

CHAPTER 20

**Anatomy of the Heart and Great Vessels**

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**INTRODUCTION**

Chest radiography is used for the initial evaluation of most cardiac patients. Echocardiography enables additional detailed imaging of the internal cardiac anatomy and function. Contrast-enhanced CT is capable of providing critical information, particularly for pericardial or intracardiac disease. MR imaging adds three-dimensional (3D) tomographical and motion studies of the myocardium, valves, and chambers without using ionising radiation or intravascular contrast agents. Satisfactory cardiac imaging requires familiarity with all imaging techniques and knowledge of 3D anatomy.

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*The Asian-Oceanian Textbook of Radiology, 2003.  
 Edited by Wilfred C.G. Peh & Yoshihiro Hiramatsu.*

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**RADIOGRAPHY**

**Indications**

1. Assessment of the shape and size of the heart, and its individual chambers.
2. Evaluation of the pulmonary vasculature, which mirrors the physiological pressure and volume state of the cardiopulmonary system.
3. Assessment of the size and location of the aorta, and major systemic veins.
4. Evaluation of extracardial anomalies that may be associated with heart disease.
5. Follow-up study of the severity of heart disease.

**Anatomy**

The four-chambered heart is located primarily in the anterior left hemithorax, with the left ventri-

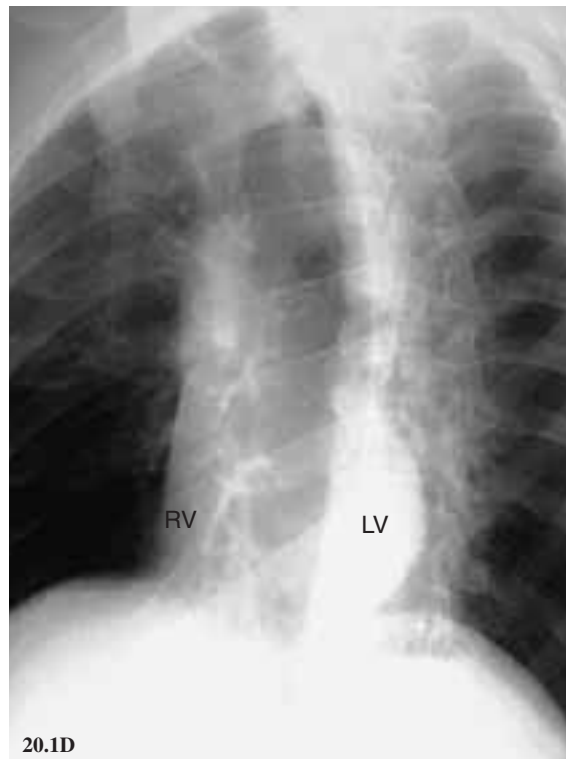
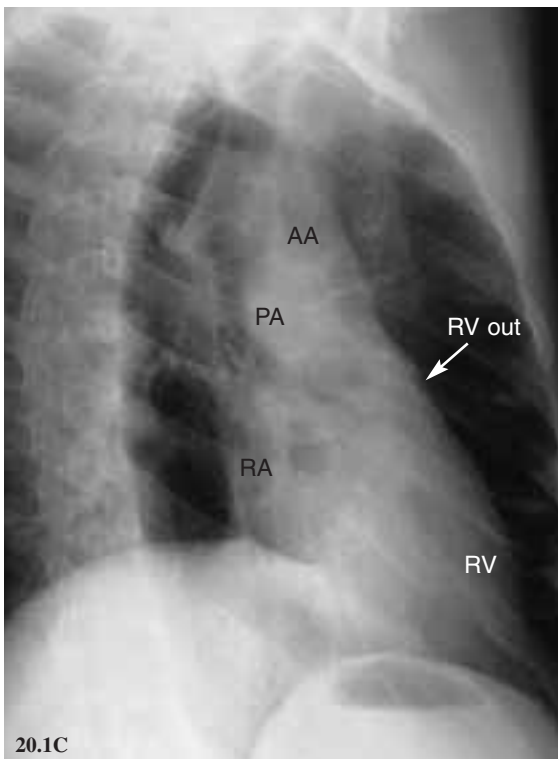
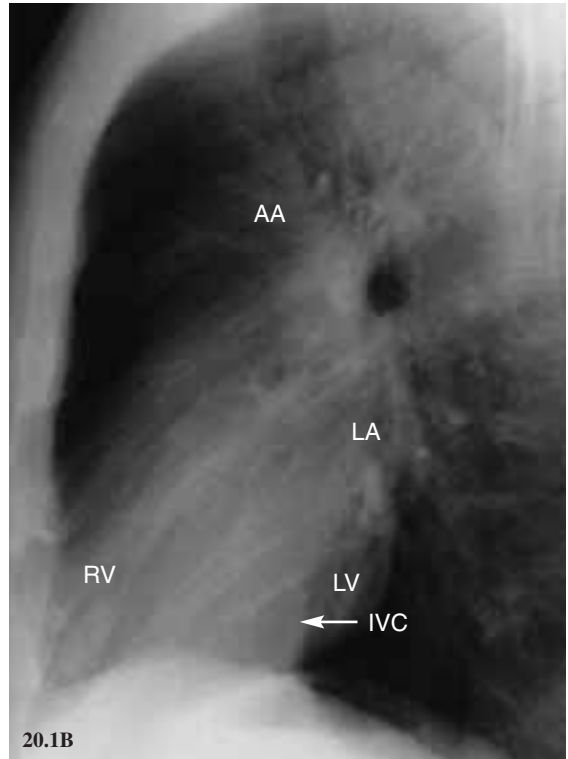
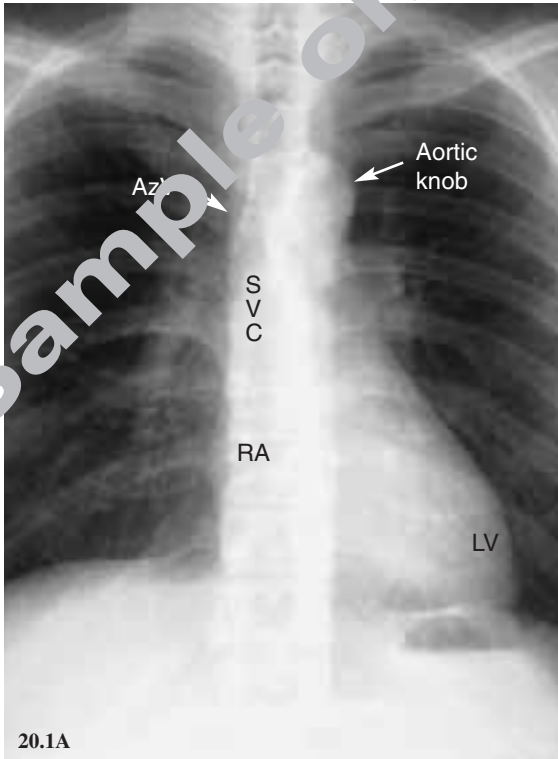


Fig. 20.1: Chest radiographs in various projections. (A) Posteroanterior view. (B) Lateral view. (C) RAO view. (D) LAO view. (Key: SVC: superior vena cava, AzV: azygos vein, IVC: inferior vena cava, RA: right atrium, RAA: right atrial appendage, RV out: right ventricular outflow tract, PA: pulmonary artery, LA: left atrium, LV: left ventricle, AA: ascending aorta).

cle (LV) lying on the left hemidiaphragm. The right atrium (RA) extends to the right of midline as it receives systemic blood from the superior vena cava (SVC), inferior vena cava (IVC), and coronary sinus. The PA and right ventricle (RV) lie primarily anterior to the planes of the left atrium (LA) and left ventricle. The RV is the most anterior chamber and abuts the sternum. The LA is subcarinal and midline in the thorax, being supplied by the right and left superior, and inferior pulmonary veins.

#### **Frontal projection (Fig.20.1A)**

The right border of the cardiac silhouette is formed primarily by the RA, with the SVC entering superiorly. The IVC is often seen at its lower margin. The left border of the heart is created primarily by the LV. The LA appendage, the pulmonary artery (PA), aortopulmonary window, and aortic knob extend superiorly.

#### **Lateral projection (Fig.20.1B)**

The anterior aspect of the cardiovascular silhouette is formed superiorly by the ascending aorta, followed by the PA, the RV outflow tract, and the RV. Slight rotation in the lateral position projects the RV to form the border anteriorly. The posterior silhouette is formed by the LA superiorly and the LV inferiorly.

#### **Right anterior oblique (RAO) projection**

(Fig.20.1C)

The anterior upper curve is formed by the ascending aorta, the middle curve by the PA and a portion of the RV infundibulum, and the lower curve by the RV. Below the descending thoracic aorta is a single curve that is formed by the atria. The IVC may be seen in the cardiophrenic angle.

#### **Left anterior oblique (LAO) projection**

(Fig.20.1D)

The anterior component is formed by the RV,

the middle component by the RA appendage, and the upper component by the ascending aorta. Below the descending thoracic aorta, the posterior cardiac border is composed by the LA and LV. Below the aortic arch, a clear space called the “aortic window” is noted. The PA is the most prominent structure that lies in the aortic window. The angle between the trachea and left main bronchus should not exceed 45 degrees. Above the aortic arch is a clear space called the “aortic triangle”.

#### **Interpretation**

Main points of film interpretation are overview, situs, heart size, chambers, great vessels, lungs, calcifications, and bones [1]. Radiography contributes to the management in three ways, namely: (1) It can help exclude lung disease as the cause of symptoms. It can exclude gross pulmonary pathology, and is valuable in pointing away from the lungs and towards the heart as the cause of symptoms. (2) It can make a positive diagnosis of heart disease. The demonstration of gross cardiac enlargement, abnormal shape, a grossly abnormal pulmonary vasculature, or possibly even pulmonary oedema will all point to heart disease as the cause of symptoms. (3) A specific cardiac diagnosis may occasionally be possible on the radiograph.

#### **Determination of cardiac size**

The size of the heart is related to body weight and height, body surface area, sex, and age. Numerous factors such as depth of respiration, thoracic deformity, and pulmonary and abdominal diseases that elevate or depress the diaphragm affect the size and shape of the cardiac silhouette. The most common measurement used is transverse diameter. In general, the greatest transverse diameter of the heart should not be more than one-half of the largest transverse measurement of the thorax. This is the easiest and quickest method of measurement of cardiac size. An adult heart that measures

more than one-half of the internal diameter of the chest is considered enlarged. The method is gross because the cardiothoracic ratio varies widely with variations in body habitus. However, it can be useful as a rough estimate of cardiac size. The cardiothoracic ratio is most useful in assessing changes in the heart size, and monitoring progression of disease or response to therapy.

