DiPiro's Pharmacotherapy: A Pathophysiologic Approach, 12th Edition

Chapter e43: Evaluation of Respiratory Function

Megan L. Carreon; Maria I. Velez; Stephanie M. Levine; Jay I. Peters

KEY CONCEPTS

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1 The function of the lungs is to maintain the arterial partial pressure of oxygen (PaO_2) and arterial partial pressure of carbon dioxide ($PaCO_2$) within normal ranges (ie, normal ventilation-perfusion ratio).

2 The air in the lung is divided into four compartments: tidal volume—air exhaled during non-exertional breathing; inspiratory reserve volume (IRV)—maximal air *inhaled* above tidal volume; expiratory reserve volume (ERV)—maximum air *exhaled* after tidal volume; and residual volume (RV)—air remaining in the lung after maximal exhalation. The sum of all four components is the total lung capacity (TLC). Pulmonary function tests will produce values consistent with normal lungs or an obstructive or restrictive disease: recognition of these values is key.

3 Obstructive lung disease is defined as an inability to get air out of the lungs. It is identified on spirometry when forced expiratory volume in the first second of expiration (FEV_1) compared to the forced vital capacity (FVC) (total amount of air that can be exhaled during a forced exhalation) (FEV_1/FVC) is less than 70% to 75% (0.70-0.75) in adults (or below the lower limit of normal [LLN] based on population studies).

4 An increase in FEV_1 of 12% (and greater than 0.2 L in adults) after an inhaled β-agonist suggests an acute bronchodilator response.

5 Restrictive lung disease is defined as an inability to get enough air into the lung and is best defined as a reduction in TLC (usually less than 80% of predicted).

6 Restrictive lung disease can be produced by a number of diseases, such as increased elastic recoil (interstitial lung disease), respiratory muscle weakness (myasthenia gravis), and mechanical restrictions (pleural effusion or kyphoscoliosis). It can also be the result of poor effort during a pulmonary function test (PFT).

7 The shape of the flow-volume loop, which includes inspiratory and expiratory flow-volume curves, and the ratio of forced expiratory and inspiratory flow at 50% of VC ($FEF_{50\%}/FIF_{50\%}$ greater than 1) may be useful in the diagnosis of upper airway obstruction.

8 Cardiopulmonary exercise testing allows for the assessment of multiple organs involved in exercise.

9 Spirometry and other pulmonary function tests in children are possible and can successfully be done with proper coaching methods and modified reference values.

BEYOND THE BOOK

BEYOND THE BOOK

Watch this brief video about when and how to perform spirometry: "Taking a Spirometry Test" from the National Heart, Lung & Blood Institute: http://https://youtu.be/Zs8Fs5HaJHs.

INTRODUCTION

The primary function of the respiratory system is to maintain normal arterial blood gases, that is, arterial partial pressure of oxygen (PaO_2) and arterial partial pressure of carbon dioxide ($PaCO_2$). To achieve this goal, several processes must be accomplished, including alveolar ventilation, pulmonary perfusion, ventilation-perfusion matching, and gas transfer across the alveolar-capillary membrane. Alveolar ventilation is achieved by the cyclic process of air movement in and out of the lung. During inspiration, the inspiratory muscles contract and generate a negative pressure in the pleural space. This pressure gradient between the mouth and the alveoli draws fresh air (tidal volume [V_T]) into the lungs. Approximately one-third of the inspired gas stays in the conducting airways (dead space), and two-thirds reach the alveoli.

1 The human lung contains a series of branching, progressively tapering airways that originate at the glottis and terminate in a matrix of thin-walled alveoli. Coursing through this matrix of alveoli is a rich network of capillaries that originates from the pulmonary arterioles and terminates in the pulmonary venules. The adequacy of respiration in each gas exchange unit depends on the apposition of a thin film of mixed venous blood with just the right amount of fresh alveolar gas. During "ideal" gas exchange, blood flow and ventilation are uniform; accordingly, there is no alveolar-arterial difference (or gradient) in the partial pressure of oxygen ($P[A–a]O_2$, sometimes called the A–a gradient). However, gas exchange is not perfect, even in the normal lung. Normally, alveolar ventilation is less than pulmonary blood flow, and the overall ventilation-perfusion ratio is 0.8 (not 1.0).

Normal expiration is a passive process, and when the inspiratory muscles end their contraction, the elastic recoil of the lung pulls the lung back to its original size and shape. This process makes the alveolar pressure positive relative to the pressure at the mouth, and air flows out of the lung. During inspiration, the respiratory muscles must overcome the elastic properties of the lung (elastic recoil) and the resistance to air flow by the airways. During expiration, the flow of air is determined primarily by the elastic recoil and airway resistance.

Different pulmonary function tests (PFTs) are used to evaluate the physiologic processes of the respiratory system. Abnormalities that can be measured by pulmonary function testing include obstruction to airflow, changes in lung size, and decreases in the transfer of gas across the alveolar-capillary membrane. Spirometry is frequently used to screen patients for evidence of obstruction or restrictive lung disease when they present with respiratory complaints. Normal PFTs values are obtained from a group of normal individuals based on age, height, sex, and race. A PFT is considered abnormal when the results fall outside the range found in 95% of people of the same age, height, and sex (95% confidence interval). This definition is arbitrary and may misclassify a small percentage of normal individuals as having lung dysfunction; it may also miss patients with mild pulmonary disease. Therefore, clinical correlation and serial pulmonary function testing may be necessary for optimal interpretation of PFTs.

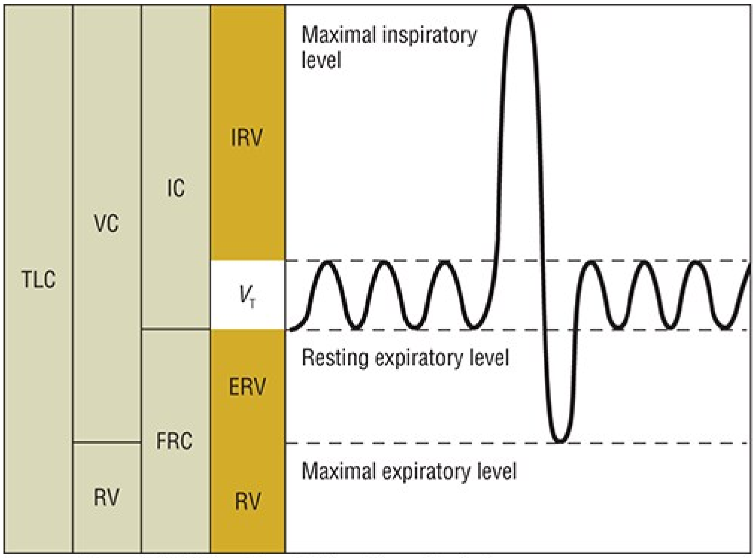
Potential uses of pulmonary function testing include evaluation of patients with known or suspected lung disease; evaluation of symptoms such as chronic cough, dyspnea, or chest tightness; monitoring of the effects of exposure to dust, chemicals, or pulmonary toxic drugs; risk stratification prior to surgery; monitoring of the effectiveness of therapeutic interventions; and objective assessment of impairment or disability.[1]

DEFINITIONS OF LUNG VOLUMES AND EXPIRATORY FLOWS

2 The air within the lung at the end of a forced inspiration can be divided into four compartments or lung volumes (Fig. e43-1). The volume of air exhaled during normal quiet breathing is the V_T. The maximal volume of air inhaled above V_T is the *inspiratory reserve volume* (IRV), and the maximal air exhaled below V_T is the *expiratory reserve volume* (ERV). The *residual volume* (RV) is the amount of air remaining in the lungs after a maximal exhalation.

FIGURE e43-1

Lung volumes and capacities. (ERV, expiratory reserve volume; FRC, functional residual capacity; IC, inspiratory capacity; IRV, inspiratory reserve volume; RV, residual volume; TLC, total lung capacity; VC, vital capacity; V_T, tidal volume)



The combinations or sums of two or more lung volumes are termed *capacities* (see Fig. e43-1). *Vital capacity* (VC) is the maximal amount of air that can be exhaled after a maximal inspiration. It is equal to the sum of IRV, V_T, and ERV. When measured on a forced expiration, it is called the *forced vital capacity* (FVC). When measured over an exhalation of at least 30 seconds, it is called the *slow vital capacity* (SVC). The VC is approximately 75% of the *total lung capacity* (TLC), and when the SVC is within the normal range, a significant restrictive disorder is unlikely. Normally, the values for SVC and FVC are very similar unless airway obstruction is present.

