17

Chest Radiography in Cardiovascular Disease

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The chest radiograph (CXR) has endured, despite all advances in technology, due to its instantaneous capture of patient health as a snapshot in time. Like photographic snapshots, CXRs can also be collected over time to tell the story of disease in a particular patient and provide valuable information at the bedside when a patient is critically ill. The CXR is the first medical imaging for a wide variety of medical conditions, including suspected cardiovascular disease (Table 17.1).[1,2]

OVERVIEW

Understanding how CXRs are made will provide an appreciation for how the best radiographs can be obtained under the most difficult of situations. Understanding the imaging process increases the value of CXRs at the bedside in the intensive care unit (ICU) where there may not be availability of immediate consultation from a radiologist. The American College of Radiology maintains evidence-based guidelines that are reviewed and updated annually by leaders in radiology and other specialties.[2-5]

Though partnership between clinicians and radiologists supports high-quality patient care while conserving patient exposure to ionizing radiation, keeping the dose "as low as reasonably achievable (ALARA)" is the principle that guides the creation of every CXR.[6]

The appearance of the heart and lungs on CXRs can be very specific for some disease processes, including congenital and acquired heart diseases, based on anatomy. Chest radiography is frequently the first imaging study ordered and may be available before the first visit with a cardiologist. Anatomic structure identification is enhanced by common calcifications and radiopaque devices that supply additional landmarks within regions of radiographically undifferentiated tissue. Fully utilizing the lateral view along with the frontal posteroanterior (PA) view, when available, maximizes the information available from CXR. Approach to the evaluation of the CXR and uses for CXR in patient care will be the central components of this chapter. The first principles presented will provide a foundation for approaching CXRs in patients with diseases beyond the examples in this chapter.

PA and Lateral CXR

Magnification of structures follows the inverse square law by which magnification increases as the square of distance. With distance, sharp edges become less sharp. These two directly related principles guide the making of the standard CXR examination including PA and lateral views, made in the erect position for adults able to stand. For the PA radiograph, the anterior chest wall is placed as close as possible to the detector, thereby minimizing magnification of the heart. Despite this, the left lung is less well imaged than the right lung due to the presence of the heart primarily in the left hemithorax. This is balanced by providing a slight advantage to the left lung on lateral radiograph by placing the receptor against the left side of the patient, providing the sharpest depiction of vessels and other structures in the left lung. The inverse square law thus results in magnification of the right hemithorax and right ribs compared with the left hemithorax and left ribs, as shown in Figures 17.1 and 17.2. Thus, when a normal CXR is made, the left lung and ribs will be projected within the right hemithorax. This is an important means by which pathology is localized. The patient's arms are positioned for both views to minimize the overlap of scapula with lungs. The lungs are positioned where sensors will best account for the difference in tissue density, thereby making an image that is correctly exposed for both heart and lungs.

The CXR is obtained at relatively high 120 to 140 kV to deliberately decrease obscuration of structures by the ribs and other bones encasing the thorax. It is for this reason that CXR may not identify calcifications, particularly larger calcifications. The radiation dose from one standard adult CXR is approximately 0.1 mSV. This is equivalent to 10 days of natural background radiation. These figures are convenient for comparing radiation dose from other imaging studies such as computed tomography (CT). The radiation exposure while on a plane flying at 40,000 feet is approximately 30% higher than our background radiation at sea level. This can be used to reassure a patient who becomes distressed about radiation exposure when many serial CXRs are required. Radiology department professional staffs include radiation physicists who can also assist with calculating patient-specific doses of ionizing radiation.[6]

Portable Chest Radiographs

The ICU is a much more complex environment in which to perform chest radiography. Safety of ICU personnel and logistics for making the best possible images benefit from partnership between radiology technologists, nurses, and respiratory therapists to secure support lines away from regions of interest. The portable CXR machine provides a lower maximum dose of radiation and may lose capability if it is battery powered as battery level decreases toward a level at which it must be recharged. This type of unit can be most desirable when ICU outlets are in short supply.[5,6]

Beyond Standard Radiographs

A hybrid type of exam is frequently performed for patients in the emergency department and for patients on stretchers. The frontal radiograph is made in the anteroposterior (AP) projection like a portable CXR while using the standard radiography equipment. If the patient can sit straight up on the stretcher, a lateral view can be made. Using the radiography room in the radiology department results in a near-standard CXR. This can be especially valuable for obese patients for whom portable CXR may be inadequate due to tube limitations regarding radiation dose. When a patient needs to be flat, the standard radiography cross-table lateral will be superior to the same examination performed at the bedside in the ICU. This can be important when a lateral view is required for localization of malpositioned support line. While it takes more effort to organize the trip to the radiology department, considered use of this strategy can improve patient care, decrease cumulative radiation dose, and decrease delay in optimizing patient care.

Inspiration-Expiration CXR

Inspiration-expiration CXR is infrequently ordered, although it can demonstrate diaphragmatic excursion and the range in apparent size of a particular patient's heart. This CXR can be obtained as PA or AP views. The expiration CXR alone can be used to increase visibility of a pneumothorax, although this is infrequently performed in academic medical centers where thoracic radiologists read all CXRs using PACS (picture archive and communication system) workstation display and tools.

Frontal CXR Variations

Oblique, lordotic, and reverse lordotic views are useful for problem solving. Forty-five-degree oblique views of the chest are familiar to cardiologists as a standard plane for evaluation of the aorta. The hallmark of the 45-degree obliquity used to image the aorta is a projection of the trachea to the right of the spine. Shallow 15-degree oblique views do not shift structures significantly, just enough to differentiate between nodules, vessels, and bone findings. Shallow oblique views are superior to lordotic and reverse lordotic views for assessment of lung nodules, especially in the lung apices. Shallow obliques are also useful for differentiating between breast nipples from lung nodules. A four view CXR refers to PA, lateral, and bilateral oblique views that can often substitute for chest fluoroscopy when used to determine whether a nodule is present. This and chest fluoroscopy have largely given way to CT for these differentiations, although CT carries more significant risk of additional findings leading to additional CT scans and anxiety for the patient. They are presented here because the equivalent information and views are frequently available in the cardiac catheterization laboratory, sparing the patient additional procedures.

Chest Fluoroscopy

Chest fluoroscopy is performed at lower kV than CXRs and is capable of detecting benign patterns of calcification in lung nodules. This function has been largely replaced by CT with chest fluoroscopy now used almost exclusively for functional evaluation of the diaphragm, referred to commonly as a "sniff" test. This is best performed as an outpatient procedure and contraindicated for patients requiring mechanical ventilation. It is best at detecting unilateral diaphragmatic paralysis and limited in value for detecting bilateral diaphragmatic paralysis because it depends on the asymmetry between the normal and abnormal hemidiaphragm. The exam begins in the erect position and is repeated in the supine position, especially when normal in the erect position, in order to decrease the effectiveness of accessory muscles or respiration. Abdominal muscles in particular are unable to adequately move the hemidiaphragms in the supine position. Deep inspiration and deep expiration demonstrate the overall diaphragmatic excursion. The sniff maneuver, breathing sharply through the nose while the mouth is closed, will provoke paradoxical motion, whereby the paralyzed hemidiaphragm will rise during the special sniff maneuver. A patient report of sleep position is often revealing as sleeping on a paralyzed hemidiaphragm will tend to awaken the patient. This is because the lung that is down does the primary work of breathing. This positional difference can also be exploited with radiography.

