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The Normal Heart

Introduction

Our purpose in this short volume is to show how echocardiographers can demonstrate nowadays the morphological details of congenitally malformed hearts with as much accuracy as the morphologist who holds the heart in his (or her) hands. Recognition of the abnormal, of course, depends on a thorough knowledge of the normal. This is nowhere more true than in the analysis of congenitally malformed hearts. Cardiac structures can often be thought to be abnormal simply because they occupy an unexpected location; yet, in strict anatomical terms, they can still be considered as 'normal'. In this opening chapter, therefore, we will demonstrate the features of the various components of the normal heart, comparing the anatomical features with cross-sectional echocardiographic images. This pattern, of comparing anatomy in autopsied hearts with cross-sectional echocardiographic images, will be followed throughout the remainder of this book.

The Cardiac Chambers and Arterial Trunks

The echocardiographer dealing with acquired heart disease, and the pathologist, usually describe the heart in terms of 'right' and 'left' sided chambers. In reality, the 'right' chambers are more anteriorly positioned within the body (Fig. 1.1), but the convention of using 'right' and 'left' is unlikely to disappear. At any event, in the normal heart, it is difficult to argue with the use of these terms. Problems arise in congenitally malformed hearts, however, since the chambers that would normally be described as 'right' may occupy a left-sided position, and vice versa. The continuing

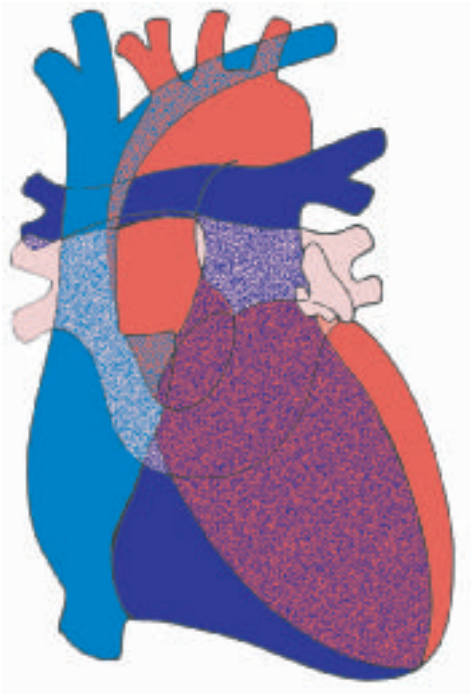

Figure 1.1 There is considerable overlap between the right heart chambers (blue) and left heart chambers (red) when the cardiac silhouette is viewed from the front.

use of 'right' and 'left', when the chambers being described do not occupy these locations, is confusing, but difficult to avoid. The difficulty is overcome in congenitally malformed hearts by adding the description 'morphologically' to 'right' and 'left'. This is not necessary when describing the normal heart. An important feature of the normal heart, nonetheless, and particularly important to the echocardiographer, is that its long axis is not parallel to the long axis of the body (Fig. 1.2). This means that the ventricles are inferior and to the left of the atriums, rather than sitting beneath them as in the St Valentine's heart. The relationships of the 'right' and 'left' structures of the normal heart are further complicated by the marked twisting of the ventricular outflow tracts. The aorta, even though emerging from the left ventricle (and, therefore, a 'left' component of the heart) has its valve in the right-sided position relative to the pulmonary valve (Fig. 1.3). Indeed, it is the appreciation of this central 'keystone' location of the aortic valve which leads to the proper interpretation of echocardiographic images.

The Morphologically Right Atrium

The right atrium, anatomically, is divided into the venous component, the vestibule, the septum, and the appendage (Fig. 1.4). The venous component receives

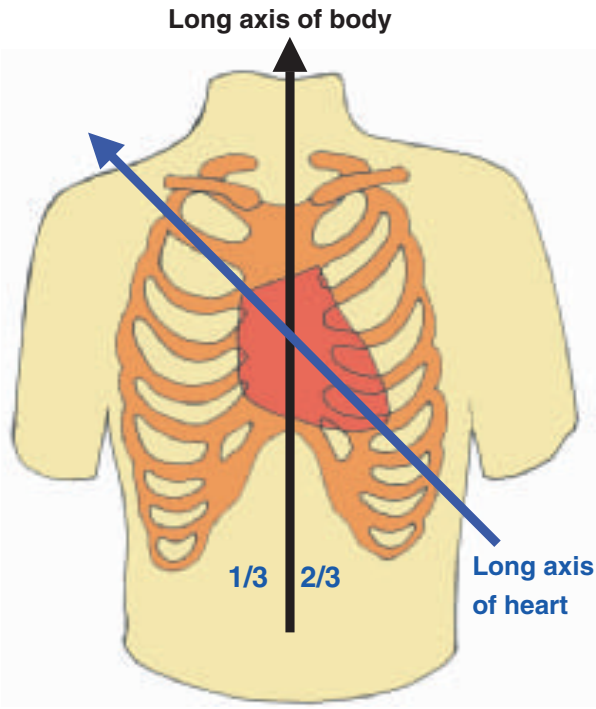

Figure 1.2 The long axis of the heart is at an angle to the long axis of the body. Two-thirds of the cardiac mass is to the left of the midline. The sternum, rib cage and lungs obscure much of the heart when viewed from the front.