Total lung capacity (TLC) is the volume of air in the lung after a maximal inspiration and is the sum of the four primary lung volumes (IRV, V_T, ERV, and RV). Its measurement is difficult because the amount of air remaining in the chest after maximal exhalation, RV, must be measured by indirect methods. The definition of restrictive lung disease is based on a reduction in TLC (ie, an inability to get air into the lung or restriction to air movement during inhalation).

The *functional residual capacity* (FRC) is the volume of air remaining in the lungs at the end of a quiet expiration. It is the sum of RV and ERV. FRC is the normal resting position of the lung; it occurs when there is no contraction of either inspiratory or expiratory muscles and normally is 40% of TLC. *Inspiratory capacity* (IC) is the maximal volume of air that can be inhaled from the end of a quiet expiration and is the sum of V_T and IRV.

FVC, which represents the total amount of air that can be exhaled, can be expressed as a series of timed volumes. The *forced expiratory volume in the first second of expiration* (FEV_1) is the volume of air exhaled during the first second of the FVC maneuver. Although FEV_1 is a volume, it conveys information on obstruction because it is measured over a known time interval. FEV_1 depends on the volume of air within the lung and the effort during exhalation; therefore, it can be diminished by a decrease in TLC or by a lack of effort. A more sensitive way to measure obstruction is to express FEV_1 as a ratio of FVC. This ratio is independent of the patient's size or TLC; therefore, FEV_1/FVC is a specific measure of airway obstruction with or without restriction. Normally, in adults older than 20 years, this ratio is greater than or equal to 80% (0.80), and any value less than 80% to 75% (0.80-0.75) suggests obstruction. In children and young adults (age 5-20 years), an FEV_1/FVC ratio less than or equal to 85% (0.85) is considered a sign of obstruction.[2]

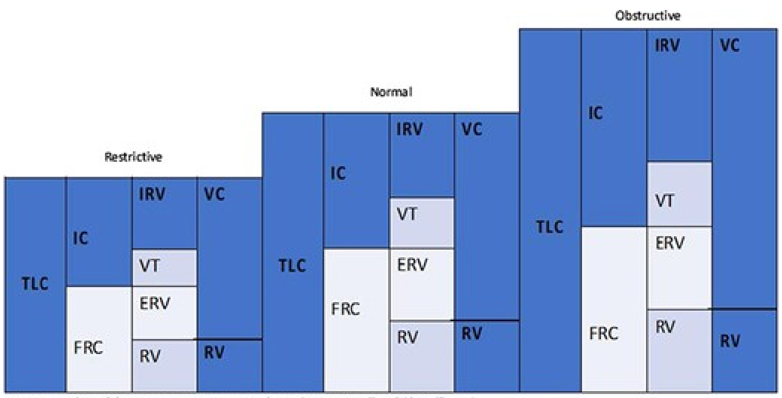
Flow is defined as the change in volume with time, forced expiratory flow (FEF) can be determined graphically by dividing the volume change by the time change. The *FEF during 25% to 75% of FVC* ($FEF_{25\%-75\%}$) represents the mean flow during the middle half of the FVC. $FEF_{25\%-75\%}$, formerly called the *maximal mid-expiratory flow*, is used frequently in the assessment of small airways. The *peak expiratory flow* (PEF), also called *maximum forced* *expiratory flow* (FEF_{max}), is the maximum flow obtained during FVC. This measurement is often used in the outpatient management of asthma because it can be measured with inexpensive peak flow meters.

All lung volumes and flows are compared with normal values obtained from healthy subjects. There are significant ethnic and racial variations in normal values, and all PFTs should report that race/ethnic adjustment factors have been used. This is especially important in African American subjects who exhibit a greater proportion of their height in the waist-to-leg length. If not corrected for race/ethnicity, many subjects will have restrictive lung functions. The 2005 American Thoracic Society–European Respiratory Society (ATS–ERS) guidelines for the interpretation of PFT results recommended that, for spirometry in the United States, the National Health and Nutrition Examination Survey (NHANES) III reference be used for subjects aged 8 to 80 years and the Wang equation used in subjects younger than 8 years.[3] In 2012, an ERS task force called the Global Lung Initiative (GLI), released spirometry reference equations that were based on over 90,000 spirometry results collected worldwide from healthy, nonsmoking individuals aged 3 to 95 years and from different ethnicities with the purpose of providing a continuous spirometry reference range that spanned all ages. The reference equations obtained from this initiative provide the most reliable spirometric prediction and therefore have been endorsed by all major international respiratory societies.[4]

Depending on the classification of the disease state that the patient may have, you should expect to see a difference between the values. A patient's pulmonary function tests will produce values consistent with normal lungs or with obstructive or restrictive disease. Figure e43-2 depicts how different restrictive and obstructive lung diseases affect the lung volumes and capacities in relation to normal lung volumes and capacities.

FIGURE e43-2

Lung volumes and capacities—normal vs restrictive and obstructive lung diseases.



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Spirometry/Flow-Volume Loop

Spirometry is the most widely available and useful PFT.[5] The test takes only 15 to 20 minutes to perform, carries minimal risks, and provides information about obstructive and restrictive disease. Spirometry allows for the measurement of all lung volumes and capacities except RV, FRC, and TLC; it also allows the assessment of FEV_1 and $FEF_{25\%-75\%}$. During the test, patients are asked to take a maximal inspiration and forcefully exhale.

Spirometry measurements can be reported in two different formats—standard spirometry (Fig. e43-3) and the flow-volume loop (Fig. e43-4). In standard spirometry, the volumes are recorded on the vertical (*y*) axis and the time on the horizontal (*x*) axis. In flow-volume loops, the volume is plotted on the horizontal (*x*) axis, and flow (derived from volume/time) is plotted on the vertical (*y*) axis. The shape of the flow-volume loop can be helpful in differentiating obstructive and restrictive defects and in diagnosing upper airway obstruction (Fig. e43-5). This curve gives a visual representation of obstruction, where the expiratory descent becomes more concave (Fig. e43-5 Panel B). The spirometry should be performed three times to ensure that the results are reproducible (less than 200 cc variation).

FIGURE e43-3

Standard spirometry. Curve 1 is for a normal subject with normal FEV_1; curve 2 is for a patient with mild airway obstruction; curve 3 is for a patient with moderate airway obstruction; curve 4 is for a patient with severe airway obstruction.

(BPTS, body temperature saturated with water vapor)

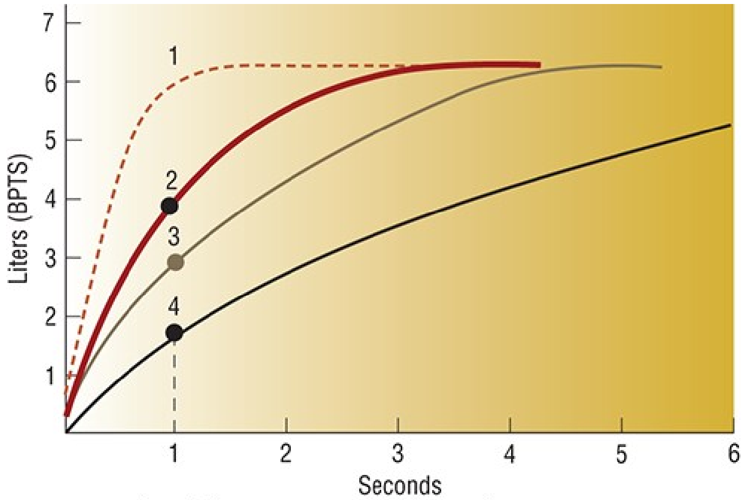


FIGURE e43-4

Normal flow-volume loop. Flows are measured on the vertical (*y*) axis, and lung volumes are measured on the horizontal (*x*) axis. Forced vital capacity (FVC) can be read from the tracing as the maximal horizontal deflection. Instantaneous flow (V_{max}) at any point in FVC also can be measured directly.

Normal flow-volume loop. Flows are measured on the vertical (*y*) axis, and lung volumes are measured on the horizontal (*x*) axis. Forced vital capacity (FVC) can be read from the tracing as the maximal horizontal deflection. Instantaneous flow (V_{max}) at any point in FVC also can be measured directly.