Decubitus Views

Although decubitus position in adults is most often used for evaluation of pleural effusion size and mobility, the decubitus position in an adult will also result in the upper lung being held in inspiration. Restoration of a sharp costophrenic sulcus can confirm mobility of the pleural effusion when it shifts into the mediastinum. Paired right and left lateral decubitus views are not always needed for diagnostic purposes, but the paired images will provide inspiratory examination of both lungs in a patient who is unable to stand or cooperate in taking a deep breath.

TABLE 17.1 American College of Radiology (ACR) Appropriateness Criteria for Cardiac Diseases Algorithms for Disease Group Specific Workup Using Multiple Imaging Modalities and Appropriate Use for Specific Imaging Modalities

PRESENTATION OF SYMPTOMS AND INITIAL IMAGING	SPECIFIC APPROPRIATENESS CRITERIA
Asymptomatic Patient	**At Risk for Coronary Artery Disease (CAD)**
Acute chest pain	Possible acute coronary syndrome (ACS)
	High probability of CAD
	Low probability of CAD
	Suspected aortic dissection
	Suspected pulmonary embolism
Blunt chest trauma	Suspect cardiac injury
Chronic chest pain	High probability of CAD
	Low to intermediate probability of CAD
Heart failure	New-onset and chronic heart failure
Adult congenital heart disease	Known or suspected congenital heart disease
Use of chest radiograph (CXR)	Routine CXR
	Portable CXR

From American College of Radiology. Appropriateness criteria table, for cardiac diseases. (https://acsearch.acr.org/list). Accessed 3/11/2021.

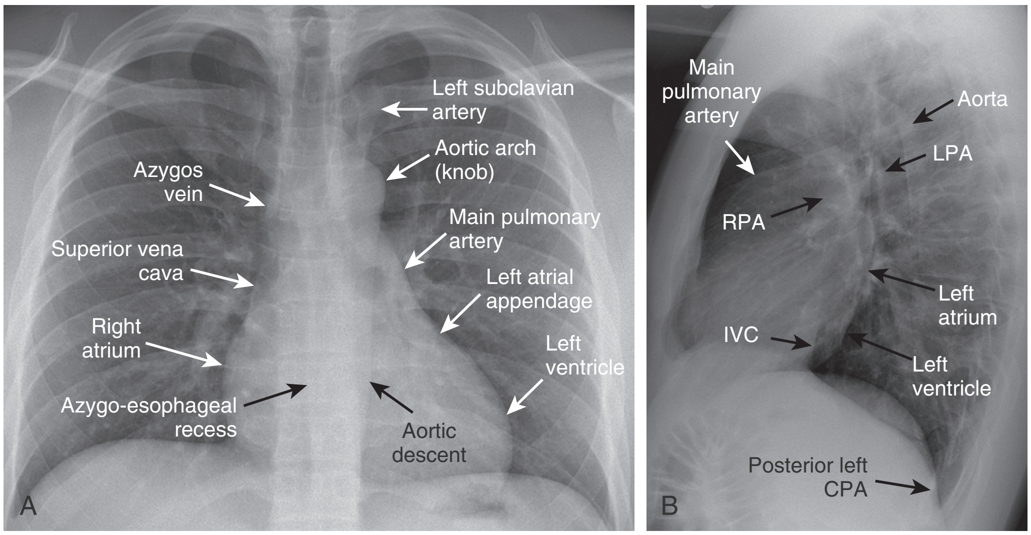

FIGURE 17.1 Normal standard two-view chest radiograph. PA **(A)** and lateral **(B)** views of the chest depict various normal cardiovascular structures. *CPA,* costophrenic angle; *IVC,* inferior vena cava; *LPA,* left pulmonary artery; *RPA,* right pulmonary artery. (From Javidan-Nejad C, Balla S. The chest radiograph in cardiovascular disease. In Zipes DP, et al. (editors): Braunwald's Heart Disease: A Textbook of Cardiovascular Medicine. 11th ed. Philadelphia: Elsevier; 2019, pp 252-260.)

APPROACH TO CXR EVALUATION

A systematic approach to the evaluation of the PA-lateral CXR is greatly facilitated by placing the two views side by side. When looking at PA and lateral views together, levels are matched based on readily visible anatomy. The top of the aortic arch, the carina (at approximately the same level as the bottom of an ectatic aorta), and pulmonary venous confluence are accessible for basic orientation on the lateral view. This provides a check on any hypothesis about localization based on any frontal view. Discordance requires a new hypothesis. This strategy, combined with imaging physics and a few basic radiographic signs, derives maximum information from every CXR.[7]

Radiographic Densities

Radiographic densities are air, fat, water, calcification, and metal. Water density is the density of a wide variety of soft tissues including fluid, muscle, and solid organs. The differentiation of fat in regions of air can also result in water attenuation for pleural and pericardial fat. Calcifications provide delineation of anatomic structures for which we do not have a radiographic difference in density. These, and an ever-increasing variety of radiopaque devices, help to provide internal anatomic landmarks in the heart on CXRs. Some, such as the intra-aortic balloon pump and with luck some replacement valves, can also reveal the phase of the cardiac cycle in which a radiograph has been obtained.

The limited differentiation of tissues requires a lexicon for CXR in order to communicate accurately the findings and the significance of the findings. The most basic of terms, cardiac silhouette must be understood to include more than just the heart. The cardiac silhouette may become enlarged by one or more chamber enlargements. A pericardial effusion surrounding the heart can also enlarge the cardiac silhouette. We expand this to cardiovascular silhouette to include the aorta, great vessels, pulmonary artery, and vascular pedicle. To this we add the entire mediastinum when we refer to the cardiomediastinal contour. Pulmonary vascular redistribution is an important term from the point of view of cardiology practice.

Interpreting CXR Pearl

The most valuable advice about looking at CXRs in medical school came to me from an elderly radiologist who said, "The answer is in the jacket." When caring for a patient who has had many CXRs, you can often find the same findings on a prior CXR and read the radiologist's report to support your own reading of a new CXR that has not yet been interpreted by a radiologist. It is even more valuable to expand this concept to include looking at other modalities in the now-virtual radiology jacket. The information that might be gained from ordering a CT scan may already be available from a prior examination, saving money, time, and radiation exposure.

