

UNIT TWO: OVERVIEW OF SPIROMETRY

A. Definition of Spirometry

Spirometry is a medical screening test that measures various aspects of breathing and lung function. It is performed by using a **spirometer**, a special device that registers the amount of air a subject inhales or exhales and the rate at which the air is moved into or out of the lungs.

Spirograms are tracings or recordings of the information obtained from the test. The most common spirometric tests require that the subject exhale as forcefully as possible after taking in a full, deep breath. The subject's effort is called the **forced expiratory maneuver**.

B. Types of Spirometers

There are two types of spirometers: 1) those that record the amount of air exhaled or inhaled within a certain time (volume) and 2) those that measure how fast the air flows in or out as the volume of air inhaled or exhaled increases (flow). Both are used in screening for lung disease. (Standards for spirometric equipment are discussed in **Unit Eight: Overview of Standards for Spirometric Equipment**.)

1. Volume Spirometers

Volume spirometers record the forced expiratory maneuver as it is produced. When the subject breathes into a mouthpiece, the air moves a cylinder, a plastic bell, or a rubber or plastic diaphragm, which in turn moves a pen that traces a curve on a moving paper graph. The water seal, dry rolling seal, and bellows spirometers are the three most widely used types of volume spirometers (6, 9).

Key Features

1. Tracings record volume in relation to time. The "y" (vertical) axis plots volume in liters and the "x" (horizontal) axis plots time in seconds. (See **Figure 2- 1. Normal Volume Time Curve**.)

FIGURE 2- 1. NORMAL VOLUME TIME CURVE

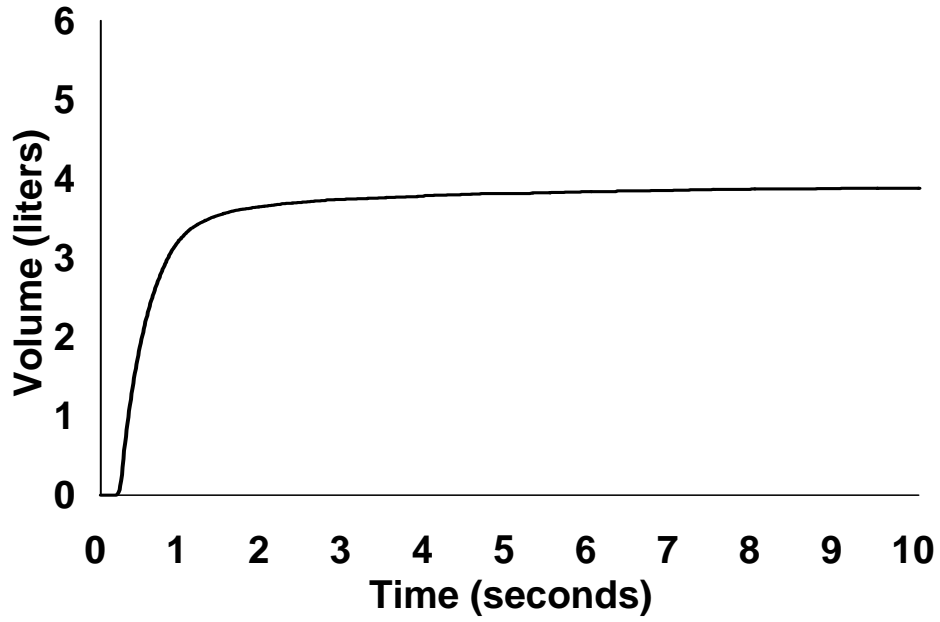
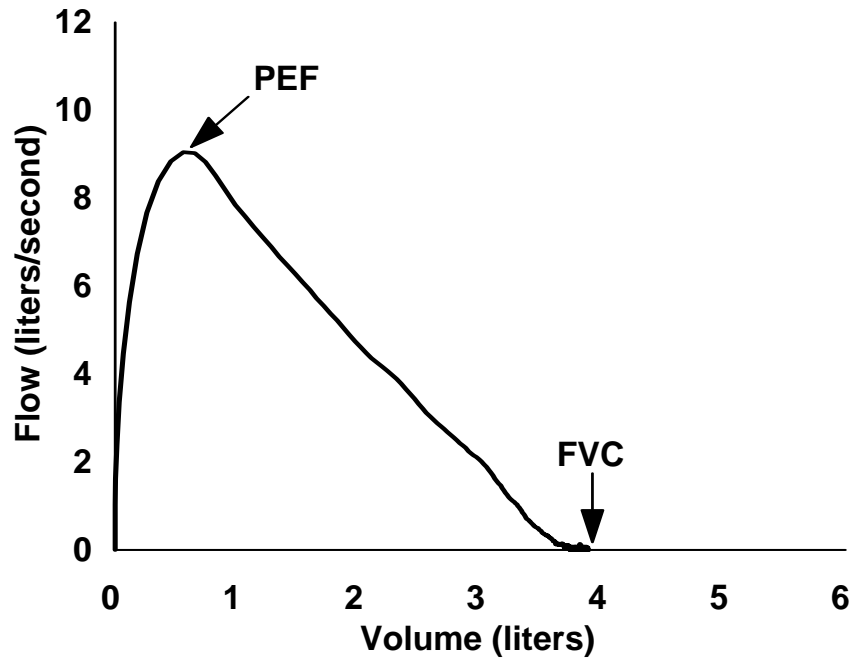


