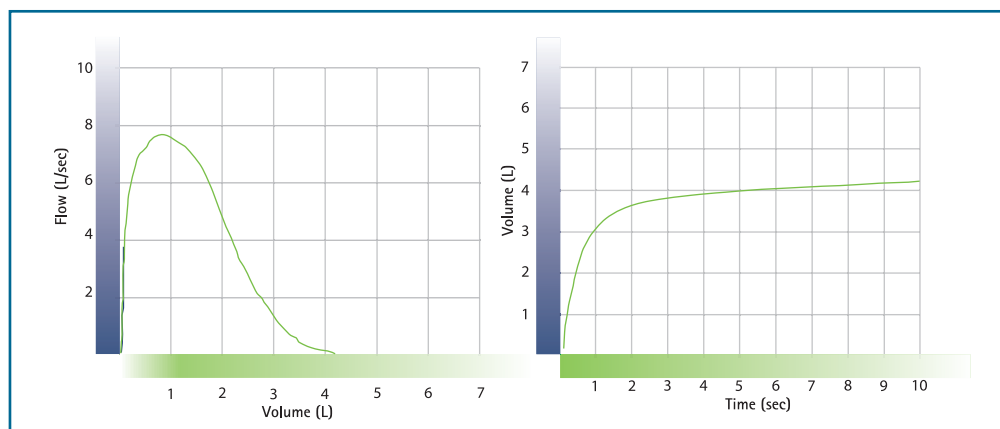


# Spirometry in the Diagnosis and Management of Lung Disease

**Spirometry Results in Healthy Individuals.** Healthy people are able to inhale maximally and then exhale quickly (without obstruction). Their FVC and FEV1 are normal (approximately 80% of predicted or greater), and their ratio (FEV1/FVC) is normal (approximately 80% or greater for children and approximately 70% or greater for adults).

**Patient Example: Elmer**

During a clinic visit for removal of a bunion, an 81-year-old man asks for a “lung breathing test.” He has no respiratory problems but wants to know if his lungs are still working well. His apparent age upon physical examination is only 60 years, and you detect no physical abnormalities.



		% of Predicted
FVC	4.2 L	127
FEV1	3.1 L	114
FEV1/FVC (%)	74%	

**Pattern: N**

**Comment:** Despite his advanced age, Elmer performed a high-quality spirometry test. Note the sharp peak on his flow-volume curve. His results show a normal FVC, normal FEV1, and a normal ratio (N). Because of his normal results, post-bronchodilator testing was not performed.

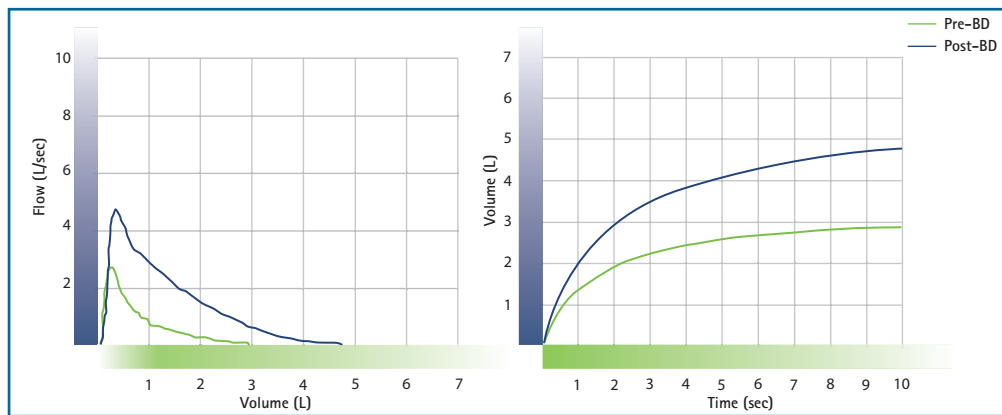
***Chronic Dyspnea Workup.*** Many lung diseases begin slowly and insidiously and finally manifest themselves with the nonspecific symptom of dyspnea on exertion. Pulmonary function tests (PFTs) are an essential component of the workup of such patients. In the outpatient clinic setting, initial spirometry testing followed by further tests step-wise to refine the diagnosis is a cost-effective method of carrying out PFTs. When a patient is hospitalized and a diagnosis is needed within a day or two, a battery of PFTs may be ordered, often including spirometry before and after the administration of a bronchodilator and the determination of absolute lung volumes and diffusing capacity (DLCO). If the cause of dyspnea on exertion remains uncertain following these tests, cardiopulmonary exercise testing should be considered.