CXR Anatomy

PA Radiograph

The heart border is composed of a series of landmarks, right heart border being the normal heart landmark that extends to the right of the spine. The interface with the lung is provided by the right atrium. A minimally dilated aorta is often seen just above the right ventricle in adult patients, especially those with hypertension and heart disease (Fig. 17.3). A small double density is often created by this divergence that is also coincidentally at the same level as the junction of the superior vena cava and the right atrium, frequently referred simply as the cavo-atrial junction, an important landmark for vascular support line placements. The superior vena cava can be followed to the right paratracheal region above the level of the azygous arch (see Fig. 17.1). The azygous vein drains into the superior vena cava at the level of the carina, allowing it to appear as an almond-shaped structure along the right side of the tracheobronchial angle. The upper limit of the normal size range for this structure is 11 mm, a useful guide for determining pulmonary vascular engorgement. The aortic arch will cross over the trachea with variable visibility depending on patient age and disease. The side of the aortic arch is fundamental for determination of situs. In infants and children, this may need to be inferred by the side on which it creates an impression on the trachea. With age and disease, the aorta becomes a major landmark by which one can imagine picking up the mediastinum. The normal left-sided aorta will descend to the left of the spine. As it enlarges and elongates, it will become a tortuous retrocardiac structure. Great vessels emanating from the aorta course upward and may be seen at and above the clavicles. Coming down the left side of the cardiovascular silhouette brings the eye to the main pulmonary and left pulmonary artery. The pulmonary arteries introduce subtle asymmetry due to the difference in arterial position relative to airways. The left hilum is 1 to 2 cm higher than the right hilum, creating what is referred to as the hilar angle. Alterations in hilar angle indicate volume loss in one or both lungs. The AP window is at the point where the direction of the contours changes from aorta to left pulmonary artery. This space may be enlarged by invagination of lung only in the case of absence of the pericardium that binds the aorta and pulmonary artery together. The upper portion of the left heart border is created by the left atrium and most prominent when the left atrial appendage is enlarged as in mitral valve disease. The lower left heart border is created by the left ventricle. Midline structures include posterior and anterior junction lines, and the azygo-esophageal line that defines the azygo-esophageal recess behind the heart. Additional midline structures that are also frequently visible include the manubrium and hiatal hernia. After completing the tour of the heart border, the right ventricle will not have been border forming, only seen if enlarged and creating a double density sign.

Lateral Radiograph

The first heart border encountered on the lateral chest radiographic is the right ventricle in continuity with the main pulmonary artery with the aorta seen more posteriorly and extending higher (see Fig. 17.1). The upper posterior heart border is created by the left atrium. Left atrial enlargement can elevate the left mainstem bronchus on the frontal radiograph. The lower posterior border of the heart is created by the left ventricle. The inferior vena cava creates an interface extending up from the diaphragm. In a well-positioned lateral radiograph of a 70 kg man with a normal size heart, the left ventricle would extend less than 1.7 cm posterior to the IVC and 2 cm above the diaphragm. A handy rule of thumb is to use up 2 cm and back 2 cm for a more forgiving reference relative to the position and size of the patient. Left ventricular enlargement can create the appearance of right ventricular enlargement on the lateral radiograph due to mass effect elevating the right ventricle. The right pulmonary artery is seen with the heart more anteriorly while the left pulmonary artery is higher and more posterior. The aortic-pulmonary window lies between the aorta and left pulmonary artery. The right paratracheal region will be projected with and just anterior to the trachea.

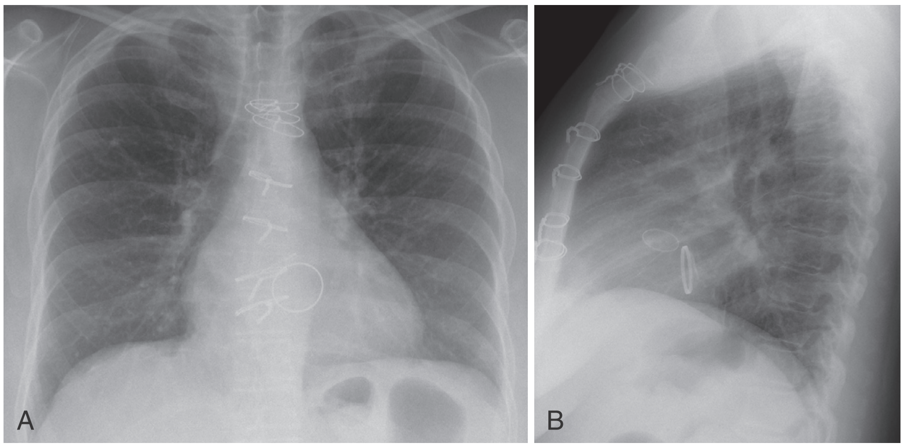

FIGURE 17.2 PA and lateral chest x-ray in a patient with bioprosthetic aortic and mitral valves. A, PA view reveals mitral valve ring and linear appearance of aortic valve ring that is in center of heart. The mitral valve is located inferior to the aortic valve. **B,** Lateral view shows typical magnification of the right hemithorax and right ribs compared with the left hemithorax and left ribs. Mitral valve annulus is posterior to the aortic valve.

Common Anatomic Variants

Understanding anatomic variants in anatomy on chest x-rays is facilitated by an understanding of embryology. The heart itself arises from mesoderm within the trilaminar embryonic disc. It begins as a pair of tubes within the pericardial cavity and folds under the direction of cilia. In absence of cilia, folding will be random, with equal probability for each fold in the development of normal situs. Aortic arches are formed sequentially from paired pharyngeal arches (previously referred to as branchial arches). A sequence of remodeling leads to the normal asymmetric arrangement of great vessels. The paired system provides opportunities to recover from missed steps in sequence. The variations in arch anatomy are well known. Variations also occur beyond the aortic arch, using vessels that connect between right and left circulation to overcome small errors in development. Resulting tortuosity of the aorta may become more apparent as vessels enlarge over the life cycle.

Azygous Lobe Variant

Incomplete migration of the azygous vein during embryologic development can result in the azygous vein being variably placed or mobile within an azygous fissure. Although not strictly speaking a lobe, it is often referred to as the azygous lobe variant. It is extremely rare for the azygous vein to leave the fissure even in the setting of a large pneumothorax. The normal almond-shaped azygous vein normally measuring up to 11 mm in transverse diameter will not be seen abutting the carina. It is important to recognize this variant as dilation of the azygous vein contributes to widening of the vascular pedicle that can be valuable observation in the setting of pulmonary vascular engorgement.

Aortic Arch Variants

Anatomic arch anomalies arise from developmental differences in embryology, often as compensation for slight differences or "mistakes" in development as the paired aortic arches are joined.

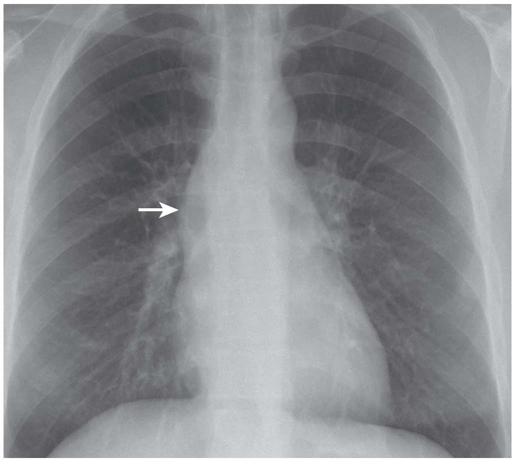

FIGURE 17.3 Ectatic ascending aorta *(arrow)* in a patient with aortic stenosis.