FIGURE 2- 2. NORMAL FLOW VOLUME CURVE



2. On most volume devices, the tracing is mechanically produced during the subject's expiratory maneuver. This type of spirogram is sometimes called a "real time" tracing. "Real time" tracings are useful for the following reasons:
 - a. The technician can easily determine when to end the test by watching the subject's effort being recorded as it happens. However, some volume devices do not produce a real time tracing. Instead, the tracing is printed after the forced expiratory maneuver has ended and the computer has completed its calculations. If the volume/time tracing is electronically produced, the technician should watch a digitized version of the tracing on a computer screen.
 - b. Mechanically produced tracings permit hand calculations of spirometric values (see **Unit Five: Basic Spirometric Calculations**). Even if the computer system fails, the data from the tracings can still be analyzed.
 - c. Computers or microprocessors are not needed for basic operations.
3. Some volume spirometers are easily portable and operable under a variety of environmental conditions.
4. A leak test and a three liter syringe calibration check are easy to perform (see **Unit Three: The Quality Assurance Program**).
5. Many volume spirometers can produce flow/volume curves and loops, with the addition of special electronic or digital circuitry.

Other Considerations

1. Volume spirometers hold their calibration months to years better than flow spirometers.
2. When using volume/time tracings, it is not practical to determine by hand the peak expiratory flow (PEF - the point of maximal air flow during the forced expiratory maneuver) or instantaneous flows at a given volume. However, it is possible to add special equipment that will allow this information to be obtained. Flow-volume displays can also be derived from many volume spirometers that are equipped with a potentiometer or digital encoder connected to a PC.
3. Coughs and submaximal efforts are not as obvious as they are on flow/volume tracings. The significance of coughs during a forced expiratory maneuver is discussed in **Unit Four: Spirometric Technique**.
4. Some volume spirometers are heavy, cumbersome to move, and may be prone to fostering mold or bacterial growth if not cleaned properly.

2. Flow Spirometers

Flow spirometers measure how quickly air flows past a detector and then derive the volume by electronic means. They record the flow rate at very brief intervals, such as 30-300 times a second, and use the data obtained to reconstruct the flow rate at each point in time and volume. This process is called digitization. The most common types of flow spirometers are the pneumotachographs, hot wire anemometers, and rotating vanes (6, 7).

Key Features

1. Tracings measure flow in relation to volume. The "y" (vertical) axis plots the rate of air flow in liters per second and the "x" (horizontal) axis plots volume in liters. (See **Figure 2- 2. Normal Flow Volume Curve.**)
2. Flow/volume tracings are useful for several reasons, including:
 - a. The peak expiratory flow (PEF) and instantaneous flow at any given volume can be easily determined and the patterns of slow or hesitant starts are easier to recognize.
 - b. It is very easy to detect a cough because the flow drops to zero with no air flow when the glottis closes.
 - c. It is easy to detect a possible artifact, such as occlusion from the subject's tongue or dentures, because the peak flow will be variable or reduced.
 - d. Many flow spirometers can also print flow/volume loops. These give information about inspiration as well as exhalation.
3. The computer can produce a volume-time tracing from the digitized flow rate data. However, the tracings are not mechanically produced.
4. Flow spirometers are usually lighter and more portable than volume spirometers.
5. Disposable, single-use flow sensors, available on some flow spirometers eliminate the (extremely low) risk of cross-contamination.