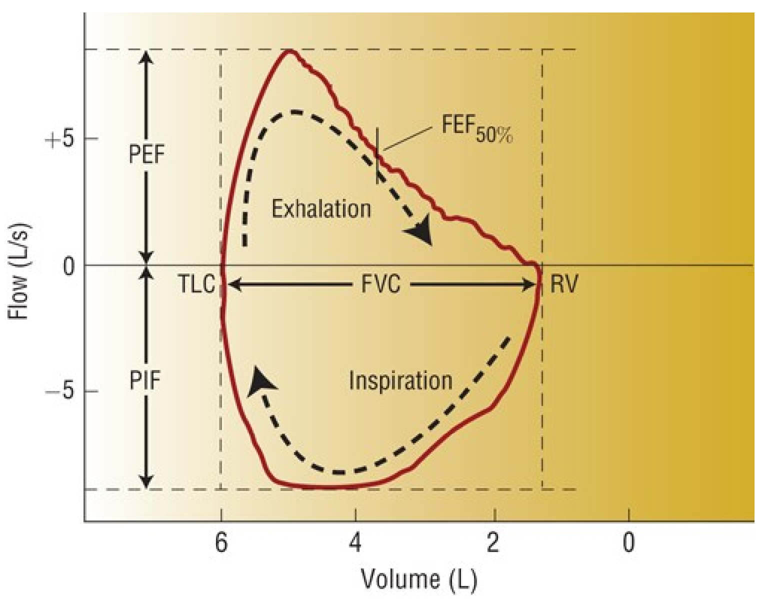
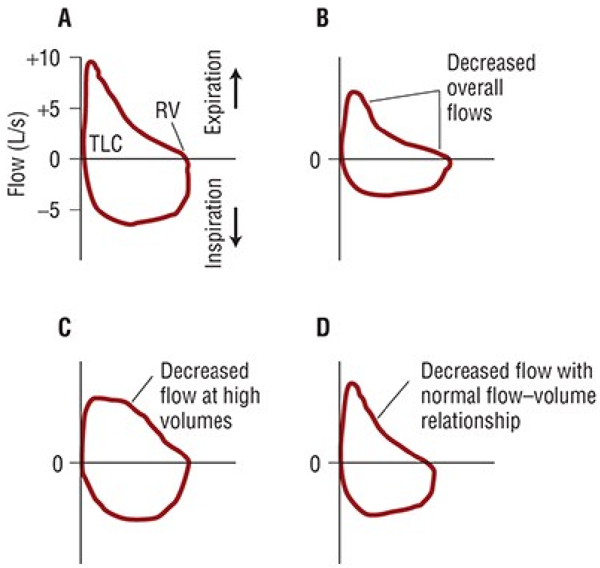


FIGURE e43-5

(*A*) Flow-volume loop depicting mild obstruction characterized by decreased flow at low lung volumes. (*B*) Moderate airflow obstruction is characterized by a more concave curve. (*C*) Variable intrathoracic obstruction in which peak flow is decreased at higher lung volumes with normalization of the curve at lower lung volumes. (*D*) Restrictive lung disease with a curve that is decreased in width but with a normal shape. (RV, residual volume; TLC, total lung capacity)



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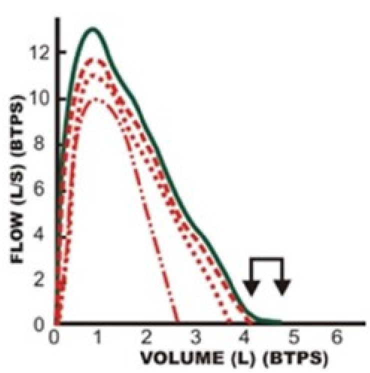
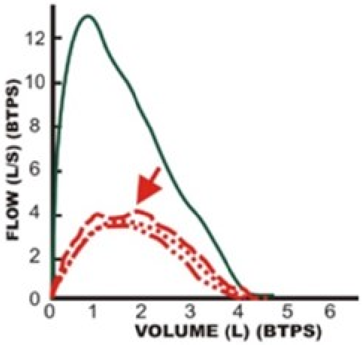
Spirometry is an indicator and foundational starting point to properly diagnosing and developing a treatment plan based on results, but the accuracy of the results is a priority. When performing spirometry, adequately coaching the patient from beginning to end is necessary. There are common problems that occur when spirometry is performed, which must be identified in order to properly diagnose and treat patients. Some of the most common issues that you will see include the following: normal curves are represented by the green curve and red curves represent the issue).[6]

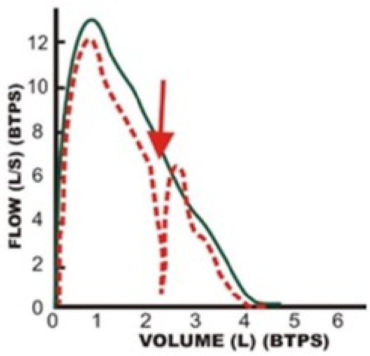
- Sub-maximal inhalation—An incomplete inhalation is a serious problem that frequently occurs.



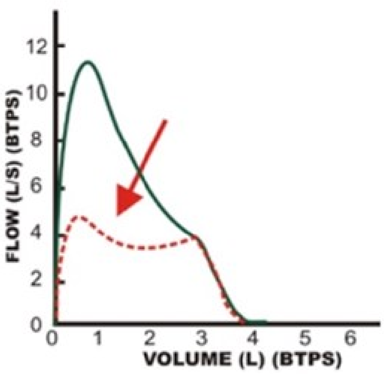
- Sub-maximal blast—When a patient fails to blast out fast and hard at the beginning of a test, the results will produce falsely low numbers, possibly leading to an inaccurate diagnosis. Recognition of this problem is best seen at the peak of the curve. You will see that it does not form a sharp peak but instead creates a decreased and rounded curve.



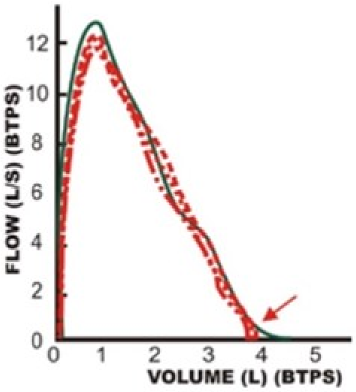
- **Coughing within the first second of exhalation**—Coughing in the first second of the blast-out creates a high probability for the FEV_1 measurement to be analyzed incorrectly. This is best seen in the deep dip occurring immediately after the peak.



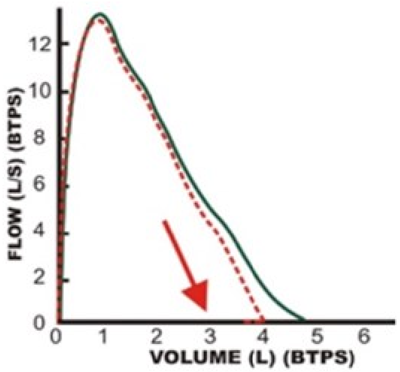
- **Variable efforts**—Variable efforts are patient-dependent and can commonly be corrected with adequate coaching from the clinician. You typically see this when the patient is not blasting out at one speed but instead consistently exhales into the spirometer at changing flows. You will recognize this in the curve when it fails to reach a peak and creates a more flat curve.



- **Early termination**—When performing spirometry, the patient must exhale for a minimum of 6 seconds. If the patient ends the blast-out early that attempt cannot be utilized to diagnose and treat the patient. Early termination can best be seen in the curve when it drops down to zero prior to plateauing on the baseline.



- **Leaks**—Leaks can be found within the spirometer, the mouthpiece, and also the patient. If you find that your machinery and mouthpiece are functioning well with no leaks, check the patient. Look for a good mouth seal and nose piercings (these can create a leak), and ensure that nose clips are being worn. You will recognize leaks as the curves drop off to baseline and begin to run back toward zero.



Contraindications to performing PFTS include myocardial infarction within the last month, unstable angina, recent thoracoabdominal surgery, recent ophthalmic surgery, thoracic or abdominal aneurysm, and current pneumothorax.

Lung Volumes

Spirometry measures three of the four basic lung volumes but cannot measure RV. RV must be measured to determine TLC. TLC should be measured anytime; VC is reduced in order to confirm or exclude the presence of restriction. The four methods for measuring TLC are helium dilution, nitrogen washout, body plethysmography, and chest x-ray measurement (planimetry).[7] The first two methods are called *dilution techniques* and only measure lung volumes in communication with the upper airway. In patients with airway obstruction who have trapped air, dilution techniques will underestimate the actual volume of the lungs. Planimetry measures the circumference of the lungs on the posteroanterior and lateral views of a chest x-ray film and estimates the total lung volume.