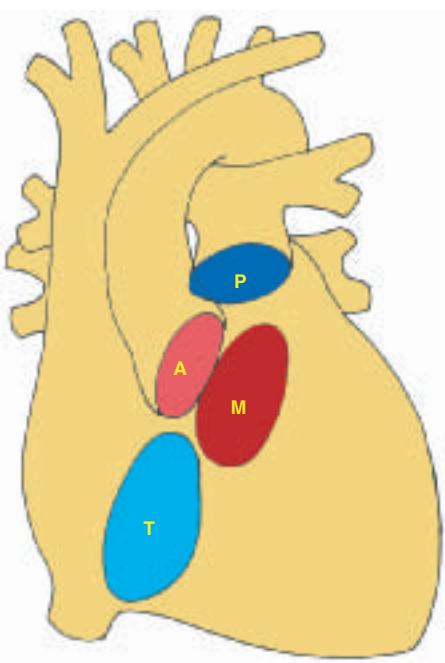

Figure 1.3 The pulmonary (P) and tricuspid (T) valves are well separated from one another. The valves of the left heart, the aortic (A) and mitral (M), are adjacent to one another.

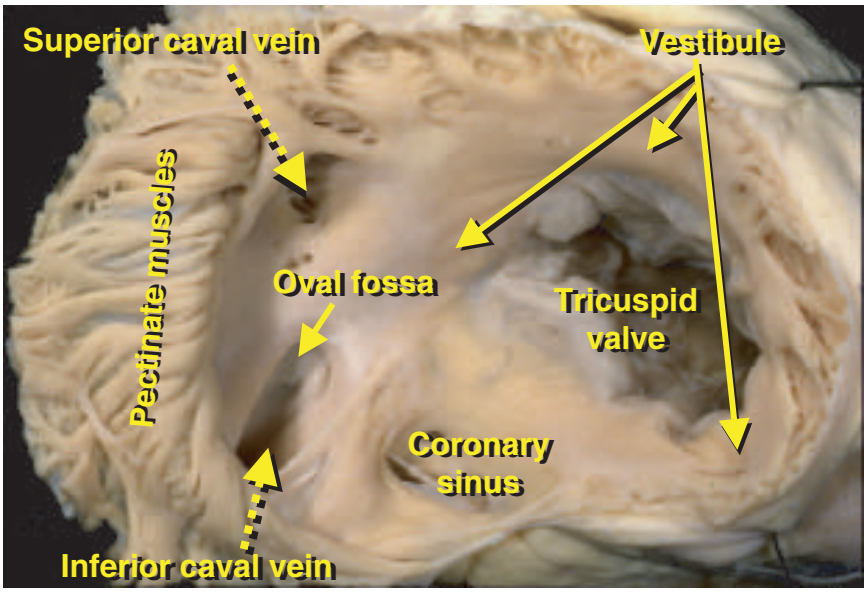

Figure 1.4 The morphologically right atrium is dissected to display its endocardial aspect. An extensive array of pectinate muscles arises from the terminal crest. The vestibule to the tricuspid valve is smooth.

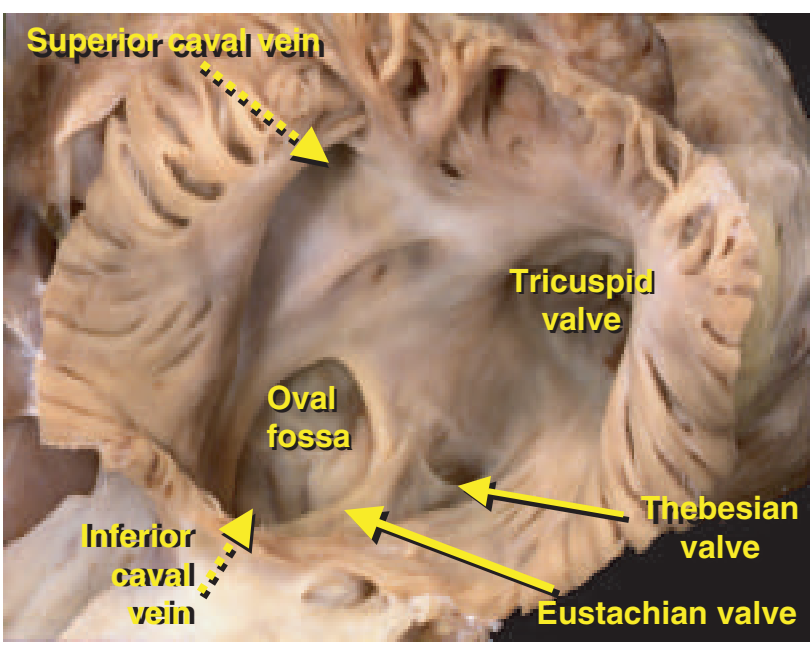

Figure 1.5 The Eustachian valve guards the orifice of the inferior caval vein while the Thebesian valve guards the coronary sinus.

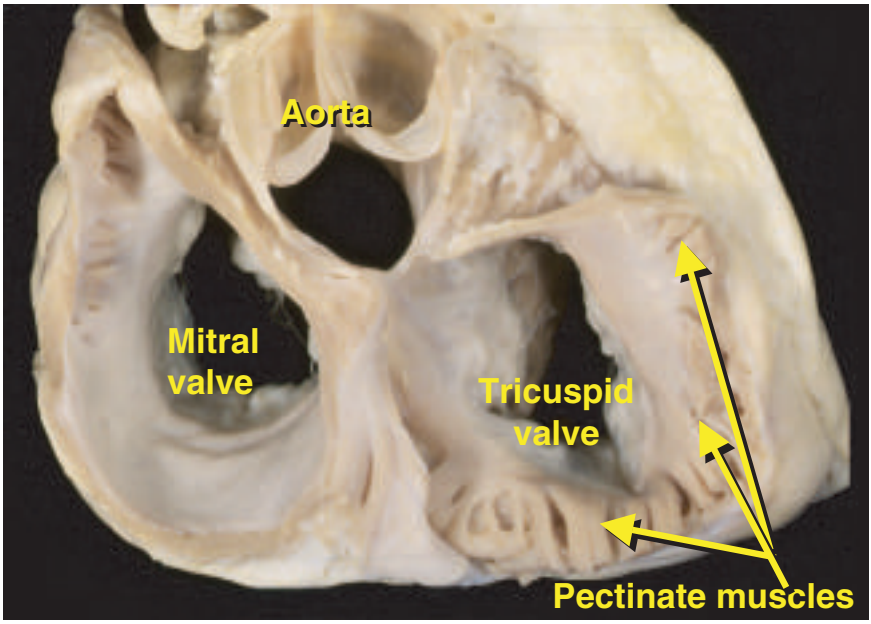

Figure 1.6 This dissection of the base of the normal heart shows the array of pectinate muscles that is characteristic of the morphologically right atrium. In contrast, the pectinate muscles are confined to the atrial appendage on the left side, leaving a smooth left atrial wall.