Other Considerations

1. The tracings are not produced during the actual maneuver but instead are reconstructed afterwards from the computerized information that has been recorded. There is no "real time" or "hard-copy" tracing that is recorded independently of the electronic system. This can be a problem for the following reasons:

- a. The equipment must include a computer, microprocessor, or other electronic circuitry; so if the electronic system fails completely, there is no tracing on which to calculate spirometric values by hand.
 - b. On some systems, the technician has to rely on the computer to decide when to end the test.
 - c. Since the tracing is reconstructed, it will usually correspond to the printout. Therefore hand calculations may not provide a reliable way to check that the system is working properly.
 - d. The Cotton Dust Standard and other federal regulations require tracings. According to the Cotton Dust Standard, "the tracing must be stored and available for recall and must be of sufficient size that hand measurements may be made (10)." (See **Appendix E. OSHA Cotton Dust Standard, Appendix D.**)
2. The Forced Expiratory Volume in One Second (FEV_1) cannot be calculated by hand unless the time is indicated in seconds on a flow-volume tracing. The FEV_1 is one of the basic spirometric calculations used in medical surveillance. It is discussed in more detail later in this unit and in **Unit Four: Spirometric Technique** and **Unit Five: Basic Spirometric Calculations**.
 3. Some flow spirometers are harder to calibrate than volume spirometers and may lose their calibration over time if not well maintained. Flow spirometers may also be less accurate in determining volumes since volume must be derived from the flow signal.

C. Important Measures of Ventilatory Performance

Certain diseases or conditions affect the rate at which air can move through the lungs (obstructive diseases) or the ability of the lungs to expand (restrictive diseases). (See **Unit One: Overview of Pulmonary Anatomy and Physiology** and **Appendix C. Overview of Occupational Lung Disease** for more information). Since spirograms reveal both the rate of air flow and the volume of air moved, they identify individuals who have these diseases or conditions.

Three measurements obtained through spirometry are particularly useful: **forced vital capacity (FVC)**, **forced expiratory volume at one second (FEV_1)**, and the **ratio of the FEV_1 to the FVC**. Computerized spirometers frequently print out six or more measures of flow or volume. However, for most purposes, the FVC and FEV_1 suffice. The FVC is the total volume of air exhaled after a **Forced Expiratory Maneuver** (the act of exhaling as hard and fast as possible after maximal inspiration). FVC should not be confused with **vital capacity**, which is defined as the maximum amount of air that the subject can breathe out after the deepest inspiration, whether or not the air was exhaled forcefully. In subjects without airways obstruction, the FVC is usually equal to the VC. The FEV_1 is the amount of air that a person breathes out during the first second of a forced expiratory maneuver. (See **Figure 2- 3. FVC and FEV_1 on a Normal Volume Time Curve** and **Figure 2- 4. FVC and FEV_1 on a Normal Flow Volume Curve.**)

The ratio of the FEV₁ to the FVC is obtained by dividing the FEV₁ by the FVC. (See **Unit Five: Basic Spirometric Calculations** for instructions on computing these measurements.)

A person with a low FVC may have a restrictive disease while a low FEV₁/FVC ratio may indicate an obstructive disease. (See **Figure 2- 5. Normal and Restrictive Pattern Volume Time Curves**, **Figure 2- 6. Flow Volume Curves**, **Figure 2- 7. Normal and Obstructive Pattern Volume Time Curves**, and **Figure 2- 8. Flow Volume Curves**.) For example, on the average, 70-80% of the FVC is exhaled in the first second from a person who is healthy, while a person with airways obstruction may only be able to exhale 60% or less of the FVC in the first second, even though the FVC may be normal. A person with a low FVC typically will also have a low FEV₁, indicating a possible restrictive pattern. Some individuals may also show evidence of a combination of both airways obstruction and a low FVC. (See **Figure 2- 9. Normal and Mixed Pattern Volume Time Curves** and **Figure 2- 10. Flow Volume Curves**.) It should be noted that some clinicians may consider these curves to show an obstructive pattern instead of a mixed pattern. In many cases, the low FVC of a mixed impairment pattern is secondary to the air-trapping and incomplete expiration of moderate or severe airways obstruction. **Table 1. Lung Diseases and Spirometry Results** shows the possible relationships between spirometry results and lung disease.

