test is a standardized test in which the patient walks for 6 minutes while the oxygen hemoglobin saturation is measured. A decrease in saturation is abnormal and suggests impaired gas exchange capabilities, and a reduction in distance walked is a means of detecting deterioration of overall function due to lung disease.

In summary, pulmonary function tests, in conjunction with the history and physical examination, can be used to diagnose pulmonary disorders and assess severity and response to therapy, as illustrated in the flow diagram (E-Fig. 15-4).

Analysis of Exhaled Breath

Exhaled breath includes monoxides (nitric oxide and carbon monoxide) and volatile organic compounds (VOCs) that are produced endogenously by normal metabolism or in pathologic states such as cancer and inflammation. These compounds can be measured by gas chromatography, spectroscopy or other chemical means and serve as biomarkers of pulmonary inflammation or cancer. Exhaled nitric oxide is elevated in asthma, and clinical use of this biomarker has been approved by the U.S. Food and Drug Administration for diagnosis and evaluation of asthma exacerbation or quiescence. Similarly, unique patterns of exhaled VOCs provide a "fingerprint" that may identify lung cancer. Cytokines and other similar compounds in the condensate phase of exhaled breath are being investigated for possible applications in inflammatory lung diseases (e.g., cystic fibrosis, bronchiectasis). Other nonpulmonary diseases such as malabsorption syndromes and *Helicobacter pylori* infection are also detected by analysis of exhaled breath.

EVALUATION OF LUNG STRUCTURE

Chest Radiography

Generally, the evaluation of a patient with lung disease begins with routine chest radiography and then proceeds to more specialized techniques such as computed tomography (CT) or magnetic resonance imaging (MRI). Ideally, the chest radiograph consists of two different films, a posteroanterior (PA) radiograph and a lateral radiograph (E-Fig. 15-5). Many pathologic processes can be identified on a PA chest radiograph, and the lateral view adds valuable information about areas that are not well seen on the PA projection. In particular, the retrocardiac region, the posterior bases of the lung, and the bony structure of the thorax (e.g., the vertebral column) are better visualized on the lateral radiograph. The PA chest radiograph is obtained with the patient standing with his or her back to the x-ray beam and the anterior chest wall placed against the film cassette. The chest radiograph should be obtained while the patient takes the deepest breath possible. If the patient is too weak to stand or too sick to travel to the radiology department, the cassette is placed behind the patient's back, and the x-ray beam travels from anterior to posterior (AP film). The quality of a portable film is not that of a standard PA film, but it still provides valuable information.

The examination of a chest radiograph should be systematic so that subtle abnormalities are not missed. It should include evaluation of the lungs and pulmonary vasculature, the bony thorax, the heart and great vessels, the diaphragm and pleura, the mediastinum, the soft tissues, and the subdiaphragmatic areas. Abnormalities that are visible on a chest radiograph include pulmonary infiltrates, nodules, interstitial disease, vascular disease, masses, pleural effusions and thickening, cavitary lung disease, cardiac enlargement, some airway diseases, and vertebral or rib fractures. In addition to the PA and lateral chest radiographs, the lateral decubitus projection is often used to identify the presence or absence of pleural effusion. The decubitus view is particularly useful in determining whether blunting of the costal phrenic sulcus is caused by freely flowing pleural fluid or related to pleural thickening. Chest radiography, in concert with a good history and physical examination, allows the clinician to diagnose chest disease in many circumstances.

Fluoroscopy

Fluoroscopic examination of the chest is useful for evaluating motion of the diaphragm. This technique is particularly helpful in diagnosing unilateral diaphragm paralysis. A paralyzed hemidiaphragm moves paradoxically when the patient is instructed to inhale or to forcefully sniff. However, fluoroscopy is limited when evaluating for bilateral diaphragm paralysis. Apparently normal descent of the diaphragm during inspiration, caused by compensatory respiratory strategies employed by the patient with bilateral diaphragm paralysis, leads to false-negative results. False-positive results are caused by paradoxical hemidiaphragm motion, which can be seen in as many as 6% of normal subjects during the sniff maneuver. Alternatively, two-dimensional B-mode ultrasound imaging of the diaphragm can be used to visualize diaphragm contraction during inspiration. With this technique, the diaphragm muscle is visualized in the zone of apposition of the diaphragm to the rib cage. Absence of contraction correlates with absence of active transdiaphragmatic pressure and indicates diaphragm paralysis. This technique can be used to diagnose both bilateral and unilateral diaphragm paralysis.

Ultrasonography

In ultrasonographic studies, sound waves in the frequency range of 3 to 10 MHz are reflected off internal tissues to produce images of viscera such as the liver, kidney, and heart. The air-filled lung cannot be imaged directly, but over the last decade, an understanding of various *artifacts* generated by ultrasound beams traversing normal and abnormal lung have led to increased application of ultrasound for imaging of the lung, particularly in the intensive care unit. Ultrasonography can rapidly and reliably detect a pneumothorax, pleural effusion, consolidation, and even pulmonary edema with sensitivity and specificity similar to those of a chest radiograph (Fig 15-24). It is routinely used in real time to direct invasive procedures such as thoracentesis, pericardiocentesis, and placement of a pleural, central venous, or arterial catheter. Other applications of pulmonary ultrasound include assessment of volume status by imaging inferior vena cava collapsibility with respiration and assessment of right ventricular function. Ultrasound can be used to evaluate diaphragm function, as described earlier. Ultrasonic imaging is noninvasive, rapidly and easily applied, relatively low-cost, readily portable to the bedside, and, because it does not use radiation, safe for repeated use on a patient.