### Cardiac silhouette [2]

#### Size

The cardiothoracic ratio should not exceed 0.5 on a 72-inch erect posteroanterior radiograph, or 0.6 on a portable or anteroposterior (AP) examination. Other factors should be considered, such as the presence of epicardial fat pads and pectus deformity.

#### Shape

Various contour effects can be clues to underlying disease. “Water bottle” configuration occurs with pericardial effusion or generalised cardiomyopathy. “Hypertrophy” configuration describes increased afterload, whereas dilatation occurs with failure of diastolic overload. “Straightening” of the left heart border is seen with rheumatic heart disease and mitral stenosis.

#### “Moguls of the heart”

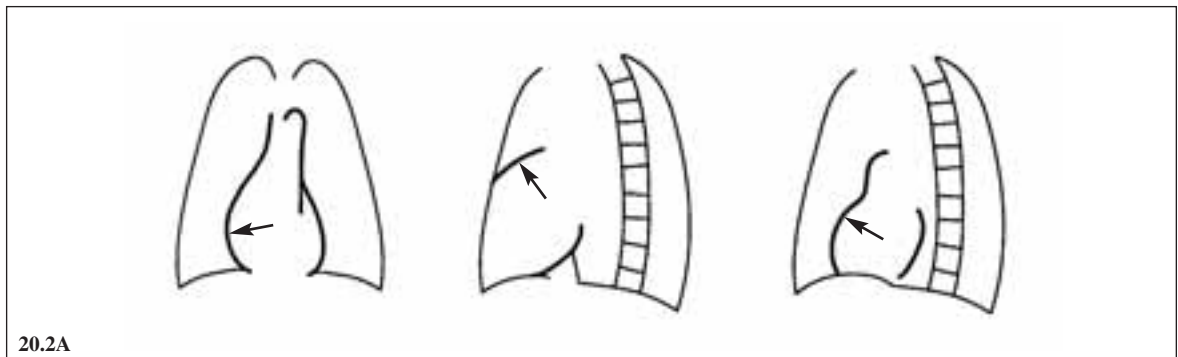
Skiing the moguls of the heart refers to the left

mediastinal outline beginning at the aortic knob. A prominent knob is a clue to ectasia, aneurysm, or hypertension. Notching or “figure three” sign of the aorta suggests coarctation of the aorta. The second mogul is the main PA segment. Excessive convexity is seen with post-stenotic dilatation, chronic obstructive pulmonary disease, PA hypertension, left-to-right shunts, and pericardial defects. Severe concavity suggests right-to-left shunts. The third mogul is a prominent LA appendage that, in 90% of cases, indicates prior rheumatic carditis. It is rarely seen with other causes of LA enlargement. The fourth mogul is a bulge just above the cardiophrenic angle, and is seen with ventricular aneurysm infarction. A fifth bulge at the cardiophrenic angle is caused by pericardial cyst, prominent fat pad, or adenopathy.

### Cardiac chamber enlargement [2,3] (Fig.20.2)

#### Right atrial enlargement (Fig.20.2A)

This is more difficult to define on chest radiographs than LA enlargement, but fortunately, it is less common. Clues include a prominent atrial bulge too far to the right of the spine, measuring more than 5.5 cm from the midline on a well-positioned posteroanterior radiograph. Another sign is elongation of the RA convexity to exceed 50% of the mediastinal or cardiovascular shadow. RA enlargement usually accompanies RV enlargement.



20.2A

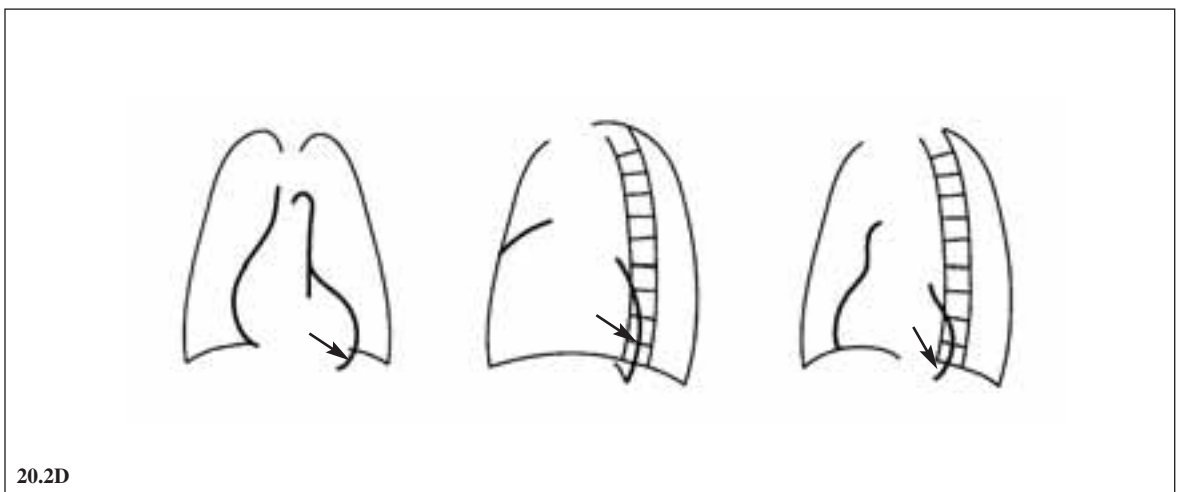
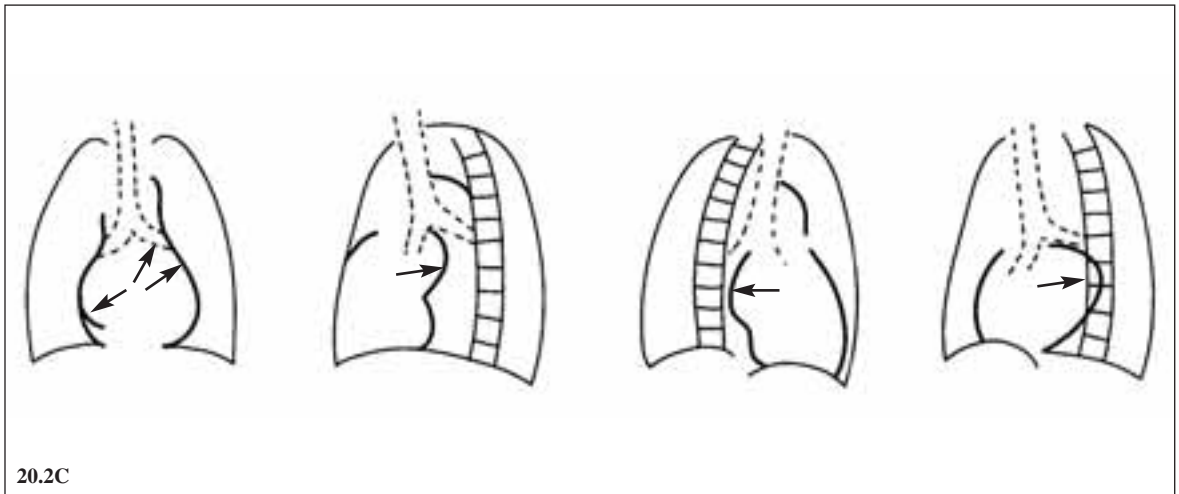
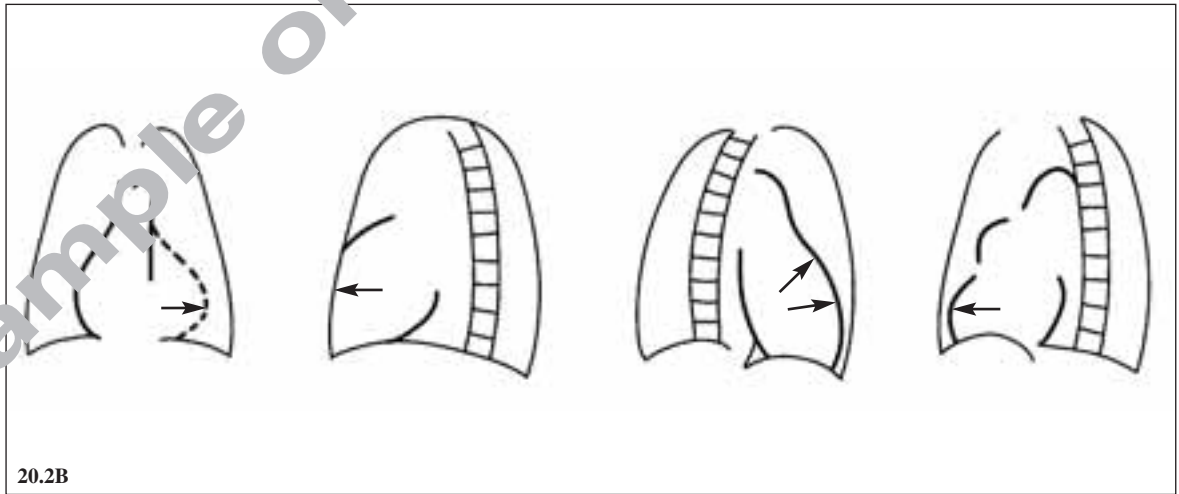
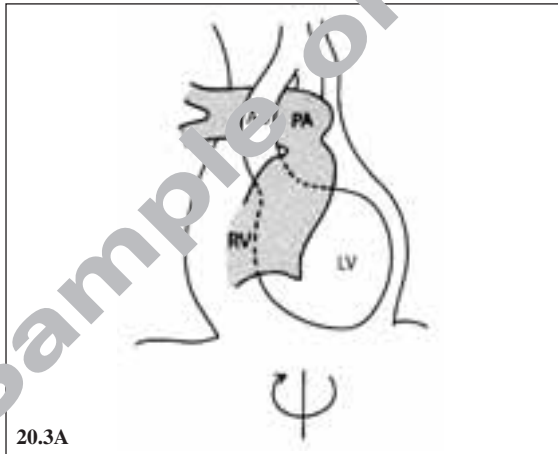
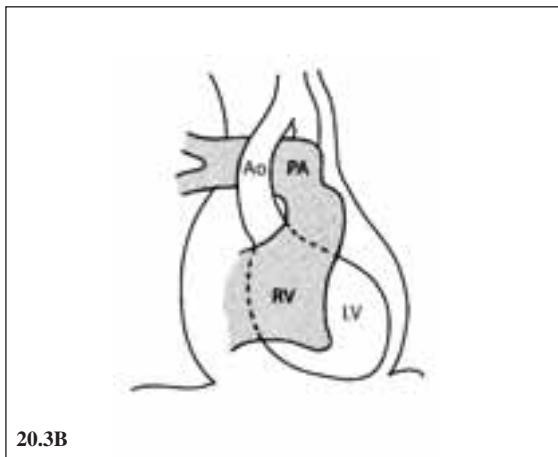


