14 PULMONARY FUNCTION AND RELATED TESTS

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OBJECTIVES

After completing this chapter, the reader should be able to

- Identify common pulmonary function tests and list their purpose and limitations
  a. Spirometry
  b. Peak expiratory flow rate
  c. Body plethysmography
  d. Carbon monoxide diffusion capacity
  e. Specialized tests
     i. Bronchial provocation test
     ii. Six-minute walk test
     iii. Pediatric pulmonary function testing
     iv. Carbon monoxide breath test
     v. Exhaled nitric oxide breath test
- Describe how pulmonary function tests are performed and discuss factors affecting the validity of the results
- Interpret commonly used pulmonary function tests, given clinical information
- Discuss how pulmonary function tests provide objective measurement to aid in the diagnosis of pulmonary diseases
- Discuss how pulmonary function tests assist with monitoring efficacy and toxicity of various drug therapies

Pulmonary function tests (PFTs) provide objective and quantifiable measures of lung function and are useful in the diagnosis, evaluation, and monitoring of respiratory disease. Diagnosis and monitoring of many pulmonary diseases, including diseases of gas exchange, often require measurement of the flow or volume of air inhaled and exhaled by the patient. Spirometry, a test that measures the movement of air into and out of the lungs during various breathing maneuvers, is the most frequently used PFT. Clinicians use spirometry to aid in the diagnosis of respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD). Other tests of lung function include lung volume assessment, carbon monoxide diffusion capacity (DLCO), exercise testing, and bronchial provocation tests. PFTs can be used to monitor lung function after thoracic radiation, lung transplantation, or during administration of medications with potential toxicity to the lungs. Arterial blood gases (ABGs) can be measured with PFTs and are useful to assess lung function (interpretation of ABGs is discussed in Chapter 13). This chapter discusses the mechanics and interpretation of PFTs.

ANATOMY AND PHYSIOLOGY OF LUNGS

The purpose of the lungs is to take oxygen from the atmosphere and exchange it for carbon dioxide in the blood. The movement of air in and out of the lungs is called *ventilation;* the movement of blood through the lungs is termed *perfusion*.

Air enters the body through the mouth and nose and travels through the pharynx to the trachea. The trachea splits into the left and right main stem bronchi, and these bronchi deliver inspired air to the respective lungs. The left and right lungs are in the pleural cavity of the thorax. These two spongy, conical structures are the primary organs of respiration. The right lung has three lobes, while the left lung has only two lobes, thus leaving space for the heart. Within the lungs, the main bronchi continue to split successively into smaller bronchi, bronchioles, terminal bronchioles, and finally alveoli. In the alveoli, carbon dioxide is exchanged for oxygen across a thin membrane separating capillary blood from inspired air.

The thoracic cavity is separated from the abdominal cavity by the diaphragm. The diaphragm, a thin sheet of dome-shaped muscle, contracts and relaxes during breathing. The lungs are contained within the rib cage but rest on the diaphragm. Between the ribs are two sets of intercostal muscles, which attach to each upper and lower rib. During inhalation, the intercostal muscles and the diaphragm contract, which enlarges the thoracic cavity. This action generates a negative intrathoracic pressure, allowing air to rush in through the nose and mouth down into the pharynx, trachea, and lungs. During exhalation, these muscles relax, and a positive intrathoracic pressure causes air to be pushed out of the lungs. Normal expiration is a passive process that results from the natural recoil of the expanded lungs. However, in people with rapid or labored breathing or obstruction, the accessory muscles and abdominal muscles often must contract to help force air out of the lungs more quickly or completely.

The ability of the lungs to expand and contract to inhale and exhale air is affected by the compliance of the lungs, which is a measure of the ease of expansion of the lungs and thorax. Processes that result in scarring of lung tissue (e.g., pulmonary fibrosis) can decrease compliance, thus decreasing the flow and volume of air moved by the lungs and increase the work to breathe. The degree of ease in which air travels through the airways is known as *resistance*. The length and radius of the airways as well as the viscosity of the gas inhaled determine resistance. A patient with a high degree of airway resistance may not be able to take a full breath in or to exhale fully (some air may become trapped in the lungs).