the superior and inferior caval veins together with, at the junction with the septal component, the coronary sinus. The terminal crest (crista terminalis) divides the venous component from the appendage, and pectinate muscles branch from the crest at right angles to run into the appendage. Fibro-muscular webs attach to the crest in the regions of the openings of the inferior caval vein and the coronary sinus. These are the so-called venous valves, the Eustachian valve in relation to the inferior caval vein, and the Thebesian valve at the coronary sinus (Fig. 1.5). There is a fibrous structure which runs from the union of these valves into the septum between the coronary sinus and the oval fossa as the tendon of Todaro. The most characteristic anatomic feature of the morphologically right atrium is the extension of the pectinate muscles around the atrioventricular junction (Fig. 1.6). The junction between the appendage and venous component is particularly wide. The septal surface is made up of the floor and inferior rim of the oval fossa, the superior rim of the fossa, the so-called 'septum secundum', being an infolding of the atrial wall between the superior caval vein and the right pulmonary veins (Fig. 1.7). The coronary sinus opens into the right atrium having extended through the left inferior atrioventricular groove. We used to think that the atrial surface of the triangle of Koch was also a septal structure. We now know that a fibro-adipose tissue plane separates this wall from the crest of the ventricular septum. The vestibule of the morphologically right atrium is smooth-walled, and supports the attachments of the leaflets of the tricuspid valve.

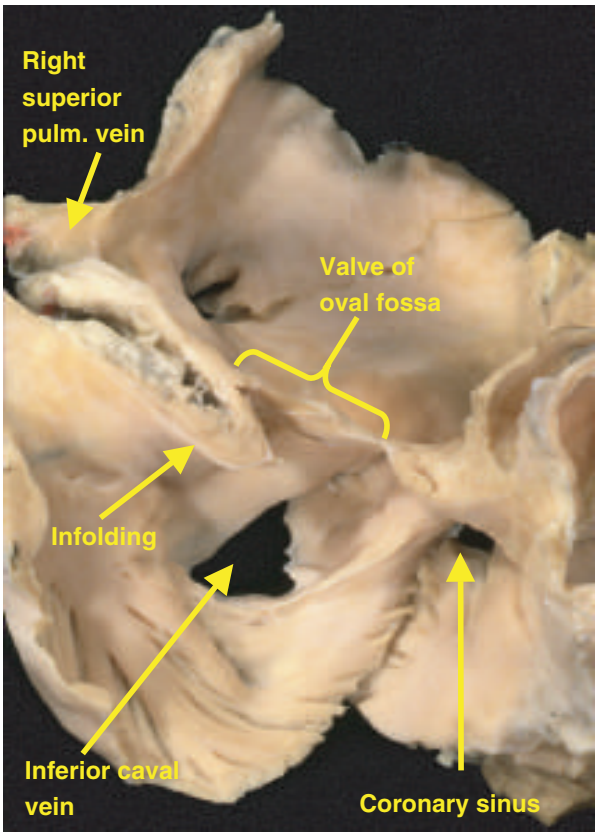

Figure 1.7 This longitudinal section through the heart profiles the atrial septum which is marked by the oval fossa. The atrial septum is not as extensive as suggested by the right atrial view as displayed in Fig. 1.4. The infolding of the right atrial wall ('septum secundum') forms the muscular rim around the oval fossa.

The Morphologically Left Atrium

The left atrium, like its morphologically right counterpart, has a venous component, a septal surface, a vestibule and an appendage. Unlike its partner, it also possesses an extensive body (Fig. 1.8). The venous component, with smooth walls, receives the four pulmonary veins. The septal surface is roughened on its left atrial aspect, and is the flap valve of the oval fossa. The flap valve overlaps the infolded atrial walls (the 'septum secundum') superiorly. Even if the flap valve is not fused with the rim of the oval fossa, there will be no shunting across the septum as long as the pressure in the left atrium exceeds that in the right. Indeed, probe patent foramens are found in up to one-third of the normal population. The vestibule of the left atrium supports the leaflets of the mitral valve and is smooth. The body of the atrium is best appreciated in the setting of the totally anomalous pulmonary venous connection, giving volume to the chamber in the absence of the venous component.

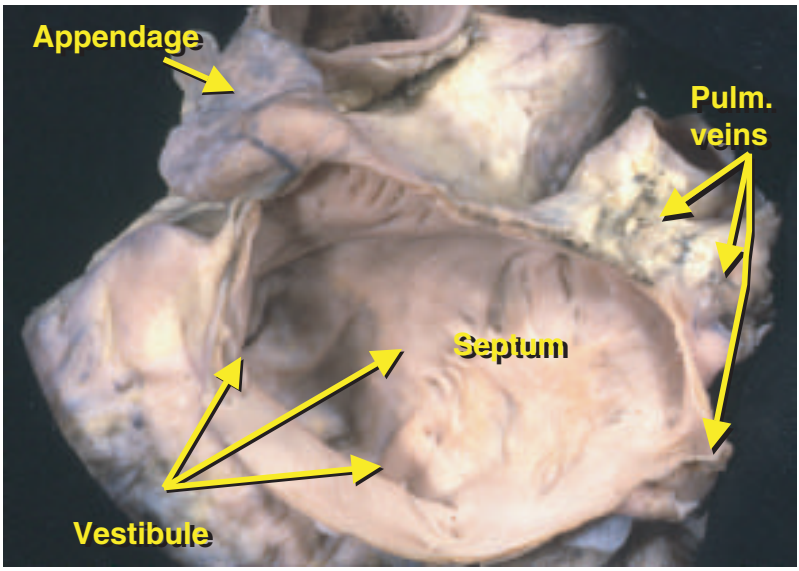

Figure 1.8 The endocardial aspect of the left atrium is displayed to show its relatively smooth wall compared to the right atrium. The flap valve of the oval fossa is the septal area.