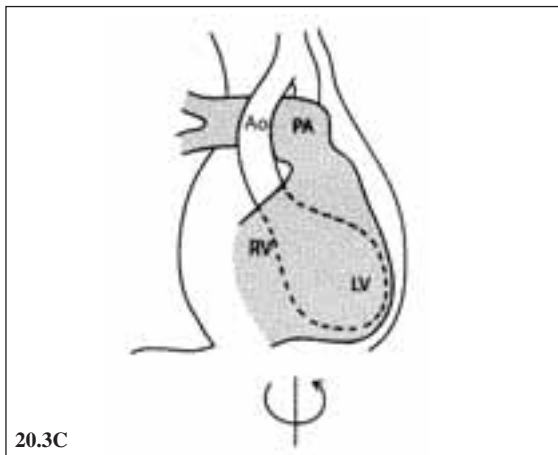
Fig. 20.2: Diagrams show the enlargement of each cardiac chamber on the chest radiograph (various projections). (A) RA enlargement. (B) RV enlargement. (C) LA enlargement. (D) LV enlargement. Arrows indicate the localised prominence of the cardiac silhouette.



20.3A



20.3B



20.3C

Fig. 20.3: Diagrams shows the rotation of the heart. The heart is fixed by the aortic branches and veins at the vascular pedicle, and can rotate along the long axis according to the degree of RV or LV enlargement. Rotation is in the clockwise or counter-clockwise direction as viewed from the diaphragmatic side. (A) Counter-clockwise rotation of the heart in LV enlargement. (B) Normal. (C) Clockwise rotation of the heart in RV enlargement.

**Right ventricular enlargement (Fig.20.2B)**

Enlargement of the RV outflow tract results in lengthening of the anterior ventricular wall, which is manifested radiographically by prominence of the distal RV or pulmonary conus. The result is an anterior bulge in the upper anterior cardiac contour just below the PA. There often is associated enlargement of the PA, which adds to the anterior prominence of the upper border of the heart in this projection. When this occurs, there is more prominence and convexity of the PA segment in the frontal projection than in a normal subject. This results in straightening or convexity of the left upper cardiac contour below the aortic knob. When the RV enlargement becomes greater, the heart tends to be rotated to the left, so that the conus of the RV may become border-forming [4] (Fig.20.3A). In the lateral projection, the anterolateral bulge in the region of the RV outflow tract reduces the size of the retrosternal space between the upper cardiac border and the sternum. The PA also contributes to this narrowing. When the RV inflow tract enlarges, the diaphragmatic portion of this ventricle is increased in length, resulting in an anterior rounding or bulge in the right ventricular area. This enlargement may displace the LV posteriorly and elevate the cardiac apex, as seen in the frontal projection.

**Left atrial enlargement (Fig. 20.2C)**

LA enlargement is best confirmed by measuring the distance from the mid-inferior border of the left main stem bronchus to the right lateral border of the left atrial density. This distance is less than 7 cm in 90% of patients with LA enlargement, and this has been proven by echocardiography. Less sensitive signs of LA enlargement include splaying of the carinal angle, uplifting of the left main stem bronchus, and prominence of the LA appendage. On occasion, the enlarged LA displaces the descending thoracic aorta to the left. Massive LA enlarge-

ment may result in the LA becoming border-forming on the right side, so-called “atrial escape”. On lateral views, an enlarged LA displaces the left bronchus posteriorly, with the bronchi creating right and left legs for the “walking man” sign. An enlarged LA may also indent the oesophagus.

#### **Left ventricular enlargement (Fig. 20.2D)**

Elongation of the LV outflow tract produces an increase in length of the LV segment making up the left lateral cardiac contour. The second sign of enlargement of this tract is rounding of the contour of the LV. As a result of this downward and leftward enlargement, the cardiac apex may extend below the dome of the diaphragm and be projected over the air-filled gastric fundus. With counter-clockwise rotation of the heart as viewed from the diaphragmatic side, the aortic knob and ascending aorta become prominent, the cardiac waist becomes concave, and the contour of the LV becomes round, producing the specific features of “aortic configuration” [4] (Fig.20.3B).

Enlargement of the LV inflow tract, which follows that of the outflow tract, produces posterior enlargement. In addition to the enlargement downwards, to the left, as well as posteriorly, disease causing increased left ventricular work may result in concentric hypertrophy of this chamber. The lateral view shows an enlarged LV extending behind the oesophagus. The Hoffman-Rigler sign for LV enlargement exists when the LV extends more than 1.8 cm posterior to the posterior border of the LV and IVC. This sign requires a true lateral radiograph. False-positives occur if the lateral view is obliqued, or if there is volume loss in either lower lobe. This sign can be quickly applied by using one of the “2 cm fingertips” for a quick check without a ruler.

## **ULTRASONOGRAPHY**

### **Indications**

#### **Two-dimensional echocardiography (real-time echocardiography)**

1. Assessment of the size, shape, and movement of any of the cardiac chambers and valves.
2. Functional status of cardiac valves in terms of stenosis or regurgitation.
3. The presence of additional pathological features in any cardiac chamber or on any valve (e.g. vegetation, tumour, thrombus).
4. Assessment of congenital heart disease.
5. Assessment of pericardial disease.
6. Assessment of thoracic aortic and aortic root disease.

#### **Doppler echocardiography**

1. Diagnosis and quantitation of regurgitant or stenotic valves.
2. Diagnosis of abnormal communications.
3. Determination of some intracardiac pressures.

#### **Trans-oesophageal echocardiography**

1. Diagnosis of suspected aortic pathology, particularly acute dissection.
2. Diagnosis of complex mitral and aortic valve pathology, particularly in prosthetic valves.
3. Evaluation of suspected infective endocarditis.
4. Evaluation of the LA in cases of possible intracardiac thrombus.
5. Evaluation of some cases of complex congenital heart disease.
6. Examination of patients with poor precordial echo “windows”.
7. Monitoring of LV function before, during, or after surgery.
8. Planning and evaluation of intracardiac repairs during surgery.

#### **Anatomy [5] (Fig.20.4)**

#### **Long-axis view**

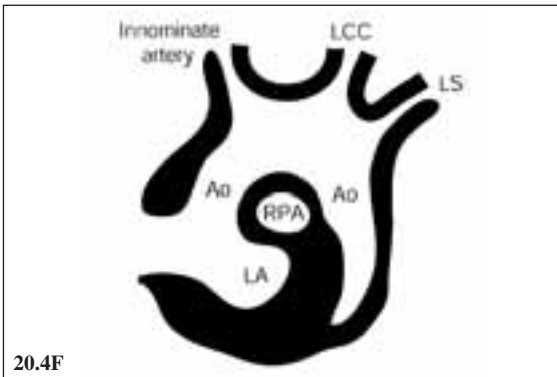
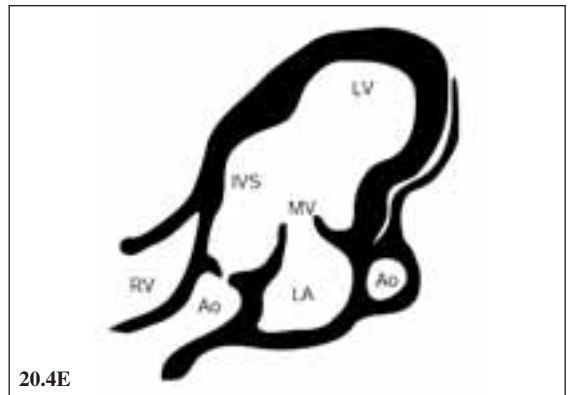
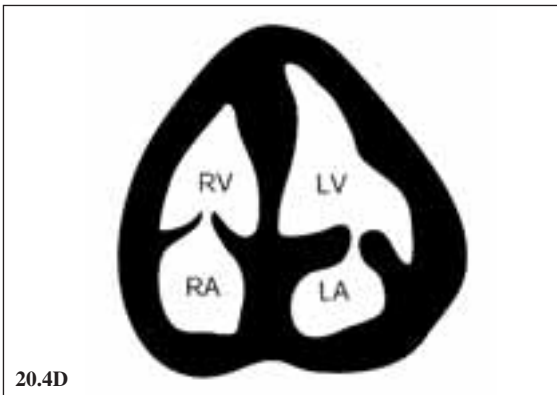
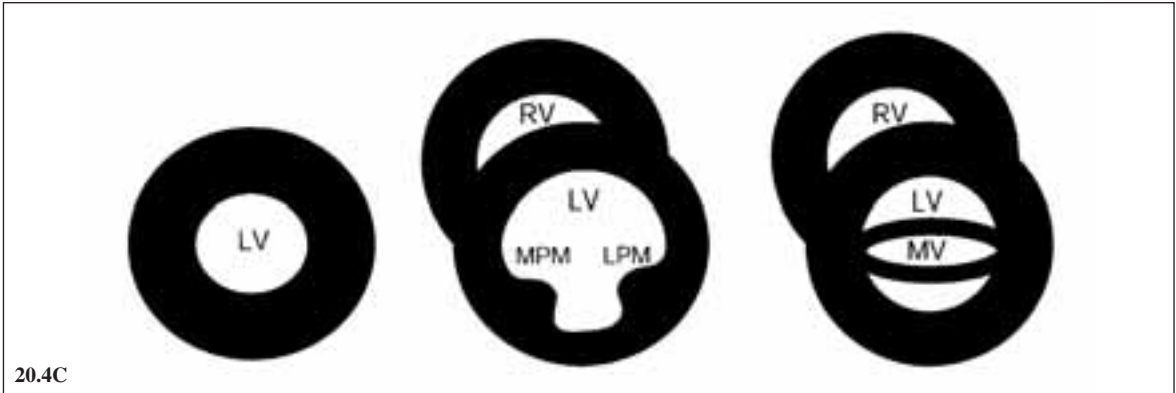
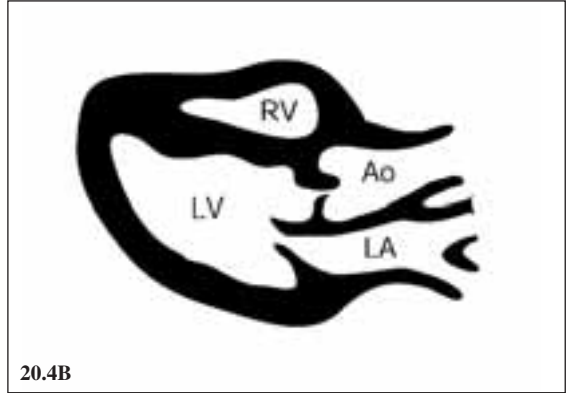
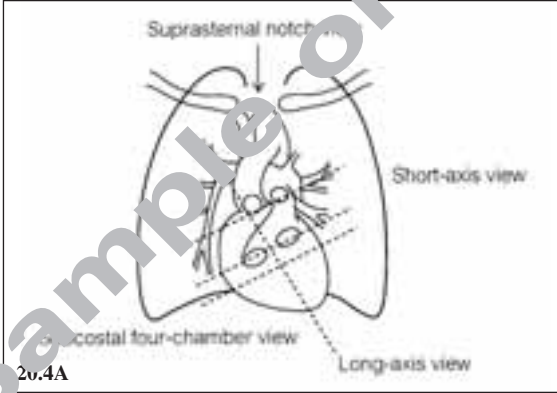


