Medical Education Systems, Inc.

PFT

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Pulmonary Function Testing

Learning Objectives

Upon successful completion of this course, you will be able to:

- **Define the term "pulmonary function testing"**
- **Identify the significance of and uses for these tests**
- **Identify the basic concepts of normal pulmonary physiology that are involved in pulmonary function testing**

Introduction

Pulmonary function testing has come into widespread use since the 1970s. This has been facilitated by several developments. [1,2] Because of miniaturization and advances in computer technology, microprocessor devices have become portable and automated with fewer moving parts. Testing equipment, patient maneuvers, and testing techniques have become widely standardized throughout the world through the efforts of professional societies. Widely accepted normative parameters have been established.

Definition

Pulmonary function testing is a valuable tool for evaluating the respiratory system, representing an important adjunct to the patient history, various lung imaging studies, and invasive testing such as bronchoscopy and open-lung biopsy. Insight into underlying pathophysiology can often be gained by comparing the measured values for pulmonary function tests obtained on a patient at any particular point with normative values derived from population studies. The *percentage of predicted normal* is used to grade the severity of the abnormality. Practicing clinicians must become familiar with pulmonary function testing because it is often used in clinical medicine for evaluating respiratory symptoms such as dyspnea and cough, for stratifying preoperative risk, and for diagnosing common diseases such as asthma and chronic obstructive pulmonary disease.

Pulmonary function tests (PFTs) is a generic term used to indicate a battery of studies or maneuvers that may be performed using standardized equipment to measure lung function. PFTs can include simple screening spirometry, formal lung volume measurement, diffusing capacity for carbon monoxide, and arterial blood gases. These studies may collectively be referred to as a *complete pulmonary function survey*.

Before a spirogram can be meaningfully interpreted, one needs to inspect the graphic data (the volume-time curve and the flow-volume loop) to ascertain whether the study meets certain well-defined acceptability and reproducibility standards. Tests that fail to meet these standards can provide useful information about minimum levels of lung function, but, in general, they should be interpreted cautiously. The interpretive strategy usually involves establishing a pattern of abnormality (obstructive, restrictive, or mixed), grading the severity of the abnormality, and assessing trends over time. Various algorithms are available. Automated spirometry systems usually have built-in software that can generate a preliminary interpretation, especially for spirometry; however, algorithms for other pulmonary function studies are not as well established and necessitate appropriate clinical correlation and physician oversight.

Physiology

Basic concepts of normal pulmonary physiology that are involved in pulmonary function testing include mechanics (airflows and lung volumes), the ventilation-perfusion interrelationship, diffusion and gas exchange, and respiratory muscle or bellows strength. Ventilation is the process of generating the forces necessary to move the appropriate volumes of air from the atmosphere to the alveoli to meet the metabolic needs of the body under a variety of conditions. Simply, the contraction of the diaphragm and other inspiratory muscles expands the thorax, generating negative pressure in the pleural space. One component of pleural pressure, known as *transpulmonary pressure,* causes a flow of air into the airways and lungs (inspiration). When the transpulmonary and alveolar pressures equilibrate, airflow stops, the inspiratory muscles relax, and the lungs and chest wall elastic recoil raise pleural pressure, forcing air out of the lungs (expiration).

With a forced exhalation, the early portion of the spirometry maneuver is characterized by high flows, mostly from large airways, and the latter portion is characterized by low flows with a larger contribution from the smaller airways. [3] Forced inspiration is generally not flow limited and is a function of overall muscular effort. In contrast, a variety of factors affect expiratory flow, including the overall driving pressure, airway diameter, overall distensibility of the lungs and chest wall, dynamic airway collapse (from a flow-limiting segment), and muscular effort. The overall driving pressure is the pressure head at the alveolus, or Palv, which is the difference between pleural pressure (Ppl) and negative transpulmonary pressure (Ptp). So:

$$Palv = Ppl + Ptp$$

The mechanism for the maximal expiratory airflow limitation seen in normal airways results from the gradual drop in pressure inside the conducting airways from the alveoli to the mouth, creating a transmural pressure gradient with the pleural pressure. This can cause dynamic airway compression and narrowing or closure of airways that have lost elastic recoil support from the lung parenchyma.

Battery of maneuvers

Pulmonary function studies use a variety of maneuvers to measure and record the properties of four lung components. These include the airways (large and small), lung parenchyma (alveoli, interstitium), pulmonary vasculature, and the bellows-pump mechanism. Various diseases can affect each of these components.

Spirometry

Spirometry is the most commonly used lung function screening study. It generally should be the clinician's first option, with other studies being reserved for specific indications. Most patients can easily perform spirometry when coached by an appropriately trained technician or other health care provider. The test can be administered in the ambulatory setting, physician's office, emergency department, or inpatient setting. The indications for spirometry are diverse (Box 1). It can be used for diagnosing and monitoring respiratory symptoms and disease, for preoperative risk stratification, and as a tool in epidemiologic and other research studies.

Box 1: Indications for Spirometry
Diagnostic

To evaluate symptoms

1. Chest pain
2. Cough
3. Dyspnea
4. Orthopnea
5. Phlegm production
6. Wheezing

To evaluate signs

1. Chest deformity
2. Cyanosis
3. Diminished breath sounds
4. Expiratory slowing
5. Over-inflation
6. Unexplained crackles

To evaluate abnormal laboratory tests

1. Abnormal chest radiographs
2. Hypercapnia
3. Hypoxemia
4. Polycythemia

To measure the effect of disease on pulmonary function
To screen persons at risk for pulmonary diseases

1. Smokers

2. Persons in occupations with exposures to injurious substances

Some routine physical examinations
1. To assess preoperative risk
2. To assess prognosis (lung transplant, etc.)
3. To assess health status before enrollment in strenuous physical activity programs

Monitoring

To assess therapeutic interventions
1. Bronchodilator therapy
2. Steroid treatment for asthma, interstitial lung disease, etc.
3. Management of congestive heart failure
4. Other (antibiotics in cystic fibrosis, etc.)

To describe the course of diseases affecting lung function
1. Pulmonary diseases
2. Obstructive small airway diseases
3. Interstitial lung diseases
4. Cardiac diseases
5. Congestive heart failure
6. Neuromuscular diseases
7. Guillain-Barré syndrome

To monitor persons in occupations with exposure to injurious agents
To monitor for adverse reactions to drugs with known pulmonary toxicity

Evaluation of Disability or Impairment

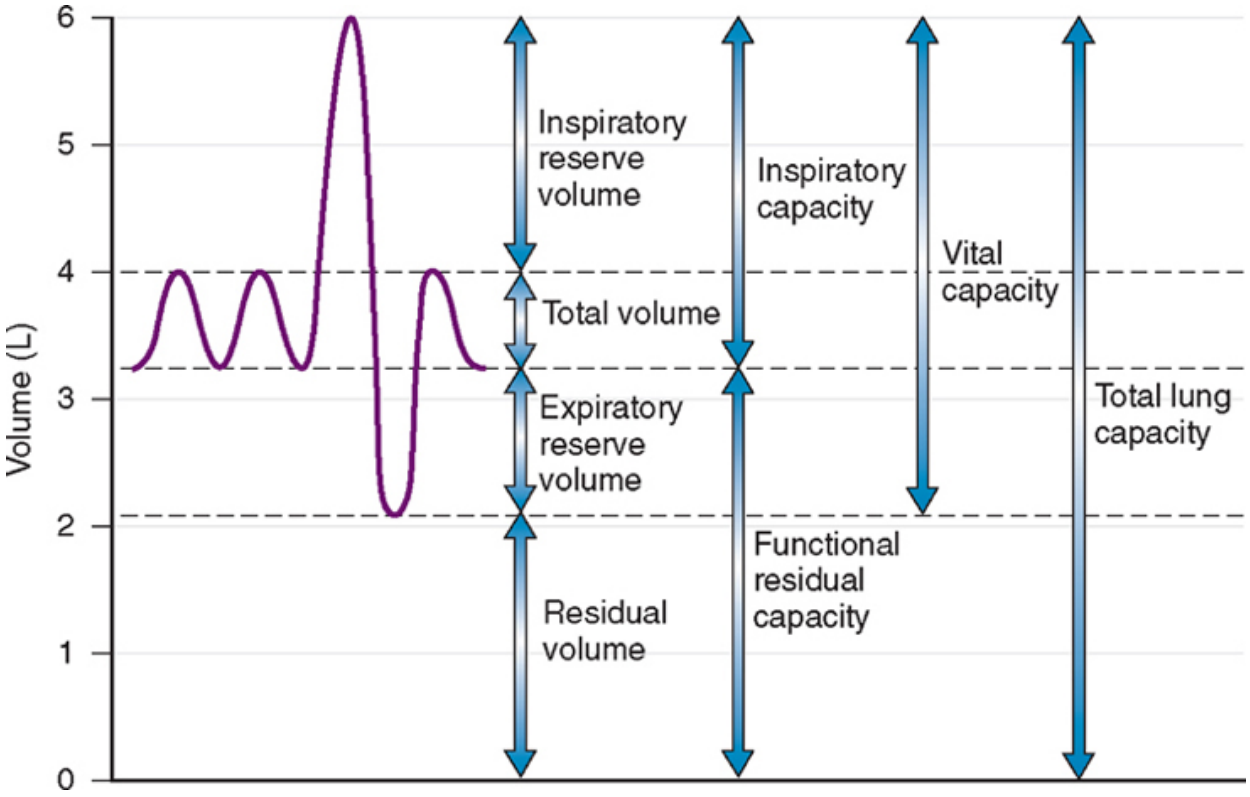
To assess patients as part of a rehabilitation program
1. Medical
2. Industrial
3. Vocational

To assess risks as part of an insurance evaluation
To assess persons for legal reasons
1. Social Security or other government compensation programs
2. Personal injury lawsuits
3. Other

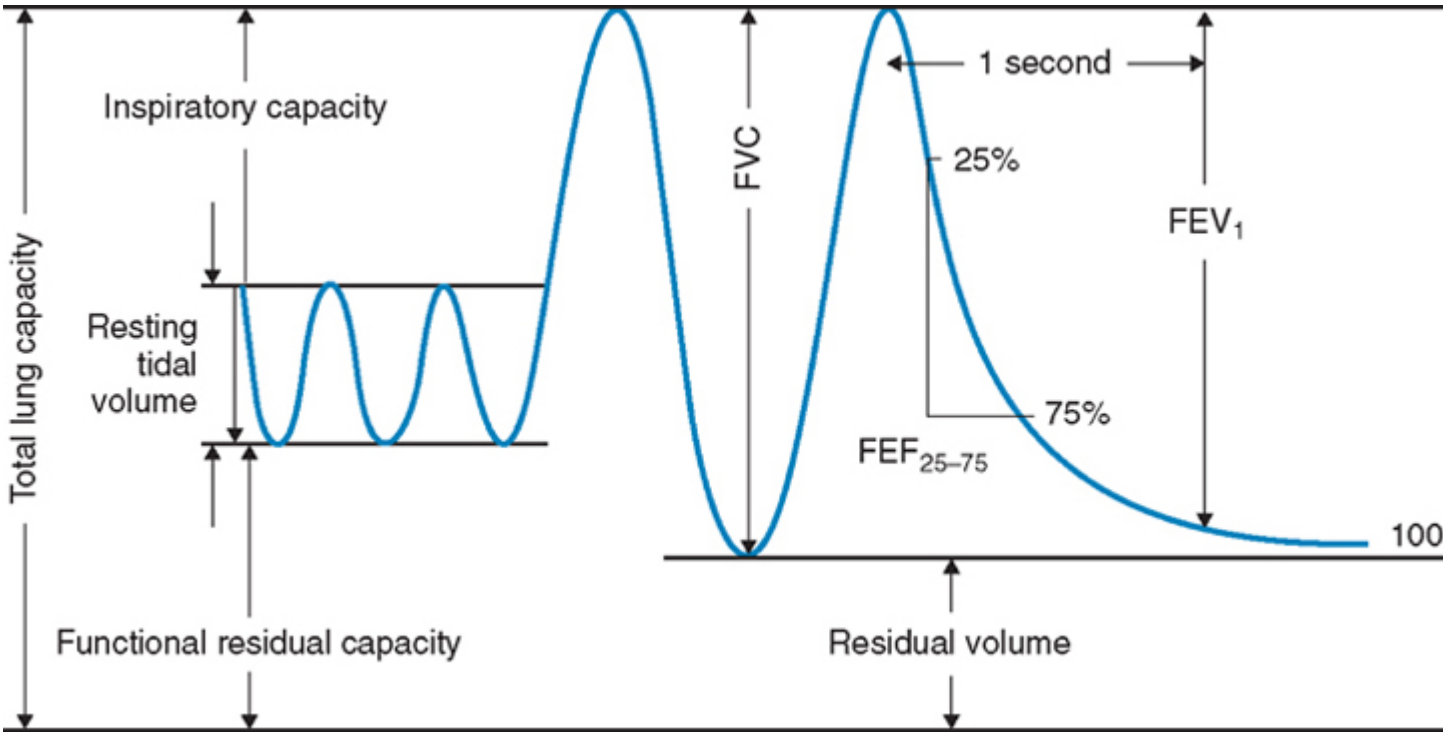
Public Health

- Epidemiologic surveys
- Comparison of health status of populations living in different environments
- Validation of subjective complaints in occupational or environmental settings
- Derivation of reference equations

Spirometry requires a voluntary maneuver in which a seated patient inhales maximally from tidal respiration to total lung capacity and then rapidly exhales to the fullest extent until no further volume is exhaled at residual volume [3] (Figs. 1 and 2). The maneuver may be performed in a forceful manner to generate a forced vital capacity (FVC) or in a more relaxed manner to generate a slow vital capacity (SVC). In normal persons, the inspiratory vital capacity, the expiratory SVC, and expiratory FVC are essentially equal. However, in patients with obstructive small airways disease, the expiratory SVC is generally higher than the FVC. This difference might, however, be due partly to the difficulty in maintaining a *maximum* expiratory effort for an extended time period without experiencing dizziness or lightheadedness.



The waterless, rolling seal type, and Stead-Wells water seal type is an instrument that directly measures the volume of air displaced or measures airflow by a flow-sensing device, such as a pneumotachometer or a tube containing a fixed resistance to flow (Box 2). [2] Today, most clinical pulmonary function testing laboratories use a microprocessor-driven pneumotachometer to measure air flow directly and then to mathematically derive volume.



Box 2: Types of Spirometers
Volume

- Bellows
- Rolling seal
- Water
- Dry

Flow Sensing (Pneumotach)

- Fleisch
- Screen
- Hot-wire
- Turbine

Adapted from Miller WF, Scacci R, Gast LR: Laboratory Evaluation of Pulmonary Function. Philadelphia, JB Lippincott.

A spirogram is a graphic representation of bulk air movement depicted as a volume-time tracing or as a flow-volume tracing. Values generated from a simple spirogram provide important graphic and numeric data regarding the mechanical properties of the lungs, including airflow (forced expiratory volume in 1 second [FEV_1] along with other timed volumes) and exhaled lung volume (FVC or SVC). The measurement is typically expressed in liters for volumes or in liters per second for flows and is corrected for body temperature and pressure of gas that is saturated with water vapor.

Data from a spirogram provide important clues to help distinguish obstructive pulmonary disorders that typically reduce airflow, such as asthma and emphysema, from restrictive disorders that typically reduce total lung volumes, including pulmonary fibrosis and neuromuscular disease.

A number of spirometry standards have been developed over the years. The American Thoracic Society standardization guidelines for acceptability and reproducibility criteria are shown in Box 3. [4] A well-trained pulmonary function technician usually coaches the patient through the session until the demonstrated reproducibility of key parameters suggests the results represent the best possible measure of lung function at that time.

Box 3: Acceptability and Reproducibility Criteria for Spirograms

Acceptability Criteria

Free from artifacts

1. Cough or glottis closure during the first second of exhalation
2. Early termination or cutoff
3. Variable effort
4. Leak
5. Obstructed mouthpiece

Good start

1. Extrapolated volume is <5% of FVC or 0.15 L, whichever is greater or
2. Time to PEF is <120 ms (optional until further information is available)

Satisfactory exhalation

1. 6 sec of exhalation and/or a plateau in the volume-time curve or
2. Reasonable duration or a plateau in the volume-time curve or
3. The subject cannot or should not continue to exhale

Repeatability Criteria

After three acceptable spirograms have been obtained, apply the following tests.