Body plethysmography, or body box, is the most accurate technique for lung volume determinations. It measures all the air in the lungs, including trapped air. The principle of the measurement of the body box is Boyle's gas law ($P_1V_1 = P_2V_2$): a volume of gas in a closed system varies inversely with the pressure applied to it. The changes in alveolar pressure are measured at the mouth, as well as pressure changes in the body box. The volume of the body box is known. Lung volumes can be determined by measuring the changes in pressures caused by panting against a closed shutter. The measurement of lung volumes provides useful information about the elastic recoil of the lungs. If elastic recoil is increased (as in interstitial lung disease), lung volumes (TLC) are reduced. When elastic recoil is reduced (as in emphysema), lung volumes are increased.

OTHER PULMONARY FUNCTION TESTS

Carbon Monoxide Diffusing Capacity

The diffusing capacity of the lungs (D_L) is a measurement of the ability of a gas to diffuse across the alveolar-capillary membrane.[8] Carbon monoxide is the usual test gas because normally it is not present in the lungs and is much more soluble in blood than in lung tissue. When the diffusing capacity is determined with carbon monoxide, the test is called the *diffusing capacity of lung for carbon monoxide* (DLCO). Because DLCO is directly related to alveolar volume (V_A), it is frequently normalized to the value D_L/V_A, which allows for its interpretation in the presence of abnormal lung volumes (ie, after surgical lung resection).

The diffusing capacity will be reduced in all clinical situations where gas transfer from the alveoli to capillary blood is impaired. Common conditions that reduce DLCO include lung resection, emphysema (loss of functioning alveolar-capillary units), and interstitial lung disease (thickening of the alveolar-capillary membrane). Normal spirometry and lung volumes with reduced DLCO should suggest the possibility of pulmonary vascular disease (eg, pulmonary embolus and pulmonary hypertension), anemia, or early interstitial lung disease.

Pulmonary Gas Exchange

The essential function of the lungs is to maintain blood gas homeostasis. Arterial blood gas measurement plays an important role in the diagnosis and management of patients with pulmonary disease and should be ordered whenever hypoxemia, hypercapnia (CO_2 retention), and/or acid-base disorders are suspected clinically. Every time arterial blood gas determinations are ordered, the A–a gradient (the difference between partial pressure of oxygen [PO_2] in the alveolus and PO_2 in arterial blood) should be calculated. This is accomplished by computer on all automated blood gas machines, and a normal $P(A–a)O_2$ can be calculated using the formula (age/4) + 4 or 2.5 (0.21 × age). The presence of hypoxemia with a normal A–a gradient usually implies alveolar hypoventilation (eg, sedative overdose). Most patients develop hypoxemia secondary to mismatching of ventilation and perfusion, and $P(A–a)O_2$ will be significantly elevated.

Oxygen saturation, as measured by pulse oximetry (SpO_2), is widely used in clinical practice for monitoring arterial saturation. A pulse oximeter is a small battery-operated device that is placed on the finger or the earlobe. The device emits and reads the reflected light from capillary blood and estimates the saturation. Although SpO_2 is clinically useful, SpO_2 is only an estimate of arterial saturation. Actual arterial oxygen saturation (SaO_2) can be ±2% to 4% (0.02-0.04) of the oximetry reading. The error may be even greater with saturation less than 80% (0.80). Pulse oximeters do not measure carboxyhemoglobin, and SpO_2 may be overestimated significantly in patients with smoke inhalation or in smokers. Initial validation of pulse oximetry with direct measurement of SaO_2 is recommended in any critically ill patient.

Exercise Testing

Cardiopulmonary exercise testing allows for the assessment of multiple organs involved in exercise and has benefits over other assessments of the cardiac system or pulmonary system alone. The major indications for exercise testing are to determine exercise capacity, evaluate dyspnea on exertion, evaluate exercise-induced bronchospasm, and assess suspected arterial desaturation during exercise.[9–13] Exercise testing can also be useful in the evaluation of ventilatory or cardiovascular limitations to work, assessment of general fitness or conditioning, evaluation of disability, the establishment of safe levels for exercise, evaluation of drug therapy, determining the need and liter flow for supplemental oxygen therapy during exercise, assessment of the effects of a rehabilitation program, and preoperative assessment before lung resection.[9–15]

Tests for general fitness include the 6-minute walking distance and the Harvard step test[10,12]. For the 6-minute walking distance, the subject simply walks a predetermined route or circuit as fast as possible for 6 minutes. The subject is allowed to stop and rest, but the clock continues to run. The greater the distance covered, the better the patient's general fitness and exercise tolerance. For healthy elderly subjects, a distance of 631 ± 93 m is considered normal and a change of 54 m in between tests is considered significant. For the Harvard step test, the subject steps up and down on a 20-in. (51 cm) step at a set rate for 5 minutes. A 1-minute rest period is followed by a measurement of the subject's recovery heart rate. The lower the recovery heart rate time, the better the subject's general fitness.

Exercise testing is performed to determine if exercise results in arterial oxygen desaturation (drop in oxygen saturation >4% [0.04] with physical activity).[10,11] The test may be useful for quantifying the level of exertion the patient can perform during the activities of daily living as well as determining appropriate levels of supplemental oxygen therapy. Typically, this test is done using a treadmill or cycle ergometer. A baseline measurement of arterial blood gas values or pulse oximetry is followed by up to 6 minutes of exercise, during which time the patient is monitored for oxygen desaturation using pulse oximetry. If significant desaturation occurs (saturation less than 88% [0.88]), the test is terminated. In the event of oxygen desaturation, the test can be repeated to determine the level of supplemental oxygen therapy needed to compensate for the desaturation that otherwise would occur.

When more formal exercise testing is needed for some of the indications previously listed (eg, dyspnea evaluation, evaluation of ventilatory or cardiovascular limitations to work, evaluation of disability, and preoperative assessment before lung resection), exercise tolerance tests or cardiopulmonary stress testing can be performed. Tests include the measurement of oxygen consumption ($\dot{V}O_2$VO2), carbon dioxide production ($\dot{V}CO_2$VCO2), minute volume (V E), tidal volume (V_T), respiratory rate, SpO_2, heart rate, blood pressure, and recording or monitoring of the electrocardiogram. Exercise increases workload in a linear fashion until a maximum oxygen consumption level ($\dot{V}CO_{2max}$VCO2max) is reached. Consequently, VO_{2max} is a measure of an individual's muscular work capacity.[9–13] Normal is approximately 1,700 mL/min (28 mL/s) for a sedentary person and up to 5,800 mL/min (97 mL/s) for a trained athlete.[16] This compares with a resting VO_{2max} of approximately 250 mL/min (4.1 mL/s). Ventilatory equivalents for oxygen, carbon dioxide, and O_2 pulse are often calculated. The ventilatory equivalent for oxygen is a measure of the efficiency of the ventilatory pump at various workloads.[9,11,12]

O_2 pulse is an estimate of oxygen consumption per cardiac cycle and can be decreased with cardiac problems. A normal O_2 pulse is 2.5 to 4 mL/beat at rest and increases to 10 to 15 mL/beat during strenuous exercise.[9–11]

The anaerobic threshold is the point during strenuous exercise at which anaerobic metabolism and lactic acid production begin.[9,11,12] CO_2 increases with exercise at about the same rate until the subject's anaerobic threshold is reached. From that point on, CO_2 increases faster than O_2, and this change can be used to estimate the anaerobic threshold. A breath-by-breath plot of the ventilatory equivalents for O_2 and CO_2 also can be used to determine the anaerobic threshold. The anaerobic threshold is a measure of fitness in normal subjects, and aerobic training can delay the anaerobic threshold.[9,11]

For exercise tolerance testing, the patient typically is subjected to either a constant workload (steady-state tests) or an increasing workload (progressive multistage tests) using a cycle ergometer or treadmill.[9,11] With progressive multistage tests, the patient exercises to exhaustion, or the occurrence of an adverse reaction, at which point the test is stopped. Safety during exercise testing is of major importance, and rigorous guidelines for the termination of the test should be followed. Both types of tests can be used to determine. A limit to exercise, as indicated by a decrease in, can result from (a) poor conditioning, (b) pulmonary limitation, (c) cardiac limitation, or (d) poor effort. In the case of poor conditioning, SpO_2 and O_2 pulse will be normal. With a pulmonary limitation to exercise, SpO_2 will be reduced, and O_2 pulse will be normal or reduced. With a cardiac limitation to exercise, SpO_2 will be normal, and O_2 pulse will be reduced.

Table e43-1 summarizes the indications and contraindications for exercise testing. Table e43-2 summarizes the findings during maximum exercise associated with poor conditioning, pulmonary limitations to exercise, and cardiac limitations to exercise.