***Diagnosing Asthma.*** Spirometry testing before and after the administration of a bronchodilator is indicated during the initial workup of patients suspected of having asthma and during most follow-up office visits. Spirometry provides an objective measure of therapeutic response in the management of asthma patients. Measuring the lung function of patients with asthma often leads to the identification of a more severe asthma category. Thus, the measurement of lung function with a spirometer can be more accurate than subjective assessment based on patient reports of recent respiratory symptoms. Elderly persons with asthma are less likely than younger patients to perceive the severity of their asthma.

***Diagnosing Bronchial Hyper-Responsiveness (BHR).*** Coughing, wheezing, or chest tightness following exercise or exposure to cold air, dust, or fumes suggest bronchial hyper-responsiveness (BHR) or “twitchy airways.” In these patients, baseline spirometry may be near normal with only a small increase in the FEV1 following administration of a bronchodilator. Commonly, the patient is asked to return for retesting when symptoms occur; however, this can delay the diagnosis and may be impractical. A methacholine challenge test will usually confirm the diagnosis of BHR or asthma.

### Patient Example: Joyce

A 45-year-old tax accountant consults you because of a chronic cough, occurring mostly at night, for more than 2 years. She reports occasional shortness of breath while walking up stairs and, more recently, coughing, some chest tightness, and shortness of breath after walking on level ground. She smoked a pack of cigarettes a day from age 18 to age 40 but quit because her older brother, also a smoker, was diagnosed with emphysema. Another brother had asthma during childhood, but he outgrew it during high school. She denies any allergies or workplace exposures. Her physical examination is normal. Her lung sounds are clear.



	Pre-BD*	% of Predicted	Post-BD	% of Predicted
FVC	2.9 L	57	4.7 L	92
FEV1	1.2 L	28	2.3 L	<b>53</b>
FEV1/FVC	41%		49%	

Pattern: Obs, BD+

**Comment:** Joyce's history is consistent with COPD, asthma, gastroesophageal reflux disease (GERD), or a combination thereof. Pre-BD spirometry results indicate severe airways obstruction, as shown by the "drooping" or "scooping" pattern on the flow-volume curve, which is verified by the low FEV1/FVC ratio (only 41%). This pre-BD pattern is consistent with either COPD or asthma. However, the patient's FEV1 nearly doubles on repeat spirometry 15 minutes after administration of albuterol (post-BD). This large positive response to a bronchodilator confirms asthma. Her post-BD FEV1 (53% of predicted) places her in the *severe*, persistent asthma category.

Patients like Joyce will almost certainly respond very well to treatment with asthma controller medications.

See the Appendix (p. 33) for a sample handout that may be given to patients with asthma symptoms who have performed spirometry testing. Be sure to write in the FEV1 % of predicted (in bold above) for the patient to take home.

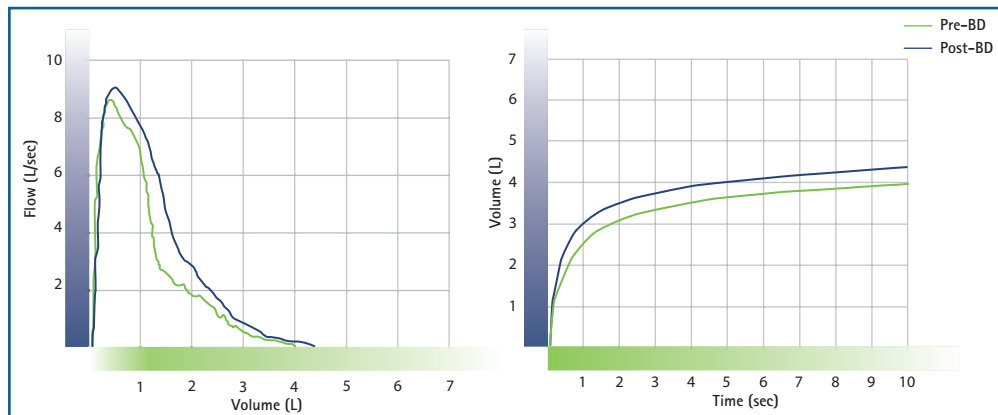
\*Each pre- and post-BD spirometry test session consists of at least three FVC maneuvers. However, for clarity in this and the following examples, data and graphs show only the best maneuver from each test session.