1. Are the two largest FVCs within 0.2 L of each other?
2. Are the two largest FEV_1s within 0.2 L of each other?

If both of these criteria are met, the test session may be concluded.
If both of these criteria are not met, continue testing until:

1. Both of the criteria are met with analysis of additional acceptable spirograms or
2. A total of eight tests have been performed or
3. Save a minimum of three best maneuvers

Adapted from American Thoracic Society: Single-breath carbon monoxide diffusing capacity (transfer factor). Recommendations for a standard technique—1995 update. Am J Respir Crit Care Med

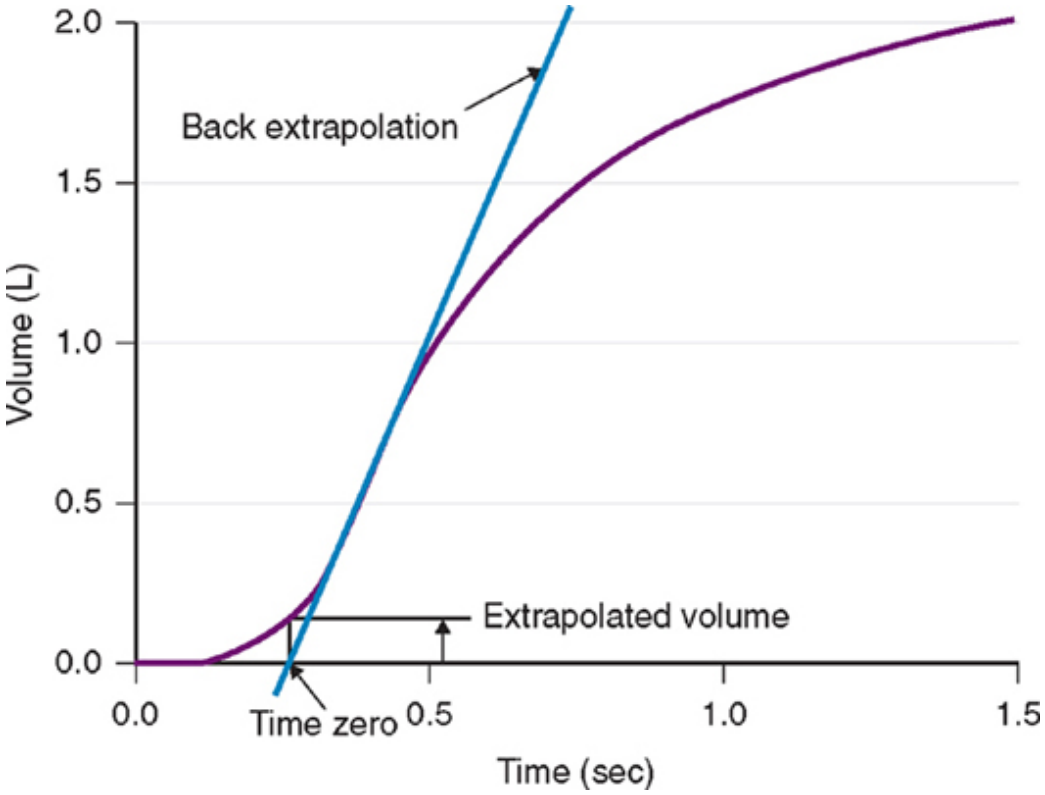
Forced Expiratory Volume in 1 Second

The FEV_1 is the most widely used parameter to measure the mechanical properties of the lungs. In normal persons, the FEV_1 accounts for the greatest part of the exhaled volume from a spirometric maneuver and reflects mechanical properties of the large and the medium-sized airways. In a normal flow-volume loop, the FEV_1 occurs at about 75% to 85% of the FVC. This parameter is reduced in obstructive and restrictive disorders. In obstructive diseases, FEV_1 is reduced disproportionately to the FVC, reducing the FEV_1/FVC ratio below the lower limit of normal and indicates airflow limitation. In restrictive disorders, the FEV_1, FVC, and total lung capacity are all reduced, and the FEV_1/FVC ratio is normal or even elevated.

Forced Vital Capacity

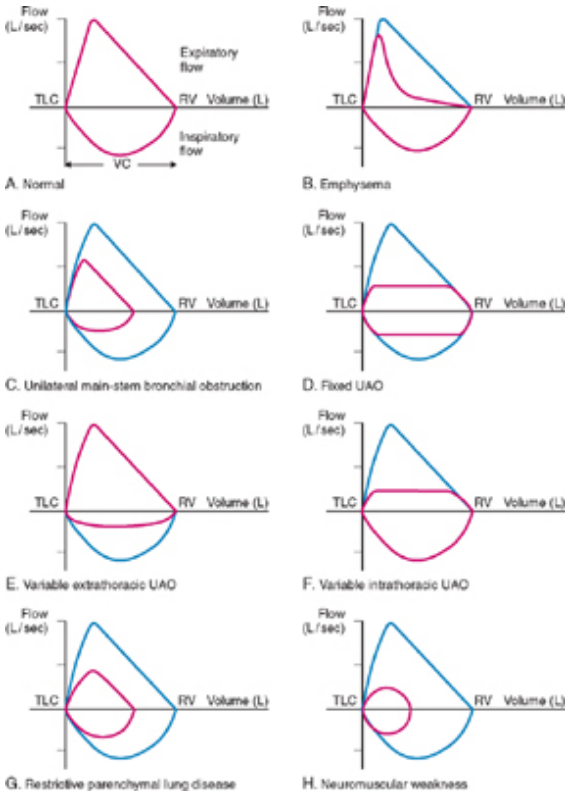
FVC is a measure of lung volume and is usually reduced in diseases that cause the lungs to be smaller. Such processes are generally termed *restrictive* and can include disorders of the lung parenchyma, such as pulmonary fibrosis, or of the bellows, including kyphoscoliosis, neuromuscular disease, and pleural effusion. However, a reduction in FVC is not always due to reduced total volumes and can occur in the setting of large lungs hyperinflated due to severe airflow obstruction and air trapping, as in emphysema. In this setting, the FVC is decreased due to reduced airflow, air trapping, and increased residual volume, a phenomenon referred to as *pseudorestriction*. Reduced FVC can occur despite a normal or increased total lung volume. Therefore, FVC is not a reliable indicator of total lung capacity or restriction, especially in the setting of airflow obstruction. The overall accuracy of the FVC for restriction is about 60%. [5]

Volume-Time Tracing and Flow-Volume Loop



The volume-time tracing and flow-volume loop ascertain the technical adequacy of a maneuver and therefore the quality of the data (see Box 3) as well as identifying the anatomic location of airflow obstruction. The volume-time tracing is most useful in assessing whether the end-of-test criteria have been met, whereas the flow-volume loop is most valuable in evaluating the start-of-test criteria. The technique of back-extrapolation of the start of the test to establish a zero time point on the volume-time tracing has been carefully defined and provides a uniform start point for timed measurements. It corrects for delayed or hesitant starts that might otherwise be mistaken for a falsely reduced FEV_1. Standards for acceptability define limits for the degree of hesitation that can still yield an acceptable FEV_1 (see Box 3). The loss of elastic recoil characteristic of emphysema results in airflow limitation during the maximal forced exhalation that may be grossly underestimated if the patient applies less than maximal expiratory force. Such efforts may still be deemed acceptable using the criteria of extrapolated volume. The time to peak flow appears to have excellent usefulness in identifying such efforts in this population (time to peak flow will be greater than 120 msec when effort is submaximal), but it is not yet a recommended acceptability criterion (Fig. 3).

The shape of the flow-volume loop can indicate the location of airflow limitation, such as the large upper airways or smaller distal airways (Fig. 4). With common obstructive airflow disorders, such as asthma or emphysema, the disease generally affects the expiratory limb and can reduce the effort-dependent peak expiratory flow as well as subsequent airflows that are independent of effort. The descending limb of the expiratory loop is typically concave. In contrast, several unusual anatomic disorders that narrow the large airways can produce a variety of patterns of truncation or flattening of either one limb of the loop (variable upper airway obstruction) or both limbs of the loop (fixed upper airway obstruction).



Additional Tests

A variety of parameters selectively reflect small airways. [6] These include measures of flow from a spirogram, such as the maximal midexpiratory flow (MMEF) or forced expiratory flow at 25% to 75% vital capacity (FEF_{25-75}). The FEF_{25-75} is the slope of the spirogram between the 25th and the 75th percentiles of an FVC maneuver. Normal values and lower limits of normal for the FEF_{25-75}% have been published. [7] Care must be taken to use the statistically defined lower limit of normal and avoid assessing this parameter using the percentage of predicted normal value because the lower limit of normal falls significantly with age.

The closing volume from a single-breath N_2 test and frequency-dependent dynamic lung compliance also can be used to detect small airways disease. It is believed that small airways dysfunction can precede and exist separately in the setting of a normal FEV_1 and FVC. The hypothesis is that smokers might have isolated small airways dysfunction and that there is an obligatory passage through a silent period during which only sensitive tests are impaired. However, there is a greater coefficient of variation for these tests of small airways function. In addition, because these measures are vitally influenced by lung volumes, they cannot be interpreted separately without volume correction. Therefore, in practice, these tests have not been particularly helpful to practicing clinicians, and the American Thoracic Society does not recommend their use for detecting small airways disease. [6] Normal values for a new parameter to assess small airways function, the FEV_3/FVC ratio, are available, but this parameter has not yet been sufficiently validated. [8]

Bronchoprovocation

To define whether nonspecific airway hyperreactivity is a mechanism for atypical chest symptoms of unclear origin, inhalational challenge tests are often used in the pulmonary function laboratory. [9,10,11] Methacholine and histamine are the agents most often used with this procedure, although other agents may also be useful. Methacholine is considered safe, can be used in outpatient clinics, and has no systemic side effects.

When the baseline spirogram is relatively normal, inhalational challenge may be performed by aerosolizing progressive concentrations of methacholine by a dosimeter. This is typically performed as a five-stage procedure with five different increasing concentrations. After each stage, the patient performs a spirometry. When there is a 20% reduction in the FEV_1, the test is terminated and is considered positive for airway hyperreactivity. The provocative concentration dosage level of the inhalational agent required to produce a 20% reduction in the FEV_1 is labeled PC_{20FEV1}. If the drop in FEV_1 is less than 20% after five stages of this procedure, the challenge test is considered negative for airway hyperreactivity. A PC_{20FEV1} of less than 8 mg/mL suggests clinically important airway hyperreactivity.

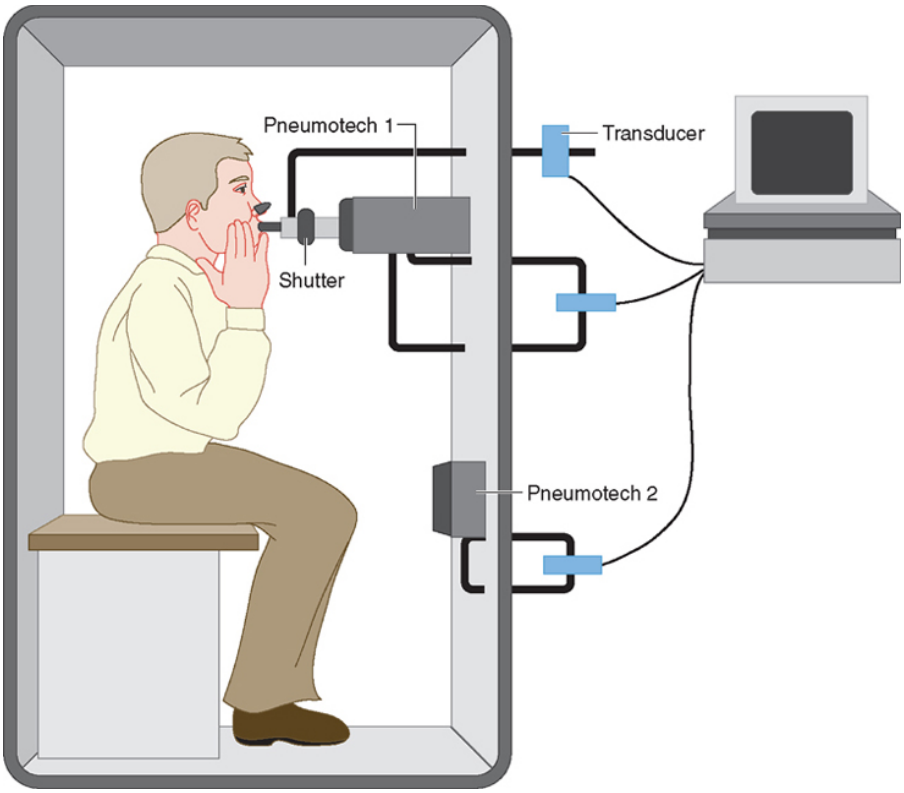
Bronchial hyperreactivity, as assessed by this inhalational challenge procedure, is very sensitive for the presence of active or current asthma. A positive test strongly suggests bronchial asthma. However, this test may be falsely positive in a variety of conditions, including chronic obstructive pulmonary disease, parenchymal respiratory disorders, congestive heart failure, recent upper respiratory tract infection, and allergic rhinitis. A negative inhalational challenge with methacholine or histamine has been believed to exclude active symptomatic asthma as a cause for the patient's chest symptoms; however, a recent study suggests that significant changes in another measure of airway function, specific airways conductance (SGaw), can occur during a methacholine challenge in the absence of a significant change in FEV_1. This study was duplicated in our laboratory with the same results (unpublished).

Lung Volumes

Because spirometry is an expiratory maneuver, it measures exhaled volume or vital capacity but does not measure residual volume, functional residual capacity (resting lung volume), or total lung capacity. Vital capacity is a simple measure of lung volume that is usually reduced in restrictive disorders; however, reduction in the vital capacity measured during spirometry should prompt measurement of lung volumes to confirm the presence or absence of a true restrictive ventilatory disorder.

Other pulmonary function methodology is required to formally measure total lung capacity, which is derived from the addition of functional residual capacity (FRC) to inspiratory capacity obtained from spirometry. [2] FRC is usually measured by a gas dilution technique or body plethysmography. Gas dilution techniques are based on a simple principle, are widely used, and provide a good measurement of all air in the lungs that communicates with the airways. A limitation of this technique is that it does not measure air in noncommunicating bullae, and therefore it can underestimate total lung capacity, especially in patients with severe emphysema.

Gas dilution techniques use either closed-circuit helium dilution or open-circuit nitrogen washout. They are based on the inhalation of a known concentration and volume of an inert tracer gas, such as helium, followed by equilibration of 7 to 10 minutes in the closed-circuit helium dilution technique. The final exhaled helium concentration is diluted in proportion to the unknown volume of air in the patient's chest (residual volume). Usually, the patient is connected at the end-tidal position of the spirometer; therefore, the lung volume measured is FRC. In the nitrogen-washout technique, the patient breathes 100% oxygen, and all the nitrogen in the lungs is washed out. The exhaled volume and the nitrogen concentration in that volume are measured. The difference in nitrogen volume at the initial concentration and at the final exhaled concentration allows a calculation of intrathoracic volume, usually FRC.



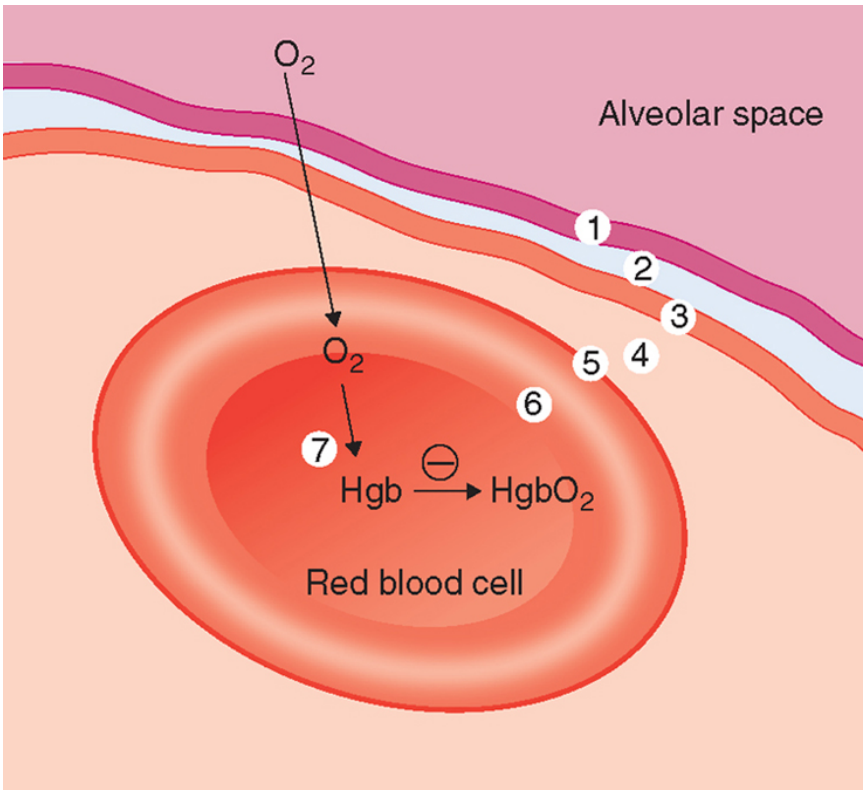
Body plethysmography is an alterative method of measuring lung volume that takes advantage of the principle of Boyle's law, which states that the volume of gas at a constant temperature varies inversely with the pressure applied to it. The primary advantage of body plethysmography is that it can measure the total volume of air in the chest, including gas trapped in bullae. Another advantage is that this test can be performed quickly. Drawbacks include the complexity of the equipment as well as the need for a patient to sit in a small enclosed space. A patient is placed in a sitting position in a closed body box with a known volume (Fig. 5). From the FRC, the patient pants with an open glottis against a closed shutter to produce changes in the box pressure proportionate to the volume of air in the chest. The volume measured by this technique is referred to as *thoracic gas volume* (TGV) and represents the lung volume at which the shutter was closed, typically FRC.

After the FRC is measured by any of these techniques, measurement of lung subdivisions (inspiratory capacity, expiratory reserve volume, vital capacity) ensues, ideally while the patient is still on the mouthpiece. From these volumes and capacities, the residual volume and total lung capacity can be calculated.