FIGURE 2-3. FVC AND FEV₁ ON A NORMAL VOLUME TIME CURVE

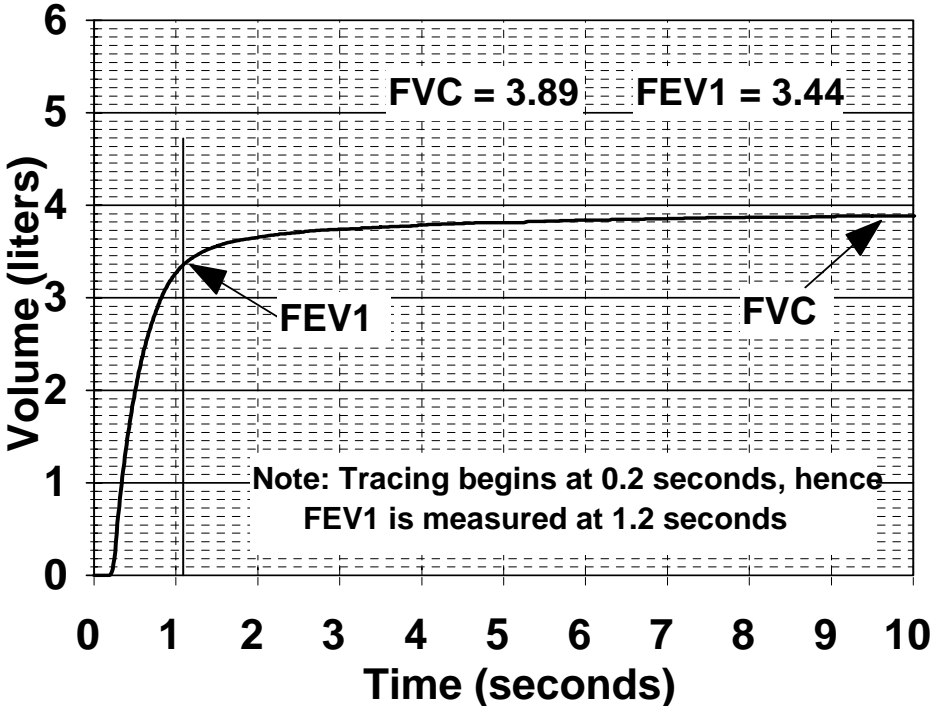
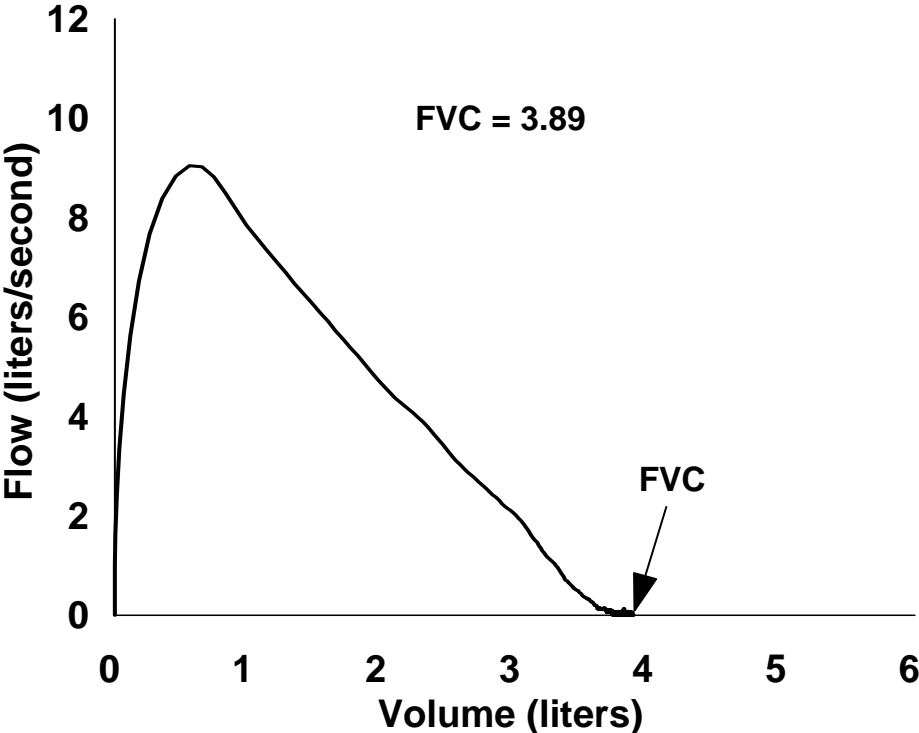