**Categorizing Asthma Severity.** Spirometry is useful in determining the severity of asthma, or the degree of disease control. In chronic asthma, an FEV1 above 80% of predicted suggests mild asthma or reasonable control (if the patient is being treated with an asthma-controller medication). An FEV1 between 60% and 80% of predicted suggests moderate persistent asthma or poorly controlled asthma, and a FEV1 below 60% of predicted suggests severe persistent, or uncontrolled asthma.

**Patient Example: Amber**

A 32-year-old elementary school teacher presents with a lifelong history of mild, intermittent asthma requiring only occasional rescue inhaler use. Two months ago she had an upper respiratory infection with chest tightness and wheezing which responded promptly to inhaled albuterol four times a day for a week. Since then, she reports awaking with a cough and mild shortness of breath about once a week. Her lungs are clear on examination. Based on her history, you might categorize her asthma as intermittent. However, you perform spirometry, just to be sure.



	Pre-BD	% of Predicted	Post-BD	% of Predicted
FVC	4.0 L	93	4.4 L	102
FEV1	2.5 L	71	3.0 L	86
FEV1/FVC	63%		68%	

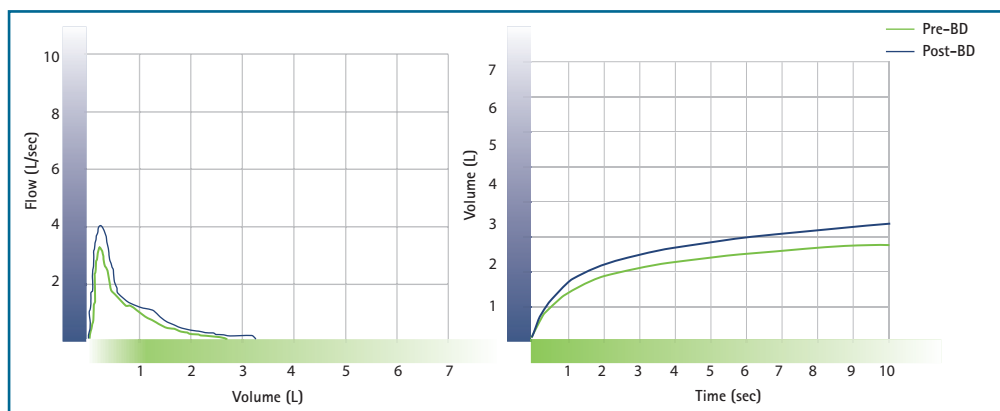
**Pattern: Obs, BD+**

**Comment:** Despite a high peak flow (8.5 L/s=510 LPM), Amber's pre-BD bowl-shaped flow-volume curve is characteristic of airways obstruction as verified by her low FEV1/FVC ratio (63%). Her FEV1 is 71% of predicted pre-BD, increasing to 86% of predicted following albuterol (BD+). Her pre-bronchodilator spirometry test reveals that she has moderate, *persistent* asthma. Daily inhaled corticosteroids are prescribed. At her 2-month follow-up visit, she reports that she is now able to exercise without coughing or chest tightness and has not used her rescue inhaler at all during the previous 4 weeks. Her follow-up spirometry values are within the normal range, suggesting that the treatment suppressed airways inflammation and that she has good asthma control.

**Detecting COPD in Adult Smokers.** Spirometry is the best means to detect the borderline-to-mild airways obstruction of early COPD due to cigarette smoking. In these patients, the FEV1/FVC ratio is below 70% even after administration of a bronchodilator. Once the diagnosis of COPD is established, the course (or response to therapy) of mild-to-moderate COPD is best followed by measuring changes in the FEV1. Continued smoking in a patient with airways obstruction often results in an abnormally rapid decline in FEV1 over time (more than 0.5 L lost per decade). Successful smoking cessation usually results in a small increase in FEV1 during the first year, followed by a nearly normal rate of FEV1 decline thereafter.

**Patient Example: Sarah**

A 52-year-old respiratory therapist consults you because her roommate has been complaining about her chronic cough and expectoration. She admits to a productive cough most mornings for more than 5 years and occasional sinus headaches; otherwise, she reports “perfect health.” Sarah does not exercise much and denies ever being short of breath. Her only medication is estrogen replacement therapy following a surgical menopause 3 years ago. Her physical examination is normal, but you notice rather excessive facial wrinkling, moderate obesity, and yellow staining of her right index finger.