Diffusing Capacity

Understanding gas diffusion through the lungs requires recognizing the basics of the gas exchange interface and of the various forces at work by which oxygen and carbon dioxide move by molecular diffusion.

Diffusion is limited by the surface area in which diffusion occurs, capillary blood volume, hemoglobin concentration, and the properties of the lung parenchyma that separate the alveolar gas from the red blood cell with the capillary (alveolar-capillary membrane thickness, presence of excess fluid in the alveoli) (Fig. 6). [2]



Because all lung volume is not exchanged, most gas exchange occurs as a function of diffusion independent of bulk flow. The role of ventilation is to reset concentration of the bulk flow of gas with the ambient air and to provide a constant gradient for oxygen and carbon dioxide. As spirometry measures the components of this bulk flow exchange, diffusing capacity measures the forces at work in molecular movement with its concentration gradient from the alveolar surface through to the hemoglobin molecule. [12] The clinical test diffusing capacity of the lung most commonly uses carbon monoxide as the tracer gas for measurement because of its high affinity for binding to the hemoglobin molecule. This property allows a better measurement of pure diffusion, such that the movement of the carbon monoxide in essence only depends on the properties of the diffusion barrier and the amount of hemoglobin. The properties of oxygen and its relatively lower affinity for hemoglobin compared with carbon monoxide also make it more perfusion dependent; thus, cardiac output can influence actual measurement of oxygen diffusion measurements. [12]

Diffusing capacity of the lung for carbon monoxide (DL_{CO}) is the measure of carbon monoxide transfer. In Europe, it is often called the *transfer factor of carbon monoxide,* which describes the process more accurately. DL_{CO} is a measure of the interaction of alveolar surface area, alveolar capillary perfusion, the physical properties of the alveolar capillary interface, capillary volume, hemoglobin concentration, and the reaction rate of carbon monoxide and hemoglobin. After a number of simplifications, the commonly used clinical tests to measure DL_{CO} are based on a ratio between the uptake of carbon monoxide in milliliters per minute divided by the average alveolar pressure of carbon monoxide. [13] Overall, DL_{CO} is expressed as the uptake of carbon monoxide in milliliters of gas at standard temperature and pressure, dry, per minute, and per millimeter of mercury driving pressure of carbon monoxide. In principle, the total diffusing capacity of the whole lung is the sum of the diffusing capacity of the pulmonary membrane component and the capacity of the pulmonary capillary blood volume. [12,13]

All methods for measuring diffusing capacity in clinical practice rely on measuring the rate of carbon monoxide uptake and estimating carbon monoxide driving pressure. [12] The most widely used and standardized technique is the single-breath breath-holding technique. In this technique, a subject inhales a known volume of test gas that usually contains 10% helium, 0.3% carbon monoxide, 21% oxygen, and the remainder nitrogen. The patient inhales the test gas and holds his or her breath for 10 seconds. The patient exhales to wash out a conservative overestimate of mechanical and anatomic dead space. Subsequently, an alveolar sample is collected. DL_{CO} is calculated from the total volume of the lung, breath-hold time, and the initial and final alveolar concentrations of carbon monoxide. The exhaled helium concentration is used to calculate a single-breath estimate of total lung capacity and the initial alveolar concentration of carbon monoxide. The driving pressure is assumed to be the calculated initial alveolar pressure of carbon monoxide. The calculated DL_{CO} is a product of the patient's single-breath estimate of total lung capacity multiplied by the rate of carbon monoxide uptake during the 10-second breath hold.

Hemoglobin concentration is a very important measurement in interpreting reductions in DL_{CO}. Because the hemoglobin present in the alveolar capillaries serves as a carbon monoxide sink such that oxygen and carbon monoxide are removed from dissolved gases, the concentration gradient from alveolar to arterial blood remains relatively constant in favor of dissolved gas flow toward the arterial circulation. In this way, a DL_{CO} may be decreased when the patient is anemic. Because the level of hemoglobin present in the blood and diffusing capacity are directly related, a correction for anemic patients ($DL_{CO}c$) is used to further delineate whether a DL_{CO} is decreased due to anemia or due to parenchymal or interface limitation. Recent work suggests strongly that the practice of dividing the calculated DL_{CO} by the single-breath estimate of total lung capacity (VA) to correct for low lung volumes (the DL/VA ratio) can yield a large number of false-negative results, and this practice should be used cautiously if at all.

A list of conditions associated with abnormal DL_{CO} is listed in Box 4. [6] Diseases such as interstitial pulmonary fibrosis or any interstitial lung disease can make the DL_{CO} abnormal long before spirometry or volume abnormalities are present. Low DL_{CO} is not only an abnormality of restrictive interstitial lung disease but also can occur in the presence of emphysema. In emphysema, the lung volumes may be normal or hyperinflated; therefore, the DL/VA is not useful.

Additionally, the loss of alveolar surface area, the pathologic lesion of emphysema, is not proportionate to volume. Thus, one can understand that other obstructive entities that predominantly affect the airways can have similar spirometry, but a low DL_{CO} implies a loss of alveolar surface area consistent with emphysema. Unfortunately, it is not always this simple. Some forms of interstitial lung disease can have components of restrictive physiologies, such as low lung volume and clear evidence of decreased diffusion but also can have airway flow limitation. Sarcoidosis and Wegener's granulomatosis can produce an endobronchial component of airway webs or strictures, limiting flow before overt volume loss, and sufficient interstitial granulomatous inflammation to reduce the DL_{CO}.

Box 4: Processes Associated with Alterations in DL_{CO}

Obstructive Lung Diseases

- Cystic fibrosis
- Emphysema

Parenchymal Lung Diseases

- Drug reactions (e.g., amiodarone, bleomycin)
- Idiopathic
- Interstitial lung disease
- Lung disease caused by fibrogenic dusts (e.g., asbestosis)
- Lung disease caused by biologic dusts (e.g., allergic alveolitis)
- Sarcoidosis

Pulmonary Involvement in Systemic Diseases

- Dermatomyositis-polymyositis
- Inflammatory bowel disease
- Mixed connective tissue disease
- Progressive systemic sclerosis
- Rheumatoid arthritis
- Systemic lupus erythematosus
- Wegener's granulomatosis

Cardiovascular Diseases

- Acute and recurrent pulmonary thromboembolism
- Acute myocardial infarction
- Fat embolization
- Mitral stenosis
- Primary pulmonary hypertension
- Pulmonary edema

Other

- Acute and chronic ethanol ingestion
- Bronchiolitis obliterans with organizing pneumonia (BOOP)
- Chronic hemodialysis
- Chronic renal failure
- Cigarette smoking

- Cocaine freebasing
- Diseases associated with anemia
- Marijuana smoking

Increases In DL_{CO}

- Diseases associated with increased pulmonary blood flow (e.g., left-to-right intracardiac shunts)
- Diseases associated with polycythemia
- Exercise
- Pulmonary hemorrhage

DL_{CO}, diffusing capacity of carbon monoxide.

On the other end of the spectrum, alveolar hemorrhage or congested capillary beds can actually increase the DL_{CO}. Hemoglobin trapped in proximity to alveolar gas will absorb carbon monoxide despite the actual severe limitation of gas exchange and oxygen delivery.

As for spirometry, predicted formulas have been established for DL_{CO} and DL/VA. Differences in race have been observed in normal subjects, and a race correction of 7% is allowed for African American patients. [6]

Exhaled Nitric Oxide

The measurement of exhaled nitric oxide as a reflection of airway inflammation is gaining rapid acceptance as a pulmonary function test. Normal values have been shown to depend on the exhaled flow rate during the measurement. The test is repeated until three reproducible results are obtained. The mean value is reported. Patients are asked to inspire to total lung capacity and then exhale into an analyzer using a steady, controlled exhaled flow rate. The test is rapid and safe and can be performed by most patients. The normal values shown in Table 2 are for a measurement flow rate of 50 mL/sec. [14]

Table 2: Exhaled Oral Nitric Oxide

	Volume (ppb)		
Category	**Adult**	**Child**	**Interpretation**
Normal	5-20	5-15	Normal
High normal or increased	20-35	15-25	Moderately raised exhaled nitric oxide can indicate underlying airway inflammation Colds and influenza can transiently raise exhaled nitric oxide, and some patients have higher baseline exhaled nitric oxide levels than others
Elevated	>35	>25	Indicates ongoing eosinophilic inflammation Symptomatic patients are likely to respond to steroids Possible causes (if already on steroids) include poor compliance, recent allergen exposure, inadequate steroid dose, and poor steroid response Not all patients

with high exhaled nitric oxide levels experience symptoms

Equipment

A detailed discussion of equipment is beyond the scope of this chapter. The American Thoracic Society has gone to great lengths to standardize and publish detailed recommendations regarding spirometry, lung volumes, and diffusing capacity. [4,12] These guidelines include the selection of equipment, important technical considerations for variability, and standardization between laboratories for the maneuver. Box 3 lists the acceptability and reproducibility criteria for an adequate spirogram. Table 1 summarizes equipment quality control as recommended by the American Thoracic Society, [4] and Box 5 lists the suggested performance standards for an office spirometer.

Table 1: Equipment Quality Control Summary

Test	Minimum Interval	Action
Volume	Daily	3-L syringe check
Leak	Daily	3 cm H_2O constant pressure for 1 min
Linearity	Quarterly Weekly (flow spirometers)	1-L increments with a calibrating syringe measured over the entire volume range (flow spirometers simulate several different flow ranges)
Time	Quarterly	Mechanical recorder check with stopwatch
Software	New versions	Log installation date and perform test using known subject

Adapted from American Thoracic Society: Single-breath carbon monoxide diffusing capacity (transfer factor). Recommendations for a standard technique.

Box 5: Performance Standards for an Office Spirometer

A volume spirometer should:
Accumulate volume for greater than 30 sec
Accommodate volumes of up to 7 L
Be accurate to within 3% or 50 mL of a test volume
A flow-sensing spirometer should:
Be able to measure flows up to 12 L/sec
Be accurate to within 5% or 0.2 L/sec
Both need:
Regular maintenance
Routine checks of accuracy of the spirometer and the computer

Adapted from American Thoracic Society: Single-breath carbon monoxide diffusing capacity (transfer factor). Recommendations for a standard technique

Normality and predicted equations

Studies from a healthy population indicate that parameters of lung function, such as FEV_1 or FVC, are affected most signifi-cantly by standing height, age, gender, race, and, to a lesser extent, weight. [7,15–21] If we assume that lung function has a normal gaussian distribution, then a wide range of values may be considered normal. [1] Because there is no absolute cut-off point for what is normal in biologic systems, an arbitrary statistical approach is widely used to define the lowest 5% of the population, or abnormal. Over the years, many regression equations have been generated by several investigators using different methodologies to study a variety of population cohorts. [7,15,17] The recommendation is for clinical laboratories to choose a published reference standard that is most similar to the typical patient population at a given institution as well as the testing methods used. The most commonly used standards are those of Morris and colleagues, [19] Crapo and colleagues, [20] Knudson and col leagues, [21] and the National Health and Nutrition Examination Survey (NHANES III). [7] These reference standards are based on a cohort of normal subjects of similar age, height, and race, with *normal* being defined as persons without a history of smoking or disease that can affect lung function.

Many approaches have been developed to determine the normal range of spirometry. [6] These approaches have included using a fixed percentage of predicted (75%) and a fixed FEV_1-to-FVC ratio, (>0.70), although both of these approaches have no statistical basis and are not recommended.

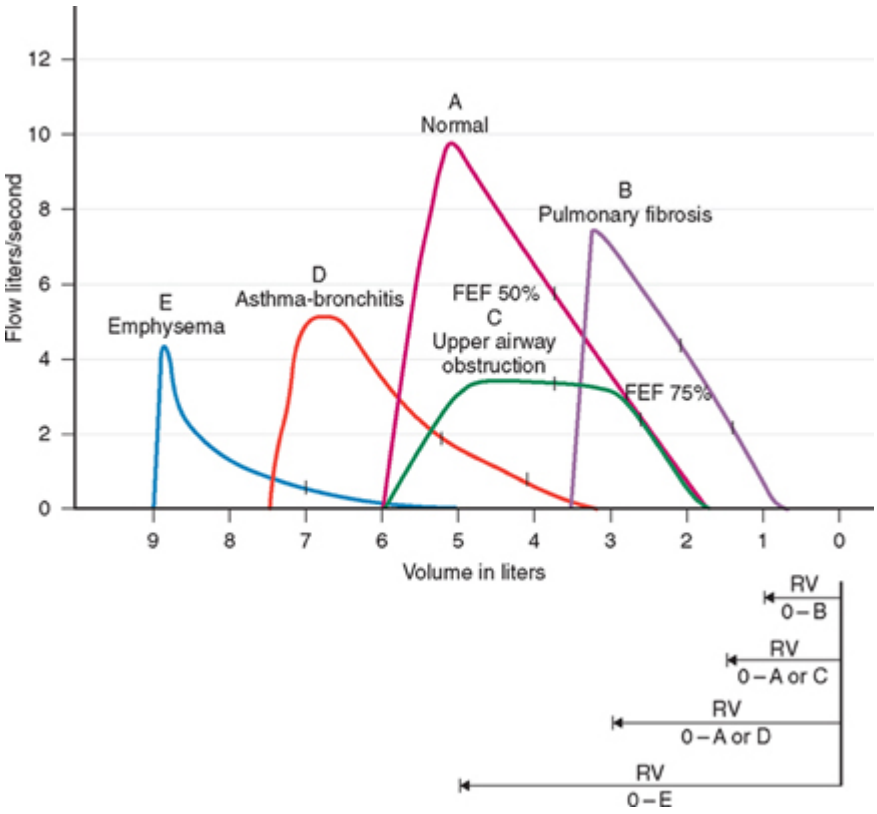
The American Thoracic Society recommends using the concept of lower limit of normal by identifying the lowest 5% of a population, or patients that fall outside the limits of 1.645 standard deviations from the mean. [6] This value may be calculated by multiplying 1.645 times the standard error of estimate (1.645 × SEE).

Weight is less important as a predictor of lung function. Obese patients might have abnormal spirometry (decrease in FVC) based on the diaphragm's ability to displace the intra-abdominal fat. Body weight has little impact on intrathoracic volume.

Race plays an important role in determining normal lung function; it has been recognized that persons of different races for any given height and age have proportionately different lung volumes. Specifically, based on anthropometric differences, the lung function for African Americans is systematically lower compared with whites. [6] The American Thoracic Society recommends a 12% correction for African Americans for FEV_1, FVC, and total lung capacity. The FEV_1-to-FVC ratio in African Americans may be slightly higher compared with whites. A 7% correction for lower values is recommended for FRC and residual volume. However, race-specific reference standards are preferred.

Over time, the NHANES III reference equations will likely become the standard in most pulmonary function testing laboratories around the country. [7] The methodologies and the sample size are most robust for this dataset, as well as being representative of the American population.

Clinical interpretive strategies



Spirometry

In 1991, the American Thoracic Society issued a position statement regarding interpretive strategies, which forms the basis for PFT interpretation in practice. [6] As previously discussed, spirometry is the most widely used screening test of lung function or pulmonary function studies. It is usually the first test to be performed and interpreted. Supplemental studies may be conducted as needed, such as a formal lung volume measurement, diffusing capacity, methacholine provocation test, or cardiopulmonary exercise studies. Spirometry is usually adequate for preoperative risk assessment and stratification. It is also often adequate for rotated obstructive lung disease, such as emphysema or asthma. However, when a patient's symptoms or clinical history cannot be explained by findings on spirometry or when multiple coexisting processes (e.g., dyspnea with both heart and lung disease) are present, then further testing is usually warranted.

In a simplistic way, respiratory disease can be classified as *obstructive* or *restrictive* processes. Obstructive disorders, such as emphysema or asthma, are characterized by airflow limitation, have increased lung volumes with air trapping, and have normal or increased compliance (based on pressure volume profile). In contrast, restrictive disorders such as pulmonary fibrosis are characterized by reduced lung volumes and an increase in overall stiffness of the lungs (with reduced compliance) (Fig. 7). Box 6 summarizes the common obstructive and restrictive lung diseases.