TABLE e43-1

Indications and Contraindications for Exercise Testing

Indications • Dyspnea on exertion • Exercise-induced bronchospasm • Suspected arterial desaturation with exercise • Evaluation of ventilatory limitations to exercise • Evaluation of cardiac limitations to exercise • Assessment of general fitness or conditioning • Evaluation of cardiopulmonary disability • Establishment of safe levels for exercise • Evaluation of drug therapy • Determining the appropriate use of supplemental oxygen therapy • Establishing an exercise prescription for a rehabilitation program • Assessment of the effect of a rehabilitation program • Evaluation of specific disease states or conditions (eg, asthma, chronic obstructive pulmonary disease [COPD], interstitial lung disease, pulmonary vascular disorders, coronary artery disease, other vascular disorders, neuromuscular disorders, obesity, anxiety-induced hyperventilation) • Assessment before resection • Assessment before lung volume reduction surgery or lung transplantation
Contraindications • PaO_2 <40 mm Hg (5.3 kPa) on room air $PaCO_2$ >70 mm Hg (9.3 kPa) • FEV_1 <30% of predicted • Recent (within 4 weeks) myocardial infarction, unstable angina pectoris • Second- or third-degree heart block, rapid ventricular/atrial arrhythmias, orthopedic impairment • Severe aortic stenosis, congestive heart failure, uncontrolled hypertension, limiting neurologic disorders • Dissecting/ventricular aneurysms, severe pulmonary hypertension • Thrombophlebitis or intracardiac thrombi • Recent systemic or pulmonary embolus • Acute pericarditis

TABLE e43-2

Typical Findings During Maximum Exercise with Poor Conditioning, Pulmonary Limitations to Exercise, and Cardiac Limitations to Exercise

Test Parameter	Poor Conditioning	Pulmonary Limitation	Cardiac Limitation
$\dot{V}CO_{2max}$ VCO2max	↓	↓	↓
SpO_2	N	↓	N
O_2 pulse	N or ↓	N or ↓	↓
Anaerobic threshold	↓ or N	↓ or N	↓
Ventilatory reserve[a] (MVV – V_{Emax})	N	↓	N or ↓

N, normal.

[a]Ventilatory reserve = maximum voluntary ventilation (MVV) – minute volume during maximum exercise (V_{Emax}).

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Respiratory Muscle Function

The maximum inspiratory pressure (MIP) and maximal expiratory pressure (MEP) are indirect measures of the respiratory muscles' function. During these tests, patients are asked to take a maximum breath, on inhalation for MIP and on exhalation for MEP, against a closed valve. The pressure measured during these maneuvers reflects the pressure developed by the respiratory muscles, plus the passive elastic recoil pressure of the respiratory system, including the lung and chest wall. These tests can be of use in assessing the severity, functional consequences, and progress of patients with neuromuscular diseases.[15] The following table lists the ranges of normal values based on age and gender.[14]

Age	7-13 years	13-35 years	18-65 years	65-85 years
Male	MIP: −77 to −114	MIP: −114 to −121	MIP: −92 to −121	MIP: −65 to −90
	MEP: 99 to 161	MEP: 92 to 95	MEP: ≈140	MEP: 140 to 190
Female	MIP: −71 to −108	MIP: −65 to −85	MIP: −68 to −79	MIP: −71 to −108
	MEP: 74 to 126	MEP: 92 to 95	MEP: ≈95	MEP: 90 to 130

Another respiratory muscle function test commonly utilized is the sniff nasal inspiratory pressure (SNIP). This maneuver is done by wedging a bung into one nostril, through which a thin catheter connected to a pressure transducer has been passed (completely obstructs flow through that nostril).[14] The clinician will instruct the patient to "sniff" (inhale through the unobstructed nostril as strongly as possible), and the pressure will be measured, producing the value that represents the inspiratory muscle strength.

Producing the results for the three mentioned muscle function tests above is highly dependent on patient effort and may produce inaccurate results without proper cooperation. The clinician's enthusiasm efforts, encouragement methods, attitude, and coaching are great contributors to the results obtained.

Impulse Oscillometry

Impulse Oscillometry is a non-invasive test in which pressure oscillations are applied at the mouth to measure pulmonary resistance and reactance of the total respiratory system. This technique is effort-independent and requires minimal cooperation, which is a major advantage in testing children, older adults, and patients with physical or intellectual disabilities. This test has not been applied to large populations to generate predicted values, and in some cases, the endpoints show high variability; therefore, is not as widely used as spirometry in the adult population.[17]

Fractional Exhaled Nitric Oxide

According to the ATS clinical practice guidelines,[16] the measurement of fractional nitric oxide (NO) concentration in exhaled breath (FENO) is a quantitative, noninvasive, simple, and safe method of measuring eosinophilic airway inflammation that provides a complementary tool to other ways of assessing airways disease, including asthma and its response to therapy (inhaled corticosteroids). A low FENO (<25 ppm) indicates that eosinophilic inflammation and response to inhaled steroids is less likely whereas increased FENO (>50 ppm) indicates responsiveness to corticosteroids.

There is wide variability in pulmonary function test reports among laboratories. The American Thoracic Society (ATS) recently released recommendations for the presentation of PFT results; recommendations from this statement include the standard report of reference values based on the GLI, display of normal limits for each test, report of barometric pressure, and a grading system for test quality.[18]

LUNG DISEASES

Obstructive Lung Disease

3 Obstructive lung disease implies a reduced capacity to get air through the conducting airways and out of the lungs. This reduction in airflow may be caused by a decrease in the diameter of the airways (bronchospasm decrease in driving pressure). The most common diseases associated with obstructive pulmonary functions are asthma, emphysema, and chronic bronchitis; however, bronchiectasis, infiltration of the bronchial wall by tumor or granuloma, aspiration of a foreign body, and bronchiolitis also cause obstructive PFTs. The standard test used to evaluate airway obstruction is spirometry.

Standard spirometry and flow-volume loop measurements include many variables; however, according to ATS guidelines, the diagnosis of obstructive and restrictive ventilatory defects should be made using the basic measurements of spirometry.[3,5] A reduction in FEV_1 (with normal FVC) establishes the diagnosis of obstruction. In restrictive lung disease, the patient has an inability to get air into the lung, which results in a reduction of all expiratory volumes (FEV_1, FVC, and SVC). In obstructed patients, a better measurement is the ratio FEV_1/FVC. Patients with restrictive lung disease have reduced FEV_1 and reduced FVC, but FEV_1/FVC remains normal. Although a normal FEV_1/FVC ratio is greater than 75% to 80% (0.75-0.80), the ratio is age-dependent, and slightly lower values may be normal in older patients. Younger children have increased lung elastic recoil and may have higher ratios. Children should have a FEV_1/FVC greater than or equal to 90% (0.90). According to the 2018 National Asthma Education and Prevention Program and the most recent Global Imitative for Asthma (GINA) guidelines, any value below this value should be considered a sign of obstruction, even if the FEV_1 and FVC are within the normal range.[2] Caution should be used in interpreting obstruction when FEV_1/FVC is below normal, but both FEV_1 and FVC are within the normal range because this pattern can be seen with healthy, athletic subjects as well as subjects with mild asthma. Clinical judgment and response to bronchodilator challenge are often required to separate out these two groups. In children, the improvement in FEV_1 often is the only way to document mild-to-moderate obstructive lung disease.

In screening spirometry performed in office practice, forced expiratory volume in 6 seconds (FEV_6) can be used in place of FVC. FEV_6 is a more reproducible number when obtained by less skilled personnel. The measurement of $FEF_{25\%\text{-}75\%}$ also is abnormal in patients with obstructive airway disease. This test has so much variability that it adds little to the measurement of FEV_1 and FEV_1/FVC.

Although there is no standardization for interpretation of the severity of obstruction, most pulmonary laboratories state that FEV_1/FVC less than 70%

(0.70) of the predicted value is diagnostic for obstruction, and the degree of obstruction is based on the percent predicted of FEV_1. FEV_1 between 80% and 100% of the predicted value is a mild obstruction, 79% and 50% of the predicted value is moderate obstruction, 49% and 30% is consistent with severe obstruction, and less than 30% of the predicted value is classified as severe obstruction.[19] In patients with obstruction, a dose of a bronchodilator (eg, albuterol or isoproterenol) by metered-dose inhaler is given during the initial examination. An increase in FEV_1 greater than 12% and greater than 0.2 L suggests an acute bronchodilator response.[3,5] It is important to remember that bronchodilator responsiveness is variable over time, and therefore, the lack of an acute bronchodilator response should not preclude a short trial of albuterol and/or corticosteroids.