FIGURE 2-4. FVC AND FEV₁ ON A NORMAL FLOW VOLUME CURVE



**FIGURE 2-5. NORMAL AND RESTRICTIVE PATTERNS
VOLUME TIME CURVES**

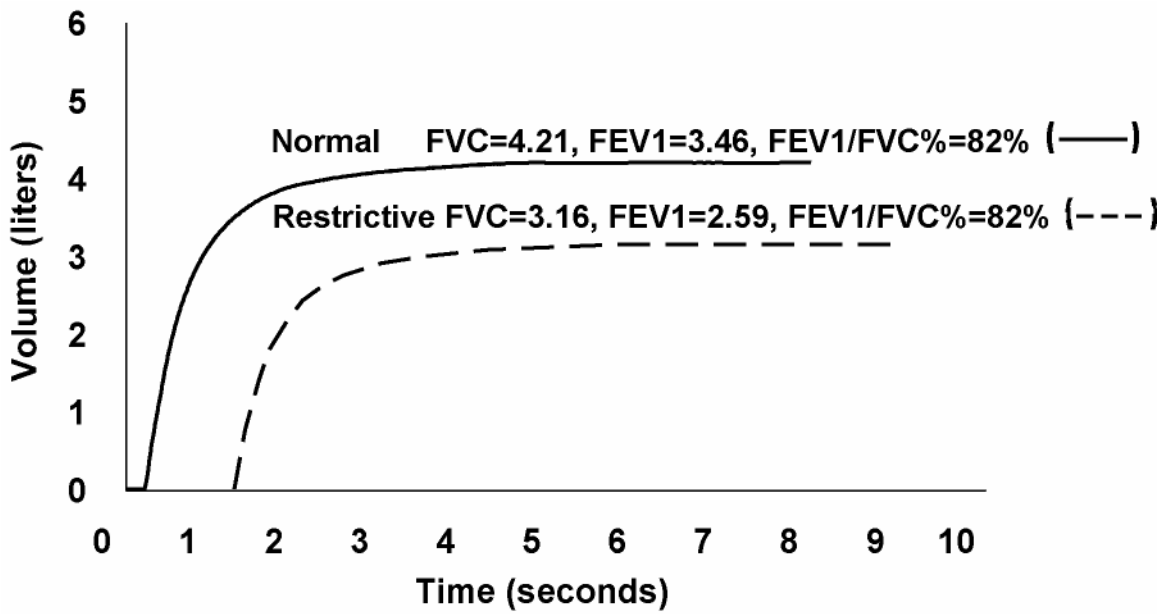
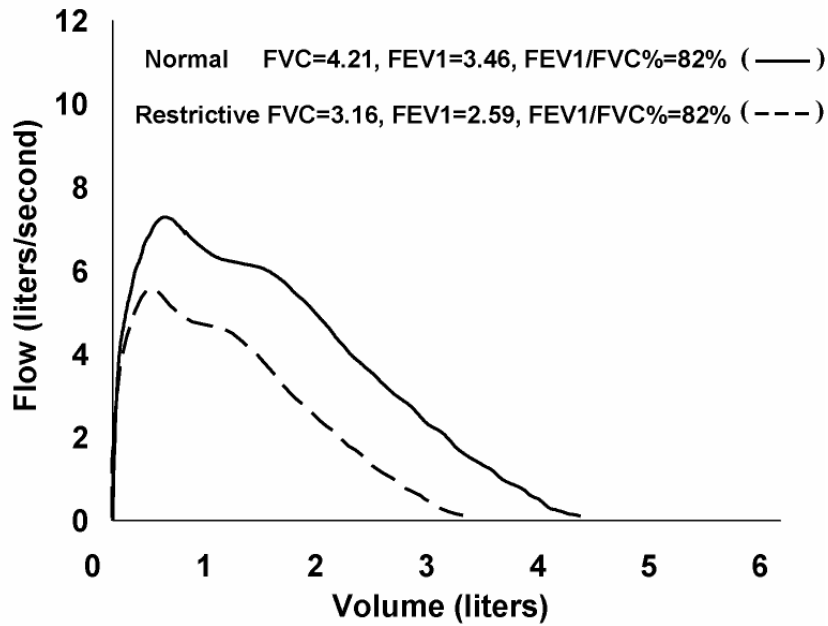