Fig. 20.4: Diagrams show normal US scans of the heart. (A) Four common views. (B) Long-axis view. (C) Short-axis views. (D) Apical four-chamber view. (E) Apical two-chamber views. (F) Suprasternal notch view. (Key: RA: right atrium, RV: right ventricle, RPA: right pulmonary artery, LA: left atrium, MV: mitral valve, LV: left ventricle, MPM: posteromedial papillary muscle, LPM: anterolateral papillary muscle, IVS: interventricular septum, Ao: aorta, LCC: left common carotid artery, LC: left subclavian artery).

**Location:** The transducer is in the third or fourth intercostal space so that the beam is parallel to a line from the right shoulder to the left flank. The image is oriented so that the LA and LV are posterior, and the LA and aorta are on the left.

#### *Short axis view*

**Location:** The transducer is in the third or fourth intercostal space but the beam is perpendicular to the long-axis view. Several levels are usually scanned, from cephalad to caudad: great arteries, plane of mitral valve, and plane of papillary muscles.

#### *Apical four-chamber view*

**Location:** The patient is placed in the left lateral decubitus position. The transducer is at maximum point of impulse. The image is oriented so that the RV and LV are anterior, and the LV and LA are to the right.

#### *Apical two-chamber view*

This view is also known as the RAO view of the LV. **Location:** The transducer is placed at the maximum point of impulse and directed in a plane parallel to the IVS. The image is oriented so that the LV is anterior.

#### *Suprasternal notch view*

**Location:** The transducer is placed in the suprasternal notch with inferior and posterior beam angulation. The images are oriented so that the ascending aorta is on the left, and the descending aorta is on the right.

### **Clinical applications**

The use of ultrasonography (US) in examination of the heart has increased greatly in the past 20 years. It is now a well-established and widely-used diagnostic tool. Ultrasonographical investigation is a non-invasive, safe, and comfortable study that

demonstrates valve and chamber motion as well as wall thickness and size. Doppler examination allows determination of the cross-sectional area of a valve and quantification of gradients. It is of value in the study of hypertrophic cardiomyopathies, with and without associated subaortic stenosis, and in the study of the congestive cardiomyopathies in which there is chamber dilatation. With US, LV diameter and outflow configuration may be determined. Qualitative assessment of the size of the RV and LV is also possible. The size of the LA can be measured accurately, and left atrial myxoma or other intra-atrial tumours can be detected. US is also useful in the investigation of congenital heart diseases. In addition, it is the most sensitive method for determining the presence of pericardial effusion. Trans-oesophageal placement of the ultrasound transducer adds additional information, and is particularly useful in assessing the descending aorta.

## **COMPUTED TOMOGRAPHY**

### **Indications**

1. Pericardial diseases: Depiction of pericardial fluid collection, pericarditis, constrictive pericarditis, pericardial tumour, pericardial fat, and pericardial cyst.
2. Valvular diseases: Depiction of valvular deformity and thickening, calcification, and thrombi.
3. Myocardial diseases: Depiction of cardiomyopathy, myocardial tumour, sarcoidosis, and amyloidosis.
4. Ischaemic heart diseases: Identification of coronary artery calcification, aneurysm, ventricular aneurysm, and myocardial ischaemia.
5. Aortic diseases: Depiction of aortic aneurysm, aortic dissection, Takayasu arteritis, and aortic arch anomaly.
6. Great venous diseases: Depiction of acquired

- occlusion by thrombi and emboli, congenital anomalies, interruption of IVC, and azygos continuation.
7. Patency of aortic coronary bypasses.
  8. Evaluation of stenotic diseases.
  9. Identification of myocardial characteristics.
  10. Determination of morphology and cardiac function.
  11. Assessment of blood flow and myocardial perfusion.
  12. Evaluation of the size and shape of the heart.
  13. Evaluation of the positional relationships of the cardiac chambers, congenital aortic anomalies and vascular rings.

### Basic technical considerations

#### *Conventional CT*

Conventional (non-spiral) CT acquires image data one slice at a time. The patient holds his or her breath, a slice is taken, the patient breathes, the table moves, and the sequence is repeated. This technique requires at least two to three times the total scanning time of spiral CT for any given patient scan volume, making optimisation of scanning during maximum contrast opacification more difficult.

#### *Spiral CT*

Spiral CT, also called helical CT, is performed by moving the patient table at a constant speed through the CT gantry while scanning continuously with the X-ray tube rotating around the patient. A continuous volume of image data is acquired during a single breath-hold. This technique dramatically improves the speed of image acquisition, enables scanning during optimal contrast opacification, and eliminates artifacts caused by misregistration and variations in patient breathing. Volume acquisition enables retrospective reconstruction of multiple overlapping slices, improving visualisation of small lesions, and allowing high-detail 3D CT angiography.

#### *Multidetector-row CT*

Recently, multidetector-row (multislice spiral) CT has been introduced as a new alternative in cardiac imaging. The entire heart can be covered in one single breath-hold, even if 1 mm thick slices are acquired. Spiral acquisition allows for overlapping image reconstruction, a prerequisite for high-quality 3D reformations. Using retrospective ECG gating, motion-free images can be reconstructed in any specific phase of the cardiac cycle. In an optimised heart scan, a temporal resolution of 125 msec can be achieved.

#### *Ultrafast CT*

Ultrafast CT has the ability of fast scanning and rapid repetition of scans that is enough to examine a beating heart. Volume mode refers to scanning with table incrementation. ECG-triggered 100 msec scans are commonly used in cardiac applications, and 300-500 msec scans in non-cardiac examinations. Cine mode scanning is rapid repetition of 50 msec scans with shortest interscan delay time in the same level, and is suitable for assessment of cardiac contractility. Flow mode scanning is repetition of scans at the same level with determined interscan delay time (every second, every heart beat), and is comparable to dynamic scanning in conventional scanners.

In morphological assessment, depiction of small thrombi, stenotic pulmonary arteries in complex anomalies, pericardial diseases and cardiac tumours are thought to be the best indications of ultrafast CT. CT assessment of myocardial characteristics depends on abnormal density of myocardium, such as early defects and late enhancement after contrast administration. Late enhancement is sensitive for detection of myocardial infarction and an early defect is well correlated to severe coronary stenosis. Left ventricular volume and ejection fraction measured by ultrafast CT are correlated with those of left ventriculography. Cardiac output is

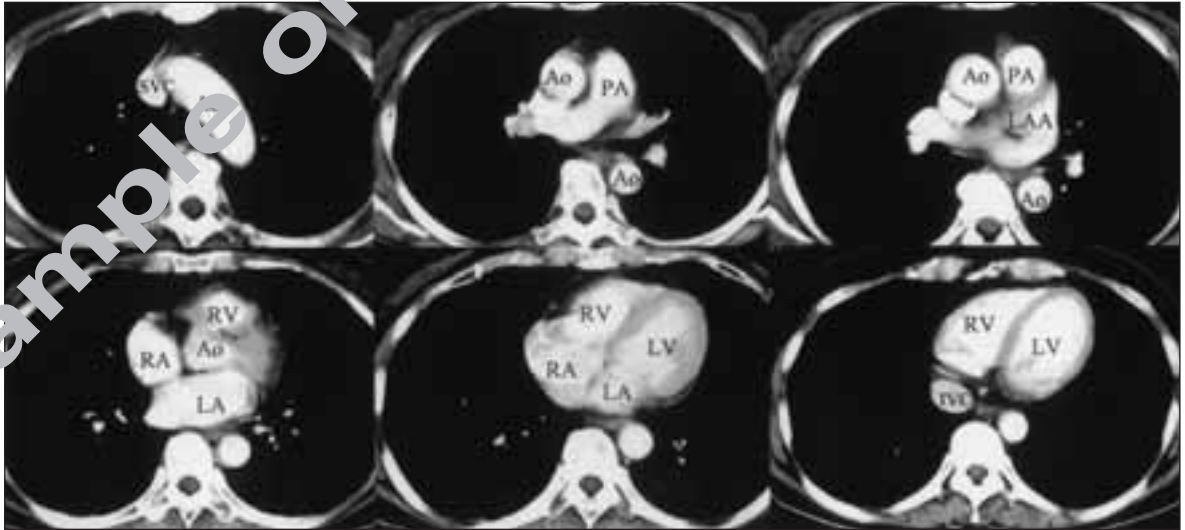


Fig. 20.5: Normal axial CT scans of the heart. (Key: SVC: superior vena cava, IVC: inferior vena cava, RA: right atrium, RV: right ventricle, PA: pulmonary artery, LA: left atrium, LAA: left atrial appendage, LV: left ventricle, Ao: aorta).

easily calculated from the dilution curve of contrast agent obtained by flow mode study. Flow study is also used for evaluation of patency of aorto-coronary bypass grafts. Myocardial perfusion study using time-density analysis of myocardium in flow mode scanning is a unique application of ultrafast CT. Ischaemic myocardium is detected, and calculated myocardial blood flow is compatible with clinical assessment of ischaemia.