Localization Within Cardiac Silhouette

Chest radiography is not able to differentiate between fluid and muscle, resulting in a very homogeneous density of the heart. The fluid density of the heart can be separated from three different distinct radiographic densities: fat, calcification, and metal.

Fat

In a normal heart, epicardial fat immediately adjacent to the heart and pericardial fat outside the pericardium are seen without separation, if visible at all on CXRs. The fat in these locations can be separated by a pericardial effusion. This is most frequently seen on the lateral CXR immediately behind the anterior chest wall. This is sometimes referred to as the "Oreo cookie" sign and can be sensitive for small pericardial effusion. On the frontal view of the chest, globular enlargement of the heart is more likely to raise concern for pericardial effusion with the heart appearing to be in a "water bottle" (Fig. 17.4). Large pericardial effusions can cause the edge of the heart to be differentiated from the effusion going around the heart on either or both frontal and lateral views.

Calcifications

Calcifications are powerful definers for intracardiac anatomy with localization based primarily on anatomy.[8] Coronary artery calcifications are frequently visible on CT although infrequently reported on chest radiography. Thoracic aortic calcification is a common finding and in extreme cases deserves the term "porcelain aorta" (Fig. 17.5). Mitral annulus calcification with characteristic "C" shape and location on both frontal and lateral CXRs is very easily identified (Fig. 17.6). This C-shaped fibrocalcification is frequently found in older patients (see Chapter 75) and provides a good reference for internal cardiac anatomy. If very exuberant, it can obstruct inflow to left ventricle and be associated with ischemic and, rarely, embolic stroke. Aortic valve calcification is infrequently seen by comparison, but the fact that these two valves share a common attachment can be helpful to identify smaller amounts of calcification in the aortic valve.

Differentiating calcified muscle from pericardial calcification is facilitated by the anatomy itself (Figs. 17.7 and 17.8). Pericardial calcification can extend over boundaries between cardiac chambers. It will be best seen on the view in which it is most closely perpendicular to the direction of the x-ray beam and may be completely inapparent on the opposite orthogonal view. Calcific pericarditis completely encasing the heart can be diagnosed by chest radiography alone. Pericardial calcifications can be caused by infection, most commonly tuberculosis, and intrapericardial hemorrhage (see Chapter 86).

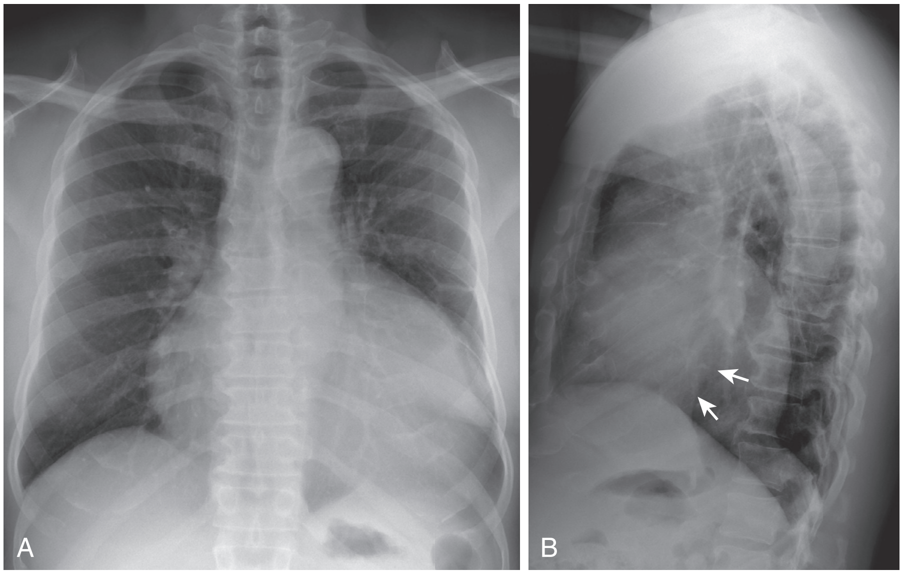

FIGURE 17.4 PA **(A)** and lateral **(B)** chest radiographs in a patient with a large pericardial effusion. The PA view reveals marked enlargement of heart with a hot water bottle shape. This can also have shape of an Erlenmeyer flask. The lateral view reveals the normal size heart *(arrows)* inside the pericardial effusion. Separation of epicardial from pericardial fat may be most apparent anteriorly.

Pulmonary Vasculature

Pulmonary edema can occur through both increased pressure and increased permeability of vessels and these may be seen in combination (Fig. 17.9). Permeability edema can occur with or without diffuse alveolar damage. Distension of pulmonary veins most typically appears as cephalization on supine radiographs. The distribution of pulmonary edema follows the course of least resistance within any given patient position. Cephalization, dependent on the presence of upper lobe vessels, may be absent in the setting of significant emphysema. A patient position preference may introduce lateralization.[9]

Slowly evolving pulmonary edema is more likely to produce pulmonary interlobular septal thickening due to veins and lymphatics. This process produces what are usually referred to as Kerley B lines along with small pleural effusion(s) (Fig. 17.10). Kerley B lines are most apparent at the right lung base on the frontal chest x-ray. Visualization of Kerley B lines can become permanent due to hemosiderin deposition following repeated episodes of interstitial pulmonary

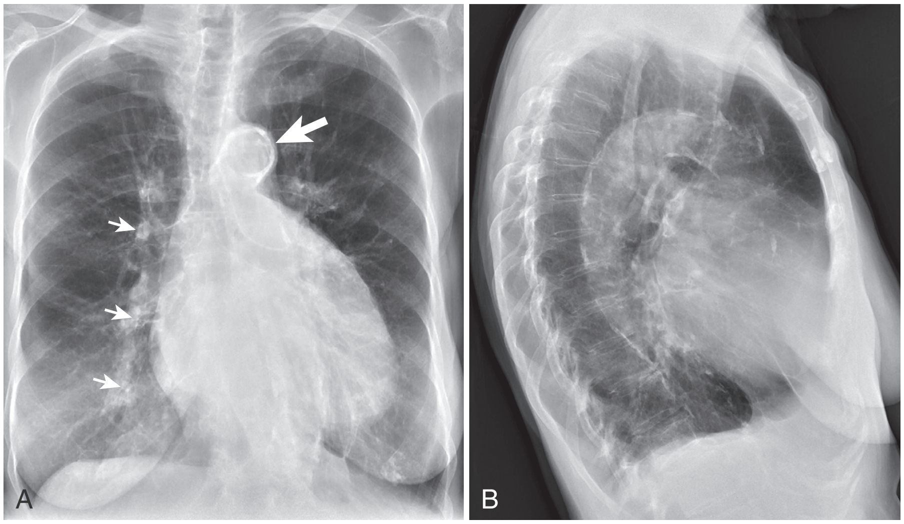

FIGURE 17.5 PA **(A)** and lateral **(B)** chest radiographs in a patient with aortic calcification. This is best seen on the PA view with long summation shadow-gram of aortic arch *(large arrow)*. The PA view also shows calcification of tracheobronchial tree *(small arrows)*, which is occasionally encountered in patients receiving warfarin. The lateral view reveals extensive calcification of aorta as well as origins of great vessels and coronary arteries.