The pectinate muscles are much less obvious within the left atrium, being confined within the appendage, which itself has a narrow, tubular junction with the rest of the chamber (Fig. 1.9). Only occasionally do pectinate muscles spill into the body of the atrium. Unlike the situation in the right atrium, they never extend around the atrioventricular junction. The appendage also differs markedly from the normal right appendage in terms of its shape, but this is variable in malformed hearts. It is the morphology of the junctions between the venous components, the appendages and the vestibules which is the most reliable marker for the morphologist to differentiate between the morphologically right and left atriums. It has yet to be established if this distinction can consistently be made echocardiographically, but the shape of the appendages can certainly be distinguished in normal hearts.

The Morphologically Right Ventricle

The right ventricle possesses inlet, apical trabecular and outlet components. The pathway between them swings from inferiorly and rightwards to superiorly and leftwards within the ventricular mass (Fig. 1.10). The inlet component surrounds and supports the leaflets and tension apparatus of the tricuspid valve. The leaflets occupy septal, antero-superior and inferior (or mural) locations within the atrioventricular junction (Fig. 1.11). The most characteristic feature of the tricuspid valve, particularly for the echocardiographer, is the presence of tendinous cords attaching its septal leaflet to the ventricular septum (Fig. 1.12). Another useful marker is the moderator

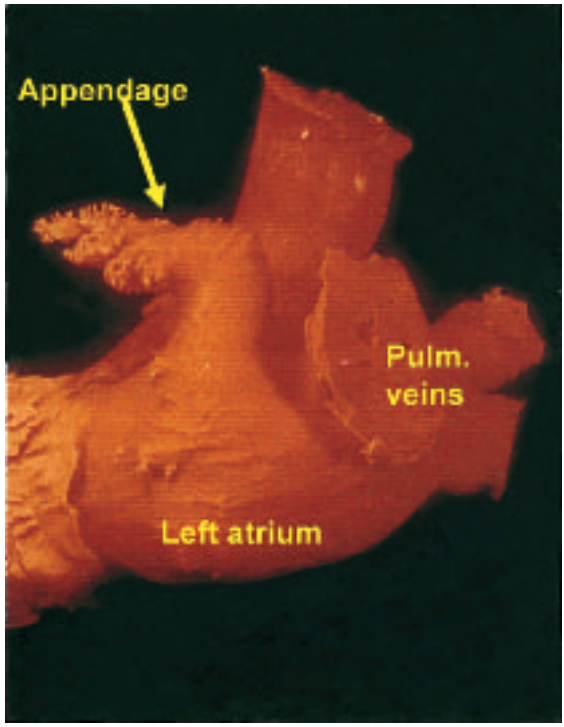

Figure 1.9 This endocast of the left atrium shows the rough region (pectinate muscles) confined to the appendage.

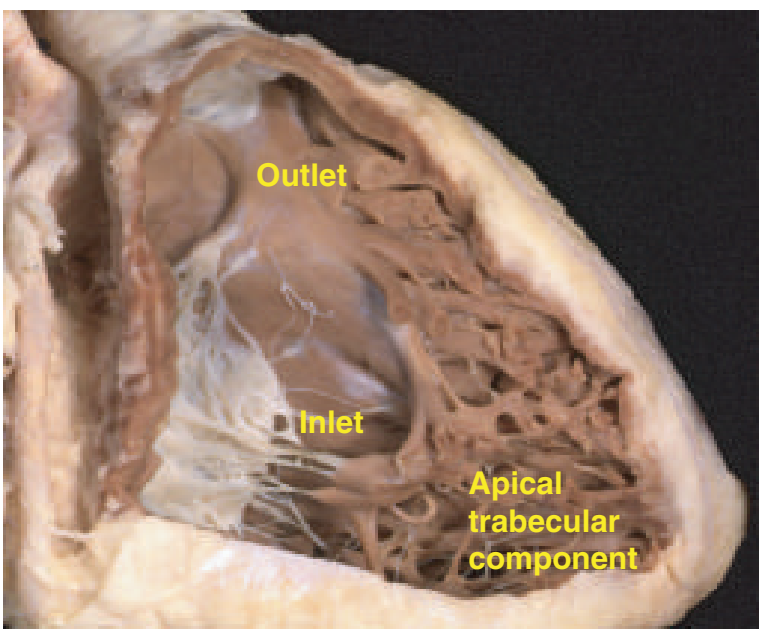

Figure 1.10 The cavity of the right ventricle is displayed by removing its anterior wall. Note the coarse trabeculations in the apical component.