Ultrafast CT scan provides excellent image quality due to negligible motion artifacts, and there is no necessity for breath-holding. Rapid repetition of scans provides short examination time, marked enhancement of tissues by rapid contrast injection, complete examination of organs during the early phase of contrast injection followed by delayed scans, and reduction of the total amount of contrast agent. Consequently, ultrafast CT is highly diagnostic, less invasive, and has wide acceptability by patients, as compared with conventional scanners.

#### Anatomy (Fig.20.5)

The long axis of the heart runs diagonal to the horizontal CT plane. After the patient has been given a sufficient amount of contrast material, the

individual chambers of the heart can be demonstrated on CT scans which, according to the level of the slice, will show the varying relationship of size and position of different chambers to one another. The RV is scanned at its broadest point in the caudal sections of the heart. The conically-arched LV is scanned more cranially at its point of greatest diameter. The thick left ventricular wall and the interventricular septum are readily demonstrated on CT scans. Papillary muscles are often well-demarcated. Because of its thin wall, the myocardium of the RV is only subtly outlined. Visualisation of the atria, including the right cardiac auricle, is unequivocal. The maximum anteroposterior diameter of the LA measures 4 cm to 5 cm in healthy individuals. Calcification of segments of the coronary arteries proximal to the aorta can be demonstrated on unenhanced scans. In dynamic CT, visualisation of these segments can also be enhanced by intravenous contrast material. Valvular calcification can also be readily demonstrated on CT scans.

Cardiac phase-controlled scanning (ECG gating) improves the quality of the images, thus improving the radiologist's ability to measure the actual thickness of myocardial walls in different

cardiac phases. It is now possible to evaluate the systolic and end-diastolic volumes, as well as the ejection fraction, by means of CT. In most recent developments, the imaging quality of moving cardiac structures has been improved by ultrafast cine-CT techniques, with scan times of 50 msec. According to the severity of the condition, minor to substantial enlargement of the ventricle can be seen on CT scans. The interventricular septum rotates towards the right in patients with left-sided cardiac stress, and towards the left in those with right-sided cardiac stress. The apex of the ventricle is normally rounded, and thickening of the ventricular walls is not usually found.

Epicardial fat is depicted on CT scans as a hypodense space between the pericardium and the myocardium. Since the intrinsic structures of the myocardium are surrounded by epicardial fat, the thickness of the pad of fat is variable. It is especially prominent near the pathways of venous inflow and arterial outflow, but the amount of paracardiac fat and fat near the apex of the heart can vary greatly. Since the common membrane of the pericardium and the mediastinal pleura is only partial, additional spaces that are also filled with mediastinal fat can develop. Due to the physiology of the pericardium, approximately 25 ml of fluid is found in the cleft of the pericardial space, which has a small recess in its folds. The region of hypodense epicardial fat should be scanned tangentially in the region of maximum circumference of the heart to obtain the best CT images. Physiological pericardial fluid is usually found in the retroaortic pericardial recess, but is seldom seen in the preaortic sinuses.

## MAGNETIC RESONANCE IMAGING

### Indications

#### *Congenital disease*

1. Evaluation of thoracic aortic anomalies.
2. Definition of the presence, central connection, and size of the pulmonary arteries in pulmonary

atresia, tetralogy of Fallot, and other right-sided obstructive lesions.

3. Definition of the intracardiac and extracardiac morphology of complex ventricular anomalies.
4. Determination of pulmonary venous connections and other pulmonary venous anomalies.
5. Monitoring the status of patients after various surgical procedures.
6. Determination of situs abnormalities.
7. Identification of systemic venous anomalies.
8. Measurement of blood flow: separately in the right and left pulmonary arteries.
9. Measurement of the gradient across coarctation of the aorta and surgical conduits.
10. Measurement of collateral blood flow in coarctation.

#### *Acquired disease*

1. Ischaemic heart disease: Determination of the presence, size, and location of prior myocardial infarctions; determination of the presence of residual myocardium in a region under consideration for revascularisation; differentiation of viable myocardium from scar; demonstration of regional myocardial function and perfusion: demonstration of the anatomy of the major coronary arteries and assessment blood flow and vasodilator reserve in these vessels; and identification of complications of myocardial infarctions.
2. Pericardial disease: Diagnosis of constrictive pericardial disease; and the evaluation of pericardial effusions.
3. Myocardial disease: Determination of the location, severity and quantification of myocardial hypertrophy in hypertrophic cardiomyopathy; and ejection fraction in dilated cardiomyopathy.
4. Right ventricular dysplasia: Confirmation of the clinical or electrophysiological suspicion of this

diagnosis by the demonstration of fatty replacement of RV myocardium or regional contraction abnormality of the RV.

5. Valvular heart disease: Identification and quantification of the severity of valvular regurgitation and monitoring of ventricular function; and velocity-encoded cine MR imaging for estimating gradients in valvular stenosis and the volume of valvular regurgitation.
6. Paracardiac and intracardiac masses: Evaluation of the presence, location, and extent of masses; and differentiation of tumour from clot.

### Basic technical considerations

#### *Conventional spin-echo imaging*

The most common pulse sequence traditionally used for cardiac imaging is a conventional spin-echo (SE) sequence gated to the cardiac cycle in a multislice mode. The repetition time (TR) is equal to the RR interval, and a minimum echo time (TE) of 10 - 20 msec is used. The T1 time of the myocardium is in the order of 800 msec, therefore only moderate T1-weighting is achieved using this method. These images are commonly referred to as black blood images. Because the TR depends on the RR interval, imaging times are typically long. Image quality depends on consistent ECG gating and lack of patient motion during the relatively long acquisition times. However, the contrast differences between the heart, epicardial fat, and the ventricular cavities are relatively good.

T2-weighting is achieved by gating at several multiples of the RR interval, together with a TE of 80 - 100 msec. Imaging times are quite long. The quality of T2-weighted images is lower than the quality of T1-weighted images. T2-weighted images are usually not necessary for anatomical evaluation of the heart but are more helpful for characterisation of cardiac or paracardiac masses.

#### *Fast spin-echo imaging*

Fast spin-echo T2-weighted images should be used, if available, because they provide shorter imaging times and better image resolution than conventional SE images. Typical echo train lengths are 8 to 16. Because of the high signal intensity of fat on fast SE images, chemical shift fat suppression is frequently used. This technique also has the benefit of decreased respiratory motion artifacts. Fast SE imaging with multiple inversion-recovery pulses can be used to obtain black blood images.

#### *Cine gradient-echo imaging*

Cine imaging for cardiac MR imaging consists of a motion picture loop of various phases of the cardiac cycle. These fast acquisition techniques are combined with ECG gating. The two general schemes for obtaining the gated images are retrospective and prospective gating. Prospective gating, using segmented K-space acquisition, is the predominant mode of cine imaging and has widespread applications. Cine MR imaging uses very short TR intervals and short TE intervals. The short acquisition time is possible because of the use of a reduced flip angle, and the echo signal is generated by reversal of the field gradients. The frames are laced together in a cine format to simulate real-time motion of the cardiac tomograms. Because of the very short TE, substantial signal is acquired from blood, and it appears white on the images.

#### *Segmented K-space and echo planar hybrid techniques*

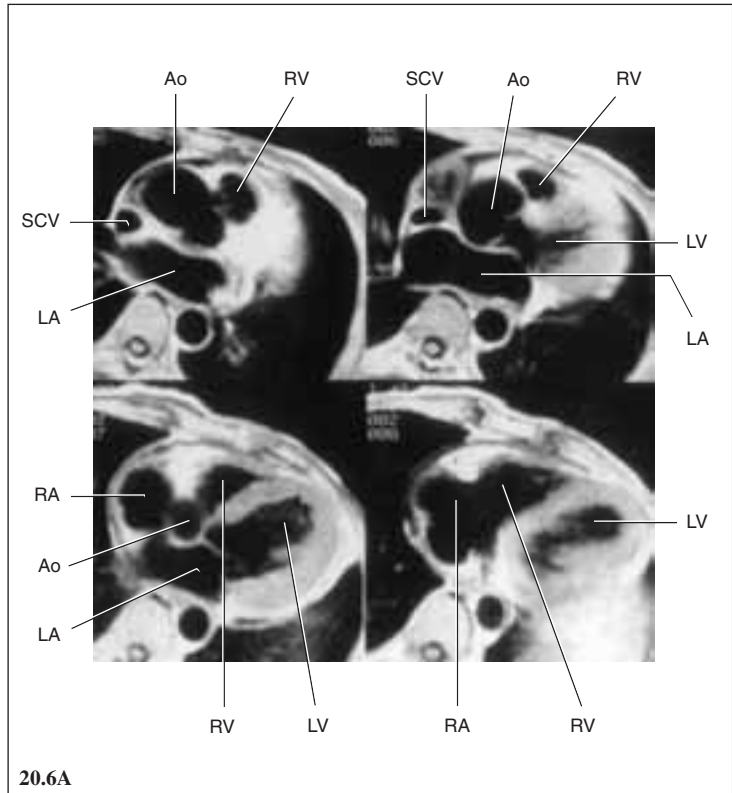
The imaging speed of the standard segmented K-space technique may be further improved by sampling additional echoes with extra read out gradient lobes, as is done in echo planar imaging (EPI). Hybrid spoiled gradient-recalled echo planar imaging (SPGR/EPI) reduces several problems associated with standard single-shot EPI and yet maintains some of the speed advantage.