	Pre-BD	% of Predicted	Post-BD	% of Predicted
FVC	2.7 L	63	3.3 L	77
FEV1	1.3 L	38	1.6 L	47
FEV1/FVC	48%		48%	

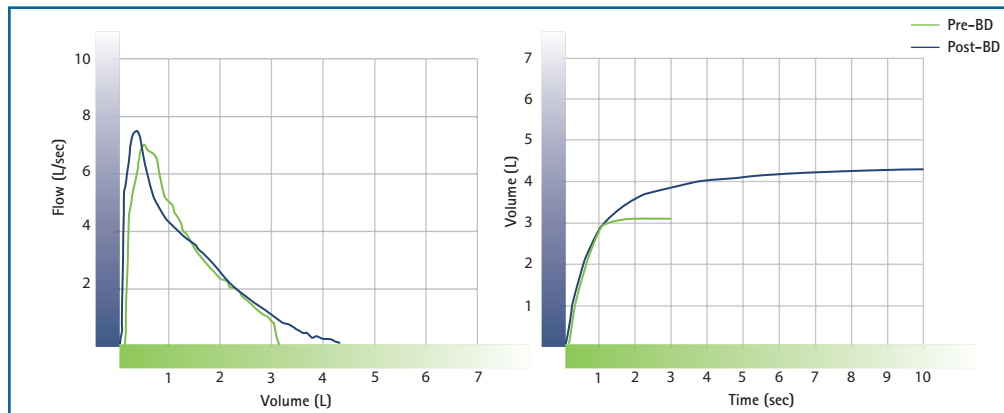
**Pattern: Obs, BD-**

**Comment:** Sarah's spirometry shows a pattern of severe airways obstruction with an FEV1 of only 38% of predicted. Her flow-volume curve has the shape and appearance of a rat's tail. On repeat spirometry, 30 minutes after administration of an albuterol inhaler and ipratropium, her FEV1 increased only slightly (BD-). You diagnose COPD. Sarah admits to smoking since age 17 and, faced with these results, would like to quit. You prescribe bupropion and refer her to a smoking cessation program.

**Chronic Bronchitis in Adult Smokers.** Spirometry is also useful in the diagnosis and detection of other lung ailments associated with smoking. Some smokers develop chronic lung infections associated with a persistent cough that may be a sign of early COPD. Many smokers ignore symptoms until they become severe. It is at this time that such patients present to your office.

**Patient Example: Billy**

The wife of a 55-year-old auto mechanic with an aversion to seeking medical attention became worried when she saw blood in a napkin as he coughed during an episode of a bad cold. She encouraged him to get a chest x-ray and see a doctor. Billy is a long-time cigarette smoker and says he feels “fine.” He claims there haven’t been any repeat instances of blood when he coughs; rather, his expectorations are now back to their “normal yellow color,” as they have been for the past 30 years. He checked NO for all of the symptom questions on your medical history form. However, upon further questioning, he admits to having to stop to catch his breath whenever he climbs stairs. His father had a heart attack at age 47 and died suddenly at age 52. Billy wants you to make sure that his heart is normal. His blood pressure is 150/90 mmHg, heart sounds are normal, and his lungs are slightly noisy on forced exhalation. You ask the nurse in your office to perform spirometry.



	Pre-BD	% of Predicted	Post-BD	% of Predicted
FVC	3.1 L	91	4.3 L	126
FEV1	2.9 L	97	2.9 L	97
FEV1/FVC	94%		67%	

**Pattern: Obs, BD-**

**Comment:** Billy’s pre-BD flow-volume curve shows the pattern of airways obstruction, but the graphs reveal that he quit exhaling too soon, after only 3 seconds, so his FVC was underestimated. His further attempts were more successful. He has no FEV1 increase (BD-) following albuterol, but he blows out for a much longer time. His FVC and FEV1 are normal post-BD, but his FEV1/FVC is abnormally low (67%), confirming obstruction. You tell him that he has chronic bronchitis and COPD, and that although his chest x-ray currently shows no signs of heart failure or lung cancer, you worry that his risk of a future heart attack or lung cancer is high. You strongly recommend smoking cessation and nicotine patches but note through your office window that he lights up another cigarette heading for his pickup truck in the parking lot.

**Smoking and Spirometry.** The National Lung Health Education Program (NLHEP) recommends that all cigarette smokers over age 45 should have spirometry performed by their primary care physician. Incipient COPD can be detected in smokers in an obstructive pattern on spirometry testing at least a decade before other signs or symptoms of COPD develop. Spirometry allows the physician to confidently tell the smoker that he or she may develop COPD (emphysema) and refer him or her to a local smoking cessation resource. These patients are more likely to successfully quit smoking than are smoking patients who have not undergone spirometry testing. If spirometry is normal, you should express relief that the smoker is not showing signs of COPD but convey your concern that he or she remains at high risk of heart attack, stroke, and/or lung cancer. Give the patient a handout like the one in the Appendix (p. 31) for adult smokers.