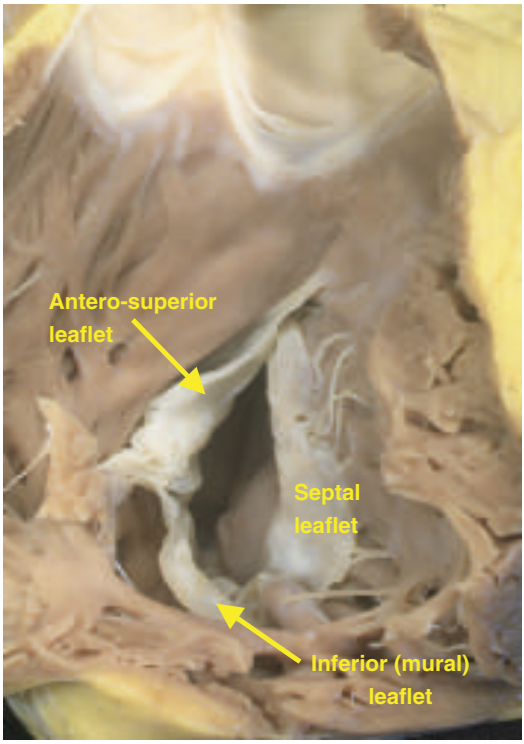

Figure 1.11 The orifice of the tricuspid valve is viewed from the apex of the right ventricle. The three leaflets are displayed.

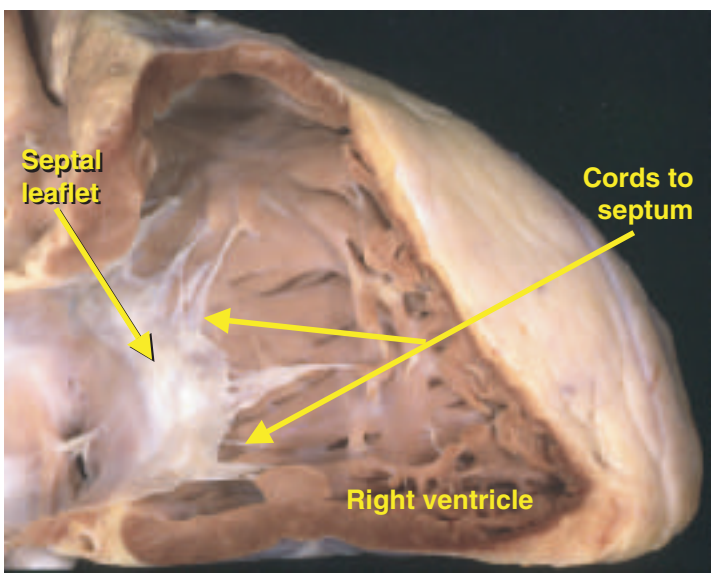

Figure 1.12 This view of the septal aspect of the right ventricle shows insertions of tendinous cords from the septal leaflet to the septum.

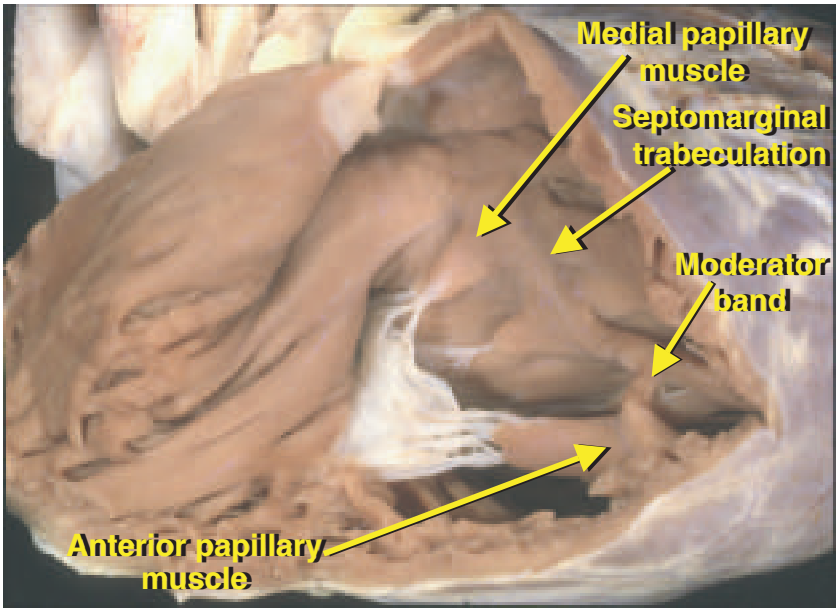

Figure 1.13 The parietal wall is reflected to show the cavity of the right ventricle. The moderator band extends from the septum across the ventricular chamber.

band, usually a broad muscular strap that crosses the ventricular cavity (Fig. 1.13). The apical trabecular component of the right ventricle has characteristically coarse trabeculations (Fig. 1.10). This is the best morphological criterion for ventricular identification in those chambers that lack an inlet and do not possess a tricuspid valve, but cannot always be used by the echocardiographer. The leaflets of the pulmonary valve are supported completely by the muscular infundibulum. It is important to note that much of the 'septal' surface of the infundibulum is, in reality, a free-standing muscular sleeve, which is separated from the aorta by extracardiac space (Fig. 1.14). Previously, we had argued incorrectly that this component of the infundibulum was an outlet septal structure. In reality, only a small part of the infundibulum, namely that inserted between the limbs of the prominent right ventricular muscle bundle called the septomarginal trabeculation, is truly a muscular outlet septum. The rest of the posterior margin of the infundibulum, which forms the supraventricular crest (crista supraventricularis), is the infolded roof of the ventricle. Additional trabeculations, the septoparietal trabeculations, are found extending around the anterior parietal margin of the infundibulum (Fig. 1.15).

The ventricular septum itself has muscular and membranous components, the latter being very small. Because of the central 'keystone' location of the aorta, part of the muscular septum separates the inlet of the right ventricle from the outlet of the left. In the normal heart, therefore, it is very difficult to distinguish inlet, apical and outlet septal components. The entire muscular septum is best considered as a continuous entity.