**Echo planar imaging**

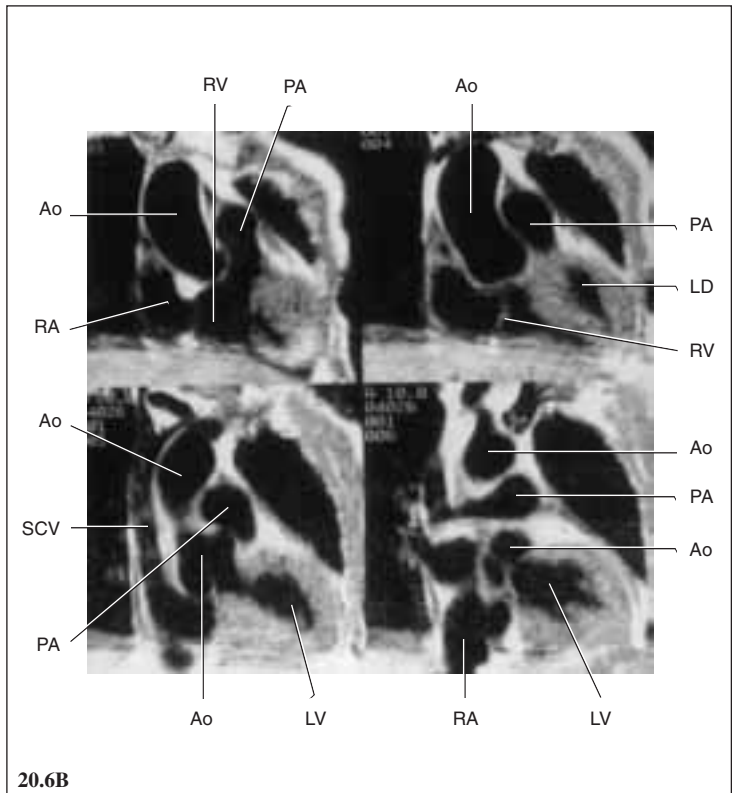
EPI is the fastest MRI imaging technique. It can provide an image in an acquisition time of 40 - 50 msec. EPI sequences can be either spin-echo EPI or GRE EPI. In addition, preparation pulses can be used to increase the T<sub>2</sub>-weighting of the imaging. Inversion recovery EPI is very sensitive to T<sub>1</sub> contrast effects such as those produced by low doses of MR contrast agent.

**Blood flow mapping with phase-contrast techniques**

Contrast between the myocardium or aorta and flowing blood may be provided by one of two general techniques: time-of-flight (TOF) or phase-contrast (PC) methods. In TOF imaging, unlabelled spins from blood outside of the imaging plane or volume continually wash in and wash out of the image. Because stationary tissues are relatively saturated by multiple radiofrequency (RF) pulses, flowing blood has a much higher signal intensity. This phenomenon is referred to as flow-related enhancement. Alternatively, PC methods generate contrast between stationary and moving tissues as a result of velocity-induced phase shifts of moving spins in a magnetic field gradient. The induced phase shift is directly proportional to the velocity so that PC methods allow quantitative measurement of the velocity of flow. Absolute flow can be calculated by multiplying the linear blood velocity by the cross-sectional area of the blood vessel.



20.6A



20.6B

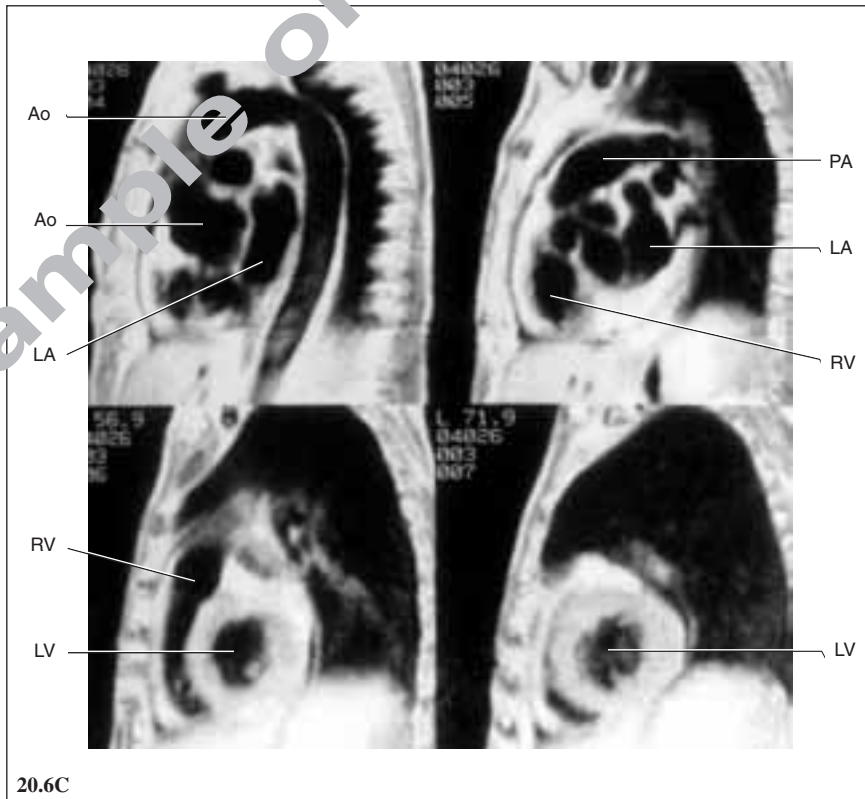


Fig. 20.6: Normal MR images of the heart. (A) Axial plane. (B) Coronal plane. (C) Sagittal plane. (Key: SVC: superior vena cava, IVC: inferior vena cava, RA: right atrium, RV: right ventricle, PA: pulmonary artery, LA: left atrium, LAA: left atrial appendage, LV: left ventricle, AA: ascending aorta).

### Imaging planes

In MR imaging, the heart can be imaged in any plane regardless of the availability of acoustic windows. In routine imaging, transverse, sagittal and coronal planes (Fig.20.6) are generally sufficient to depict most of the common clinical problems encountered. The heart is rotated leftwards and caudally by about 30-45 degrees. Long-axis and short-axis oblique images are generally acquired only when precise intracardiac localisation of a pathological process is needed.

### MR angiography

TOF MR angiography (MRA) relies on flow-related enhancement, in which fully magnetised blood enters into the imaging plane. TOF MRA

(both 2D and 3D) is less effective when blood flow is at low velocity (slow flow) because the progressive saturation occurs within the field-of-view (FOV). PC MR angiography produces an image by measuring the phase of the transverse magnetisation as it moves along the magnetic field gradient. Slow flow does not limit PC MRA, provided only that the flow-encoding gradient strength is selected properly.

### Anatomy (Fig.20.6)

The normal contrast between blood and myocardium on MR images results in clear delineation of the ventricular and atrial septa. Endocardial surfaces are well-demonstrated, including the moderator band of the RV and papillary muscles. Atrioventricular valves are so thin and mobile that they are not always visualised. These valves are most commonly depicted during the systolic phase of the cardiac cycle. During diastole, they lie against the endocardial surface of the ventricle and are not generally distinguishable. The epicardial surface of the heart is generally well-delineated by epicardial fat.

ECG gating is essential for depiction of cardiac anatomy. Transverse images at the base of the heart display the normal relationship of the great vessels. The base of the aorta is situated to the right and posterior to the outflow portion of the RV. The thickness of the muscles of the RV outflow tract mea-

tures less than 5 mm. The origin and/or proximal portions of the right and left coronary arteries are sometimes depicted at the base of the heart. Near the base of the heart, the right atrial appendage lies to the right and anterior to the base of the aorta.

The body of the LA lies behind the aortic root. The entrances of all four pulmonary veins into the LA can usually be identified by examining transverse images at two or more levels through the LA. The left upper pulmonary vein is frequently visualised on tomograms immediately above the first level at which the LA is seen. It is usually possible to identify the three major portions of the atrial septum, namely: the sinus venous septum, secundum septum, and primary septum.

Gated images sharply discriminate the endocardial interface between flowing blood in the LV chamber and the myocardium. The myocardium has medium signal intensity. The myocardial intensity shows a relative decrease (compared with fat) on the second-echo image compared with the first-echo image. The epicardial interface between the myocardium and pericardial fat (high intensity) or the pericardium (low intensity) is also well-defined. The papillary muscles of the LV and moderator band of the RV are defined. At some phases of the cardiac cycle (late systole), when blood is nearly motionless in the LV, there is high signal intensity at the various regions in the LV chambers. This is especially evident in patients with a slow heart rate.

The inflow, outflow, and membranous portions of the ventricular septum can be distinguished on transverse images. The short atrioventricular septum separating the right atrium and LV can be also distinguished. Demonstration of the diaphragmatic surface of the LV can be accomplished with gated sagittal or coronal images. Images in these planes also demonstrate segments of the ventricular septum. Portions of the proximal coronary arteries near

their origin are frequently visualised on transverse planes near the base of the heart. The right coronary artery in the atrioventricular groove, as shown on transverse images, is the most frequently visualised portion of the coronary arterial system. Because the heart lies obliquely in the thorax, the three standard orthogonal planes are not aligned along the true long and short axes of the heart.

## ANGIOCADIOGRAPHY [6]

### Indications

#### *Cardioangiography*

1. Measurement of chamber pressure.
2. Detection of intracardiac shunts.
3. Characterisation of myocardial performance.
4. Quantification of valvular stenoses and regurgitation.
5. Imaging of cardiac anatomy.

#### *Coronary arteriography*

1. For evaluation of known coronary artery disease before bypass surgery or percutaneous transcatheter coronary angioplasty (PTCA).
2. For diagnosis of the cause of chest pain of uncertain aetiology.
3. Often performed in association with catheterisation for valve or myocardial disease in the absence of angina.
4. In post-operative (or post-PTCA) investigation to determine the status of the coronary vessels and any bypass grafts, if symptoms recur.

#### *Thoracic aortography*

1. Evaluation of shunts arising at the aortic level.
2. Diagnosis of coarctation of the aorta.
3. Diagnosis of aortic aneurysm and aortic dissection.
4. Diagnosis of aortic valvular diseases.
5. Diagnosis of Takayasu arteritis.
6. Diagnosis of pulmonary sequestration.