A patient's functional *lung age* can be calculated by some spirometers and may serve as a prompt for smokers to quit. Lung age is determined by calculating the age at which the patient's measured FEV1 would be considered normal. Smokers whose lung age is greater than their actual age may then realize that smoking has caused their lungs to deteriorate and "age" faster than normal. Calculating lung age is not appropriate for non-smokers and patients with asthma.

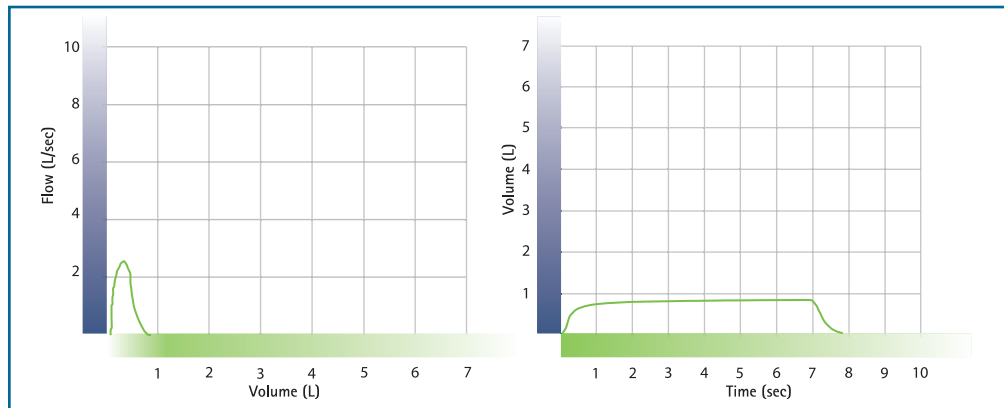
**Detecting Restriction of Lung Volume.** There are a number of disorders which lead to a restriction of the lungs (reduction in lung volume). These restrictive disorders may be divided into three groups: (1) intrinsic lung diseases which cause inflammation or scarring of the lung tissue (interstitial lung diseases) or fill airspaces with exudate or debris (acute pneumonitis); (2) extrinsic disorders of the chest wall which mechanically compress the lungs or limit their expansion; and (3) neuromuscular disorders which decrease the ability of the respiratory muscles to inflate and deflate the lungs. Spirometry is useful in detecting reduced lung volume caused by restriction but rarely aids in the differentiation between the specific causes. Some disorders, however, may be obvious from the history, physical examination, or chest x-ray.

Restriction leads to a decrease in all lung volumes—FVC, residual volume (RV), and total lung capacity (TLC). Spirometry measures FVC, the volume of air that can be exhaled rapidly after the patient takes as deep a breath as possible. At the end of a maximal exhalation, there is still a residual volume of air left in the lungs. The TLC is the sum of the FVC and the RV. **In the absence of obstruction**, a reduction in the FVC measured by spirometry is consistent with reduced inflation, no obstruction of the lungs (RINO), often due to restriction.

When spirometry results reveal both a decreased FEV1/FVC ratio and reduced FVC, two possibilities exist. The most common cause of this pattern is moderate-to-severe chronic airways obstruction (an FEV1 less than about 1.5 L) causing an increase in the amount of air left in the patient's lungs at the end of maximal exhalation (hyperinflation and an increased residual volume), necessarily associated with a low FVC. The second possibility is that a patient with COPD or asthma also has a superimposed restrictive disorder. Ordering complete PFTs (including TLC and DLCO) from a hospital-based pulmonary function laboratory and comparing the most recent chest x-ray with previous ones can often resolve this question.

**Patient Example: Frank**

A 57-year-old welder retired last year, moved from out-of-state, and finally got in to see you as his new primary care physician. He reports a 2-year history of mild shortness of breath when golfing or climbing stairs. Frank also reports an occasional dry cough that has been ongoing for a few years. He has never smoked and was a good football player in high school. His entire family is alive and well. His physical exam is normal, except for scattered, fine “Velcro” type crackles.