To have an adequate exchange of the gases, there must be a matching of ventilation (V) and perfusion (Q) at the alveolar level. An average V:Q ratio, determined by dividing total alveolar ventilation (4 L/min) by cardiac output (5 L/min), is 0.8. A mismatch of ventilation and perfusion may result from a shunt or dead space. A shunt occurs when there is flow of blood adjacent to alveoli that are not ventilated. This could be physiologic (e.g., at rest some alveoli are collapsed or partially opened but perfused) or pathologic when alveoli are filled with fluid (e.g., heart failure), cellular debris (e.g., pneumonia) or collapsed (e.g., atelectasis). A shunt can also occur when airways are obstructed by mucus or collapse on exhalation (e.g., COPD). In a shunt, blood moves from the venous circulation to the arterial circulation without being oxygenated.

Dead space occurs when there is ventilation of functional lung tissue without adjacent blood flow for gas exchange. Dead space can be physiologic (e.g., the trachea) or pathologic due to obstruction of blood flow (e.g., pulmonary embolism). There are a couple of mechanisms that the body uses to normalize the V:Q ratio such as hypoxic vasoconstriction and bronchoconstriction. When the V:Q ratio is low, hypoxic vasoconstriction leads to decreased perfusion to the hypoxic regions of the lungs, thus redirecting perfusion to functional areas of the lungs, which leads to an increase in the V:Q ratio. When the V:Q ratio is high, the bronchi constrict in areas that are not well perfused. This leads to a decrease in the amount of ventilation to areas that are not well perfused, a decrease in the amount of alveolar dead space, and a decrease in the V:Q ratio.

For the respiration process to be complete, gas diffusion must occur between the alveoli and the pulmonary capillaries. By the diffusion mechanism, gases equilibrate from areas of high concentration to areas of low concentration. Hemoglobin (Hgb) releases carbon dioxide and adsorbs oxygen as it diffuses through the alveolar walls. If these walls thicken, diffusion is hampered potentially causing carbon dioxide retention, hypoxia, or both. Membrane formation with secondary thickening of the alveolar wall may result from an acute or chronic inflammatory process such as interstitial pneumonia and pulmonary fibrosis. The pulmonary diffusing capacity is also reduced in the presence of a V:Q mismatch, loss of lung surface areas (e.g. emphysema, lung resection), or decrease in oxygen carrying capacity (e.g., anemia). The various PFTs can measure airflow in or out of the lungs, indicate how much air is in the lungs, and provide information on gas diffusion, or specific changes in airway tone or reactivity.

CLINICAL USE OF PULMONARY FUNCTION TESTING

PFTs are useful in many clinical situations. They aid in the diagnostic differentiation of various pulmonary diseases. For example, with obstructive lung diseases (e.g., asthma or COPD), the underlying pathophysiology is a reversible or persistent blockage in the airways. Obstructive diseases usually decrease the flow rate of air (liters/min) but have a lesser impact or no impact on the total volume per breath. In restrictive diseases (e.g., kyphosis or sarcoidosis), the lungs are limited in the amount of air they can contain. Restrictive diseases usually decrease the total volume of air per breath with little impact or no impact on the flow rate of air. **Table 14-1** summarizes common pulmonary disease states with PFT results.

In addition, serial PFTs allow tracking of the progression of pulmonary diseases and the need for or response to various treatments. They also help to establish a baseline of respiratory function prior to surgical, medical, or radiation therapy. Subsequent serial measurements then aid in the detection and tracking of changes in lung function caused by these therapies. Similarly, serial PFTs can be used to evaluate the risk of lung damage from exposure to environmental or occupational hazards. **Table 14-2** summarizes the selected uses of PFTs.

PULMONARY FUNCTION TESTS AND MEASUREMENTS

There are no normal ranges for PFTs that can be applied to everyone. In general, PFTs use equations based on the individual's age, height, and sex to calculate predicted normal values from the population. The individual's measurement is then compared to the predicted population measurement. If the individual's measurement falls below the predicted measurement, this information is used in the diagnostic assessment of the patient.

Spirometry

Spirometry is a PFT that helps detect airway obstruction, manifested in asthma or COPD. Spirometry measures the maximum amount of air that can be exhaled by the patient after complete inhalation. The physical forces of the airflow and the total amount of air inhaled and exhaled are converted by transducers to electrical signals, which are displayed on a computer screen.

During this maneuver, a *volume-time curve*—a plot of the volume exhaled against time—and a *flow-volume curve* or *flow-volume loop*—a diagram with flow (L/sec) on the vertical axis and volume expired on the horizontal axis (L)—are generated as the report (**Figure 14-1**). After the data are generated, the patient's spirometry results are generally compared to the predicted values for people of similar age, height, and sex. The predicted values are data gathered from the National Health and Nutrition Examination Survey, the Centers for Disease Control and Prevention, and the National Center for Health Statistics. The flow-volume curve is visually