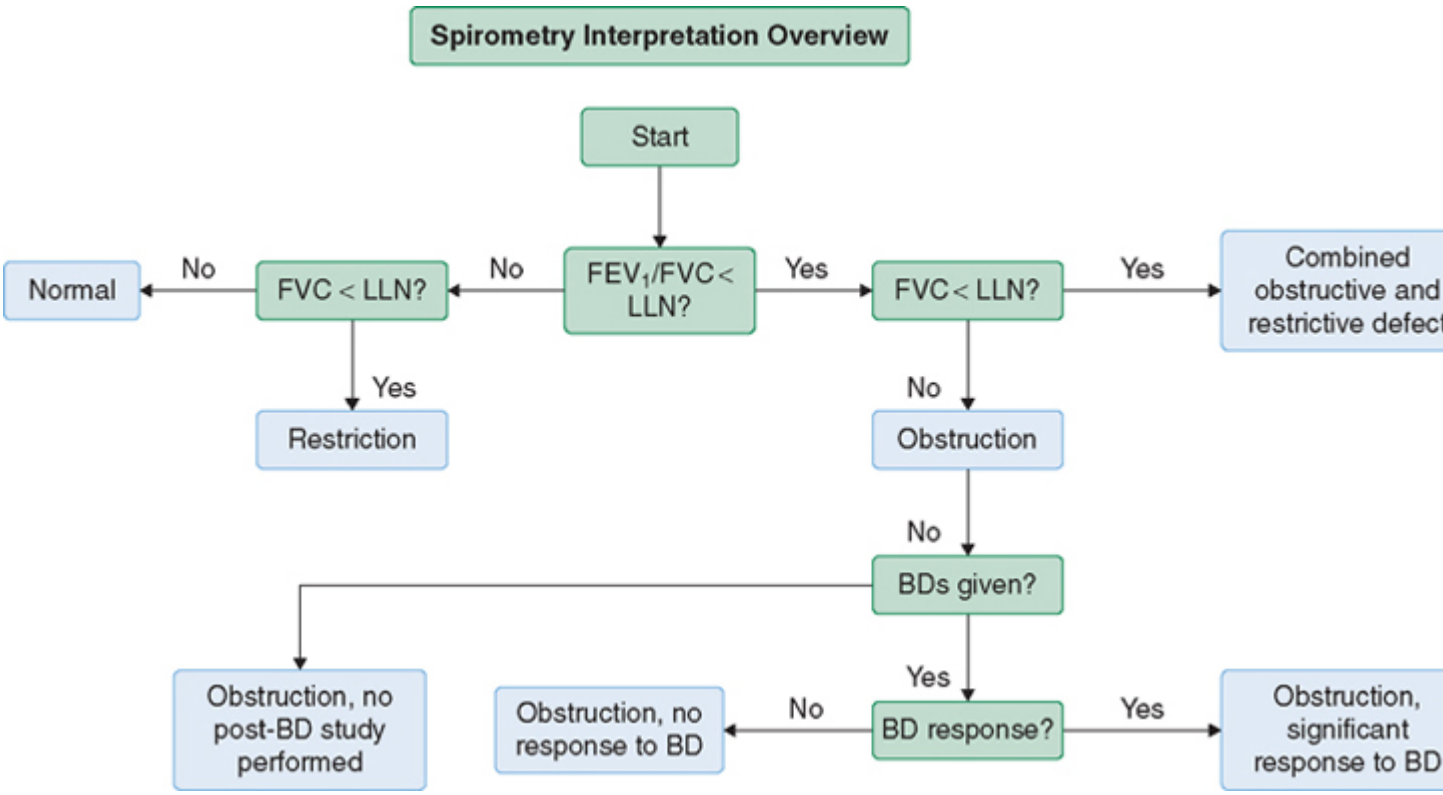
Box 6: Common Restrictive and Obstructive Lung Diseases

Common Obstructive Lung Diseases

- Asthma
- Asthmatic bronchitis
- Chronic obstructive bronchitis
- Chronic obstructive pulmonary disease (includes asthmatic bronchitis, chronic bronchitis, emphysema, and the overlap between them)
- Cystic fibrosis
- Emphysema

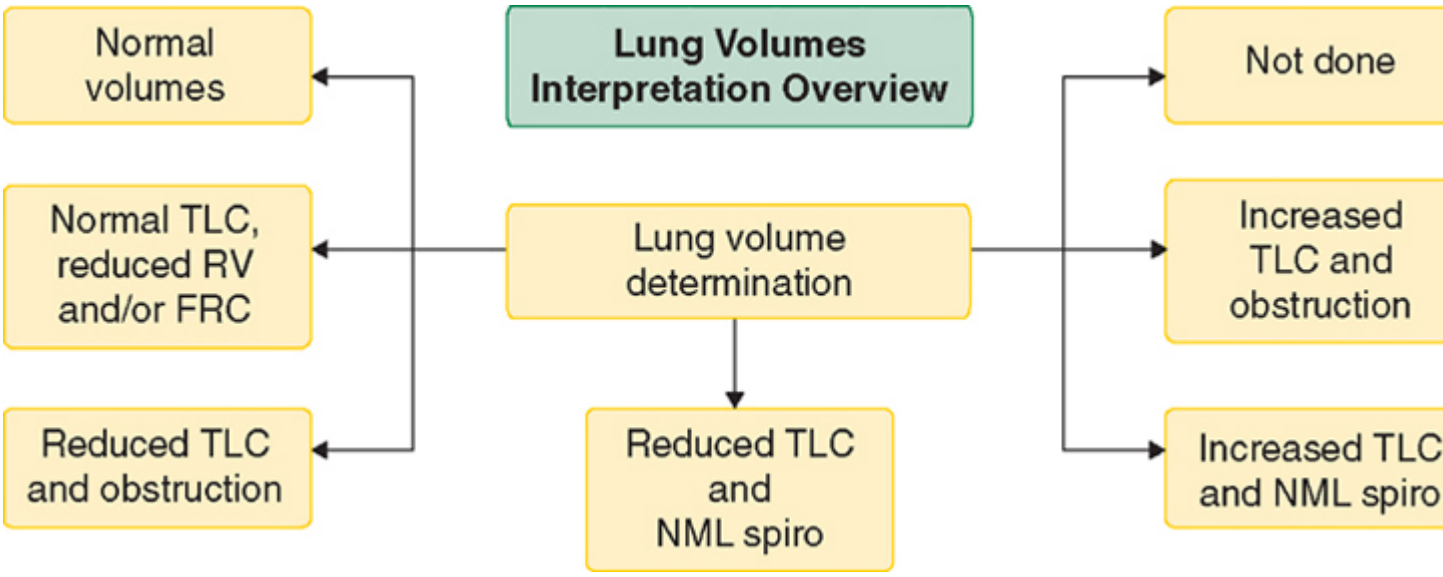
Common Restrictive Lung Diseases

- Beryllium disease
- Congestive heart failure
- Idiopathic pulmonary fibrosis
- Infectious inflammation (e.g., histoplasmosis, mycobacterium infection)
- Interstitial pneumonitis
- Neuromuscular diseases
- Sarcoidosis
- Thoracic deformities



Once the technical adequacy of the spirogram has been established, the next step is to classify whether the study is normal or has an obstructive pattern, a restrictive pattern, or a mixed obstructive and restrictive pattern. Figure 8 summarizes this algorithm. In general, the measured values are compared with the lower limits of normal predicted values from one of the published studies. Airflow obstruction exists, by definition, when the ratio of FEV_1 to FVC is below the lower limits of normal. When this ratio is above the lower limits of normal, obstruction is usually excluded. However, occasionally, early termination or short expiratory time can artifactually reduce FVC and falsely normalize the FEV_1/FVC ratio to mask obstruction.

Once the presence of airflow obstruction is established, then a typical approach in the laboratory is to administer two puffs of inhaled albuterol and repeat the spirogram after 15 minutes to establish bronchodilator responsiveness. Lack of bronchodilator response certainly does not exclude asthma, and the result needs to be used in the context of a patient's clinical history.



Lung Volumes

Because the FVC is not a reliable measure of total lung capacity, spirometry can only suggest a restrictive process and, in general, should be followed up by lung volume measurement. The algorithm for lung volume interpretation is shown in Figure 9. When spirometry suggests a restrictive process or when the abnormalities seen on the spirogram do not adequately explain a patient's clinical history, then formal measurements of lung volume are helpful. Box 7 summarizes the American Thoracic Society's criteria for grading the severity of lung function abnormalities. Total lung capacity can be particularly helpful when a patient has severe airflow obstruction and has a reduction in FVC. In this case, a normal or increased total lung capacity excludes an associated restrictive process, and the reduction in FVC is actually a pseudorestriction.

Box 7: Example of Criteria for Assessing the Severity of Abnormalities

Normal

The test is interpreted as within normal limits if both the VC and the FEV_1/VC ratio are in the normal ranges.

Obstructive Abnormality

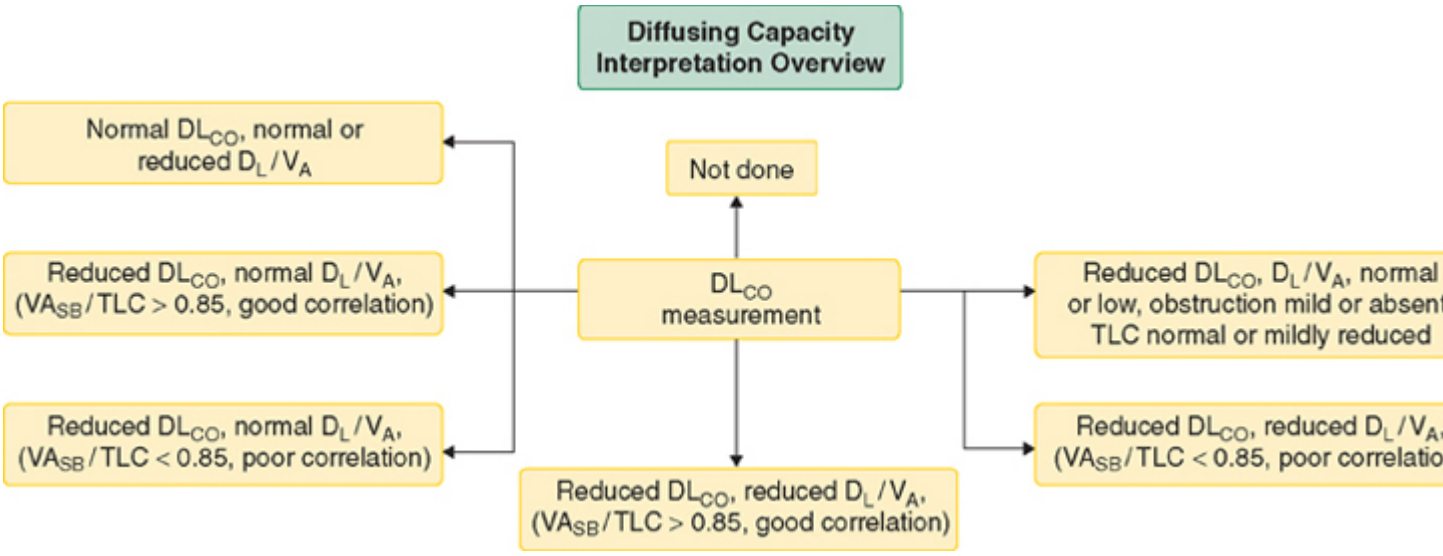
The test is interpreted as showing obstructive abnormality when the FEV_1/VC ratio is below the normal range. The severity of the abnormality might be graded as follows:
May be a physiologic variant: Predicted FEV_1 ≥100%
Mild: Predicted FEV_1 <100% and ≥70%
Moderate: Predicted FEV_1 <70% and ≥60%
Moderately severe: Predicted FEV_1 <60% and ≥50%
Severe: Predicted FEV_1 <50% and ≥34%

Restrictive Abnormality

The test is most reliably interpreted as showing restrictive abnormality on the basis of total lung capacity. If this total lung capacity not available, one may interpret a reduction in the VC without a reduction of the FEV_1/VC ratio as a restriction of the volume excursion of the lung. The severity of the abnormality might be graded as follows:
Based on the TLC
Mild: Predicted TLC < LLN but ≥70%
Moderate: Predicted TLC <70% and ≥60%
Moderately severe: Predicted TLC <60%
Based on Spirometry

- Mild: Predicted VC < LLN but ≥70%
- Moderate: Predicted VC <70% and ≥60%
- Moderately severe: Predicted VC <60% and ≥50%
- Severe: Predicted VC <50% and ≥34%
- Very severe: Predicted VC <34%

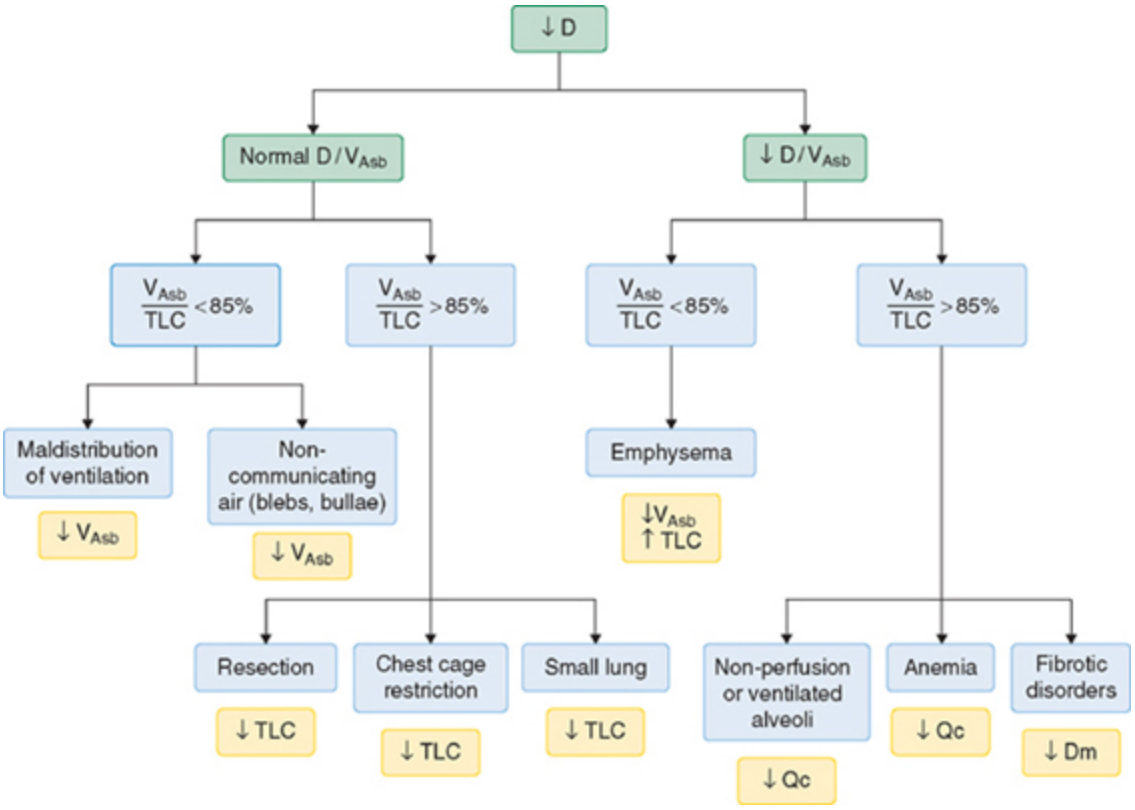
FEV_1, forced expiratory volume in 1 second; LLN, lower limit of normal; TLC, total lung capacity; VC, vital capacity.; Adapted from American Thoracic Society: Lung function testing: Selection of reference values and interpretative strategies



Diffusing Capacity of Carbon Monoxide

Diffusing capacity is a pulmonary function test that is commonly performed to help further characterize abnormalities in spirometry or lung volume measurements. The DL_{CO} has greater degrees of variability between laboratories and requires some level of expertise to perform reliably.

Several processes can affect diffusing capacity (see Box 4). Our proposed approach to the interpretation of diffusing capacity is shown in Figures 10 and 11. A pattern of diffusing capacity reduced proportionate to airflow obstruction (a proportionate reduction in FEV_1 and DL_{CO}) is typical for emphysema. A DL_{CO} is reduced proportionately to a reduction in total lung capacity in the context of restrictive abnormalities suggests a parenchymal process such as pulmonary fibrosis. An isolated or disproportionate reduction in diffusing capacity along with either normal or fairly well preserved mechanics suggests predominantly a pulmonary vascular process such as primary pulmonary hypertension or thromboembolic disease.



Anemia or carboxyhemoglobinemia (from smoking) could affect the measured DL_{CO}.[10] The concept of a reduced DL_{CO} that normalizes after correction for a lung volume measurement is often used to describe an extrathoracic or extraparenchymal disease process such as resection, obesity, or neuromuscular disease.[2] However, as noted previously, this approach has many limitations.

Summary

- Lung function testing helps us to understand the physiologic working of the lungs and chest mechanics.
- Pulmonary function testing is the primary method used to diagnose, stage, and monitor various pulmonary diseases.
- Lung function testing requires operators to follow published guidelines for administering and interpreting tests.

Respiratory Bronchiolitis-Associated Interstitial Lung Disease: Pulmonary Function Tests

Pulmonary Function Tests

The level and nature of functional impairment in (respiratory bronchiolitis-associated interstitial lung disease) RBILD has varied in clinical series,[3,5,12] but despite the bronchiolocentric nature of disease, both restrictive and obstructive abnormalities have been documented, with a mixed, predominatly restrictive ventilatory defect, in association with a moderate reduction in the carbon monoxide diffusing capacity (DL_{CO}), probably the most prevalent picture. The degree of airflow obstruction tends to be mild. The level of functional impairment is a defining diagnostic feature in RBILD, in making the distinction from respiratory bronchiolitis. However, as observed by Fraig et al,[7] it remains unclear why some patients with moderately extensive fibrotic change radiating from bronchioles have little or no abnormal pulmonary function signal.