FIGURE 2-6. FLOW VOLUME CURVES



**FIGURE 2-7. NORMAL AND OBSTRUCTIVE PATTERNS
VOLUME TIME CURVES**

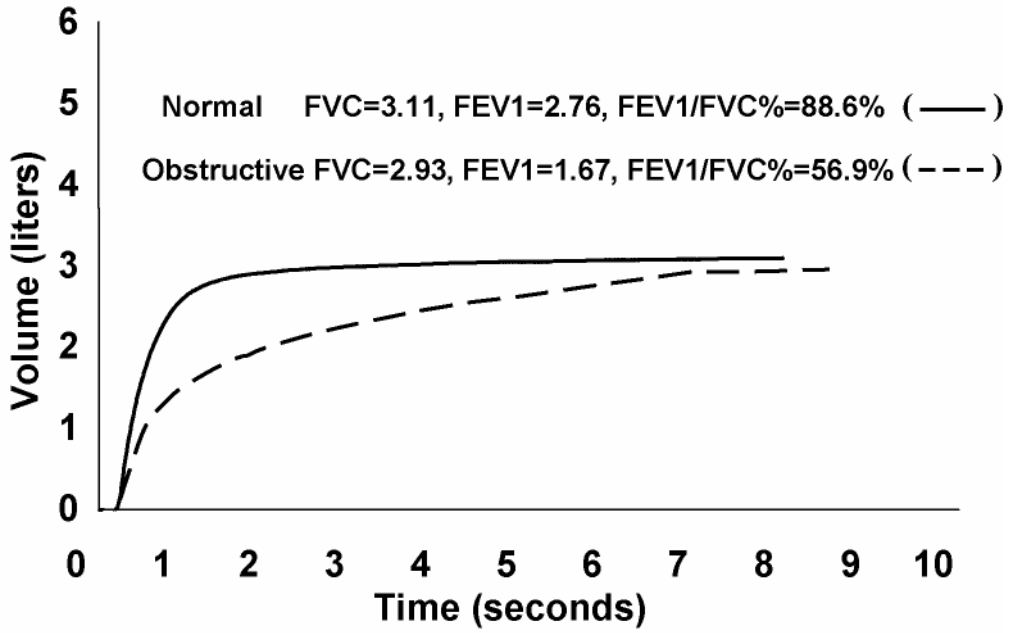
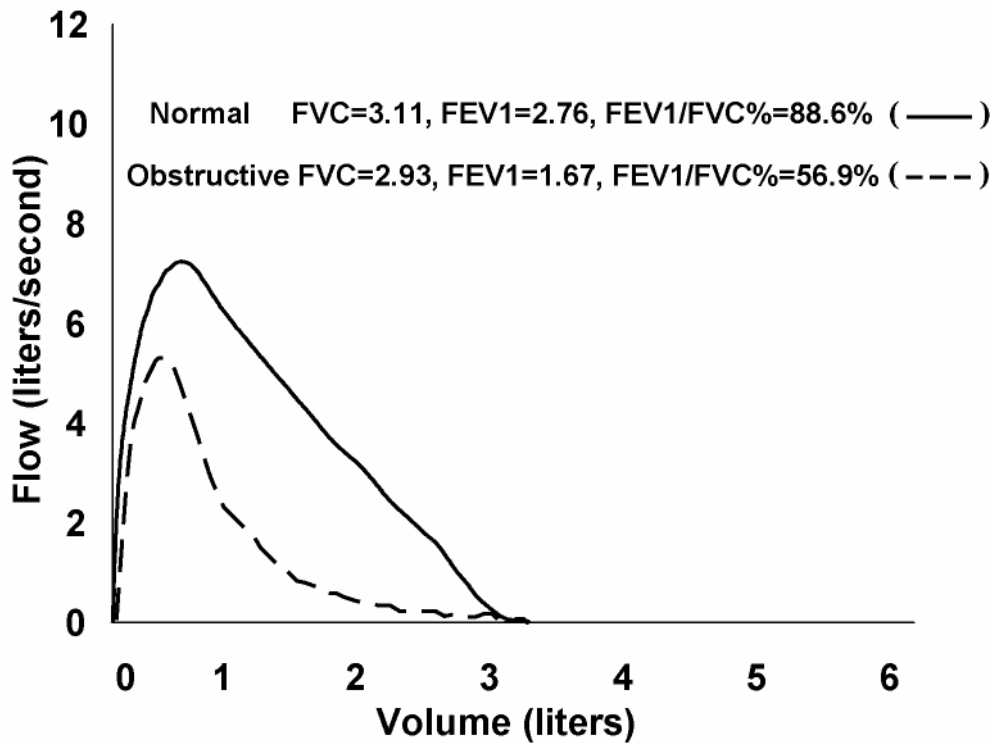