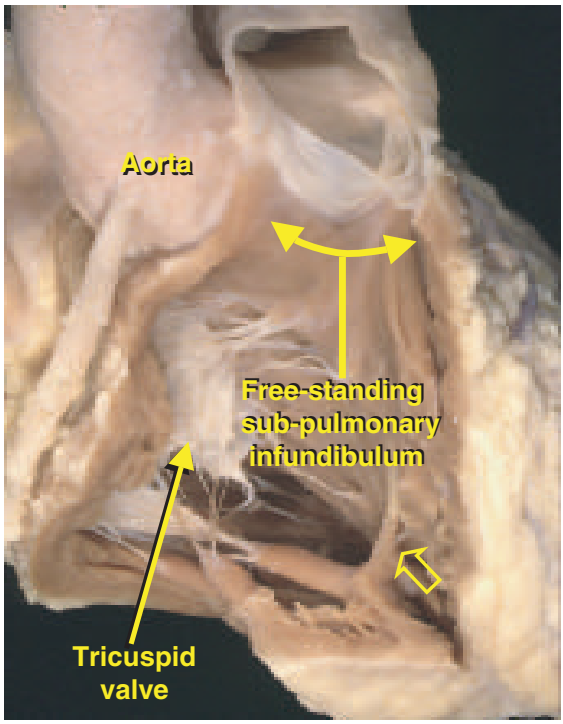

Figure 1.14 The pulmonary valve is supported by a cone of right ventricular myocardium — the sub-pulmonary infundibulum. The aortic root is exposed in this dissection by removing the parietal part of the ventriculo-infundibular fold. The open arrow denotes the moderator band.

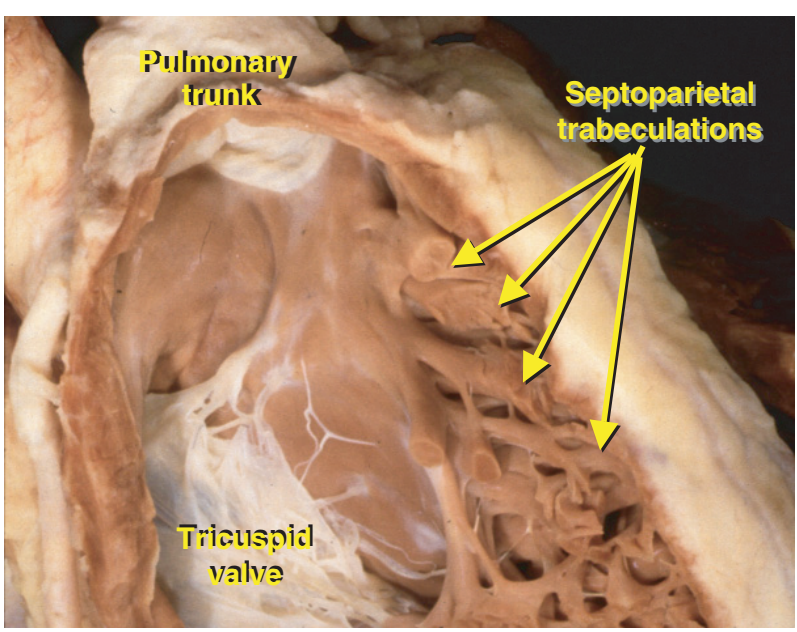

Figure 1.15 Several septoparietal trabeculations have been cut across in this dissection that displays the right ventricular outflow tract.

The Morphologically Left Ventricle

Like its morphologically right counterpart, the left ventricle has inlet, apical trabecular and outlet components (Fig. 1.16). The inlet component contains and surrounds the mitral valve, which has aortic and mural leaflets, so named because of their relationship with the leaflets of the aortic valve and the parietal atrioventricular junction, respectively (Fig. 1.17). The zone of apposition between the two leaflets has antero-lateral and postero-medial ends, the so-called commissures, each supported by one of the paired left ventricular papillary muscles. The most characteristic echocardiographic feature of the mitral valve is that it has no cordal attachments to the ventricular septum (Fig. 1.18). The apical part of the ventricle has fine criss-crossing trabeculations, and the septal surface is smooth. The leaflets of the aortic valve are supported in semilunar fashion but, unlike the pulmonary valve, the leaflets are attached in part to fibrous structures, specifically the leaflets of the mitral valve and the membranous septum, and in part to the muscular walls of the ventricle.

The Aorta

The aorta springs from the centrepoint of the base of the heart and curves upwards to the aortic arch, where it gives rise to the brachiocephalic arteries. The three sinuses

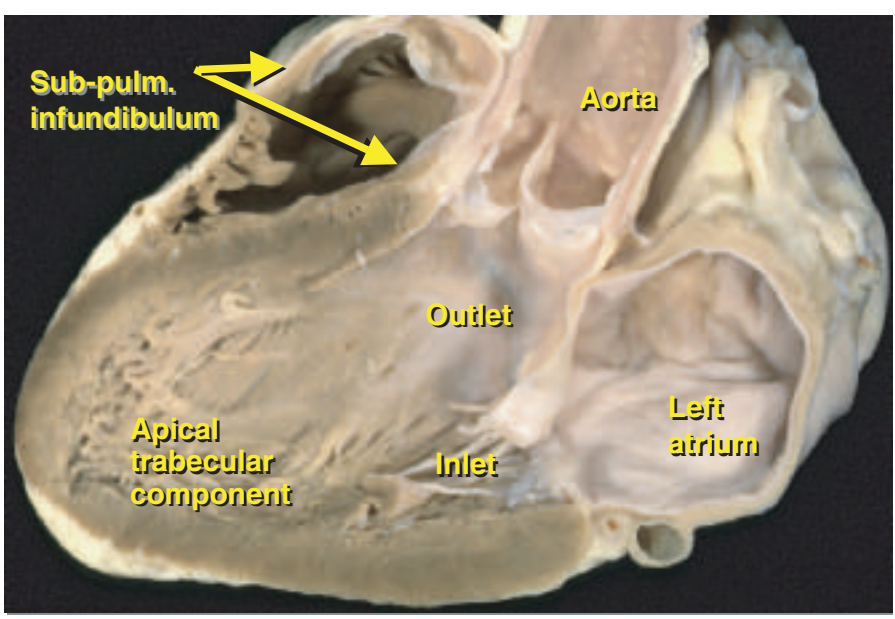

Figure 1.16 This section through the long axis of the heart simulates the echocardiographic section obtainable through the parasternal window. The three components of the left ventricle are shown. The criss-crossing muscular bundles in the apical component are finer than that in the right ventricle (compare with Fig. 1.10).