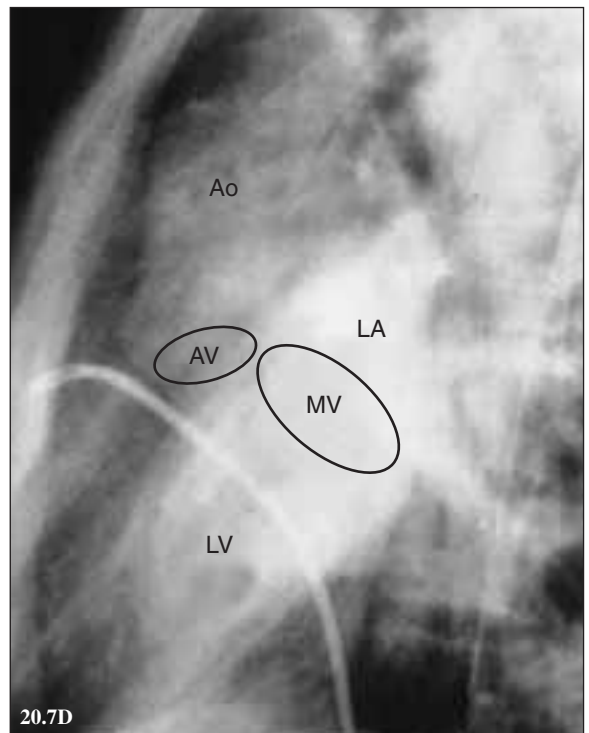
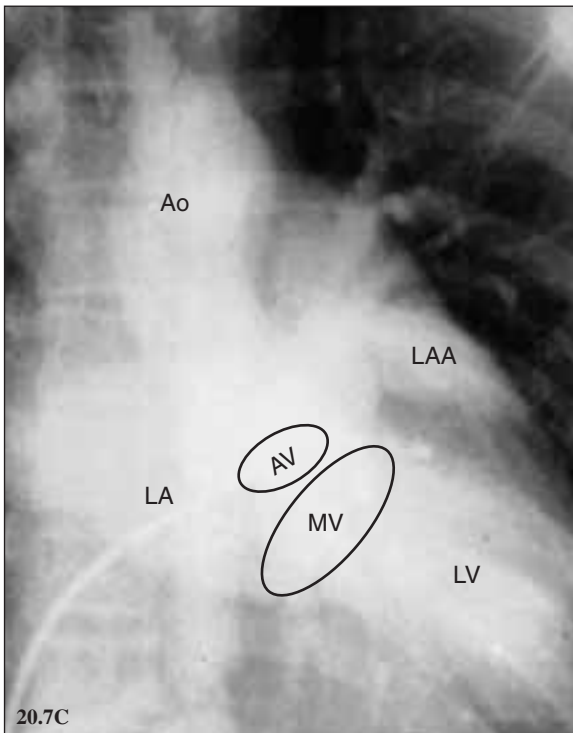
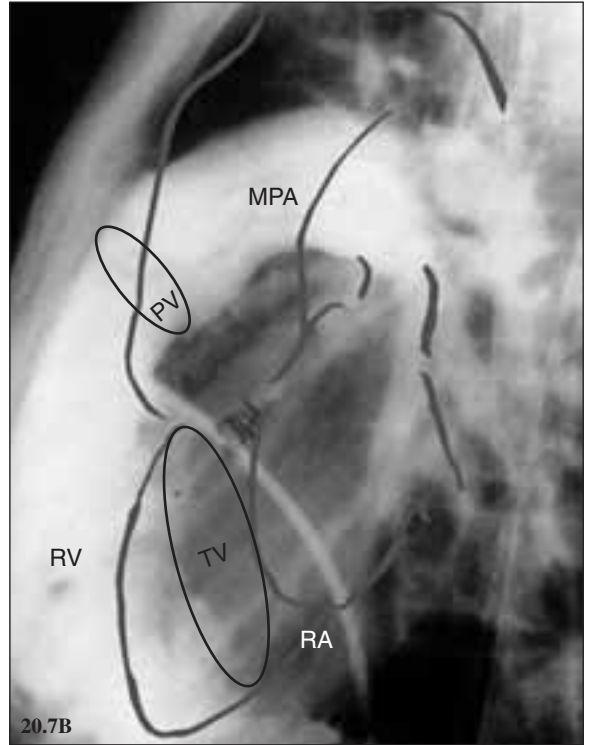
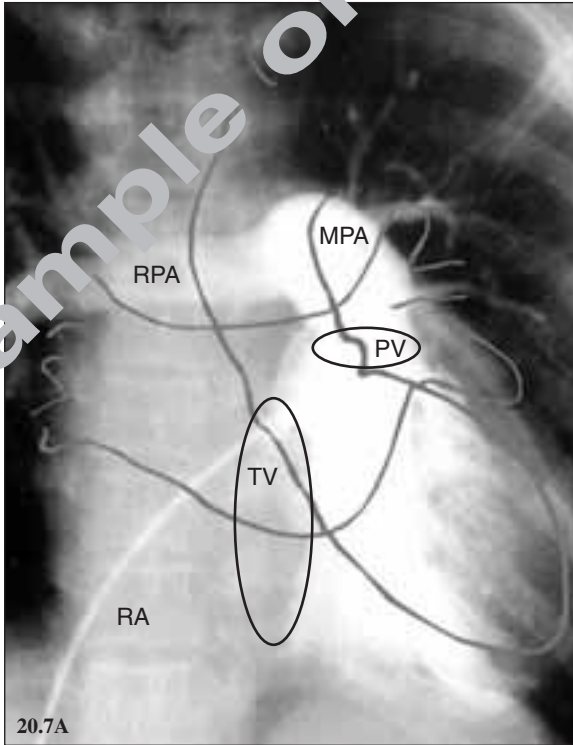


Fig. 20.7: Normal angiocardiograms. (A) Frontal projection (arterial phase). (B) Lateral projection (arterial phase). (C) Frontal projection (venous phase). (D) Lateral projection (venous phase). (Key: SVC: superior vena cava, RA: right atrium, TV: tricuspid valve, RV: right ventricle, PV: pulmonary valve, MPA: main pulmonary artery, RPA: right pulmonary artery, LA: left atrium, LAA: left atrial appendage, MV: mitral valve, LV: left ventricle, AV: aortic valve, Ao: aorta).

## Technique

### *Angiocardiography* (Fig.20 7)

This method of contrast agent- aided cardiac visualisation is used in the diagnosis of acquired cardiac disease and congenital cardiac malformation. Selective angiocardiography, in which a small amount of contrast material is injected into the desired chamber or vessel during cardiac catheterisation, is also used extensively. Pigtail, pre- shaped or balloon catheters introduced by the transfemoral or transbrachial approach are used. Power injection techniques are used for all types of angiocardiography except for coronary arteriography.

Cine angiography yields images with resolution of 0.1 mm, thus this technique is the best way to accurately visualise the moving heart and vessels. Because processing of cine film takes 20 - 30 minutes, video recording on tape or disk is done at the time of cine fluoroscopy so that the result can be viewed quickly. The image intensifiers may be chosen for single, double, or triple mode operation. Video recording also allows stop-frame techniques and slow-motion analysis. Digital subtraction angiography is useful in imaging the aortic arch where the background frame has little motion.

Angiocardiography is mostly performed with projections that align the X-ray beam with the axis of the heart. The RAO view profiles the long axis of right and left ventricles parallel to the interventricular septum. In the LAO view, the interventricular and interatrial septae are aligned perpendicular to the film plane. Compound angulation is frequently used to align the X-ray beam orthogonal to the heart. In addition to RAO and LAO projections, the image intensifier is tilted toward the head or foot of the patient. In a cranial projection, the image intensifier angles toward the head of the patient whereas in a caudal projection, the image intensifier angles toward the patient's feet.

Although angiocardiographical techniques can provide exquisite information, the less invasive techniques of CT and MR imaging with intravenous contrast injection generally produces sufficient information for diagnosis and management of a wide variety of cardiovascular problems.

### *Coronary arteriography*

Judkins catheters are the most commonly used catheters. Right and left Judkins catheters have different shapes. Low osmolar contrast agents are usually used, as hyperosmolarity leads to ECG changes. After selective catheterisation of the coronary artery, hand injections of contrast material verify the size and flow of the artery. The left coronary artery (LCA) generally requires 7-9 ml of contrast material at rates of 4-6 ml/sec, whereas 6-8 ml at 3-5 ml/sec is sufficient for the smaller right coronary artery (RCA). The catheter tip should not be left wedged in the coronary ostium, as this occludes blood flow. 5000 U of intravenous heparin is used, and it is reversed by 50 mg of protamine.

### *Aortography*

Contrast material is injected into the aorta via a pigtail catheter introduced through one of its major branches, and is placed into a desired position in the aorta. The examination has a place in the investigation of patients with congenital and acquired problems of the aortic arch. It is used in infants with congestive heart failure in whom there is evidence of a left-to-right shunt, and in whom a patent ductus arteriosus is suspected. Coarctation of the aorta in infants may also cause congestive heart failure. In adults, aortography is used to define anomalies of the aortic arch and its branches, and in studies of the aortic valve and the coronary arteries. It is also useful in patients with masses adjacent to the aorta in whom aneurysm is a possibility, and in patients with suspected dissecting haematoma, traumatic, or other aneurysms. CT and MR imaging are replacing

aortography in the evaluation of many of these conditions.

## **Anatomy (Fig. 20.7)**

### **Right atrium**

The RA has an appendage with a broad opening. The inflow structures are the IVC, SVC, and coronary sinus. The RA has a roughly cylindrical shape except for the inflow region of the tricuspid valve.

### **Right ventricle**

The RV has a triangular shape on the posteroanterior view and a crescent shape on the lateral view. The RV has coarse, deep trabeculations. The moderator band usually has the largest trabeculations near the septum. The outflow tract is the infundibulum or conus, and is cylindrical. The pulmonary valve is separated from the tricuspid valve by the infundibulum; a landmark difference from the LV in which the aortic and mitral annuli join posteriorly.

### **Pulmonary arteries**

The muscular pulmonary conus extends to the semilunar, tricuspid pulmonary valve, with the pulmonary trunk extending superiorly and to the left. The left PA extends posteriorly as a continuation of the main PA, coursing over the top of the left main stem bronchus, then descending posteriorly. The right PA extends horizontally to the right, bifurcates within the pericardial sac, and exits the right hilum as the truncus anterior and interlobar arteries. The right upper lobe bronchus is eparterial, meaning that it lies above the right PA. The left main stem bronchus is hyperarterial, meaning that it lies below the PA.

The ligamentum arteriosum arises from the superior proximal left PA, and crosses through the aorticopulmonary window to the floor of the aorta. The ligamentum arteriosum is the remnant of the

ductus arteriosus. It closes functionally in the first 24 hours and closes anatomically by 10 days. Desaturated blood from the right heart circulates through the lungs and returns as oxygenated blood through the right and left superior, and inferior pulmonary veins into the LA.

### **Left atrium**

The LA has an ellipsoidal shape, and lies in the midline or slightly to the side of the bilobed lung. The LA has a smooth wall except for the appendage. The LA appendage has a narrow neck.

### **Left ventricle**

The LV has an oval shape and finer trabeculations than the RV. The mitral valve consists of anterior and posterior leaflets. The papillary muscles may have single or multiple heads, and connect about one-half of the distance between the base and the apex of the LV. A major landmark of the LV is the continuity of the mitral and aortic valves, i.e. absence of subaortic conus. Unlike the RV, there is no muscle between the aortic and mitral valves. The walls of the LV are arbitrarily divided into the five segments in the RAO projection, and into four segments in the LAO projection. The septum and the anterior leaflet of the mitral valve are better seen if cranial angulation is added in the LAO projection.