A particular difficulty, in interpreting pulmonary function abnormalities in the context of RBILD, is the frequent concurrence of emphysema, which is likely to be more extensive histologically than is apparent on HRCT. In some cases, an obstructive defect may be largely indicative of emphysema, and in other cases, the coexistence of emphysema and fibrotic abnormalities may result in paradoxically normal volumes, as seen when emphysema is associated with more extensive pulmonary fibrosis.[38] In keeping with the latter hypothesis, the reduction in $_{CO}$ is sometimes disproportionate; in two series, the $_{CO}$ was < 60% of predicted in over half the cases.[3,12] In the recent RBILD series of Park et al, the strongest functional-HRCT correlations were between arterial oxygen saturation and the extent of ground-glass attenuation, and between the alveolar arterial oxygen gradient and the presence and extent of areas of hypoattenuation.[24]

Thus, although pulmonary function test abnormalities are a key part of the distinction between respiratory bronchiolitis and RBILD, the pattern and level of functional impairment should not be used in isolation to make this judgment, which remains a nebulous gestalt of clinical, functional, and HRCT findings, with or without biopsy confirmation. In some patients, thought to have RBILD on clinical, HRCT, and histologic criteria, pulmonary function tests are normal.[17]

Clinical Features at Presentation: Prognosis and Treated Course

The most frequent presenting features are the insidious onset of exertional breathlessness and a persistent cough, not always productive of sputum.[3,5,12,18] Chest pain and weight loss also occur. There are occasional reports of fevers and haemoptysis but these are not necessarily related to RBILD and may represent coincidental lower respiratory tract infection. Bilateral end-inspiratory crackles, which may be predominantly basal, are frequent, but clubbing appears to be exceedingly rare.[12] The presence of symptoms is not a sine qua non; the diagnosis of RBILD is sometimes made in asymptomatic patients who present with radiographic and HRCT abnormalities or end-inspiratory crackles and are found to have significant functional impairment.

RBILD is widely regarded as an essentially benign disorder. This is not invariably the case, as illustrated by the development of severe hypoxemia during single-lung ventilation in a patient with RBILD,[39] and there are anecdotal reports, including a case known to the authors, of extensive underlying fine fibrosis at biopsy, not evident on HRCT. However, judging from the current limited documentation of longitudinal behavior, RBILD has a much better outcome than other forms of idiopathic interstitial pneumonia,[13] with a much better survival than seen in UIP or fibrotic nonspecific interstitial pneumonia (NSIP).[40] In the initial description of RBILD, all six patients improved or remained stable after a mean follow-up of over 3 years.[3] In a subsequent series, three of 10 cases exhibited a decline in forced vital capacity (FVC) or DL_{CO} at a mean of 4 years after presentation, despite cessation of smoking and treatment; a further four cases did not improve functionally, despite smoking cessation and, in two instances, corticosteroid therapy.[12] Intriguingly, corticosteroid and cyclophosphamide therapy was ineffective in one case, but disease regressed with cessation of smoking.[41] Park et al observed partial regression of bronchial wall thickening, ground-glass attenuation, and centrilobular micronodules on HRCT after smoking cessation and corticosteroid therapy, but areas of hypoattenuation increased in extent.[24] These observations contrast with the reported regression of respiratory bronchiolitis in the majority of patients[7]; however, it is possible that although the inflammatory component of RBILD may abate with time, associated fibrotic change, which may be more extensive in RBILD than in respiratory bronchiolitis, may be a major determinant of functional impairment. A further important contributor to lack of therapeutic response in some cases is the presence of coexistent emphysema.

The paucity of longitudinal data should be emphasized; it is likely that more detailed information in larger cohorts of RBILD patients will emerge in the next year or two. However, it is increasingly clear, from the above series and from widespread anecdotal experience, that a response to therapy is not the rule in RBILD, but may be confined to a minority or small majority of patients.

Key Clinical Issues in RBILD

Although the diagnosis of RBILD is constructed from clinical, functional, HRCT and, in some cases, histologic findings, HRCT findings are usually the most discriminatory diagnostic feature. The symptoms, clinical signs, and pattern and level of functional impairment are nonspecific, although their severity is used to distinguish between RBILD and respiratory bronchiolitis. By contrast, the HRCT features of RBILD serve to exclude a wide range of other diffuse lung diseases, including the more progressive forms of idiopathic interstitial pneumonia (UIP, fibrotic NSIP). As discussed earlier, HRCT features occasionally overlap with those of DIP, but this is seldom a major diagnostic difficulty because DIP is now a very rare disorder, and the ground-glass attenuation of DIP is generally more intense and regional than seen in RBILD.[17,32] In occasional cases, the HRCT distinction between RBILD and subacute hypersensitivity pneumonitis can pose difficulties, even to experienced radiologists, because widespread poorly formed micronodular abnormalities may be admixed with regional hypoattenuation in both diseases.[24,35] However, the smoking history is a key discriminant in this context because hypersensitivity pneumonitis is rare in smokers.

The greatest diagnostic difficulty relates to a problem that is not currently discussed in the medical literature; there are widespread anecdotal accounts of patients in whom a mixture of smoking-related pathologies are evident on HRCT, including RBILD, emphysema, limited changes of Langerhans' cell histiocytosis, areas of more extensive ground-glass attenuation suggestive of DIP, and variably extensive pulmonary fibrosis. This problem is not addressed further in the current review, in the absence of definitive prevalence data, but it does create diagnostic difficulties from time to time.

BAL may play an important diagnostic role in this context. In the initial description of RBILD, a striking increase in macrophage numbers was the cardinal abnormality[3]; this and the characteristic brown pigmentation of macrophages have been consistent subsequent observations. These findings do not discriminate between RBILD and respiratory bronchiolitis in healthy smokers: the major utility of BAL lies in the distinction between RBILD and other diffuse lung diseases. In a recent evaluation of a large cohort of patients with biopsy-proven idiopathic interstitial pneumonia, including RBILD, DIP, UIP, and fibrotic NSIP, patients with RBILD were characterized by significant increases in macrophage numbers and significant lower percentages of other cellular components.[42] A BAL neutrophilia or eosinophilia appears to be rare in RBILD. Moreover, the BAL profile of RBILD is wholly distinct from that of hypersensitivity pneumonitis, in which a prominent BAL lymphocytosis is the rule.[43] Thus, BAL findings may be an important ancillary diagnostic feature in RBILD, often obviating thoracoscopic lung biopsy when considered in conjunction with HRCT findings.

The indications for thoracoscopic lung biopsy in suspected RBILD are likely to evolve in the near future with increasing HRCT experience. However, because the histologic features, which are those of respiratory bronchiolitis, are an expected finding in current smokers, the major indication for biopsy is the suspicion of an alternative diagnosis, especially in ex-smokers. Thoracoscopic biopsy is especially likely to be warranted in patients with HRCT evidence of concurrent pulmonary fibrosis, both to exclude more progressive forms of idiopathic interstitial pneumonia and to rule out more extensive fibrotic change than is evident on HRCT. In this context, the demonstration of prominent peribronchiolar fibrosis may materially influence therapeutic expectations. However, in the majority of RBILD patients with a clinical, functional, HRCT, and BAL profile and no overt evidence of pulmonary fibrosis, the diagnostic information provided by thoracoscopic biopsy is probably of little additional value.

In the absence of definitive clinical data, the therapeutic approach tends to be largely governed by the level of pulmonary function impairment. Because spontaneous regression of disease may occur, it is generally accepted that a period of observation following smoking cessation is warranted, except in functionally severe disease. However, an empirical trial of therapy has been usual in most series when abnormalities are severe or do not regress following smoking cessation. In occasional patients with overt pulmonary fibrosis, the selection and duration of treatment may be determined by the coexisting disease process. Therapeutic experience has been confined to agents used in other forms of idiopathic interstitial pneumonia, notably corticosteroids, with or without immunosuppressive agents.[3,5,12,18,24,41] As discussed above, a response to therapy should not be expected, and the benefits of prolonged treatment with attendant side-effects have yet to be established. Thus, early cessation of treatment in nonresponders is often appropriate, unless functional impairment is severe.

Should RBILD and DIP be Viewed as Two Ends of the Same Disease Spectrum?

In recent consensus statements, RBILD and DIP have continued to be classified as separate entities, despite their common relationship to smoking and their histologic and HRCT similarities. Advocates of their amalgamation as a single entity[6,17] have emphasized the overlap in histologic and HRCT features in some patients, and have postulated a morphological continuum from asymptomatic respiratory bronchiolitis, through RBILD to DIP. However, despite the attraction of a simplification of terminology in an area that is notoriously prone to semantic complexity, we favor the retention of RBILD and DIP as separate entities for three reasons.

First, imprecision already exists in the separation of RBILD from respiratory bronchiolitis, a close call in many cases. Although the distinction is based upon disease severity, exact severity criteria for a diagnosis of RBILD have not been formulated; indeed, the diagnosis of RBILD, as opposed to respiratory bronchiolitis, has been variably based on symptoms, imaging, and pulmonary function tests in different patients. Given this fundamental imprecision, an amalgamation of RBILD with a third disorder, DIP, has the potential to add to the current diagnostic confusion.

Second, there are important differences in the clinical course and presenting features. RBILD appears to be a more benign disease process than DIP in most cases. There is no current evidence that progression occurs from RBILD to DIP.[44] RBILD is characterized by micronodular abnormalities on HRCT that are not generally seen in DIP, and the BAL profiles of the two diseases differ.[42] Furthermore, the therapeutic strategy in RBILD, in which the value of treatment may be marginal in many cases, contrasts with the more vigorous approach that is usually appropriate in DIP. The importance of distinguishing between diseases previously grouped indiscriminately as "idiopathic pulmonary fibrosis" has recently been appreciated.[45,46]

A further compelling reason to retain the current separation of RBILD and DIP is the possibility that these disorders may develop into different smoking-related lung disorders. The recent observation on HRCT of evolution from respiratory bronchiolitis/RBILD to emphysema in a few cases is intriguing,[23] and although the overall importance of this finding has yet to be established, further exploration of the interrelationship between RBILD and emphysema is warranted. Furthermore, overt pulmonary fibrosis is evident on HRCT in DIP in over 50% of cases[19,31] but has been reported in only a few patients with RBILD[5,22,27] and seems to be much less prevalent in that disease. Until the pathogenetic significance of these observations has been clarified, DIP and RBILD can still usefully be regarded as separate entities.

Pulmonary Function Tests: A Very Brief Review

Definition

Pulmonary function tests are a group of procedures that measure the function of the lungs, revealing problems in the way a patient breathes. These tests can determine the cause of shortness of breath and may help confirm the diagnosis of lung diseases, such as asthma, chronic bronchitis, or emphysema. The tests may also be performed before any major lung surgery to make sure the person will not be at risk of complications because of reduced lung capacity.

Purpose

Pulmonary function tests can help diagnose a range of respiratory diseases that might not otherwise be obvious to the clinician or the patient. These tests are important, since many kinds of lung problems can be successfully treated if detected early.

The tests are also used to measure how a lung disease is progressing, and how serious the lung disease has become. Pulmonary function tests also can be used to assess a patient's response to different treatments.

If a patient shows signs of decreased lung function relative to the normal values for a person of his or her race, sex, age, height, and weight, that person may suffer from a pulmonary disease. There are two causes of abnormal pulmonary function, obstructive lung diseases and restrictive lung diseases.

Obstructive lung diseases are characterized by a decreased ability to get air out of the lungs. A patient with an obstructive lung disease generally does not experience difficulty getting air into his or her lungs. Obstructive lung diseases are most easily remembered with the acronym CABBE: cystic fibrosis, asthma, bronchiectasis, chronic bronchitis, and emphysema.

Restrictive lung diseases are characterized by a decreased capacity to draw air into the lungs. A patient with a restrictive lung disease generally does not experience difficulty getting air out of his or her lungs. The cause of restrictive lung diseases may be either directly related to a dysfunction of the lungs (intrapulmonary) or not related to a dysfunction of the lungs (extrapulmonary). Intrapulmonary restrictive lung diseases include pneumonia, pulmonary fibrosis, and pulmonary edema. Extrapulmonary causes of restrictive lung diseases include rib fractures, head trauma, and neuromuscular disorders.

Precautions

Before any pulmonary function test is performed by a patient, the clinician ordering the test should be aware of any conditions that the patient may have that may affect the reliability of the test results. Also, because pulmonary function testing requires deep breathing, the test itself may aggravate these same conditions.

Conditions in a patient that contraindicate pulmonary function testing include: the coughing-up of blood from the respiratory tract (hemoptysis); a collapsed or partially collapsed lung (pneumothorax); an unstable heart condition, recent heart attack, or blood clot near the lungs; an abnormal localized bulging of a blood vessel (aneurysm) in the chest, abdomen, or head; recent surgery of the chest or abdomen; recent eye surgery; and current nausea or vomiting. If a patient suffers from one or more of these conditions, pulmonary function tests should be postponed until these conditions are resolved.

The patient should not wear clothing that constricts the chest area. Patients should not have eaten a heavy meal three hours or less before the test. Smokers should provide their smoking history and the time of their last cigarette. In order for pulmonary function tests to yield accurate results, the patient must be able to respond to direction; so the tests may not be useful in very young children, uncooperative patients, and physically incapacitated individuals.

Description

One of the most common of the pulmonary function tests is spirometry. This test, which can be given in a hospital or doctor's office, measures how much and how fast the air is moving in and out of the lungs. This test is covered in greater detail in the separate spirometry tests entry.

A peak flow meter can determine how much a patient's airways have narrowed. A test of blood gases is a measurement of the concentration of oxygen and carbon dioxide in the blood, which shows how efficient the gas exchange is in the lungs.

Another lung function test reveals the efficiency of the lungs in absorbing gas from the blood. This efficiency is measured by testing the volume of carbon monoxide a person breathes out after a known volume of the gas has been inhaled.

Preparation

The healthcare provider conducting a pulmonary function test should explain the test and any and all potential side effects to the patient prior to the test being performed. The health care provider should then demonstrate the proper breathing technique for the patient, and the patient should then practice this technique until he or she is able to accurately duplicate the proper technique on two consecutive trials. The health care provider should also indicate that while most side effects of pulmonary function tests are extremely rare, the patient should stop the test if he or she becomes extremely uncomfortable or feels intense pain in the head, eye, chest, or abdomen.

Prior to the test, the age, race, and sex of the patient should be recorded, along with a height measurement in stocking feet and a weight measurement. This information will allow each individual's results to be compared to normal values for people in the same demographic category.

Aftercare

There is usually no patient care required after the administration of a pulmonary function test. If a patient feels lightheaded or dizzy, he or she should lie down until the symptoms subside. In rare cases, oxygen may have to be administered to prevent pneumothorax or to restore normal breathing patterns.

Complications

In general, pulmonary function tests are safe procedures that simply require deep breathing. In very rare instances complications can occur. These include pneumothorax; increased fluid pressure between the bones of the skull and the brain (increased intracranial pressure); loss of consciousness, dizziness, and/or lightheadedness; chest pain; uncontrollable coughing; and contraction of an infection from the test equipment.

Results

Normal results

Normal test results are based on a person's age, height, weight, race, and gender. Normal results are expressed as a percentage of the predicted lung capacity for a person of the same age, height, weight, race, and sex. Any measurement within 20% of the predicted value is considered a normal result.

Abnormal results

Abnormal results mean that the person's lung capacity is less than 80% of the predicted value. Such findings usually mean that there is some degree of chest or lung disease.

Health care team roles

Pulmonary function tests are generally ordered by a primary care doctor (M.D. or D.O.) or advanced practice nurse, and performed either by a physician, nurse, or respiratory technician under the direction of a doctor specifically trained in pulmonary function testing. When the results of pulmonary function testing are inaccurate, the most frequent reason is inadequate patient education and/or technician training. It is recommended that personnel conducting pulmonary function testing have one of the following credentials: certified respiratory therapy technician (CRTT); registered respiratory therapist (RRT); certified pulmonary function technologist (CPFT); or registered pulmonary function technologist (RPFT). A doctor specializing in diseases of the lungs (pulmonologist) may be consulted to examine abnormal pulmonary function test results.

Key Terms

Asthma: A disease that causes recurrent and generally unpredictable narrowing of the larger airways of the lungs (bronchi), which makes breathing difficult. Asthma may be caused by infection, allergies, smoking, exercise, or stress.

Bronchitis: Inflammation of one or more of the airways (bronchi) that lead from the windpipe (trachea) into the lungs. Bronchitis is usually caused by an infection.

Emphysem: A disease in which the small air sacs in the lungs become damaged, causing shortness of breath. In severe cases it can lead to respiratory or heart failure.

Obstructive lung disease: Any disease that lessens a patient's ability to get air out of his or her lungs. Generally, people with obstructive lung disease do not have difficulty getting air into their lungs.

Pneumothorax: A collapsed, or partially collapsed, lung.

Restrictive lung disease Any disease that lessens a patient's ability to get air into his or her lungs. Generally, people with restrictive lung disease do not have difficulty getting air out of their lungs.

Spirometer Calibration Checks-- Is 3.5% Good Enough?

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2. David Shade, JD, and
3. Robert A. Wise, MD, FCCP

Abstract

Background: Current standards for spirometry require daily calibration checks to come within 3.5% of the inserted volume but do not require evaluation of trends over time. We examined the current guidelines and candidate quality control rules to determine the best method for identifying spirometers with suboptimal performance.

Methods: Daily calibration checks on seven volume spirometers recorded over 4 to 11 years were reviewed. Current guidelines and candidate quality control rules were applied to determine how well each detected suboptimal spirometer performance.

Results: Overall, 98% of 7,497 calibration checks were within 3.5%. However, based on visual inspection of calibration check data plots, spirometers 3 and 5 demonstrated systematic sources of error, drift, and bias. The ± 3.5% criteria did not identify these spirometers. The application of ± 2% criteria identified these spirometers (9% out-of control values in spirometers 3 and 5 vs. < 5% in other spirometers).