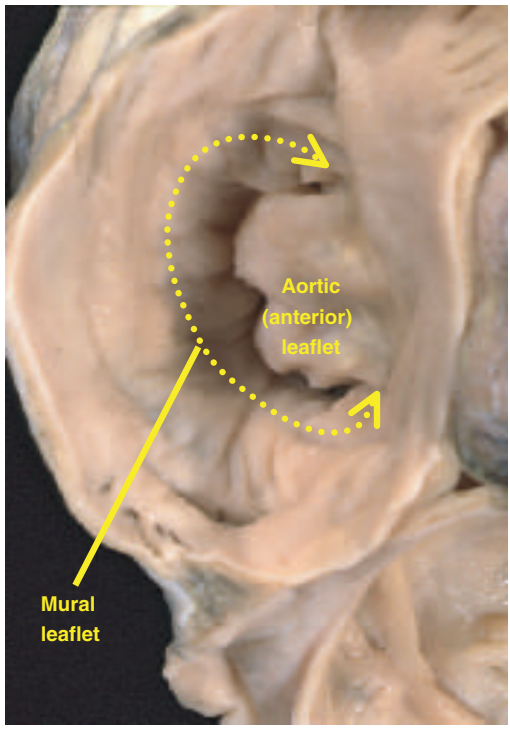

Figure 1.17 This view of the mitral valve from the left atrium shows the arrangement of its leaflets. The mural leaflet occupies nearly two-thirds of the valvar perimeter.

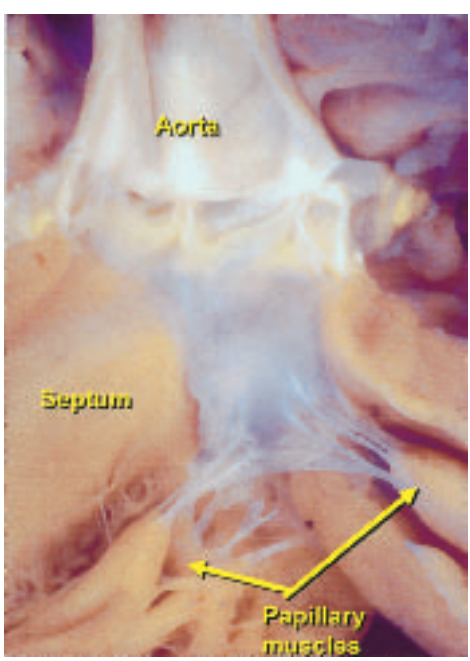

Figure 1.18 This view of the left ventricle shows that the outlet to the aortic valve is wedged between the ventricular septum and the aortic ('anterior') leaflet of the mitral valve. The mitral valve is supported by two groups of papillary muscles.

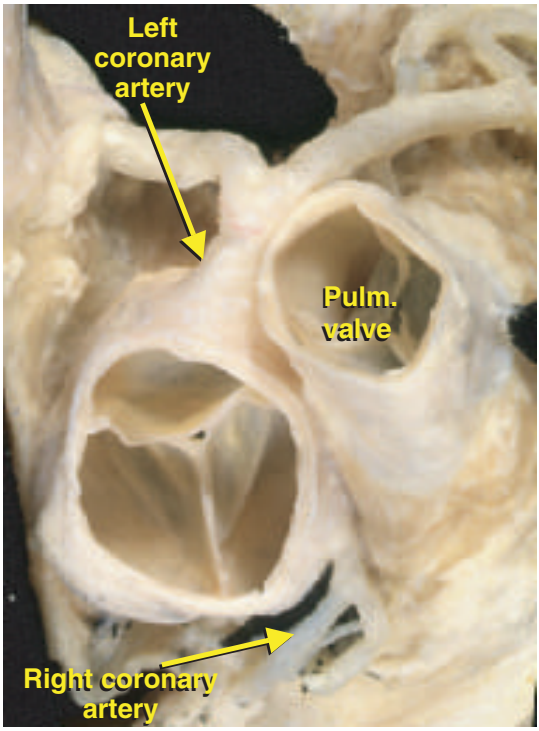

Figure 1.19 This dissection shows the aortic valve and the pulmonary valve. The coronary arteries arise from the aortic sinuses that are adjacent to the pulmonary valve. The non-facing sinus is also non-coronary.