### **Coronary artery [7] (Fig.20.8)**

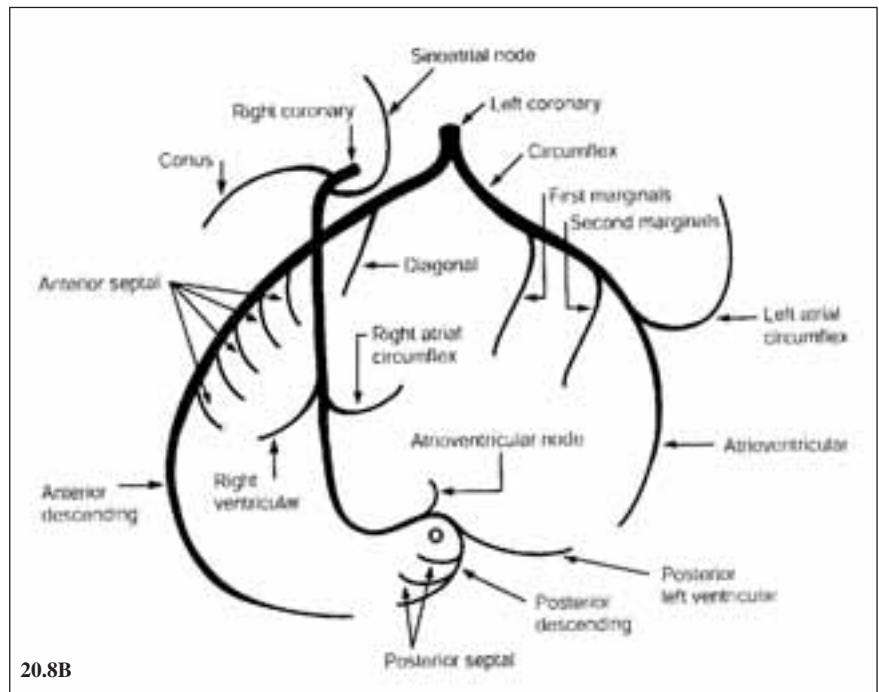
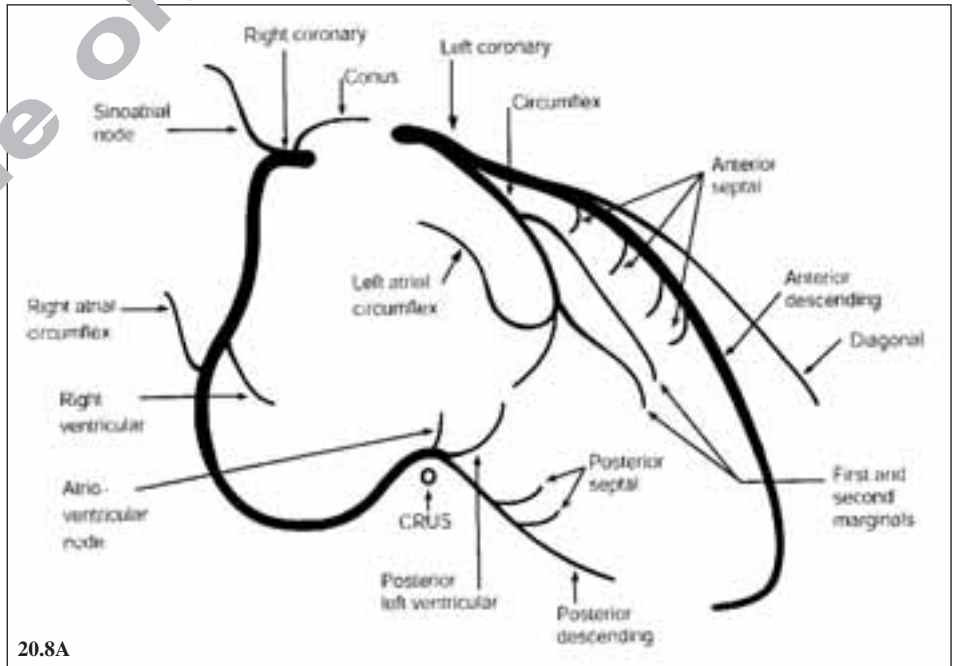
The RCA arises from the right coronary cusp, and the LCA arises from the left coronary cusp. Approximately 85% of patients are right dominant, meaning that the RCA supplies the posterior descending artery and the posterior and inferior surface of the myocardium. In 10%-12% of patients, the LCA is dominant and supplies the inferior and posterior surfaces. Approximately 4%-5% of patients are co-dominant. The left anterior descending artery (LAD) extends anteriorly in the interventricular groove. The circumflex artery

extends laterally and posteriorly under the left atrial appendage to the atrioventricular groove. The LAJ gives off several septal branches that penetrate into the septum. One or more diagonal branches extend toward the anterolateral wall. Occasionally, a conus branch comes off after

the first septal branch and extends to the right ventricular infundibulum. The circumflex artery gives off one or more obtuse marginal branches that supply the lateral wall of the LV. The RCA passes anterior and to the right between the PA and the RA. Its first branch is a conus branch to the pulmonary outflow tract. The second branch is the sinus node branch

with a smaller branch to the RA. Muscular branches extend into the right ventricular myocardium. At the posterior turn, a large acute marginal branch is often given off anteriorly toward the diaphragmatic surface of the RV. The RCA then extends posteriorly in the atrioventricular

sulcus and makes a 90 degree turn toward the apex in right dominant systems. As the posterior descending artery, it supplies branches to the diaphragmatic myocardium and the posterior one-third of the interventricular septum.



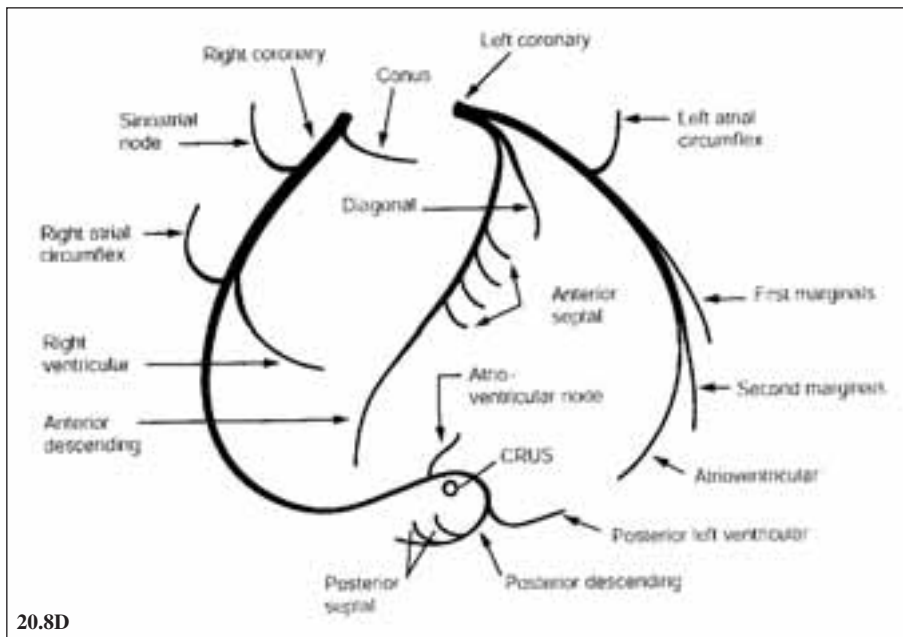
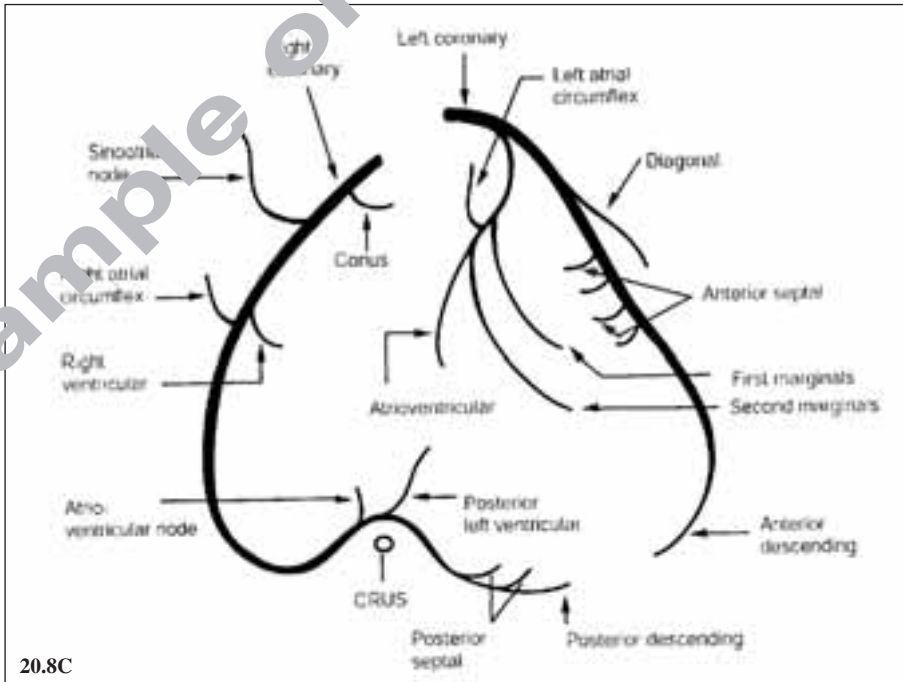


Fig. 20.8: Diagrams show anatomy of the coronary artery. (A) Anterior view. (B) Lateral view. (C) RAO view. (D) LAO view. [Adapted from reference 7].

### Aorta

The outflow tract of the LV leads into the aortic root through the aortic valve which is composed of right, left, and posterior (non- coronary) cusps. The

sinuses of Valsalva are the reservoirs created by the closure of the aortic valve, and from which the right and left coronary arteries arise. The posterior wall of the aorta is continuous with the anterior leaflet of the mitral valve and more superiorly abuts the anterior wall of the LA. The anterior wall of the aorta is continuous with the interventricular septum. After coursing superiorly and then to the left, the aorta gives off the right innominate artery, left common carotid artery, and left subclavian artery. The aortic arch is the transverse portion of the aorta that abuts the left wall of the trachea, causing a characteristic indentation.

### CONCLUSION

In the future, our understanding and

insight of the radiological anatomy of the cardiovascular system will change with the introduction of sophisticated software that allow generation of 3D images with volume rendering. Paradoxically, these

technological developments will demand a more detailed knowledge of basic anatomy of the cardiovascular system.

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