FIGURE 2-8. FLOW VOLUME CURVES



**FIGURE 2-9. NORMAL AND MIXED PATTERNS
VOLUME TIME CURVES**

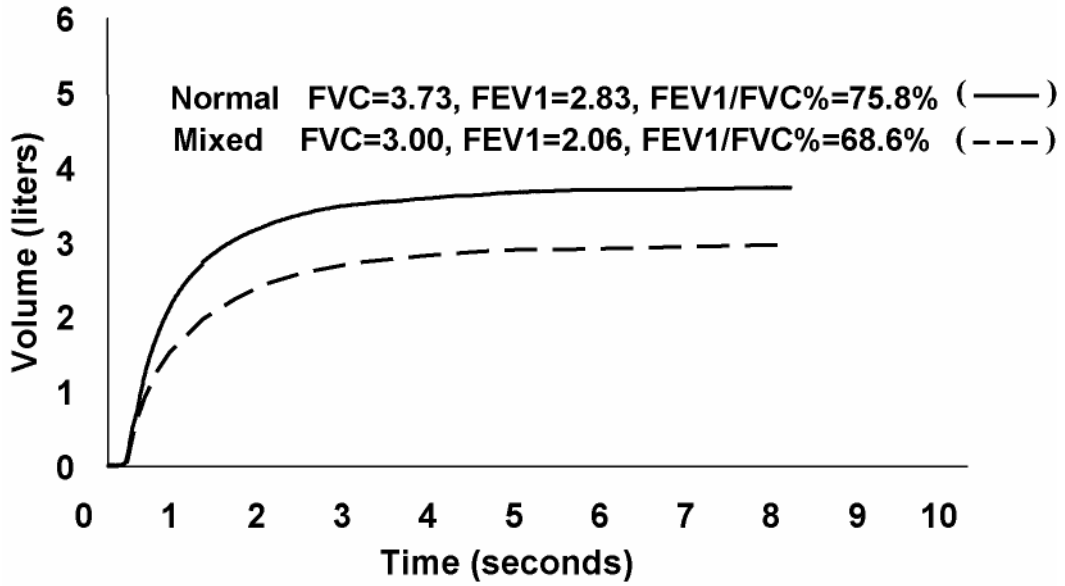


FIGURE 2-10. FLOW VOLUME CURVES

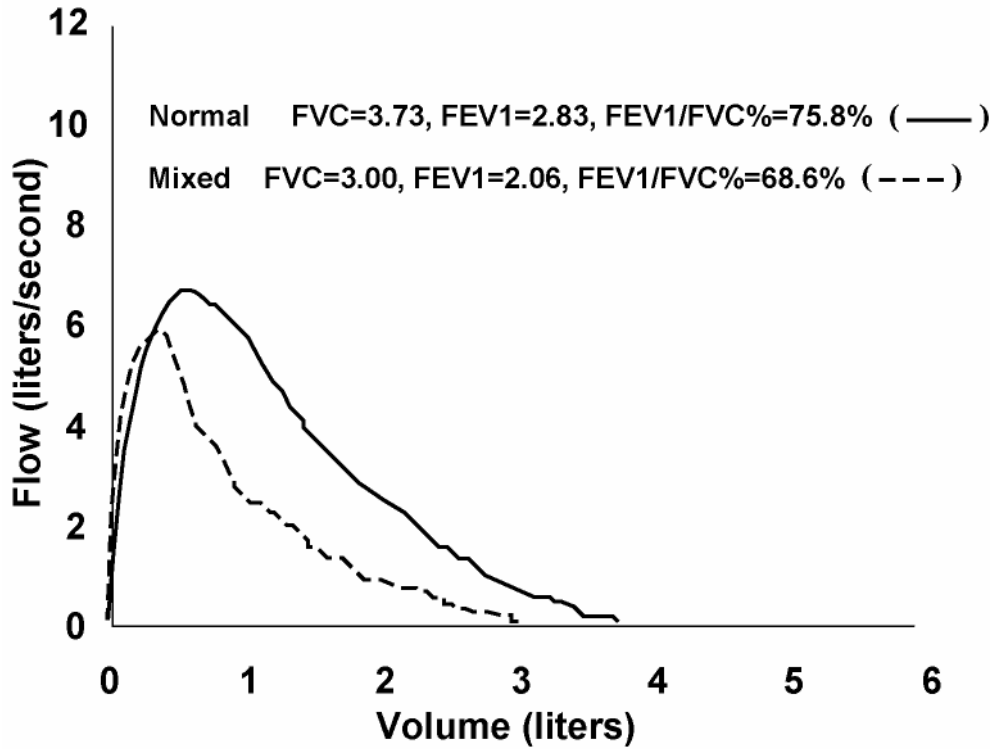


TABLE 1

LUNG DISEASES AND SPIROMETRY RESULTS

<u>Interpretation</u>	<u>FVC</u>	<u>FEV1</u>	<u>FEV1/FVC%</u>
Normal Spirometry	normal	normal	normal
Airway Obstruction	low or normal	low	low
Lung Restriction	low	low	normal
Combination of Obstruction & Restriction	low	low	low

Spirometric testing is utilized both for screening and an aid to diagnosis. As a screening tool, spirometry is performed periodically on workers at risk for occupational lung disease due to exposure to specific respiratory hazards. As a diagnostic tool, it is used when a patient has a specific medical complaint or finding, such as shortness of breath, wheezing, etc. It can also measure the effects of treatment regimens, such as use of bronchodilators or steroids.