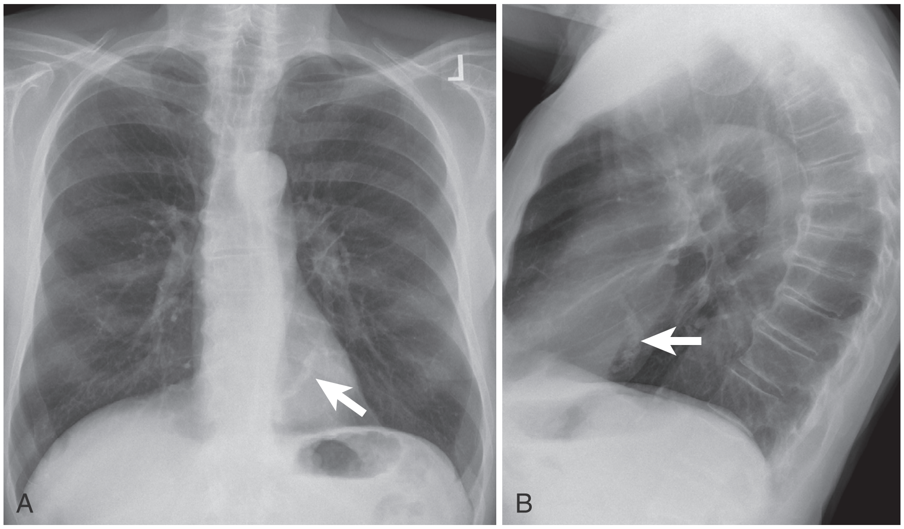

FIGURE 17.6 PA **(A)** and lateral **(B)** chest radiographs in a patient with mitral annular calcification *(arrows)*.

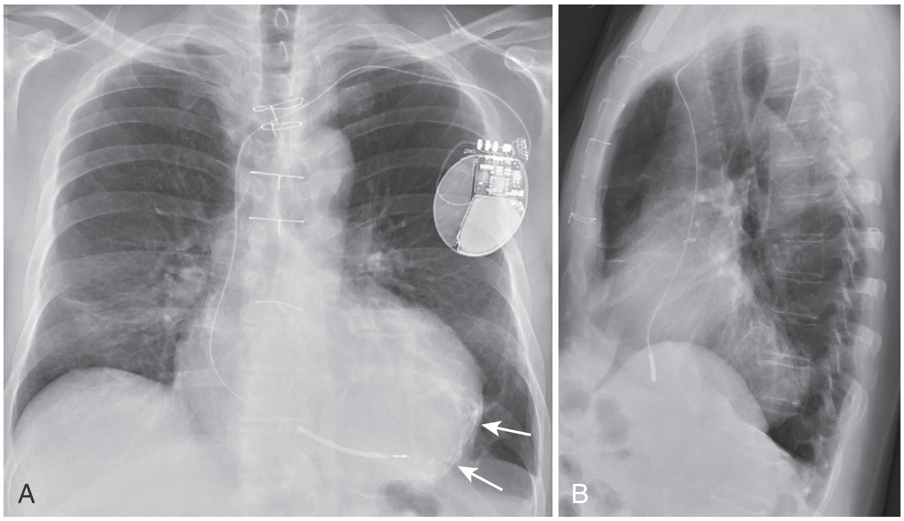

FIGURE 17.7 PA **(A)** and lateral **(B)** chest radiographs in a patient with a calcified left ventricular pseudoaneurysm *(arrows)*. The lateral view reveals posterior extension of the pseudoaneurysm.

edema or hemorrhage. Kerley B lines are also associated with viral pneumonia and lymphangitis carcinomatosis. Dilatation of pulmonary veins, blurring of pulmonary vascular margins, and fissures are subtle signs of congestive heart failure.

Pulmonary hypertension causes characteristic features involving the pulmonary vasculature. Idiopathic pulmonary hypertension causes marked enlargement of main pulmonary artery. Central pulmonary artery branches are enlarged with peripheral pruning (Fig. 17.11). Extremely large central artery branch pruning may result in normal-appearing peripheral branches despite marked decrease in size.

Support Lines and Devices

Intravascular support lines demonstrate individual anatomy extremely well. Malpositioned intravascular catheters are frequently found following the course of smaller vessels and anomalous vessels, many of which are derived from the embryologic development of the heart. The suitability of line placements in structures such as persistent left superior vena cava can be addressed by comparison with historical chest CT scan in addition to bedside assessment. Common vascular line malposition locations also include azygous vein and arch and superior intercostal vein (responsible for aortic nipple).

Radiopaque intracardiac devices include devices placed by both cardiologists and cardiac surgeons. Normal positions of the four intracardiac valve replacements and valve repair rings are readily identified on radiographs (see Fig. 17.2). Right ventricular pacemaker leads (see Fig. 17.6) characteristically rise to go through the tricuspid valve. Right atrial leads are directed anteriorly and superiorly toward the sinoatrial node. Use of a third lead to the coronary sinus has become common (see Chapter 58) with additional recent alternative placement to the atrioventricular node, seen on radiographs projected within the region of tricuspid valve. The atrial appendage occlusion device, to prevent thromboembolic events due to atrial fibrillation, is placed in the left atrial appendage as an alternative to atrial ablation and surgical maze procedures (see Chapter 66).

Pearls for Evaluating Portable CXR

The radiologist will approach the individual CXR beginning with placement of support lines, tubes, and devices. The position of the endotracheal tube terminating in the right mainstem bronchus can markedly narrow the differential diagnosis for opacification of the left hemithorax to left lung collapse. The sudden onset of a new lung parenchymal abnormality may be tied to an event such as aspiration, hemorrhage, or flash pulmonary edema. The distribution of abnormality is a powerful differentiator between these possibilities. Central distribution is characteristic of perihilar "bat wing" pulmonary edema. Hemorrhage is likely to produce asymmetric bilateral consolidation. Aspiration in the ICU setting is most often seen in left lower lobe due to the posterior angulation of the left mainstem bronchus. Sterile aspiration, also known as Mendelson syndrome, can simulate acute pulmonary edema and is frequently associated with a side hole of the enteric tube left in the esophagus, setting up a route for reflux from the stomach to the esophagus. Portable CXRs are routinely used following procedures and placement of devices to rule out hemorrhage, pneumothorax, and pneumomediastinum (Fig. 17.12).

Serial CXRs provide more information over time. Pulmonary edema will clear over 24 hours. Hemorrhage will clear more slowly with the shift from consolidation to coarse interstitial pattern, with the periphery of the lung developing sharply defined sparing with complete resolution after about 3 days. Aspiration may be transient or lead to pneumonia that will clear slowly over a longer period. Physiologic changes such as increasing and decreasing pulmonary edema can be helpful for the management of patients with heart disease.