		% of Predicted
FVC	0.8 L	55
FEV1	0.7 L	51
FEV1/FVC	88%	

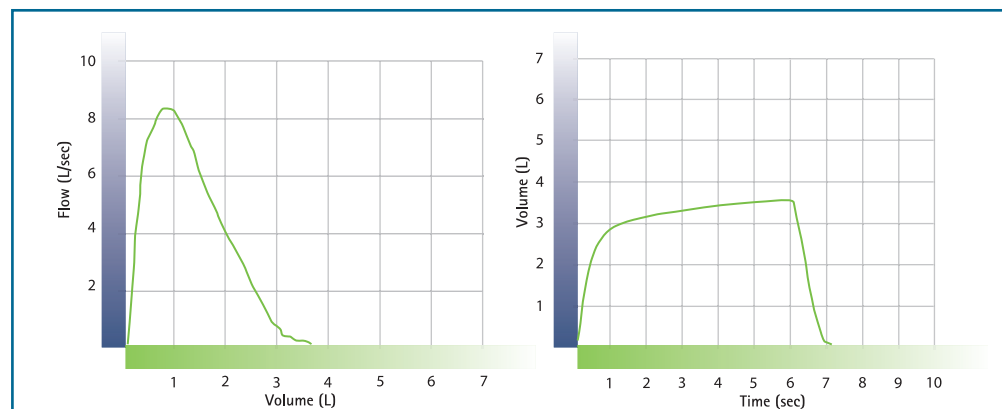
**Pattern: RINO**

**Comment:** Frank’s flow-volume curve may look normal in shape, but it is very small for an adult, and the numbers reveal a low FVC (55% of predicted) with a normal FEV1/FVC ratio (88% of predicted). This is the pattern we call reduced inflation, no obstruction (RINO). His chest x-ray showed questionable infiltrates. You order further PFTs, including a DLCO test at the local hospital. His DLCO was only 40% of predicted, with a total lung capacity of 60% of predicted, confirming restriction of his lung volumes. The pulmonologist interprets this pattern as consistent with an interstitial lung disease.



### Patient Example: Darlene

A 49-year-old fast-food manager and a life-long nonsmoker has been your patient for many years. Darlene has struggled with her weight, hypertension, and type 2 diabetes mellitus requiring treatment with an oral hypoglycemic agent. During her annual check-up, she complains of recent-onset shortness of breath which keeps her from shopping at the large local mall with her friends. She has a body mass index of 36, mild tachycardia, and a blood pressure reading of 160/95 mmHg. She also has a grade II mitral regurgitant murmur, but no gallops. Darlene's neck veins are elevated, and she has 1+ pitting ankle edema. Her lung sounds are distant but clear.



		% of Predicted
FVC	3.6 L	80
FEV1	2.9 L	91
FEV1/FVC	81%	

Pattern: N

**Comment:** Darlene has a borderline reduction in her FVC, and her FEV1 is normal. There are no signs of airways obstruction, as shown by a normal FEV1/FVC ratio (approximately 70% or greater is normal for adults). You worry about congestive heart failure (CHF) and order a chest x-ray, which shows Kerley B lines and redirection of pulmonary blood flow toward the upper lung fields. You order an echocardiogram, start her on diuretics, and recommend a low sodium diet. Upon follow-up 1 month later, she has lost 8 pounds, reports better exercise tolerance, and her FVC is now 95% of predicted. The echocardiogram shows an ejection fraction of 40% with normal wall motion and no pericardial effusion. You are now certain that her borderline low FVC was due to CHF and not obesity. During subsequent visits, you measure her FVC and weight as objective measures of therapeutic control of her CHF.



Office spirometry provides a quick, easy, and inexpensive method of detecting airways obstruction in adult cigarette smokers and patients of any age with respiratory symptoms. Spirometry also provides an objective measurement of the severity of obstructive and restrictive lung diseases and response to therapy. Airways obstruction is detected by a low FEV1/FVC ratio. Severity is determined by the FEV1 % of predicted. A clinically important, positive response to therapy is determined by an increase in the FEV1.

## Various Models of Office Spirometers



## Authors:

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**Albuterol.** An inhaled bronchodilator medication. Because albuterol acts in 10 minutes, patients can be measured with spirometry prior to (pre-BD) and after (post-BD) bronchodilator therapy. A response to albuterol (an increase in FEV1) is consistent with a diagnosis of asthma.

**American Thoracic Society (ATS).** The ATS is dedicated to providing advocacy and education for patients with lung diseases. The ATS publishes guidelines for lung function testing, including spirometry.

**BD.** A bronchodilator inhaler, such as albuterol or ipratropium.

**Bronchial hyper-responsiveness (BHR).** BHR can be measured by a methacholine challenge test. All recently symptomatic patients with asthma have BHR (twitchy airways). One goal of asthma therapy is to reduce BHR, which is closely associated with airways inflammation and obstruction.