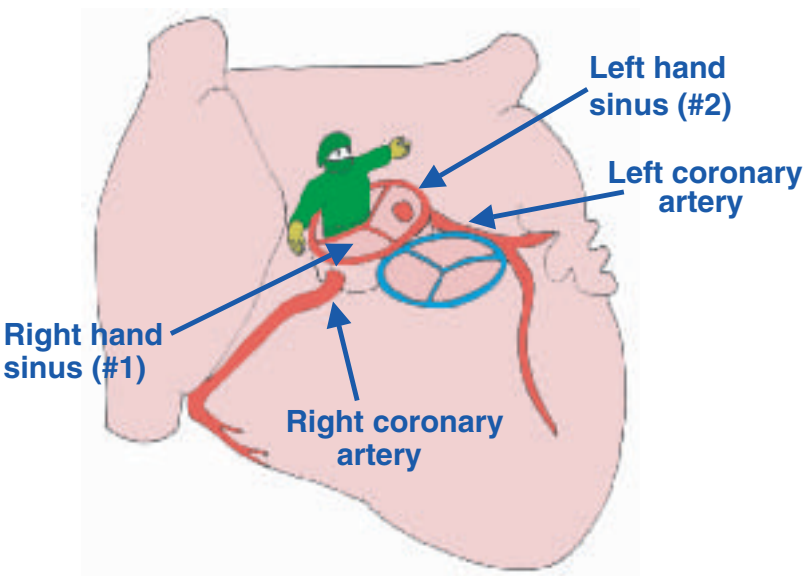

Figure 1.20 Diagram showing the descriptive convention for naming the aortic sinuses by positioning oneself at the non-facing sinus of the aortic valve. The Leiden convention designates the facing sinuses as #1 and #2.

of Valsalva support the leaflets of the aortic valve. Two of these sinuses give rise to coronary arteries. Almost without exception, these sinuses are the ones adjacent to, or 'facing', the pulmonary trunk (Fig. 1.19). Because of this relationship, the sinuses can be called the coronary aortic sinuses. They can then be distinguished as right hand and left hand facing sinuses as seen from the vantage point of the observer positioned at the non-facing sinus and looking towards the pulmonary trunk (Fig. 1.20).

The Pulmonary Trunk

The pulmonary trunk runs from the pulmonary infundibulum, where its sinuses support the leaflets of the pulmonary valve, to its bifurcation into the right and left pulmonary arteries (Fig. 1.21). Two of the sinuses of the pulmonary trunk are always adjacent to the aorta, the facing sinuses, while the third sinus is non-facing. The facing sinuses can again be considered right-handed and left-handed structures from the vantage point of the observer standing at the non-facing sinus and looking towards the aorta. In the foetal circulation, the arterial duct ('ductus arteriosus') extends from the pulmonary trunk into the descending aorta. The isthmus of the

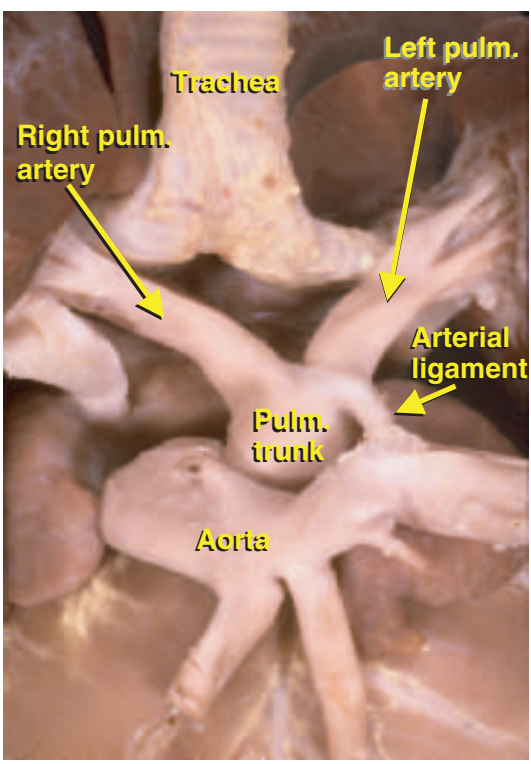

Figure 1.21 A specimen viewed from the front with the aortic arch pulled forward to show the pulmonary trunk and its bifurcation.

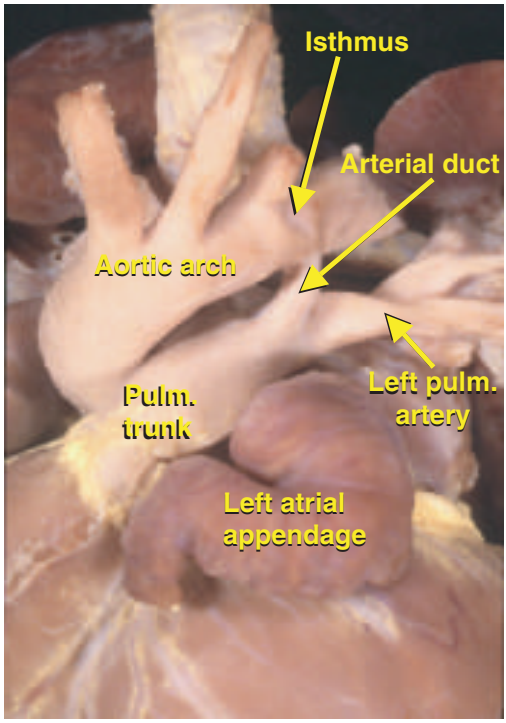

Figure 1.22 The normal aortic arch passes to the left of the trachea. The isthmus of the arch lies between the left subclavian artery and the arterial duct.

aorta is the segment between the site of take-off of the left subclavian artery and the aortic insertion of the duct (Fig. 1.22). Subsequent to birth, the duct closes and is converted to the arterial ligament.

The Cardiac Crux

In cross-sectional anatomy, the crux is an important landmark. The morphologist refers to the crux as the area on the diaphragmatic surface of the heart where the plane of the normal septal structures crosses the inferior atrioventricular groove. The echocardiographer cannot see this point on the epicardial surface. Instead, he/she can identify the echocardiographic crux at the inferior atrioventricular junction. This is the area of the atrioventricular muscular sandwich that we previously described incorrectly as the muscular atrioventricular septum (see Chapter 5). It is the off-set attachments of the leaflets of the tricuspid and mitral valves that produce the cruciate appearance on the echocardiographic image.