Viewing multiple images as a group also provides compensation between individually limited nonstandard images. An opacity due to a healed rib fracture may be more obvious on one image and avoid consideration of a pulmonary nodule in another image. The patient's progress in recovering from cardiac surgery may be followed through the succession of support line removals with an ability to point out the time and duration of a setback in recovery allowing more thoughtful consideration of potential complication that required the extended use of a particular support line or device.

Clinical ICU care has historically over-relied on routine daily portable CXRs. Harmonizing clinical care routines can increase the value of each radiograph for managing support lines, tubes, and devices and decrease the total number of images required for optimum care in the ICU. The American College of Radiology Appropriateness Criteria for CXRs in ICU patients and for routine chest radiography are maintained by periodic interdisciplinary panel review.[10]

Value of Baseline CXR. The most valuable CXRs for any patient with heart disease are baseline PA and lateral views of the chest. New baseline CXRs are generally acquired 4 to 6 weeks following cardiac surgery in order to allow time for perioperative findings to resolve. The same is not always followed for patients with medically managed heart disease, limiting evaluation for subtle changes.

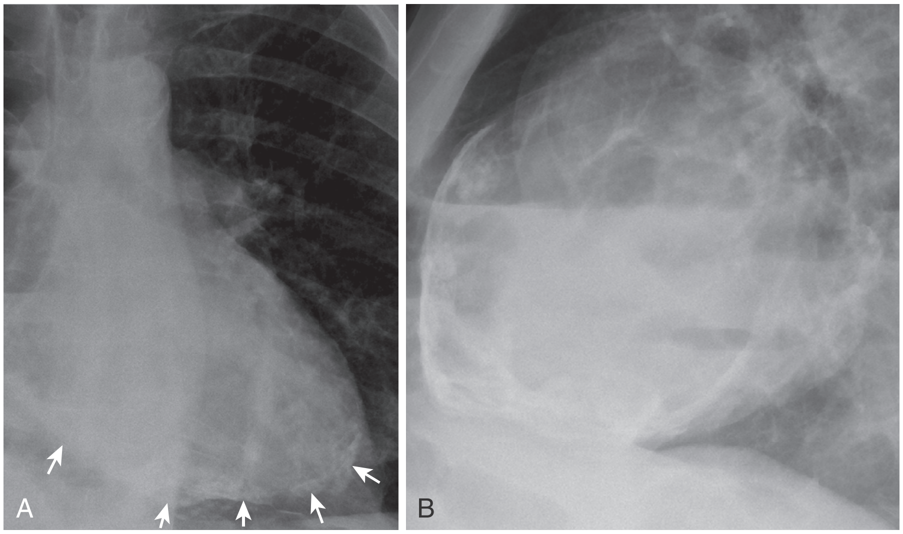

FIGURE 17.8 PA **(A)** and lateral **(B)** coned down views in a patient with constrictive pericarditis *(arrows)*. The PA view reveals pericardial calcification extending across expected cardiac chamber boundaries and extending through the atrial-ventricular groove, resulting in severe constrictive pericarditis, while the lateral view shows extensive anterior, apical, and inferior calcification.

FIGURE 17.9 PA chest radiograph in a patient with congestive heart failure. There is enlargement of the left ventricle, left atrium, and main pulmonary artery, with pulmonary venous congestion.

SPECIFIC CARDIOVASCULAR CONDITIONS

Congenital Heart Disease

The range of congenital heart disease is very broad, ranging from a single embryologic error that can go undetected throughout life to very complex abnormalities that become apparent even before birth.[11-14] Early-life diagnosed and treated congenital heart disease may have increasing physiologic consequences in adulthood for which the individual patient history will be paramount (see Chapter 82). In the context of adult heart disease, it is most valuable to focus on initial diagnosis of congenital heart disease in adults.

The most common congenital heart disease is bicuspid aortic valve. This may go undetected until a patient becomes symptomatic due to critical aortic stenosis (see Chapter 72). Dilatation of the aorta, resulting in greater ectasia of the ascending aorta, is often the primary radiologic finding (see Fig. 17.3), followed by left ventricular enlargement should the aortic valve become regurgitant.

Aortic arch anomalies reflect disordered embryogenesis during the folding of the primitive tube that becomes the heart and the integration between the dual embryonic right and left main arteries and veins. If the right and left aorta persist, a doubled aortic arch will result.

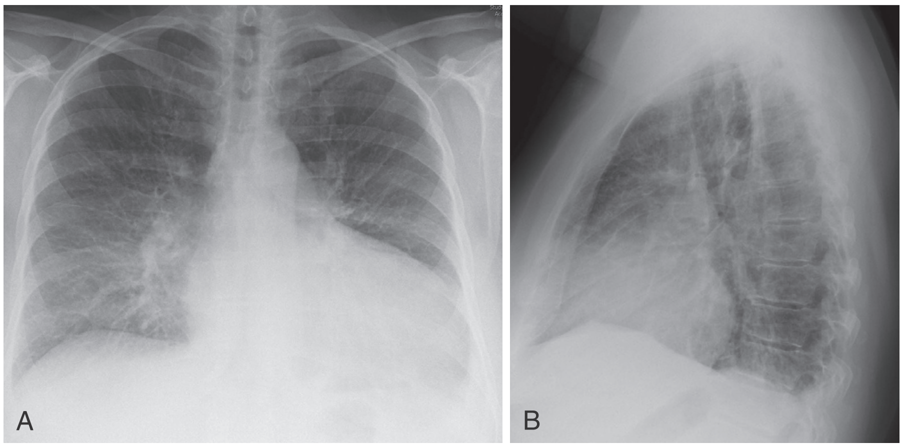

FIGURE 17.10 PA **(A)** and lateral **(B)** chest radiographs in a patient with left ventricular dilation and pulmonary edema. PA view shows venous cephalization, blurring of pulmonary vascular margins, and fissures and Kerley B lines. Lateral view shows pleural effusions.

FIGURE 17.11 PA chest radiograph in a patient with idiopathic pulmonary hypertension. Idiopathic pulmonary hypertension causes marked enlargement of main pulmonary artery. Central pulmonary artery branches are enlarged with peripheral pruning. Extremely large central artery branch pruning may result in normal-appearing peripheral branches despite marked decrease in size.

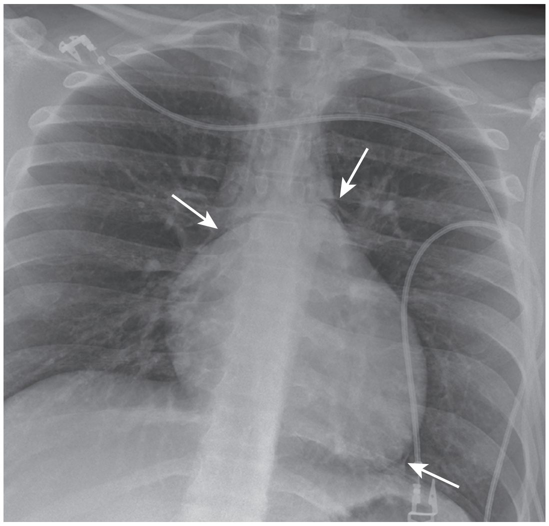

FIGURE 17.12 Portable chest x-ray demonstrating gas along central pulmonary arteries as well as around the cardiac apex *(arrows)*. Pericardial insertion is along underside of aorta, limiting gas going around the aorta within the intact pericardium.