Although all patients with obstructive lung disease of any etiology will have reduced flow rates on forced exhalation, the pattern on PFTs may be helpful in differentiating among the various etiologies (Table e43-3). Asthma is characterized by variable obstruction that often improves or resolves with appropriate therapy. Because asthma is an inflammatory disorder of the airways (predominantly large airways), DLCO is usually normal or even slightly above the normal range. Most patients with acute asthma have a bronchodilator response greater than 15% to 20%; chronic bronchitis may be limited to the airways, but the vast majority of patients with chronic bronchitis and airway obstruction have a mixture of bronchitis and emphysema and have a reduction in DLCO. Therefore, DLCO is the best PFT for separating asthma from COPD.

TABLE e43-3

Specific Patterns of Pulmonary Function in Patients with Chronic Obstructive Pulmonary Disease

		COPD	
	Asthma	Chronic Bronchitis	Emphysema
Decreased FEV_1	++++	++++	++++
Decreased FEV_1/FVC	++++	++++	++++
Increased airway resistance	++++	++++	+
Decreased DLCO	–	–/++[a]	++++
Response to bronchodilators	++++	+[b]	–[b]

DLCO, diffusing capacity of lung for carbon monoxide; FEV_1, forced expiratory volume in the first second of expiration; FVC, forced vital capacity.

[a]Most smokers with chronic bronchitis have reduced DLCO.

[b]Twenty percent of patients with chronic obstructive pulmonary disease (COPD) have a large (++++) bronchodilator response.

A recently described entity asthma-COPD overlap syndrome (ACOS) encompasses patients with persistent airflow limitation as seen in COPD and several features typically associated with asthma, including airway hyperresponsiveness and marked bronchodilator response. After the diagnosis of obstructive airway disease is established, the course and response to therapy are best followed by serial spirometry.

Airway Hyperreactivity

4 *Airway hyperreactivity* or *hyperresponsiveness* is defined as an exaggerated bronchoconstrictor response to physical, chemical, or pharmacologic stimuli. Individuals with asthma, by definition, have hyperresponsive airways. The Lung Health Study Research Group observed nonspecific hyperresponsiveness in a significant number of patients with COPD. This group of patients with airway hyperreactivity has a worse prognosis and an accelerated rate of decline in FEV_1.[20]

Some patients with asthma (especially cough-variant asthma) present with no history of wheezing and normal PFTs. The diagnosis of asthma can still be established by demonstrating hyperresponsiveness to provocative agents. The agents used most widely in clinical practice are methacholine and mannitol. Other agents used for bronchial provocation include distilled water, hypertonic saline, cold air, histamine, and exercise. Medications that can potentially affect the test and give false negative results include β2 agonists (short- and long-acting), antimuscarinic agents (short- and long-acting), theophylline, and leukotriene receptors antagonists[2] (Table e43-4). During a typical methacholine bronchoprovocation test, baseline FEV_1 is measured after inhalation of isotonic saline, and then increasing doses of methacholine are given at set intervals. Hyperresponsiveness is defined as a decline in FEV_1 greater than or equal to 20% and reversibility of obstruction to bronchodilators. The result can best be expressed as the provocative concentration needed to cause a 20% fall in FEV_1 (PC_{20}). A test is considered positive if methacholine demonstrates a PC_{20} less than or equal to 4 mg/mL or less than 60 to 80 cumulative breath units The test is considered negative if the PC_{20} is greater than 16 mg/mL. Values between 4 and 16 are considered borderline.[20] A bronchoprovocation test (methacholine or mannitol test) is contraindicated in severe airway obstruction (FEV_1 less than 60% or 1.5 L), uncontrolled hypertension (SBP greater than 200 mm Hg and DBP greater than 100 mm Hg), recent myocardial infarction or cerebrovascular accident (in the three previous months), known aortic aneurysm and recent eye surgery or intracranial pressure elevation risk.[21]

TABLE e43-4

Recommended Time to Withhold Medication Prior to Bronchoprovocation Study

Medication Types	Recommended Time to Withhold Prior to Bronchoprovocation Study
Short-acting β2 agonist	8 hours
Inhaled corticosteroids	12 hours
Short-acting anticholinergics	12 hours
Inhaled corticosteroids plus long-acting β2 agonists	24 hours
Long-acting β2 agonists	24 hours
Theophylline	24 hours
Antihistamines	72 hours
Leukotriene-receptor antagonists	96 hours

Mannitol comes in inhaled dry-powder capsules of graduated doses, which makes its administration convenient.[22] When using mannitol, a drop in FEV_1 greater than or equal to 15% from baseline (0 mg) up to a dose of 635 mg or a 10% reduction in FEV_1 between consecutive doses is considered significant and is referred to as provocative dose 15 (PD15). This test is used most frequently to establish a diagnosis of asthma in patients with normal PFTs, but it also may be useful in following patients with occupational asthma, establishing the severity of asthma, and assessing the response to treatment.

Upper Airway Obstruction

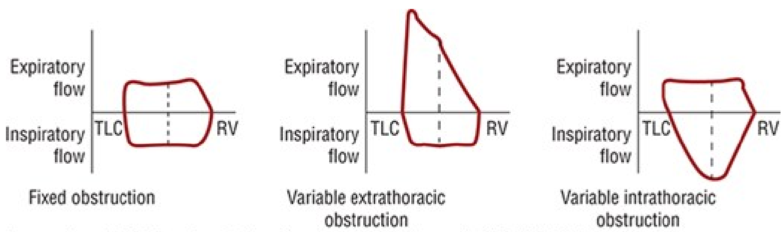
Obstruction of airflow by abnormalities in the upper airway often goes undiagnosed or misdiagnosed because of improper interpretation of PFTs. Patients have obstructive physiology and often are misclassified as having asthma or COPD. The shape of the flow-volume loop, which includes inspiratory and expiratory flow-volume curves, and the ratio of forced expiratory and inspiratory flow at 50% of VC ($FEF_{50\%}/FIF_{50\%}$ greater than 1) may be useful in the diagnosis of upper airway obstruction.[3,23]

The shape of the flow-volume curve differs depending on whether the obstruction is fixed or variable (Fig. e43-5). Fixed lesions, as in strictures from previous intubations or tracheostomy, cause a uniform caliber of the airway during inspiration and expiration. With variable lesions, the airway caliber changes with changes in intrathoracic pressure. Variable lesions are sub-classified into variable intrathoracic and variable extrathoracic. If the lesion is intrathoracic, as with tumors of the trachea, the negative pressure generated during inspiration opens the obstruction, whereas the positive pressure during expiration worsens the obstruction. If the lesion is a variable extrathoracic obstruction, as with vocal cord dysfunction, the negative pressure within the airways will pull the vocal cord toward the midline and potentiate the obstruction. In this case, there will be a plateau on the inspiratory limb of the flow-volume loop, and $FEF_{50\%}/FIF_{50\%}$ will be greater than 1. Typical flow-volume curves from upper airway obstruction are shown in Fig. e43-6.

While 80% of subjects with vocal cord dysfunction demonstrate the classical variable extrathoracic pattern, 18% present with a pattern of variable intrathoracic obstruction, and 2% present with a pattern of fixed obstruction.

FIGURE e43-6

Maximum expiratory flow-volume curves from patients with fixed obstruction, variable extrathoracic obstruction, and variable intrathoracic obstruction. (RV, residual volume; TLC, total lung capacity.)



Restrictive Lung Disease

5 *Restrictive lung disease* is defined as an inability to get air into the lungs and to maintain normal lung volumes. Restrictive lung disease reduces all the subdivisions of lung volumes (IRV, TV, ERV, and RV) without reducing airflow. Patients have normal airway resistance and FEV_1/FVC greater than 70% (0.70). A combined consensus statement from the ATS and the ERS defines restrictive and obstructive disorders.[24]

Although *restriction* could be defined as a reduction in VC or FVC with normal FEV_1/FVC, poor effort also will reduce FVC with normal FEV_1/FVC. A reduction in TLC is the most accurate measurement of restrictive lung function. As discussed earlier, TLC can be measured by various techniques. The gas dilution methods (eg, helium dilution and nitrogen washout) are unable to measure gas trapped in cysts or bullae and may underestimate the true lung volume. Therefore, TLC is best measured by plethysmography. Most restrictive lung diseases are associated with impairment or destruction of the alveolar-capillary membrane; therefore, DLCO is reduced in most patients with restrictive lung disease. The reduction in DLCO may occur prior to a reduction in lung volumes and is used as a marker of early interstitial (restrictive) lung disease. DLCO may be abnormal even with a normal chest x-ray film, and thin-sliced high-resolution computed tomographic scans of the chest (HRCT = 0.625-1.5 mm thickness) or a CT with thin cuts (2-3 mm thickness) may be required to diagnose early interstitial lung disease. Because peribronchiolar inflammation and fibrosis occur in some patients with restrictive parenchymal lung disease, $FEF_{25\%-75\%}$ may be reduced and fail to respond to bronchodilators.