**Body mass index (BMI).** A common measure of obesity, BMI is calculated as the weight in kilograms divided by the height in meters squared. A person with a BMI above 30 is usually considered overweight, and this could result in a mildly low FVC.

**Calibration syringe.** A large 3.0 L cylinder with a rubber sealed piston used to check the volume accuracy of spirometers.

**Chronic obstructive pulmonary disease (COPD).** Characterized by airflow obstruction, COPD is associated with chronic bronchitis and emphysema. It is usually caused by decades of cigarette smoking. COPD is easily detected by spirometry testing.

**Diffusing capacity (DLCO).** A test done in a pulmonary function laboratory, which gives an index of the ability of the lungs to rapidly take up oxygen. It is useful in the differential diagnosis of airways obstruction and restriction of lung volumes.

**Flow sensor.** A sensor used to measure airflow. A flow sensor is also known as a pneumotachometer. Some pneumotachometers are disposable (single-patient use), while others are permanent and can be cleaned and repeatedly re-used.

**Forced expiratory volume in 1 second (FEV1).** The FEV1 is the most important spirometry value. It measures the average flow rate during the first second of an FVC maneuver (expressed in liters).

**Forced expiratory volume in 6 seconds (FEV6).** The volume of air rapidly exhaled within 6 seconds. The NHANES III reference equations allow the FEV6 to replace the traditional FVC (see below for discussion of FVC). This makes spirometry easier for patients, since each FVC maneuver needs to last only 6 seconds. The FEV6 is also known as the FVC6.

**Forced vital capacity (FVC).** FVC is the volume of air exhaled during the maneuver named after it. The subject takes as deep a breath as possible and then quickly exhales (blasts) as much air as possible.

**Lower limit of the normal range (LLN).** Spirometry results below the LLN are considered to be abnormal. The LLN is based on reference values established by age, height, and gender in matched healthy persons.



***Metered-dose inhaler (MDI).*** A small, pressurized canister commonly used to deliver asthma medications, such as albuterol, directly to the airways.

***Methacholine challenge test.*** A test used to quickly rule out asthma in patients with symptoms suggesting asthma but who have normal spirometry results.

***NHANES III.*** The third National Health and Nutrition Examination Survey was conducted by the National Center for Health Statistics at the Centers for Disease Control (CDC). It collected information about the health and dietary habits of US residents.

***NLHEP.*** The National Lung and Health Education Program promotes the use of spirometry for the detection of COPD in adult smokers. They have published guidelines for the use of office spirometry.

***Obstruction.*** A decrease in maximal airflow rates caused by airways narrowing.

***Predicted value of a spirometry parameter.*** Determined from the regression equation from a large population study of healthy people such as NHANES III.

***Pulmonary function tests (PFTs).*** Lung function tests performed using equipment such as peak flow meters and/or spirometers. PFTs include spirometry, diffusing capacity (DLCO), absolute lung volumes, such as total lung capacity (TLC) and residual volume (RV), and other breathing tests.

***RINO.*** Reduced inflation, no obstruction. The spirometry pattern of a low vital capacity with a normal FEV1/FVC ratio. RINO is often, but not always, due to restriction.

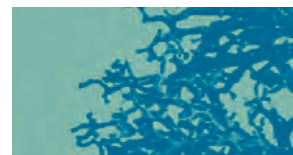
***Residual volume (RV).*** Amount of air remaining in the lungs at the end of a complete exhalation. Spirometry cannot measure the RV, which is often elevated in patients with COPD or asthma—a condition called hyperinflation.

***Restriction.*** A reduction in all lung volumes (TLC, vital capacity, and residual volume).

***Spacer.*** A device attached to MDI asthma inhalers, designed to improve deposition of the drug deeper into the patient's lungs.

***Total lung capacity (TLC).*** Amount of air in the lungs when the patient inhales as deeply as possible—also the air seen in the lungs when a chest x-ray is taken. The TLC is the sum of the FVC and the residual volume (RV).

***Two parameter spirometry.*** The most important two numbers from a spirometry test are the FEV1/FVC ratio (categorized as N, Obs, or RINO) and the FEV1 % of predicted. A ratio below 70% indicates obstruction in adults. The FEV1 % of predicted indicates the severity of the abnormality and should be provided to the patient.