The right arch is generally higher than the left arch with both impressing on the aorta.

Cilia direct the normal development of cardiac chambers to normally produce *situs solitus* with left-sided aortic arch, left-sided cardiac apex, and left-sided stomach on CXRs. Anomalous branching of the great vessels is not frequently evident on adult CXRs. One common great vessel branching anomaly can become visible on CXRs and lead to both gastrointestinal dysmotility and false identification of significant lung nodule in later life. The right subclavian artery is normally the first great vessel leaving the aortic ring. This small embryologic error can be an isolated event with the right subclavian artery arising last and coursing behind the esophagus, resulting in an aberrant subclavian artery. The artery is subject to the processes of atherosclerosis with enlargement and calcification possible in later life. When enlarged, the vessel is well seen focally displacing the trachea on the lateral view simulating a dominant upper lobe lung nodule. The vessel has a more subtle diagonal course on frontal view when enlarged that is helpful for a radiologist to avoid overcalling a lung nodule. The aberrant subclavian artery is *always* contralateral to the aortic arch. Thus a patient with a right-sided aortic arch would have a left-sided aberrant subclavian artery and lower probability of complex congenital heart disease than the alternative of mirror image branching of the aorta.

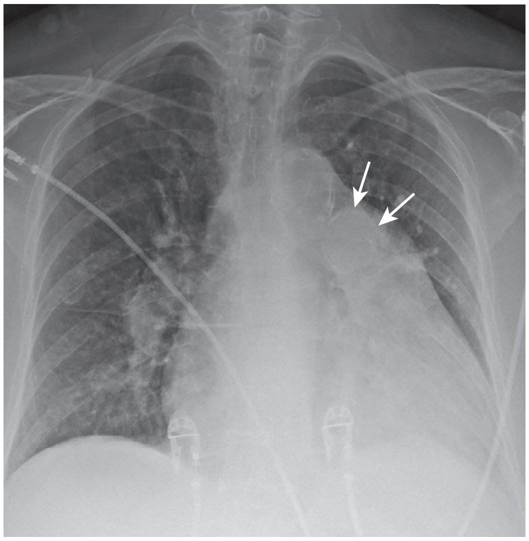

FIGURE 17.13 PA chest radiograph in a patient with congenital heart disease with pulmonary arterial hypertension. The calcified pulmonary artery *(arrows)* indicates that it has carried systemic pressure. The patient is now presenting with Eisenmenger's physiology and mild interstitial pulmonary edema. Note Kerley B lines in the base of the right lung.

Coarctation of the aorta can also be identified on CXRs. The characteristic notching of the posterior third to eight ribs that occurs in 75% of cases may be more apparent than the narrowing of the aortic arch (see Chapter 42). The rib notching occurs due to pulsatile collateral blood flow through the intercostal arteries. This feature would not be expected in pseudocoarctation due to the dilation and elongation of the aorta causing a folding of the proximal descending thoracic aorta.

In adult patients with complex forms of congenital heart disease, echocardiography, CT, and cardiac magnetic resonance imaging (MRI) are most helpful in determining cardiac chamber location, size, and function, as well as the anatomy of the great vessels (see Chapters 16, 19, and 20). However, CXRs often provide important clues for clinical diagnosis and management, including evidence of pulmonary hypertension and pulmonary edema (Figs. 17.13 to 17.16).

Acquired Heart Disease

In addition to cardiomyopathies, valvular heart disease, and coronary artery disease (CAD),[15,16] additional types of acquired heart disease include cardiac tumors, such as benign atrial myxoma and malignant sarcomas, which may be primary or secondary to prior radiation therapy, and pericardial disease.[17-19] Pericardial effusion may decrease visibility of pulmonary edema and result in long-term restriction associated with calcific pericarditis. Cardiovascular diseases are increasingly viewed in a unified fashion throughout the body, connecting stroke syndromes, aortic aneurysms, dissections, and transections.

Valvular Heart Disease

Echocardiography is the primary method for diagnosing and following valvular heart disease whether congenital, rheumatic, or degenerative (see Chapter 16). The radiographic findings of critical importance include evidence of ventricular or atrial dilation, valvular calcification, dilations of the aorta or pulmonary arteries, and evidence of pulmonary venous congestion. Most common causes of aortic valve disease include congenital bicuspid valves, acquired calcific disease, and rheumatic heart disease (see Chapters 72 and 73). Aortic regurgitation also develops commonly from primary diseases causing dilation of the aortic root and ascending aorta. Mitral valve disease primarily results from myxomatous disease and rheumatic heart disease, but mitral regurgitation can also occur as a secondary phenomenon due to left ventricular remodeling from

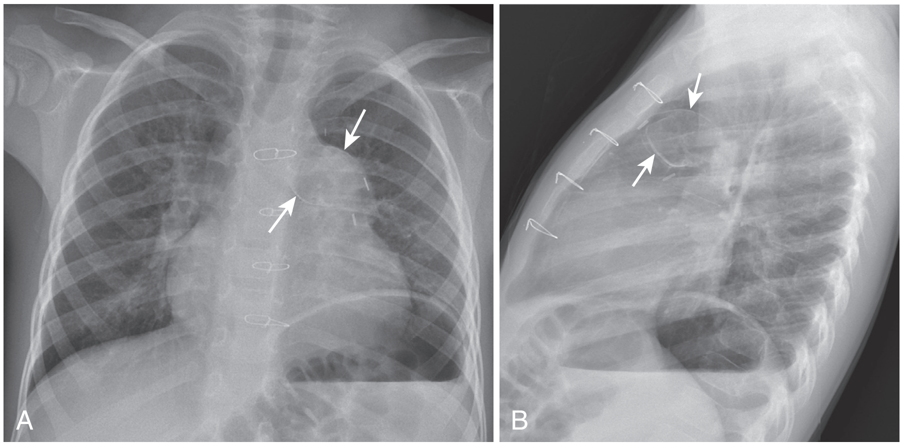

FIGURE 17.14 PA **(A)** and lateral **(B)** chest radiographs in a patient with truncus arteriosus. There is dilation of the main pulmonary artery, which is calcified *(arrows)* as a marker of chronic pulmonary arterial hypertension.