The severity of restrictive disease has not been standardized; however, many laboratories classify patients with reduced TLC as mild (TLC less 80%-70%), moderate (TLC 69%-60%), or severe (TLC less than or equal to 60%). These definitions are completely arbitrary because a patient with obstructive lung disease may start with TLC above the upper limit of normal (ie, 120%) and subsequently develop restrictive lung disease while maintaining TLC within the normal range. On the flow-volume loop, patients with restrictive disease have normal-shaped curves with a reduction in the height and width of the curve because both PEF rate and VC depend on the amount of air within the lung prior to the performance of expiratory maneuvers (see Figs. e43-3 and e43-4).

6 Restrictive lung function is caused by increased elastic recoil of the lung parenchyma (interstitial lung disease), respiratory muscle weakness, mechanical restrictions (chest wall deformities), and/or poor effort. Table e43-5 lists common causes of restrictive lung disease.

TABLE e43-5

Causes of Restrictive Lung Disease

Interstitial lung diseases

- Idiopathic pulmonary fibrosis
- Sarcoidosis
- Collagen vascular disease
- Pneumoconiosis
- Drug-induced lung disease
- Pulmonary edema

Infiltrative lung diseases

- Granulomatosis
- Tumor

Pleural diseases

- Pleural effusion
- Fibrothorax
- Pneumothorax

Chest wall diseases

- Kyphoscoliosis
- Ankylosing spondylitis
- Neuromuscular disease

Miscellaneous causes

- Obesity
- Pregnancy
- Ascites
- Paralyzed diaphragm
- Lung resection

Restrictive lung function from parenchymal lung disease usually can be differentiated from processes causing mechanical restriction as a result of chest bellows malfunction (Table e43-6). Restrictive parenchymal diseases are associated with a reduction in V_A and an increase in lung elastic recoil. All lung volumes, as well as DLCO, are reduced. Compared to patients with restriction secondary to neuromuscular disease, in patients with interstitial lung disease, the RV/TLC (normally less than or equal to 30%) and measurements of maximal inspiratory pressure (normal = −75 cm H_2O [−7.4 kPa] in males, –50 cm H_2O [−4.9 kPa] in females) remain normal. In addition, patients exhibit mild resting hypoxemia that worsens with exercise. Monitoring gas exchange during exercise may be the most sensitive test for detecting the progression of interstitial lung disease; however, this involves obtaining arterial blood during exercise, and DLCO and exercise pulse oximetry are often used in its place.

TABLE e43-6

Patterns of Pulmonary Function

	Obstructive Lung Disease		Restrictive Lung Disease	
	Asthma	COPD	Parenchymal Disease	Chest Bellows Disease
FVC	Nl or I	Nl or I	D	D
FEV_1	D	D	D	D
FEV_1/FVC	<70% (0.70)	<70% (0.70)	≥75%-80% (0.75-0.80)	≥75%-80% (0.75-0.80)
TLC	Nl or I	Nl or I	D	D
RV/TLC	Nl or I	Nl or I	Nl	I
Airway resistance	I	I	N	Nl
DLCO	Nl	D	D	Nl

D, decreased; I, increased; Nl, normal.

Mechanical restriction caused by chest bellows malfunction may result from chest wall or skeletal deformity, loss of neuromuscular function, fibrosis of the pleural space, and abdominal overdistension causing upward displacement of the diaphragm, as well as decreased diaphragm movement. The most common pulmonary function pattern seen in these patients is a decrease in TLC and VC with only a slight decrease in RV. RV is maintained in these diseases because lung compliance remains normal. DLCO is normal or only minimally reduced, and DLCO/V_A (corrected for V_A) is normal. RV/TLC often is increased in patients with restrictive chest bellows disease.

Spirometry in Children

Spirometry was originally focused on the adult population, used to diagnose and track the progression of different disease states. The tests were initially used in children to evaluate asthma. 9 Children can perform most of the pulmonary function tests that adults can, but with modifications. These modifications are important factors that play a significant role in the success of pediatric PFTs.

FEV_1 has been found to contribute to the diagnosis of obstructive lung diseases in adults, but in children, it has been found that they have higher elastic recoil than adults with faster emptying of the lung, which means that the FEV_1 can be relatively insensitive to early lung disease. Some children are able to exhale completely in 1 second.[25] For this reason, as the clinician, this must be taken into consideration when analyzing the data for a diagnosis or treatment plan.

ATS/ERS standards in children do not require a 6-second exhalation for spirometry, but instead, recommend 3 to 5 seconds for children younger than 10 years. If a child fails to blast out for a minimum of 3 seconds but is giving full effort and cooperation, the clinician can override the rejected maneuver. Another common challenge for children is performing the inspiratory maneuver during spirometry. One of the greatest challenges is performing an open-circuit spirometry test where the child inserts the mouthpiece into their post-maximal inhalation. Children's coordination is not yet well enough developed to successfully complete spirometry this way, instead, you should instruct the child to insert the mouthpiece into their mouth prior to maximal inhalation with a good seal. An experienced and well-trained clinician working in a PFT lab will have the knowledge and skillset to recognize when a child may or may not have these capabilities and how to modify the maneuver to produce the best results possible. Unlike in adults, you can utilize results that do not meet standards to aid in the diagnosis and treatment plan of a child.

When doing spirometry in children, coaching the child is key to their success. A few things to keep in mind when coaching a child through spirometry are listed as follows:

- Sit down and be at eye level with the child
- Do not use medical terminology; explain the test in elementary verbiage
- Make it a competition, challenge them to a race.
  - Who can blow out the most candles?
  - Who can blow the fastest and hardest?
- Offer incentives.
  - Candy
  - Stickers
  - Most pediatric PFT clinics will have a treasure chest
- Build trust with the child, ask questions to learn about their interest
- Do not perform the test in front of the parents
- Be energized, positive, and motivating!

Producing adequate and repeatable pulmonary function test data in children is possible. It requires patience, understanding, dedication, critical thinking, and integration to diagnose and treat a pediatric patient successfully.

ABBREVIATIONS

ACOS	asthma-COPD overlap syndrome
ATS	American Thoracic Society
COPD	chronic obstructive pulmonary disease
DL	diffusing capacity of the lungs
DLCO	diffusing capacity of lung for carbon monoxide
ERS	European Respiratory Society
ERV	expiratory reserve volume
FEF	forced expiratory flow
$FEF_{25\%-75\%}$	forced expiratory flow during 25% to 75% of forced vital capacity
$FEF_{50\%}$	forced expiratory flow at 50% of vital capacity
FEF_{max}	maximum forced expiratory flow

$FEV_{0.5}$	forced expiratory volume at 0.5 second
FEV_1	forced expiratory volume in the first second of expiration
FEV_6	forced expiratory volume in 6 seconds
$FIF_{50\%}$	forced inspiratory flow at 50% of vital capacity
FRC	functional residual capacity
FOT	forced Oscillation Technique
FVC	forced vital capacity
GINA	Global Initiative for Asthma
GLI	Global Lung Initiative
IC	inspiratory capacity
IRV	inspiratory reserve volume
NHANES	National Health and Nutrition Examination Survey
MIP	maximal inspiratory pressure
MEP	maximal expiratory pressure
$P(A–a)O_2$	alveolar–arterial difference in the partial pressure of oxygen
$PaCO_2$	arterial partial pressure of carbon dioxide
PaO_2	arterial partial pressure of oxygen
PC20	provocative concentration needed to cause a 20% fall in FEV_1
PD15	provocative dose 15
PEF	peak expiratory flow
PFT	pulmonary function test
PJP	*Pneumocystis jiroveci* pneumonia
PO_2	partial pressure of oxygen
RV	residual volume
SaO_2	arterial oxygen saturation

SpO_2	oxygen saturation as measured by pulse oximetry
SVC	slow vital capacity
TLC	total lung capacity
V_A	alveolar volume
VC	vital capacity
V_T	tidal volume

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SELF-ASSESSMENT QUESTIONS

1. The diagnosis of an “obstructive” pattern in pulmonary function testing requires one of the following:

    A. Positive bronchodilator response

    B. Increased FEV_1/FVC ratio

    C. Decreased FEV_1/FVC ratio

    D. Increased total lung capacity

2. A positive bronchodilator response is defined as:

    A. Increase in FEV_1 >500 mL

    B. Increase in FEV_1>200 mL

C. Increase in FEV_1>12%

D. Increase in FEV_1 >200 mL and 12%

3. A patient can be described as having “air trapping” on their pulmonary function testing when which of the following finding is present?