A rule stipulating out-of-control conditions when four consecutive checks exceeded 1% deviation identified suboptimal spirometers (14% and 20% out-of-control values) but maintained low error detection rates in other spirometers (≤ 2%). Other candidate rules were less effective or required longer times to error detection.

Conclusions: The current recommendation that calibration checks come within ± 3.5% of the inserted volume did not detect subtle errors. Alternative candidate rules were more effective in detecting errors and maintained low overall error-detection rates. Our findings emphasize the need for laboratories to systematically review calibration checks over time and suggest that more stringent guidelines for calibration checks may be warranted for volume spirometers. Although our general approach may also be appropriate for flow-type spirometers, the details are likely to differ since flow-type spirometers are a much more varied category of equipment.

- **calibration**
- **lung function**
- **pulmonary function test**
- **quality control**
- **spirometry**

In a series of articles,[123456] the American Thoracic Society (ATS) and the European Respiratory Society (ERS) promulgated standards for lung function testing. The standards combine and update previously published guidelines.[78910111213141516] The standards for spirometry outline equipment requirements and necessary features of a quality control program.[2] In the present study, we review historical quality control data from a large hospital-based pulmonary function laboratory to evaluate the usefulness of the current recommendations in detecting suboptimal spirometer performance, and we make new recommendations to improve spirometer quality control.

The current standards require that spirometers be calibrated to a volume accuracy of ± 3%.[2] *Calibration* is the procedure that determines the relationship between sensor-determined values of flow or volume and actual flow or volume. The guidelines for spirometry also require daily performance of calibration checks using a 3-L calibration syringe with an accuracy of ± 0.5%. *Calibration checks* are the procedures used to validate that the device is within calibration limits. The calibration check is considered acceptable if it comes within ± 3.5% of the inserted volume, accounting for the combined accuracy limits of the spirometry system and the calibration syringe.[2] If a calibration check does not fall within this recommended range, then the check should be repeated or equipment maintenance should be performed.

The standards emphasize that it is the responsibility of the individual laboratory to demonstrate equipment accuracy and precision through a quality control program. Although recommendations for required accuracy are clearly specified, standards for precision are less explicit. While methods for monitoring precision are not outlined in the 2005 ATS/ERS statement,[2] they are described in the ATS Pulmonary Function Laboratory Management and Procedure Manual (ATS procedure manual).[17] The ATS procedure manual promotes the use of statistical quality control methods to assess calibration checks. The use of Westgard rules and Levey Jennings plots, two widely used quality control practices, are recommended.[18] Westgard principles promote control rules designed to detect random (such as high variability) or systematic (such as a shift in the mean) sources of error. Levey Jennings control charts are a means of plotting the data points for visual inspection and applying combinations of rules.[19]

In our pulmonary function laboratory, volume-based spirometers are calibrated infrequently and undergo daily calibration checks. Therefore, the quality control logs provided an ideal data set to assess the longitudinal variability of 3-L syringe calibration checks. In the current study, we sought to do the following: (1) assess the variability in the calibration checks of volume-based spirometers; (2) determine whether the current guidelines identify spirometers with possible performance problems; and (3) evaluate the usefulness of statistical quality control procedures in assessing spirometry calibration checks.

Materials and Methods

Laboratory Procedures for Calibration Checks

In the outpatient pulmonary function laboratory at our institution, daily calibration checks were performed using a 3-L calibrated syringe with an accuracy of ± 0.5% according to the protocol specified in our pulmonary function laboratory procedures manual. Calibration checks were performed with the same designated syringe (series 5530; Hans Rudolph; Kansas City, MO) for all of the spirometry systems. The calibration syringe was modified so that the stop setting could not be altered to prevent adjustment. Therefore, continued accuracy of the calibration check syringe was likely. However, this syringe was not routinely sent for factory calibration. The calibration syringe was stored next to one of the spirometers away from any heating or cooling vents. The temperature of the spirometers and calibration syringe were equilibrated by back and forth motion prior to each calibration check. This was enforced by a customized computer reminder system.

Maintenance for the spirometry systems was performed according to the following schedule. On a daily basis, the system was checked for leaks and the water level was checked and adjusted in the water-sealed spirometer (spirometer 7). The policy of the laboratory was to perform a leak check before each calibration check. The hoses were changed and checked for leaks before each patient had spirometry performed. On a monthly basis, the spirometry systems were checked for linearity. Biological controls were performed on rotating members of the pulmonary function laboratory staff as part of the quality control program. Maintenance was performed with a customized, computerized reminder system and verified in an electronic maintenance log.

Spirometry calibration checks were performed by technicians on a rotating basis, largely based on staffing patterns.

All technicians who performed calibration checks were trained and certified before they were permitted to conduct independent calibration checks. Six technicians performed 86% of all calibration checks.

All calibration check values were recorded in electronic quality control logs. The values for the individual calibration checks were converted to percent deviation, defined as ([(observed volume − calibrated syringe volume)/calibrated syringe volume] × 100). If the first calibration check on a day exceeded 3% deviation, the check was considered out of range and a second calibration check was performed. If the second check was also out of range, the spirometer was investigated and appropriate maintenance was performed. The spirometer was taken out of service until corrective actions were completed and the calibration check was within ± 3% deviation. All spirometers in this analysis retained the same calibration factor throughout the course of the study. Thus, we were able to analyze the variability of the spirometry systems over time.

Longitudinal Review of Quality Control Data

The ATS procedures manual provides recommendations for the analysis of data from quality control procedures, such as calibration checks. The use of Westgard rules and the creation of Levey Jennings control charts are suggested means of analyzing quality control data. Westgard principles support the use of control rules designed to detect random or systematic sources of error. By selecting and applying combinations of control rules, random and systematic sources of error can be detected with a goal of detecting spirometer inaccuracies early, while maintaining a low probability of false rejection and a high probability of true error detection. An example of a control rule that detects random error is one that defines a violation as a single value exceeding 3 SDs from the mean. An example of a control rule that detects systematic error is one that defines a violation as four consecutive values that exceed 1 SD from the mean in the same direction. The creation of Levey Jennings charts are a means of plotting the data points and applying combinations of rules. These principles are widely applied in clinical chemistry but are less widely used in pulmonary function laboratories. In the present study, we applied quality control rules that were based on the principles of Westgard and were aimed at detecting random and systematic sources of error.

Analysis

The study was exempt from Institutional Review Board approval because equipment was the subject of the study rather than individuals. Data were obtained from electronic quality control logs. Daily calibration checks from seven spirometers were analyzed from the time of the most recent calibration through July 1, 2004. For the purposes of this analysis, duplicate calibration checks performed on the same day were eliminated. Because investigation and corrective action sometimes resulted in numerous repeat calibration checks, the first check of the day was used, even if this value was an extreme outlier. Longitudinal data were graphically displayed using box plots, histograms, and scatter plots. Candidate rules of statistical quality control were created to examine how often a spirometer would be considered out of control and whether each of the candidate criteria detected observed suboptimal spirometer performance (Table 2). Summary statistics were calculated, and quality control rules were applied using statistical software (Intercooled Stata, version 9; StataCorp; College Station, TX).

Results

The characteristics of each of the seven spirometers are displayed. The number of calibration checks for each spirometer ranged from 214 to 2,051. There were a total of 7,497 observations, each representing a first-daily calibration check maneuver using a 3-L syringe. Another 398 calibration checks (5% of the total 7,895 performed) represented post-maintenance recordings that were not included in the final analysis.

Overall, 97.6% of the 7,497 first-daily calibration checks fell within the current recommended guideline of ± 3.5% deviation and 94.7% fell within ± 2% deviation. The distribution of the percentage of deviations of all calibration checks is normal (Fig 1). The distributions of the calibration checks of the individual spirometers are displayed in box plots. Five of the seven spirometers were centered close to zero, while spirometers 3 and 5 showed positive and negative biases, respectively, and had greater variability. Spirometer 3 showed an upward shift in calibration checks, indicating bias in the positive direction. Spirometer 5 shows drift in the negative direction. In comparison, spirometer 7 showed deviations centered around zero without evidence of a secular trend. Visual inspection of calibration check data plots over time identified spirometers 3 and 5 as having suboptimal performances, and we sought to develop algorithms to compare calibration checks from these spirometry systems to those that appeared to have a more stable performance.

The percentage of trials that would deem a spirometer out of control for given out-of-range rules are displayed. With the ± 3.5% deviation criteria, only 2.4% of values were out of control, and spirometers 3 and 5 did not appear notably different from the others. Most of the values identified by the ± 3.5% criteria represented extreme outliers that were likely due to incomplete emptying of the syringe or to disconnection of the syringe during performance of the calibration check. Results for the ± 3% criteria that was in effect at the time that the calibration checks were performed appear similar to the results from the ± 3.5% criteria. Using the ± 2% criteria, all spirometers were within control 95% of the time with the exception of spirometers 3 and 5.

Candidate criteria based on a modification of Westgard rules outlined in the ATS procedures manual were applied. Using the criteria stipulating two consecutive values beyond 2% deviation, spirometers were in control 99% of the time and spirometers 3 and 5 had slightly increased out of control values. The criteria stipulating four consecutive checks beyond 1% deviation maintained a low error detection rate in all spirometers except 3 and 5, which had significantly increased error detection rates. Applying these criteria, spirometers 3 and 5 were out of control 14% and 20% of the time, respectively, while the other spirometers were out of control 0 to 2% of the time. The criteria stipulating 10 consecutive values falling on the same side of zero deemed spirometers 3 and 5 out of control nearly half of the time, while the other spirometers were out of control 2 to 31% of the time.

Because spirometer 3 appeared to demonstrate bias and spirometer 5 appeared to demonstrate drift (Fig 3), we further explored rules aimed at detecting these systematic sources of error. We created rules aimed at detecting bias and applied these. The bias rule stipulating 30 consecutive values falling on the same side of zero distinguished spirometers 3 and 5 (30.7% and 25.1% out-of-control values, respectively) from other spirometers (0.1 to 6.4% out-of-control values). The candidate criteria using fewer consecutive points were not as specific.

We concluded that this rule identified the two spirometry systems with suboptimal performances. The application of this rule would require 30 days.

We then created and applied criteria aimed at detecting drift. The drift rule stipulating four consecutive values consistently increasing or decreasing deemed 9.1% of the total values out of control; the drift rule stipulating five consecutive values consistently increasing or decreasing deemed 2.1% of the total values out of control. The latter rule generated a slightly greater percentage of out-of-control values for spirometer 3, the spirometer that appeared to be affected by bias, compared to the other spirometers, but did not distinguish spirometer 5, the spirometer that was affected by drift. We concluded that this rule did not reliably identify the presence of drift in our calibration check data.

We combined the candidate rules to create a multirule approach, modeled after the Westgard approach to statistical quality control.[19] The addition of the rule stipulating two consecutive values exceeding ± 2% deviation did not enhance the sensitivities of the ± 2% rule or the ± 3.5% rules. The addition of the rule stipulating four consecutive values beyond 1% deviation improved the sensitivities of both the ± 2% and the ± 3.5% rules in detecting the suboptimal performances in two spirometers and maintained low overall error detection rates. The addition of the bias rule stipulating 30 consecutive values falling on either side of zero lead to increased proportions of out-of-control values for spirometers 3 and 5, but many of the more stable spirometers had out-of-control values > 5% of the time. Combinations of three rules were also applied (data not shown) and did not provide much additional benefit.

Discussion

The current ATS/ERS statement[2] on standardization of spirometry emphasizes the need for quality control practices to ensure optimal equipment performance. Statistical methods, such as application of Westgard rules, for evaluating daily calibration checks over time are provided in the model ATS procedure manual.[17] Implementation of this approach requires measurement of statistical variability of calibration checks in the context of clinically important ranges. While longitudinal variability of spirometry in humans has been studied,[20,21] little is known about the contribution of machine variability over time. To our knowledge, there are no published studies documenting the variability of 3-L calibration checks in pulmonary laboratories. The present study describes the findings of a statistical quality control analysis of > 7,000 calibration checks performed in our pulmonary function laboratory over several years.

Based on visual inspection of calibration check data plots, we identified two spirometry systems that had suboptimal performances compared to the others. The current guideline of ± 3.5% accuracy for calibration checks was insensitive in identifying these spirometers. Because the laboratory was using the 3% calibration check guideline and reviewing the data 1 month at a time, the long-term longitudinal data patterns were not as obvious as they are in this retrospective review. Therefore, the problems were not diagnosed and corrected at the time of the occurrences (Table 1). Because our laboratory stores the long-term data, we were able to conduct the present analysis and examine trends in the data over longer time intervals. The value of retaining long-term calibration check data and longitudinally evaluating the data are underscored by the results of our study, and we recommend that manufacturers incorporate this ability.

We investigated several candidate rules and found that applying a more stringent criteria of ± 2% identified the two spirometers with poorer performances while maintaining a low out-of-control detection rate (< 5%) in spirometers that were stable. The use of a statistical quality control procedure stipulating four consecutive values beyond 1% deviation yielded even greater sensitivity in detecting the spirometers with suboptimal performances while maintaining a low overall error detection rate. The use of other candidate rules increased sensitivity in the detection of spirometers with suboptimal performances but at the expense of decreased specificity and/or a longer latent time to error detection.

An ideal test procedure is both accurate and precise, and the goal of laboratory quality control is to ensure both. However, the desired performance characteristics of the test depend on the clinical indication. For example, a single diagnostic test to define the presence or absence of a disease should be highly accurate. To longitudinally follow the course of disease, precision becomes more important.[22] In multicenter longitudinal studies, high degrees of accuracy and precision are important.[22] One of the goals of statistical quality control is to identify both systematic and random sources of error. The choice of the most desirable approach may depend on the trade-off between the costs and benefits of sensitivity vs. specificity, depending on the clinical indication of the test.

The results of our study only represent calibration checks from volume-based spirometers in our laboratory, all of which were of the Stead-Wells design.[23] Flow-type spirometers are less homogeneous as a group than volume-type spirometers. Some flow-based spirometers are recalibrated daily, all flow-type spirometers should have their calibration checked daily at multiple flow rates, and some use disposable sensors. Therefore, a quality control system for flow-type spirometers would have to examine the variation in volumes measured at different flow rates and take into account the variability of the calibration factor, as well as other factors. For all of these reasons, although the general principles of the rules presented in this article may apply to flow-type spirometers, it is likely that many of the details, like the recommendation to require ± 2% accuracy, may not be appropriate for some flow-type spirometers. Thus, a similar study of flow based spirometer quality control data are needed, and recommendations from this study may not be applicable to flow-based spirometry systems.

We adopted a conservative approach insofar as we used only the first calibration check performed each day. Many of these were extreme outliers, and subsequent tests performed on the same day were within range. We performed analyses using alternative methods of analyzing the data (using all values, using only the second value when duplicates occurred, and excluding only the first when duplicates occurred) and found little change in our results. This was likely because most of our data were highly accurate (98% within 3.5%). Despite the fact that we identified two spirometers with suboptimal performances, the magnitude of error was small relative to clinically important changes. However, implementation of a systematic approach to longitudinally analyze data using statistical methods of quality control will promote earlier detection of systematic error and earlier implementation of remedial action, in addition to identifying larger sources of error.

Based on the experience presented here, we found that applying a ± 2% out-of-range criteria, we were able to detect suboptimal spirometer performance whereas the current 3.5% criteria was too insensitive.

The application of criteria stipulating four consecutive values beyond 1% deviation was also very effective, as was the combination of this rule and the ± 2% or ± 3.5% criteria. The use of our drift rule (*i.e.*, a continuous upward or downward trend in successive measures) was not effective in detecting the presence of drift in our spirometer. This is likely because of random fluctuation superimposed on a very slow drift over time, which made the rule less likely to be effective. The drift rule may have been more effective if severe drift was present, in which case the severe drift would likely have been detected by the ± 3.5% rule. The use of a customized bias rule (*i.e.*, the positive or negative bias in successive measures) was effective in distinguishing the suboptimal spirometry systems but required a 30-day observation period. Applying combinations of rules was also useful in our laboratory.

Thus, we conclude that for the volume-type spirometers in our laboratory, calibration checks that exceed 2% of the inserted volume should be considered out of range and prompt investigative measures, through recalibration of the spirometer should not be taken without careful consideration. Furthermore, a prospective longitudinal evaluation of calibration checks with ongoing application of criteria that deems a spirometer out of control when four consecutive checks exceed 1% deviation is also warranted. Individual laboratories should review patterns of quality control data over time and explore implementation of statistical quality control that best fits the needs and goals of the laboratory.

Pulmonary Function Tests
Pulmonary Function Tests Can Interpret Severity of COPD

Pulmonary function tests are confusing to many patients. And, as those with heart disease are usually aware of their blood pressure and cholesterol levels, the importance of knowing your numbers when it comes to pulmonary function tests (PFTs) and COPD is commonly overlooked.

The National Lung Health Education Program is currently on a mission to encourage patients to be aware of their pulmonary function test results by focusing on their mantra "test your lungs; know your numbers." Their mission also includes increasing the percentage of doctors who use spirometers in general practice, as it is currently reported that only 30% are doing so at this time.

Knowing your numbers is just another way for you to be your own patient advocate when it comes to your health. It also gives you a method of comparison to determine how well you are responding to treatment and if your disease is progressing.