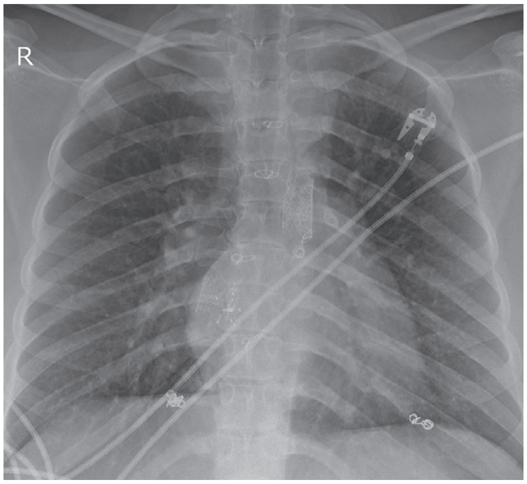

FIGURE 17.15 PA chest radiograph in a 22-year-old patient with hypoplastic left heart and a left aortic arch, initially treated with Blalock-Tausig shunt, subsequently replaced by a Glenn procedure and Fontan procedure with creation of an atrial septal defect (ASD). The ASD has been closed percutaneously, and a stent has been placed to revise the Fontan baffle to the pulmonary artery.

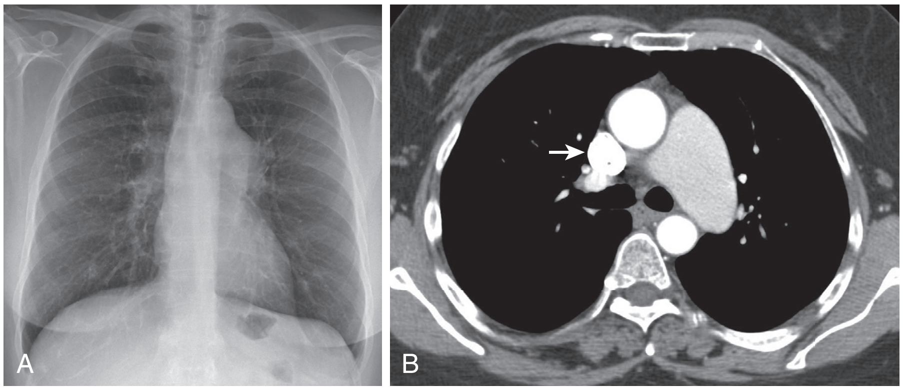

FIGURE 17.16 **Congenital pulmonic stenosis. A,** PA chest radiograph shows poststenotic dilation of the left pulmonary artery. Right pulmonary artery is normal. **B,** Axial CT image confirms enlargement of left pulmonary artery *(arrow).*

dilated cardiomyopathy or ischemic left ventricular dysfunction (see Chapter 76).

Coronary Artery Disease

Chest radiography is not a primary diagnostic modality for CAD but is central to the evaluation of chest pain[20] and postinfarction left ventricular dysfunction.

Heart Failure

CXRs are invaluable in managing patients with heart failure, including initial diagnosis and serial imaging to assess worsening signs and symptoms of heart failure (Fig. 17.17) or improvement following therapy. CXR assists in establishing baseline chamber dilation and status of the pulmonary vascular markings and also in identifying potential undiagnosed valve disease and cardiomyopathy, coexisting lung diseases such as emphysema that also alter the capillary bed capacity of lung parenchyma, and common changes to the cardiovascular silhouette related to sustained hypertension: The increased systemic pressure causes enlargement and elongation of the aorta causing it to assume an uncoiled configuration.[21]

In the outpatient setting, standard PA and lateral CXR views provide the proper snapshot for following the ongoing variations in patient physiology. The size of the heart, the appearance of lung parenchyma, and ancillary findings including lymphadenopathy and pleural effusions provide central information for medical management on an ongoing basis.

Patients with acute heart failure symptoms are seen more frequently in the emergency room and cardiac ICU where basic imaging is performed at the bedside with portable CXRs.[22]

Heart Failure CXR Pearls. Patients with symptomatic heart failure have generally had multiple episodes of pulmonary edema, leaving hemosiderin deposition along interlobular septae in lungs, which contribute to Kerley B lines. In compensated heart failure, little or no pulmonary vascular engorgement will be evident. The vascular pedicle will be normal and the central hilar vessels will be sharp. The lack of pulmonary vascular redistribution, most commonly seen as cephalization, is a very useful sign of equilibrium for a patient receiving medical management of congestive heart failure.

Cardiogenic pulmonary edema arising from rapid elevation hydrostatic pressure causes airspace filling around the pulmonary hila, resulting in bat wing pulmonary edema, sometimes referred to as flash pulmonary edema. This may occur very suddenly in the ICU whether or not it is related to myocardial infarction. As noted previously, when the onset of pulmonary edema occurs very gradually, the lymphatics provide drainage, resulting in Kerley B lines that are particularly easy to identify in the base of the right lung and typically accompanied by small pleural effusions (see Figs. 17.10 and 17.13). In the ICU setting, injury pulmonary edema may be seen in setting of sepsis and multiple organ system failure. Decreased pulmonary compliance and stiffening of lung parenchyma can lead to diffuse alveolar damage and clinical adult respiratory distress syndrome (ARDS).

Advanced Imaging in ICU

A series of portable CXRs can be thought of as a filmstrip or time lapse photography allowing a series of images to provide greater physiologic information than might be obtained from a CT scan, which is limited to a single point in time. Prior outpatient CT scans can provide valuable insight and clarification in the interpretation of portable CXR. Many emergency departments have dedicated CT scanners. A patient presenting with chest pain and shortness of breath may undergo CT angiography to detect pulmonary emboli. It also provides information about lungs, pleural effusions, and cardiovascular anatomy. CT and MRI examinations performed for inpatients are often limited by symptoms, limiting patient cooperation and breath-holding ability. For these reasons, as well as likely presence of acute confounding abnormalities, CT scan for follow-up of small lung nodules should not be performed during hospitalization. The

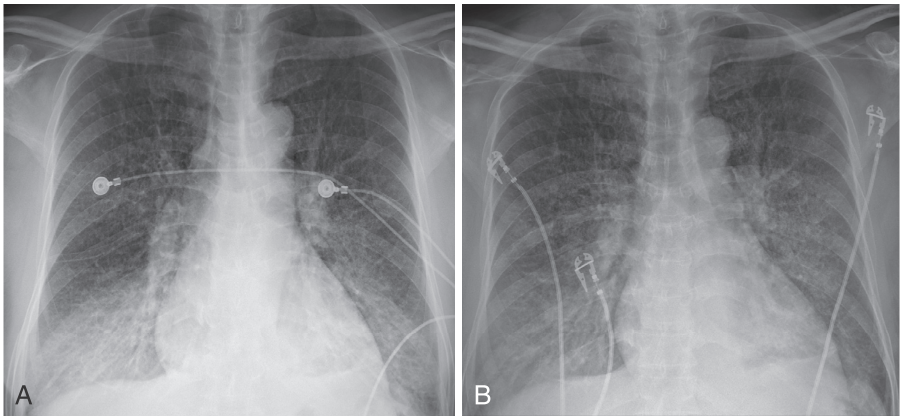

FIGURE 17.17 PA chest radiographs in a patient with chronic heart failure after several myocardial infarctions. A, CXR shows chronic interstitial pulmonary edema**. B,** CXR in the same patient following a new myocardial infarction, showing acute on chronic pulmonary edema.

American College of Radiology website provides detailed appropriateness criteria for ordering of advanced imaging including within the inpatient acute care setting.[2-6]

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