   A. Increased total lung capacity

   B. Increased residual volume

   C. Increased DLCO

   D. Increased FEV_1/FVC ratio

4. The following are causes of restrictive lung pattern in pulmonary function tests except:

   A. Pleural effusion

   B. Pulmonary fibrosis

   C. Asthma

   D. Neuromuscular disease-causing weakness of the respiratory muscles

5. A 64-year-old woman presents to the primary care physician with dyspnea on exertion and chronic cough. She is a current smoker and has been smoking one pack of cigarettes a day for 40 years. Her physician suspects the diagnosis of COPD. What set of pulmonary function test confirms the diagnosis?

Choice	FEV_1	FVC	FEV_1/FVC	TLC	RV	DLCO
A	N	N	Normal	Normal	Normal	Normal
B	N	N	Normal	Normal	Normal	Low
C	L	L	Low	Low	Normal	Normal
D	L	L	Low	High	High	Low

6. All of the following are causes of an isolated diffusion defect except:

   A. Asthma

   B. Anemia

   C. Early interstitial lung disease

   D. Pulmonary hypertension

7. A 50-year-old man with a history of prior tobacco use presents to the primary care provider for evaluation of chronic cough and progressive dyspnea. He is found to have bilateral dry crackles on physical examination. His pulmonary function testing reveal an FEV_1 0.5 L (23% predicted), FVC 0.6 L (25% predicted), and FEV_1/FVC of 79% (0.79). His total lung capacity is 48% predicted and his DLCO is 40% predicted which of the following statement correctly characterizes the observed abnormality?

A. Severe airway obstruction

B. Severe Restriction

C. Normal pulmonary function tests

D. Hyperinflation

8. What is the most likely diagnosis for the patient described above?

A. Pulmonary hypertension

B. Tracheal stenosis

C. COPD

D. Interstitial lung disease

9. Which of the following finding would you expect to see when you evaluate the flow-volume loop obtained during a forced vital capacity maneuver in a patient with a tumor causing a fixed intrathoracic airway obstruction?

A. Flattening of the inspiratory and expiratory limbs of the flow-volume loop

B. Flattening of the inspiratory limb of the flow-volume loop

C. Flattening of the expiratory limb of the flow-volume loop

D. A “scooped-out” appearance to the expiratory limb of the flow-volume loop.

10. One of the following is true regarding the lung volumes and expiratory flows:

A. The volume of air exhaled during normal quiet breathing is the V_T. The maximal volume of air inhaled above V_T is the *expiratory reserve volume*

B. *Vital capacity* (VC) is equal to the sum of IRV, V_T, and TLC

C. Total lung capacity is equal to the sum of ERV, V_T, and RV

11. Which of the following statements is correct regarding the pulmonary functions tests?

A. The spirometry is effort independent

B. Lung volume measurement with plethysmography is more reliable than dilutional methods

C. The gas used to measure the diffusion capacity of the lungs is Nitrogen

D. A bronchoprovocation challenge is positive when the FEV_1 drops by 20% after the administration of albuterol

12. The measurement of MIP (maximal inspiratory pressure) and MEP (maximal expiratory measure) can be useful for the diagnosis and follow-up of:

A. Asthma

B. Pulmonary hypertension

C. Amyotrophic lateral sclerosis

D. Alpha-one antitrypsin deficiency

13. One of the following is true regarding pulmonary function tests in patients with COPD.

    A. A positive bronchodilator response excludes the diagnosis.

    B. The lung volumes are low.

    C. The diffusion capacity is increased.

    D. The FEV_1/FVC ratio is <70% (0.70).

14. Which of the following patients is expected to have a significant drop in oxygen saturation during a 6-minute walk test?

    A. A 21-year-old female with uncontrolled asthma

    B. A 65-year-old male with diffuse alveolar hemorrhage and a DLCO of 110%

    C. A 60-year-old male with severe emphysema and a DLCO of 30%

    D. A 50-year-old female with tracheal stenosis

15. The following statement is true regarding pulmonary function testing.

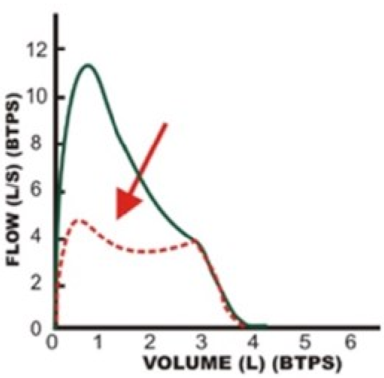
    A. PFTs can only be completed in highly specialized centers.

    B. Systolic heart failure is a contraindication for PFTs.

    C. The normal values are standard and independent of race, height, and gender.

    D. Morbidly obese patients can present with a mild restriction pattern with normal diffusion.

16. The following cure is consistent with which of the following commonly seen issues when performing spirometry on your patient?



    A. A leak in the system

    B. Variable effort

    C. Early termination

    D. Coughing in the first second

17. You have an 8-year-old pediatric patient who is performing spirometry and blasts out for 2 seconds. This maneuver is considered:

    A. Rejected; it does not meet ATS/ERS standards.

    B. Acceptable; meets ATS/ERS standards.

C. Children cannot perform spirometry.

D. Should not be rejected, it aids in the diagnosis and treatment of the child; does not meet ATS/ERS standards.

SELF-ASSESSMENT QUESTION-ANSWERS

1. **C.** Obstruction is defined as a decreased FEV_1/FVC ratio in spirometry. Both values are affected but the FEV_1 is decreased to a greater extent that makes the ratio low.
2. **D.** A positive bronchodilator response is defined by an increase of 12% and 200 mL after the administration of a β-agonist. Both criteria need to be met.
3. **B.** Air trapping is defined as the inability to fully exhale and diagnosed when the residual volume is increased above 120% normal.
4. **C.** Asthma is characterized by an obstructive pattern on spirometry, all the other pathologies have a restrictive pattern.
5. **D.** The diagnosis of COPD is based on an FEV_1/FVC ratio of <70% (0.70), patients often have increased lung volumes and decreased diffusion capacity.
6. **A.** Patients with asthma have normal and occasionally increased diffusion. All the other options decrease the diffusion capacity.
7. **B.** The patient has decreased FEV_1 and FVC with a normal ratio, the lung volumes are low which confirms the diagnosis of restriction.
8. **D.** The patient most likely has an interstitial lung disease. Classical findings for the alternative diagnoses would include—PAH: diffusion defect; tracheal stenosis: abnormal flow/volume loop; COPD: obstruction pattern on spirometry.
9. **C.** A fixed intrathoracic obstruction, for example, a central airway tumor will cause a flattening of the expiratory limb of the flow volume curve (Fig. e43-5).
10. **A.** Tidal volume is defined as the "normal" volume of air displaced between inhalation and exhalation.
11. **B.** Plethysmography is a more accurate measurement of lung volumes as it accounts for trapped air that cannot be accounted for with nitrogen washout (dilutional methods).
12. **C.** MIP and MEP are used to assess respiratory muscle strength and can be used to assess disease progression in patients with neuromuscular diseases.
13. **D.** Per most recent GOLD guidelines obstruction (in the setting of COPD) is defined as an FEV_1/FVC ratio <70% (0.70) of the predicted value.
14. **C.** Emphysema destroys the alveolar units, therefore decreasing the area of gas exchange. The other scenarios present with normal or even increased diffusion.
15. **D.** Obese patients can have low lung volumes due to the pressure of the abdomen pushing the diaphragm up. Pulmonary function test can be easily achieved in various settings and has few contraindications.
16. **B.** Variable effort. The curve lacks a sharp peak on the initial blast-out and shows no consistency in the expiratory flows.
17. **D.** Should not be rejected, it aids in the diagnosis and treatment of the child and does not meet ATS/ERS standards. Although the produced results do not meet ATS/ERS standards, because this is a pediatric patient, the data can still be utilized to aid in the diagnosis and treatment plan of the child.