Purpose of Pulmonary Function Tests

In the diagnoses of COPD, pulmonary function tests are performed to assess lung function and determine the degree of damage to the lungs.

Along with patient history, lung imaging studies and open lung biopsy, PFTs have become important for doctors in the evaluation of respiratory health.

Pulmonary function tests can be used for a number of reasons:

- Screening for the existence of lung diseases
- Determining the patient's condition prior to surgery to assess the risk of respiratory complications after surgery.
- Evaluating the ability for a patient to be weaned from a ventilator
- Assessing the progression of lung disease and the effectiveness of treatment

Three types of pulmonary function tests are used in the diagnosis of COPD - spirometry testing, diffusion studies and body plethysmography.

Spirometry Testing

The most commonly used device for lung function screening, this hand-held device can easily be used by patients with the assistance of an experienced technician. It is normally the clinician's first choice when attempting to diagnose a respiratory problem. A convenient, noninvasive procedure, spirometry can be performed in the privacy of your doctor's office or any inpatient or outpatient facility.

Spirometry requires the patient, after all air has been expelled, to inhale deeply. This maneuver is then followed by a rapid exhalation so that all the air is exhausted from the lungs.

Results of spirometry tests vary, but are based on predicted values of a standardized, healthy population.

COPD causes the air in the lungs to be exhaled at a slower rate and in a smaller amount compared to a normal, healthy person. The amount of air in the lungs will not be readily exhaled due to either a physical obstruction (such as with mucus production) or airway narrowing caused by chronic inflammation.

What is a spirometer and spirometry?

A spirometer is a device which measures the amount of air that you can blow out. There are various spirometer devices made by different companies, but they all measure the same thing. They all have a mouthpiece that you use to blow into the device. A doctor or nurse may ask you to blow into a spirometer ('spirometry') if you have chest or lung symptoms.

How is it done?

You breathe in fully and then seal your lips around the mouthpiece of the spirometer. You then blow out as fast and as far as you can until your lungs are completely empty.

This can take several seconds. You may also be asked to breathe in fully and then breathe out slowly as far as you can.

A clip may be put onto your nose to make sure that no air escapes from your nose. The above routine may be done two or three times to check that the readings are much the same each time you blow into the machine.

What does the spirometer measure?

The most common measurements used are:

- FEV1 - Forced Expiratory Volume in one second. This is the amount of air you can blow out within one second. With normal lungs and airways you can normally blow out most of the air from your lungs within one second.
- FVC - Forced Vital Capacity. The total amount of air that you blow out in one breath.
- FEV1 divided by FVC (FEV1/FVC). Of the total amount of air that you can blow out in one breath, this is the proportion that you can blow out in one second.

What can the measurements show?

A spirometry reading usually shows one of four main patterns:

- Normal
- An obstructive pattern
- A restrictive pattern
- A combined obstructive / restrictive pattern

Normal

Normal readings vary, depending on your age, size, and sex. The range of normal readings are published on a chart, and doctors and nurses refer to the chart when they check your spirometry readings.

An obstructive pattern - typical of diseases that cause narrowed airways

If your airways are narrowed, then the amount of air that you can blow out quickly is reduced. So, your FEV1 is reduced and the ratio FEV1/FVC is lower than normal. As a rule, you are likely to have a disease that causes narrowed airways if:

- your FEV1 is less than 80% of the predicted value for your age, sex and size, or
- your FEV1/FVC ratio is 0.7 or less.

However, with narrowed airways, the total capacity of your lungs is often normal or only mildly reduced. So, with an obstructive pattern the FVC is often normal or near normal.

The main conditions that cause narrowing of the airways and an obstructive pattern of spirometry are asthma and chronic obstructive pulmonary disease (COPD). So, spirometry can help to diagnose these conditions. Spirometry can also help to assess if treatment (inhalers etc) 'open up' the airways as the readings will improve if the narrowed airways become wider. As a guide, the following values help to diagnose COPD and its severity:

- COPD unlikely - FEV1 is 80% or more of the predicted value for your age, size and sex
- Mild airflow obstruction - FEV1 is 50-80% of the predicted value

- Moderate airflow obstruction - FEV1 is 30-49% of the predicted value
- Severe airflow obstruction - FEV1 is 30% or less of the predicted value

A restrictive pattern - typical of certain lung diseases

With a restrictive spirometry pattern your FVC is less than the predicted value for your age, sex and size. This is caused by various conditions that affect the lung tissue itself, or affect the capacity of the lungs to expand and hold a normal amount of air. For example, conditions that cause fibrosis or scarring of the lung such as pneumoconiosis. Or, a physical deformity that restricts the expansion of the lungs. Your FEV1 is also reduced but this is in proportion to the reduced FVC. So, with a restrictive pattern the ratio of FEV1/FVC is normal.

A combined obstructive / restrictive pattern

With this you may have two conditions, for example, asthma plus another lung disorder. Also, some lung conditions have features of both an obstructive and restrictive pattern. For example, with cystic fibrosis there is a lot of mucus in the airways which causes narrowed airways, and damage to the lung tissue may also occur.

Is spirometry the same as peak flow readings?

No. A peak flow meter is a small device that measures the fastest rate of air that you can blow out of your lungs. Like spirometry, it can detect airways narrowing. It is more convenient than spirometry and is commonly used to help diagnose asthma. Many people with asthma also use a peak flow meter to monitor their asthma. For people with COPD, a peak flow reading may be useful to give a rough idea of airways narrowing, but it can underestimate the severity of COPD. Therefore, spirometry is a more accurate test for diagnosing and monitoring people with COPD.

What preparation is needed before having spirometry?

You should get instructions from the doctor, nurse, or hospital department that does this test. Always follow these carefully. The instructions may include such things as not to use a bronchodilator inhaler for a set time before the test (several hours or more, depending on the inhaler). Also, not to have alcohol, a heavy meal, or do vigorous exercise for a few hours before the test. Ideally, you should not smoke for 24 hours before the test.

Is there any risk in having spirometry?

Spirometry is a very low risk test. However, blowing out hard can increase the pressure in your chest, abdomen and eyes. So, you may be advised not to have spirometry if you have:

- unstable angina
- had a recent pneumothorax (air trapped beneath the chest wall)
- had a recent heart attack or stroke
- had recent eye or abdominal surgery
- coughed up blood recently and the cause is not known.

Reversibility testing

Reversibility testing is done in some cases where the diagnosis is not clear. For this test, you will be asked to do spirometry as described above. You will then be given a medicine by inhaler or nebuliser which may 'open up' the airways. The spirometry test is then repeated 30 minutes or so afterwards. The aim of this is to see if your airways open wider with medication or not.

Common Terminology of Spirometry Tests Critical in Diagnosing COPD

- **VC-Vital Capacity** - The amount of air that can be forcibly exhaled from your lungs after a full inhalation.
- **FVC-Forced Vital Capacity** - The amount of air which can be forcibly exhaled from the lungs after taking the deepest breath possible.
- **FEV1-Forced Expiratory Volume in One Second** - The amount of air which can be forcibly exhaled from the lungs in the first second of a forced exhalation.
- **FEV1/FVC-FEV1-Percent (FEV1%)** - The ratio of FEV1 to FVC and tells the clinician what percentage of the total amount of air is exhaled from the lungs during the first second of forced exhalation.
- **PEFR Peak Expiratory Flow Rate**- Measures if treatment is effective in improving airway diseases such as COPD.
- **FEF-Forced Expiratory Flow** - A measure of how much air can be exhaled from the lungs. It is an indicator of large airway obstruction.
- **MVV-Maximal Voluntary Ventilation** - A value determined by having the patient inhale and exhale as rapidly and fully as possible in 12 seconds. The results reflect the status of the muscles used for breathing, how stiff the lungs are and if there is any resistance in the airways when breathing. This test tells surgeons how strong a patient's lungs are prior to surgery. If patients demonstrate poor performance on this test, it suggests to the doctor that respiratory complications may occur after surgery.

What Do the Numbers Mean?

Doctors also use spirometry testing to evaluate the severity of COPD. Your test results will be compared with tables of normal values that use variables such as age, gender, body size and race as a method of standardization.

With spirometry, test results will usually be measured twice, both before and after you are given a bronchodilator. If there is an improvement in two of three measurements, this means you will respond well to treatment.

Although there are a number of systems to choose from, the following is the method recommended by the Global Initiative for Obstructive Lung Disease (GOLD):

GOLD Spirometric Criteria for COPD Severity

GOLD Spirometric Criteria for COPD Severity		
I. Mild COPD	* FEV1/FVC < 0.7 * FEV1 >/= 80% predicted	At this stage, the patient is probably unaware that lung function is starting to decline
II. Moderate COPD	* FEV1/FVC < 0.7 * 50% </= FEV1 < 80% predicted	Symptoms during this stage progress, with shortness of breath developing upon exertion.
III. Severe COPD	* FEV1/FVC < 0.7 * 30% </= FEV1 < 50% predicted	Shortness of breath becomes worse at this stage and COPD exacerbations are common.
IV. Very Severe COPD	* FEV1/FVC < 0.7 * FEV1 < 30% predicted or FEV1 < 50% predicted with chronic respiratory failure	Quality of life at this stage is gravely impaired. COPD exacerbations can be life threatening.

How Do I Interpret My Spirometry Test?

A spirometry test is a type of pulmonary function test (PFT) that helps doctors diagnose the presence and severity of COPD. For many COPD patients, however, PFTs are one of the most misunderstood concepts of understanding the disease. In fact, the COPD Forum is literally filled with questions about PFTs, the most frequent being *"how do I interpret my spirometry test"?*

Answer: It is only natural to want to know how well your lungs are functioning. While you may be tempted to learn how to read your spirometry test yourself, or ask others to interpret them for you, in reality the test is very complicated and takes years of training to learn how to do and understand them. Why?

There is more to reading a spirometry test than just looking at a series of numbers. Before the tests are interpreted, demographic information such as age, sex, height, weight and smoking history is input into the spirometor machine. Someone who interprets your results without knowing your medical history is doing you a terrible injustice.

To get an accurate interpretation of your spirometry test, it is best to leave it up to the professionals. PFTs are interpreted from highly sophisticated tables that cannot be simplified. All patients are strongly encouraged to ask their pulmonary specialist any and all questions regarding the results of their tests. Not only will this foster the doctor-patient relationship, but it will give you peace of mind that may otherwise be lacking when someone other than your doctor attempts to read your test.

Don't be discouraged, however, because your COPD Guide is always available to help you better understand the test itself and why it is important to have one. Please present any questions you have about PFTs in the COPD Forum under the following thread:

How Important Is Your Effort in Pulmonary Function Testing?

If you feel you did not put forth your greatest effort during the test, say something - some technicians may ask that you repeat the test.

To learn more about pulmonary function testing visit the following article:

Along with spirometry testing, two other pulmonary function tests are important in the diagnosis of airway disease.

Diffusion Studies - This PFT tells you how well the oxygen that you breath moves into your bloodstream.

Definition: Lung diffusion tests help your health care provider determine how well oxygen passes from the alveoli, or air sacs, of your lungs to your bloodstream. The tests measure the "diffusing capacity of the lungs for carbon monoxide" or DLCO.

How is the Test Performed?

The test is performed by an experienced technician. You will inhale a small amount of carbon monoxide gas, hold your breath for 10 seconds, and then exhale as fast as possible. The exhaled gas is then analyzed to determine how much carbon monoxide was absorbed by your body during the breath.

How to Prepare for the Test

Preparation for lung diffusion testing is simple:

- Do not eat a heavy meal prior to the test
- Refrain from smoking at least 4 to 6 hours before the test
- If you use bronchodilators or other inhalers, be sure to check with your health care provider if you should use them prior to the test.

What Happens During the Test?

The test is performed while you are sitting down. A mouthpiece will be fitted tightly around your mouth. Clips will be placed on your nose to pinch it closed so you cannot breath through it.

Why Do I Need the Test?

Health care providers use the test to diagnose the presence of lung disease and to determine the extent of the damage, should lung disease exist.

Normal vs. Abnormal Results

Normal results are set to a standard, based on a person's age, sex and height.

Abnormal results mean that gases are not moving the way they should be across your lung tissue to your blood, which may indicate the presence of lung disease. Talk to your doctor for more information.

Risks Involved With the Test

There are no significant risks involved with lung diffusion tests.

Considerations

In order for your health care provider to make an accurate diagnosis, other pulmonary function tests may also be ordered in adjunct with lung diffusion tests.

Body Plethysmography - A test which determines how much air is present in your lungs when you take a deep breath and how much air is left in your lungs after you exhale as much as you can.

Definition: Body plethsmography is one of many pulmonary function tests which determines how much air is present in your lungs when you take a deep breath and how much air is left in your lungs after you exhale as much as you can.

In patients with COPD, the amount of air left in the lungs during the breathing process is more than normal. Body plethysmography helps your doctor know more about your lung disease and how to treat it.

How the Test is Performed

You will be required to sit in an enclosed plastic box and then, wearing a nosepiece, you will be instructed on how to breath through a mouthpiece.

Risks Involved

There are no significant risks involved with this test, however, if you have problems with claustrophobia, you may want to talk with your doctor about this prior to the test.

Also Known As: Respiratory inductance plethysmography

SPIROMETRY: The Measurement and Interpretation of Ventilatory Function in Clinical Practice

Introduction

A great deal can be learned about the mechanical properties of the lungs from measurements of forced maximal expiration and inspiration. Since Hutchinson first developed the spirometer in 1846, measurements of the so-called dynamic lung volumes and of maximal flow rates have been used in the detection and quantification of diseases affecting the respiratory system. Over the years it has become obvious that the spirometer and peak flow meter used to measure ventilatory function are as deserving of a place in the family practitioner's surgery as the sphygmomanometer. After all, who would dream of managing hypertension without measurement of blood pressure?

It is important to appreciate that the clinical value of spirometric measurements is critically dependent on the correct operation and accuracy of the spirometer, performance of the correct breathing maneuver and use of relevant predicted normal values.

Staff performing spirometry should first attend a comprehensive training course. This is important because inadequate training will result in poor quality spirometry that is of little clinical value.

This handbook-like information was written as a guide for those involved in the performance and interpretation of spirometry in clinical practice, i.e. medical practitioners and assisting nursing staff, and as an introduction to the topic for scientists and technicians. It is not intended to be an exhaustive review but rather a guide aiming to help improve the knowledge and techniques of those already doing and interpreting spirometry, and to introduce spirometry to those learning how to do it for the first time. The important facts about types of spirometers, how the test is actually performed and interpreted, and some common pitfalls and problems are covered in the main text.

Measurement of Ventilatory Function
Conventionally, a spirometer is a device used to measure timed expired and inspired volumes, and from these we can calculate how effectively and how quickly the lungs can be emptied and filled.

A spirogram is thus a volume-time curve and Figure 1 shows a typical curve. Alternatively, measures of flow can be made either absolutely (e.g. peak expiratory flow) or as a function of volume, thus generating a flow-volume curve, the shape of which is reproducible for any individual but varies considerably between different lung diseases. A poorly performed maneuver is usually characterized by poor reproducibility.

The measurements which are usually made are as follows:
1. **VC** (vital capacity) is the maximum volume of air which can be exhaled or inspired during either a maximally forced (**FVC**) or a slow (**VC**) maneuver. VC is normally equal to FVC unless airflow obstruction is present, in which case VC is usually higher than FVC.

2. **FEV1** (forced expired volume in one second) is the volume expired in the first second of maximal expiration after a maximal inspiration and is a useful measure of how quickly full lungs can be emptied.

3. **FEV1/VC** (or **FEV1/FVC**) is the FEV1 expressed as a percentage of the VC or FVC (whichever volume is larger) and gives a clinically useful index of airflow limitation.

4. **FEF25-75%** is the average expired flow over the middle half of the FVC maneuver and is regarded as a more sensitive measure of small airways narrowing than FEV1.
Unfortunately FEF25-75% has a wide range of normality, is less reproducible than FEV1, and is difficult to interpret if the VC (or FVC) is reduced or increased.

5. **PEF** (peak expiratory flow) is the maximal expiratory flow rate achieved and this occurs very early in the forced expiratory maneuver.

6. **FEF50% and FEF75%** (forced expiratory flow at 50% or 75% FVC) is the maximal expiratory flow measured at the point where 50% of the FVC has been expired (FEF50%) and after 75% has been expired (FEF75%). Both indices have a wide range of normality but are usually reproducible in a given subject provided the FVC is reproducible.

7. **FVC6** is the forced expiratory volume during the first 6 seconds and is a surrogate of the FVC. The FVC6 (and FEV1/FVC6) is gaining popularity because stopping the expiratory maneuver after 6 seconds is less demanding and easier to perform for patients with airflow obstruction and the elderly yet is similar to conventional FVC and FEV1/FVC for diagnosing and grading airflow obstruction.

All indices of ventilatory function should be reported at body temperature and pressure saturated with water vapor (BTPS). If this is not done the results will be underestimated, because when the patient blows into a ‘cold’ spirometer, the volume recorded by the spirometer is less than that displaced by the lungs.

Measurement Devices
Commonly used devices include volume-displacement and flow-sensing spirometers for use in the office or laboratory and portable devices suitable for personal use.