D. Limitations of Spirometry

Although spirometry can provide useful diagnostic and screening information, it has a few limitations. Test results can show restrictive or obstructive disease patterns, but they are not disease-specific. For example, a person's spirogram may show a low FEV₁, but a physician may not be able to determine whether the cause is from asthma, emphysema, or some other obstructive disease. Additional information, such as a physical examination, chest x-rays, and health and occupational histories, are needed to make a diagnosis.

Spirometry often can detect obstructive diseases in their early stages, but for some of the restrictive diseases, it may not be sensitive enough to show abnormalities before extensive, and in some cases, irreversible damage has been done. For example, signs of silicosis and coal worker's pneumoconiosis may be found on chest x-rays while spirometry results are still normal. Thus spirometry should not be the sole screening tool of a respiratory surveillance program. Aspects of the ideal surveillance program are described in **Appendix D. Respiratory Surveillance Programs**.

E. Accuracy and Precision

Spirometric results must be **accurate**, or free from errors, to be useful. For example, three liters of air injected into a spirometer should be recorded as three liters on the tracing. The results must also be **precise**, or repeatable. For example, a spirometer must be capable of consistently recording three liters when that amount is injected into it several times. Thus the information obtained must be comparable between different settings and from one time to another.

The American Thoracic Society (ATS) has played a major role in the standardization and upgrading of spirometric instruments and practices. The ATS document, Standardization of Spirometry--1994 Update (1), points out the serious ramifications that can result if accuracy and precision are not maintained.

Spirometry is used to affect decisions about individual employees, such as: "Does this subject have enough evidence of impaired lung function to preclude working at a specific job? Should treatment be initiated or continued? Does this person qualify for full disability compensation on the basis of impaired lung function? Answers to each of these questions based on spirometric maneuvers can have a dramatic effect on a person's lifestyle, standard of living, and future treatment.

During recent testing of commercially available spirometers, devices were found that had FVC errors as large as 1.5 L, a 25% error (11). If an inaccurate spirometer is used, especially a spirometer with poor repeatability, the improvement or degradation measured may be entirely spirometer-related and have nothing to do with the subject.

Similarly, accurate spirometers are required for epidemiologic studies. Rates of improvement or deterioration of pulmonary function measured in relation to environmental exposures and/or personal characteristics may be erroneous if inaccurate, or imprecise spirometers are used (2). What can be done to assure the most accurate and precise spirometric results? Summarized below are the "Spirometry Standardization Steps" recommended by ATS in the 1994 Update (1). Each topic is covered in more detail in other units of this guide. Where appropriate, each unit refers to both the Cotton Dust Standard and ATS Standards. (See **Appendix F. American Thoracic Society Standards** for a complete copy of Standardization of Spirometry--1994 Update.)

Equipment

1. Performance. Choose equipment that meets or exceeds the Cotton Dust and ATS Standards and has been properly validated (e.g., can demonstrate that the standards have been met). Check with the manufacturer for verification and contact independent testing laboratories for information on their spirometer validation studies. (See **Unit Eight: Overview of Standards for Spirometric Equipment**.)

2. Equipment Quality Control. Check that the equipment is functioning properly by checking the calibration, checking other equipment parameters and performing maintenance procedures at regular intervals. (See **Unit Three: The Quality Assurance Program**.)

Spirometric Results

1. Performance. Obtain the best possible results from subjects through appropriate subject preparation and coaching. (See **Unit Four: Spirometric Technique**.)
2. Calculations. Use calculation methods standardized by ATS for determining test results. (See **Unit Five: Basic Spirometric Calculations**.)
3. Acceptability. Use only results from maneuvers that are free from errors. (See **Unit Four: Spirometric Technique**.)
4. Reproducibility. Use results with minimal variability whenever possible. (See **Unit Five: Basic Spirometric Calculations**.)

Interpretation of Results

1. Reference values. Select reference values appropriate to the setting and ensure that the same values are used consistently. (See **Unit Six: Comparing Observed to Predicted Normal Values** and **Unit Seven: Comparing Changes in Follow-Up Spirograms**.)

Spirometry technicians play a critical role in obtaining accurate and precise results. They frequently have primary responsibility for seeing that quality assurance measures are carried out; selecting, preparing, and coaching subjects; and determining whether results are acceptable and reproducible. Therefore it is essential that these individuals receive comprehensive training in these areas. Although the Cotton Dust Standard does not require recertification, recent studies (12, 13) have suggested that some type of quality control program that evaluates technician skills on an ongoing basis can have a dramatic effect on improving the quality of spirometry testing.