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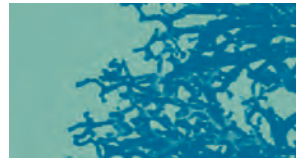
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# Appendix: Sample Patient Handouts

The following two pages may be freely duplicated for use as patient handouts. Add contact information for a local community smoking cessation resource at the bottom of the first handout.

Check the appropriate box, based on the spirometry results. Fill in the blank with the FEV1 % of predicted. If a bronchodilator (BD) was given, use the post-BD value.





### ***What Your Lung Function Results Mean For Adult Smokers***

You have just performed spirometry, the basic test of how well your lungs are working. The results indicate whether you have developed chronic obstructive pulmonary disease (COPD) due to smoking. COPD occurs in about one of every five smokers after more than 20 years of smoking. COPD slowly “eats away” at the lung’s reserves. Affected smokers are often unaware of lung disease until more than half of their lung function has been lost. Spirometry testing can detect COPD many years before symptoms occur.

- ☐ Your test result was within the normal range. You do not appear to be developing COPD. However, as a smoker, you remain at high risk of developing a heart attack, stroke, and/or lung cancer. Call the number at the bottom of this page for help with smoking cessation.
- ☐ Your test result shows mild airways obstruction, suggesting that you are a “susceptible smoker” who already shows signs of early COPD. You are unable to blow out air as quickly as normal (your FEV1/FVC is low). If you continue smoking, you will eventually develop disabling lung disease (in about 10-20 years). If you are able to successfully quit smoking sometime soon, your lung function may return to normal levels and you will probably never develop symptoms of COPD. Call the number at the bottom of this page if you would like information about local resources to help you quit smoking.
- ☐ Your test result shows moderate-to-severe airways obstruction. You have COPD. If you continue smoking, your lung disease will most likely get worse, and you will eventually become short of breath while walking, climbing stairs, or doing other exercise. It is very important that you seek help to stop smoking. If you are able to successfully quit smoking sometime soon, you will probably regain a little lung function within 3 months, and the abnormally rapid decline in your lung function which you have experienced due to smoking will be stopped. Call the number at the bottom of this page for information about local resources to help you quit smoking.
- ☐ Your test shows a low forced vital capacity (FVC). Your FVC is the total amount of air that you exhaled, in liters (similar to quarts). Values below about 80% are abnormally low and suggest that you are unable to inhale or exhale as much air as most healthy persons of your age, height, gender, and race. Obesity may be one of the causes of a mildly decreased FVC, and pneumonia is another. Consider asking your physician to review this report at some time during the next couple of months.

Your result: \_\_\_\_\_  
FEV1 % predicted

***For more information contact:***

\_\_\_\_\_  
***Date***



### *What Your Lung Function Results Mean For Those With Symptoms Suggesting Asthma*

You have just performed spirometry, the basic test of how well your lungs are working. The results may indicate whether you have asthma and its severity.

- ☐ Your test was within the normal range. If you recently had symptoms such as episodes of shortness of breath with wheezing, chest tightness, or cough, you may have asthma, but your lung function is normal today. Consider visiting a physician when you again have asthma symptoms and then repeat this spirometry test. If you already know that you have asthma, it is in good control.
- ☐ Your breathing test shows mild airways obstruction (some narrowing of your breathing tubes). You are currently unable to blow out air quickly. This result may indicate asthma that is not well controlled. Discuss with your physician medications to better control your asthma.
- ☐ Your breathing test shows moderate-to-severe airways obstruction (narrowing of your breathing tubes). You are currently unable to blow out air quickly. This result usually indicates asthma that is poorly controlled. Discuss with your physician very soon the use of medications that will help to better control your asthma and the value of peak flow monitoring.
- ☐ Your test shows a low forced vital capacity (FVC). Your FVC is the total amount of air that you exhaled, in liters (similar to quarts). Values below about 80% are abnormally low and suggest that you are unable to inhale or exhale as much air as most healthy persons of your age, height, gender, and race. Obesity may be one of the causes of a mildly decreased FVC, and pneumonia is another. Consider asking a physician to review this report at some time during the next couple of months.

Your result: \_\_\_\_\_  
FEV1 % predicted

Your peak flow after inhaling a bronchodilator was \_\_\_\_\_ LPM (liters per minute). This corresponds to \_\_\_\_\_ L/s (divide LPM by 60). You can compare this value to the peak flow that you measure using your own peak flow meter. The two numbers should match within 1 L/s (60 LPM). If your asthma is currently in good control, today's value may be close to your best peak flow reading at home.

\_\_\_\_\_  
*Date*