Volume-Displacement Spirometers

Conventional spirometers provide a direct measure of respired volume from the:
• displacement of a bell (water sealed);
• piston (rolling seal); or
• bellows (e.g. wedge bellows).

The results are normally presented as a graphic display of expired volume against time (a spirogram). The indices FEV1, FVC and VC are generally manually calculated (including correction to BTPS) from the spirogram by the operator and for this reason volume-type spirometers are considered time consuming and less convenient for routine use in the doctor's surgery.

Generally, volume spirometers are simple to use, accurate, reliable, easy to maintain and provide a clear and permanent record of the test. They are, however, less portable than flow spirometers, and more difficult to clean and disinfect.

Flow-Sensing Spirometers

Over recent years advances in electronics and microprocessor technology have led to the development of a new range of portable spirometers. Flow spirometers generally utilize a sensor that measures flow as the primary signal and calculate volume by electronic (analog) or numerical (digital) integration of the flow signal. The most commonly used flow sensors detect and measure flow from:

• the pressure drop across a resistance (e.g. pneumotach or orifice);
• the cooling of a heated wire (anemometer);
• electronically counting the rotation of a turbine blade; or
• the time of flight of an ultrasonic sound pulse directed across the expired gas flow (ultrasonic sensor).

For the general practitioner these devices have largely replaced the volume spirometer because they are usually portable and they automatically calculate a large range of ventilatory indices, provide immediate feedback on the quality of each blow, select the best result, store patient results, calculate reference values for the patient being tested and provide a print-out of the results including the spirogram and flow-volume loop. These features, together with their portability, ease of use and maintenance (e.g. cleaning and disinfection) have resulted in the increasing popularity of flow-based spirometers.

Some flow spirometers have single patient use disposable sensors, effectively eliminating the need for cleaning and disinfection. However, the accuracy of each new sensor may need to be established. Accuracy and reproducibility depend on the stability and calibration of the electronic circuitry and appropriate correction of flow and volume to BTPS conditions.

Monitoring Devices

Mechanical devices for personal use by patients, such as the peak flow meter, have been available for several decades for serial monitoring of lung function and have proven useful in the management of asthma. Most peak flow meters are robust and provide reproducible results essential for serial monitoring. However, they often have limited accuracy and, because they provide only a single effort-dependent index of ventilatory function, they have limited application in the initial assessment of respiratory diseases.

Measurements of PEF are reduced in diseases causing airways obstruction. Peak flow monitoring is particularly useful for following trends in lung function, quantifying response to treatment and identifying trigger factors in asthma.

Portable peak flow meters are a reasonably reliable tool for patients to monitor their own airway function.

Recently several small, inexpensive yet accurate battery-powered devices for measuring ventilatory function (including FEV1) have been developed, some of which can store the test data which can be downloaded onto a computer for review and statistical analysis.

Factors to Consider when Choosing a Spirometer

- Ease of use
- Provision of easy to read real-time graphic display of the maneuver
- Provision of immediate quality feedback concerning the acceptability of blows, including reproducibility
- Provision to interface with clinical software packages
- Provision of customizable final spirometry report
- Provision to print the final report
- Price and running costs
- Reliability and ease of maintenance
- Training, servicing and repair of the spirometer provided by supplier
- Ability to trial the spirometer in your setting before purchase
- Provision of a disposable sensor or a breathing circuit that can be easily cleaned and disinfected
- Provision of appropriate normal reference values with lower limits of normal
- Robustness
- Provision of a comprehensive manual describing the spirometer's operation, maintenance and calibration
- Calibration requirements
- Conformance with accepted spirometry performance standards
- Compliance with electrical safety standards

A summary of the specifications and features of spirometers currently available in Australia and New Zealand is provided in the *Spirometer Users' and Buyers' Guide*, which is published on the National Asthma Council Australia website (http://nationalasthma.org.au). Faced with such a large variety of spirometers, general practitioners have to choose an instrument suitable for use in their own surgery. Readers are advised to contact their State Asthma Foundation for further

information and advice on peak flow meters, and local respiratory laboratories regarding spirometers.

The Technique - How to Do it and Common Pitfalls and Problems

How to Do It

To ensure an acceptable result, the FVC maneuver must be performed with maximum effort immediately following a maximum inspiration; it should have a rapid start and the spirogram and flow-volume curve should be a smooth continuous curve.

To achieve good results, carefully explain the procedure to the patient, ensuring that he/she is sitting erect with feet firmly on the floor (the most comfortable position, though standing gives a similar result in adults, but in children the vital capacity is often greater in the standing position).

Apply a nose clip to the patient's nose (this is recommended but not essential) and urge the patient to:

• breathe in fully (must be absolutely full)
• seal his/her lips around the mouthpiece
• immediately blast air out as fast and as far as possible until the lungs are completely empty
• breathe in again as forcibly and fully as possible (if inspiratory curve is required and the spirometer is able to measure inspiration).

If only peak expiratory flow is being measured then the patient need only exhale for a couple of seconds. Essentials are:

• to breathe in fully (must be absolutely full)
• a good seal on the mouthpiece
• very vigorous effort right from the start of the maneuver and continuing until absolutely no more air can be exhaled
• no leaning forward during the test
• obtain at least 3 acceptable tests that meet repeatability criteria (see below)

Remember, particularly in patients with airflow obstruction, that it may take many seconds to fully exhale. It is also important to recognize those patients whose efforts are reduced by chest pain or abdominal problems, or by fear of incontinence, or even just by lack of confidence. There is no substitute for careful explanation and demonstration - demonstrating the maneuver to the patient will overcome 90% of problems encountered and is critical in achieving satisfactory results. Observation and encouragement of the patient's performance are also crucial. At least three technically acceptable maneuvers should be obtained, ideally with less than 0.15 L variability for FEV1 (and FVC) between the highest and second highest result.

Each individual test is acceptable if it meets the following acceptability and repeatability criteria.

Acceptability Criteria

• The patient followed instructions
• A continuous maximal expiratory maneuver throughout the test (i.e. no stops and starts) was achieved
and was initiated from full inspiration
• There was no evidence of hesitation during the test
• The test was performed with a rapid start
• The PEF has a sharp rise (flow-volume)
• No premature termination, i.e. expiration continued until there was no change in volume and the patient had blown for ≥3 seconds (children aged <10 years) or for ≥6 seconds (patients aged ≥10 years). However, the patient or practitioner can terminate the blow if the patient cannot or should not continue
• There were no leaks
• No cough (note FEV1 may be valid if cough occurs after the first second)
• No glottis closure (Valsalva)
• No obstruction of the mouthpiece (e.g. by the tongue or teeth)
• No evidence that the patient took an additional breath during the expiratory maneuver

Repeatability Criteria

• Obtain 3 acceptable tests, i.e. each test should meet the stated acceptability criteria
• The two largest values for FVC should agree to within 0.15L
• The two largest values for FEV1 should agree to within 0.15L
Obtain additional tests if these repeatability criteria are not met.

Results to Report

• FEV1 - report the largest value
• FVC - report the largest value
• PEF - report the largest value
• FEF25-75% - report the value from the test with the highest sum of FEV1 + FVC

It is important that the acceptability criteria be applied and unacceptable tests discarded before assessing repeatability, as the latter is used to determine whether additional tests from the three acceptable ones already obtained are required. These criteria (together with a properly maintained and calibrated spirometer) help to ensure the quality of your results.

Tests that do not fully meet the acceptability criteria may still be useful. For example, FEV1 may still be valid if cough or premature termination of the blow occurs after the first second. The report should state when the results are obtained from maneuvers that do not meet acceptability and repeatability criteria.

Patient-Related Problems

The most common patient-related problems when performing the FVC maneuver are:
1. Submaximal effort
2. Leaks between the lips and mouthpiece

3. Incomplete inspiration or expiration (prior to or during the forced maneuver)
4. Hesitation at the start of the expiration
5. Cough (particularly within the first second of expiration)
6. Glottic closure
7. Obstruction of the mouthpiece by the tongue
8. Vocalization during the forced maneuver
9. Poor posture.

Once again, demonstration of the procedure will prevent many of these problems, remembering that all effort dependent measurements will be variable in patients who are uncooperative or trying to produce low values.

Glottis closure should be suspected if flow ceases abruptly during the test rather than being a continuous smooth curve. Recordings with cough, particularly if this occurs within the first second, or hesitation at the start should be rejected. Vocalization during the test will reduce flows and must be discouraged - performing the maneuver with the neck extended often helps.

The vigorous effort required for spirometry is often facilitated by demonstrating the test yourself.

Instrument-Related Problems

These depend largely on the type of spirometer being used. On volume-displacement spirometers look for leaks in the hose connections; on flow-sensing spirometers look for rips and tears in the flow head connector tube; on electronic spirometers be particularly careful about calibration, accuracy and linearity. Standards recommend checking the calibration at least daily and a simple self-test of the spirometer is an additional, useful daily check that the instrument is functioning correctly.

Predicted Normal Values

To interpret ventilatory function tests in any individual, compare the results with reference values obtained from a well-defined population of normal subjects matched for sex, age, height and ethnic origin and using similar test protocols; and carefully calibrated and validated instruments.[1]

Normal predicted values for ventilatory function generally vary as follows:
1. Sex: For a given height and age, males have a larger FEV1, FVC, FEF25-75% and PEF, but a slightly lower FEV1/FVC.
2. Age: **FEV1**, **FVC**, **FEF25-75%** and **PEF** increase, while **FEV1/FVC** decreases, with age until about 20 years old in females and 25 years in males.After this, **all indices** gradually fall, although the precise rate of decline is probably masked
due to the complex interrelationship between age and height. The fall in FEV1/FVC with age in adults is due to the greater decline in FEV1 than FVC.
3. Height: All indices other than FEV1/FVC increase with standing height.
4. Ethnic Origin: Caucasians have the largest FEV1 and FVC and, of the various ethnic groups, Polynesians are among the lowest.

The values for black Africans are 10-15% lower than for Caucasians of similar age, sex and height because for a given standing height their thorax is shorter; normal values for Indigenous Australians may be even lower. Chinese have been found to have an FVC about 20% lower and Indians about 10% lower than matched Caucasians.
There is little difference in PEF between ethnic groups.

There is a vast literature of normal population studies, many of which have deficiencies in sample size, definition of normality, inclusion of smokers and choice of equipment. *Appendix B* provides tables of mean predicted values from a well-conducted study on a US Caucasian population[2].

Interpretation of Ventilatory Function Tests
Measurements of ventilatory function may be very useful in a diagnostic sense but they are also useful in following the natural history of disease over a period of time, assessing preoperative risk and in quantifying the effects of treatment. The presence of ventilatory abnormality can be inferred if any of FEV1, VC, PEF or FEV1/FVC are outside the normal range.

Classifying Abnormal Ventilatory Function
The inter-relationships of the various measurements are also important diagnostically. For Example:

1. A reduction of FEV1 in relation to the forced vital capacity will result in a low FEV1/FVC and is typical of **obstructive ventilatory defects** (e.g. asthma and emphysema). The lower limit of normal for FEV1/FVC is around 70-75% but the exact limit is dependent on age. The exact values by age, sex and height are given in the tables in Appendix B. In obstructive lung disease the FVC may be less than the slow VC because of earlier airway closure during the forced maneuver. This may lead to an overestimation of the FEV1/FVC. Thus, the FEV1/VC may be a more sensitive index of airflow obstruction.
2. The FEV1/FVC ratio remains normal or high (typically > 80%) with a reduction in both FEV1 and FVC in **restrictive ventilatory defects** (e.g. interstitial lung disease, respiratory muscle weakness, and thoracic cage deformities such as kypho-scoliosis).
3. A reduced FVC together with a low FEV1/FVC ratio is a feature of a **mixed ventilatory defect** in which a combination of both obstruction and restriction appear to be present, or alternatively may occur in airflow obstruction as a consequence of airway closure resulting in gas trapping, rather than as a result of small lungs. It is necessary to measure the patient's total lung capacity to distinguish between these two possibilities.

PFT Examination

Select the ***best*** answer to each of the following items. Mark your responses on the Answer Form.

1. *Pulmonary function tests* (PFTs) is a generic term used to indicate a battery of studies or maneuvers that may be performed using standardized equipment to measure lung _____.

a. capacity
b. size
c. function
d. None of the above

2. Before a spirogram can be meaningfully _____, one needs to inspect the graphic data (the volume-time curve and the flow-volume loop) to ascertain whether the study meets certain well-defined acceptability and reproducibility standards.

a. utilized
b. inspected
c. interpreted
d. None of the above

3. Basic concepts of normal pulmonary physiology that are involved in pulmonary function testing include mechanics (airflows and lung volumes), _____.

a. the ventilation-perfusion interrelationship
b. diffusion and gas exchange
c. respiratory muscle or bellows strength
d. All of the above

4. Pulmonary function studies use a variety of maneuvers to measure and record the properties of four lung components. These include the airways (large and small), _____. Various diseases can affect each of these components.

a. lung parenchyma (alveoli, interstitium),
b. pulmonary vasculature
c. the bellows-pump mechanism
d. All of the above

5. Spirometry is the most commonly used lung function screening study. The test can be administered in the _____.

a. ambulatory setting
b. physician's office
c. emergency department
d. All of the above

6. In normal persons, the inspiratory vital capacity, the expiratory SVC, and expiratory FVC are essentially_____.

a. the opposite
b. equal
c. similar
d. completely unrelated

7. A spirogram is a graphic representation of _____depicted as a volume-time tracing or as a flow-volume tracing. Values generated from a simple spirogram provide important graphic and numeric data regarding the mechanical properties of the lungs, including airflow (forced expiratory volume in 1 second [FEV_1] along with other timed volumes) and exhaled lung volume (FVC or SVC).

a. lung capacity
b. bulk air movement
c. mechanical static
d. None of the above

8. The volume-time tracing is most useful in assessing whether the end-of-test criteria have been met, whereas the flow-volume loop is most valuable in evaluating the start-of-test criteria.

a. True
b. False

9. With common obstructive airflow disorders, such as asthma or emphysema, the disease generally affects the expiratory limb and can reduce the effort-dependent peak expiratory flow as well as subsequent airflows that are independent of effort.

a. True
b. False

10. Bronchial hyperreactivity, as assessed by this inhalational challenge procedure, is very sensitive for the presence of active or current asthma. A positive test strongly suggests bronchial asthma. However, this test may be falsely positive in a variety of conditions, including _____.

a. chronic obstructive pulmonary disease
b. parenchymal respiratory disorders
c. congestive heart failure
d. All of the above

11. All methods for measuring diffusing capacity in clinical practice rely on measuring the rate of carbon monoxide uptake and estimating carbon monoxide driving pressure. The most widely used and standardized technique is the_____.

a. double-breath holding approach
b. single-breath breath-holding technique
c. mechanical ventilation
d. None of the above

12. Race plays an important role in determining normal lung function; it has been recognized that persons of different races for any given height and age have proportionately different lung volumes. Specifically, based on anthropometric differences, the lung function for _____ is systematically lower compared with whites.

a. Chinese Americans
b. African Americans
c. Japanese Americans
d. None of the above

13. Which of the following statements is True?

a. Lung function testing helps us to understand the physiologic working of the lungs and chest mechanics
b. Pulmonary function testing is the primary method used to diagnose, stage, and monitor various pulmonary diseases.
c. Lung function testing requires operators to follow published guidelines for administering and interpreting tests.
d. All of the above

14. The level and nature of functional impairment in (respiratory bronchiolitis-associated interstitial lung disease) RBILD has varied in clinical series, but despite the bronchiolocentric nature of disease, both restrictive and obstructive abnormalities have been documented.

a. True
b. False

15. The paucity of longitudinal data should be emphasized; it is likely that more detailed information in larger cohorts of RBILD patients will emerge in the next year or two. However, it is increasingly clear, from the above series and from widespread anecdotal experience, that a response to therapy is not the rule in RBILD, but may be confined to a minority or small majority of patients.

a. True
b. False

16. The cause of restrictive lung diseases may be either directly related to a dysfunction of the lungs (intrapulmonary) or not related to a dysfunction of the lungs (extrapulmonary). Intrapulmonary restrictive lung diseases include _____.

a. pneumonia
b. pulmonary fibrosis
c. pulmonary edema
d. All of the above

17. Because pulmonary function testing requires deep breathing, the test itself may aggravate these same conditions. Conditions in a patient that contraindicate pulmonary function testing include: the coughing-up of blood from the respiratory tract (hemoptysis); _____.

a. a collapsed or partially collapsed lung (pneumothorax);
b. an unstable heart condition
c. recent heart attack
d. All of the above

18. The health care provider should also indicate that while most side effects of pulmonary function tests are extremely rare, the patient should stop the test if he or she becomes extremely uncomfortable or feels intense pain in the _____.

a. head
b. eye
c. abdomen
d. All of the above

19. There is usually no patient care required after the administration of a pulmonary function test. If a patient feels lightheaded or dizzy, he or she should lie down until the symptoms subside. In rare cases, oxygen may have to be administered to prevent pneumothorax or to restore normal breathing patterns.

a. True
b. False

20. The main conditions that cause narrowing of the airways and an obstructive pattern of spirometry are asthma and chronic obstructive pulmonary disease (COPD). So, spirometry can help to diagnose these conditions. Spirometry can also help to assess if treatment (inhalers etc) 'open up' the airways as the readings will improve if the narrowed airways become wider.

a. True
b. False

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