ANATOMY

Anatomic basis of cross-sectional echocardiography

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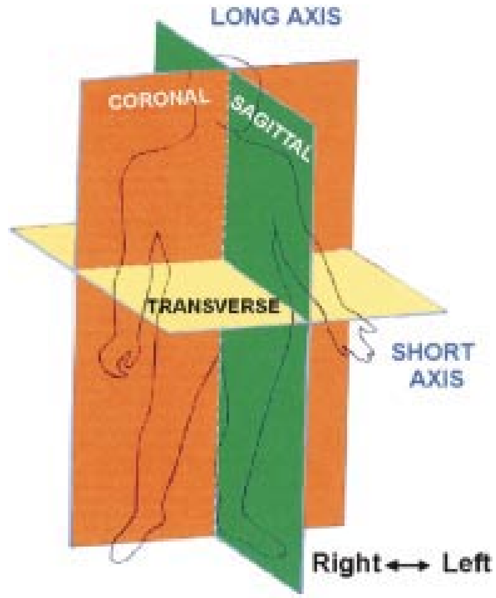

Figure 1. The so-called "anatomical position". The subject is upright and facing the observer. Any structure within the body can be described within the references of the three orthogonal planes—two in the long axis and the third in the short axis.

There can be little doubt that the cross-sectional echocardiographer will be tomorrow's anatomist. The level of discrimination of modern day echocardiographic machines is such that all but the finest details of cardiac structure are revealed in real time. Advances in three dimensional reconstruction now amplify the information obtained, and make it more amenable to clinical interpretations. It remains true, nonetheless, that the information available to the echocardiographer will be more accurately interpreted if the investigator has a good working knowledge of cardiac anatomy. This is not difficult to obtain. The basic rules and principles are exactly as we set them out in 1983.[1] As with any three dimensional structure, so as to determine the interrelationships of the cardiac components, it is necessary to obtain details as seen in the three orthogonal planes. These planes, at right angles to each other, are the equivalent of the floor plan, the frontal elevation, and the side elevation of any building. When considering the heart, however, the information obtained must be interpreted taking account of the fact that the orthogonal planes of the heart itself are very malaligned relative to the orthogonal planes of the body. The steps involved in gaining the basic knowledge, therefore, are to begin by reviewing the orthogonal planes of the body. It is then essential to understand the usual position of the heart within the body, along with the orientation of its own orthogonal planes. Thereafter, it is necessary to understand the usual positions of the cardiac chambers and valves within the cardiac silhouette. The basic anatomic information must then, self-evidently, be understood in sectional format. There are, of course, no standard sections which will always deliver the necessary information, since no two individuals have exactly identical relations of the cardiac components. So, it is not always possible to reveal cardiac structure using "standard" echocardiographic windows. The skilled echocardiographer will use any section, obtained from any echocardiographic window, to delineate the desired findings. It helps, nonetheless, to illustrate certain typical sections. The focus, however, should not be on obtaining the given section, but rather on demonstrating the required anatomy.

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Anatomic position

Structures within any part of the body are traditionally described on the basis that the subject is standing upright and facing the observer (fig 1). Within the body as thus seen, there are three basic orthogonal planes. Two are in the long axis of the body. One of these cuts the body from right to left, and produces sections in the frontal, or coronal, plane. The second plane along the long axis cuts from the front, or anterior, to the back, or posterior. This is the sagittal plane. These are, of course, any number of frontal and sagittal planes, each at right angles to the other. There are then infinite intermediate planes in the long axis, but no single one is at right angles, and hence also orthogonal. Instead, the third series of orthogonal planes is in the short axis. This series extends from the head, or superiorly, to the feet, or inferiorly. Any number of intermediate planes are similarly to be found between each of the short axis and the long axis planes, but none of these is orthogonal. It is knowledge of the three basic orthogonal planes which is sufficient to build up the three dimensional configuration of the body.[2]

Location of the heart

The heart lies in the middle mediastinal compartment of the thorax, enclosed within its pericardial sack, and sandwiched between the two pleural cavities. When projected to the

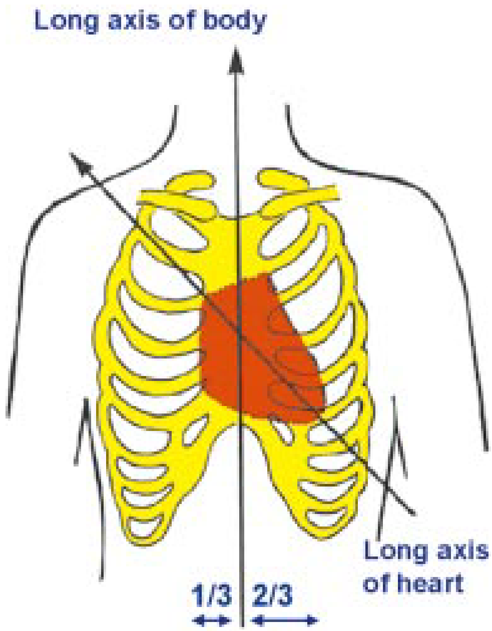

Figure 2. The heart lies in the mediastinum with its own long axis tilted relative to the long axis of the body. Appreciation of this discrepancy is important in the setting of cross-sectional echocardiography.

frontal projection, the cardiac silhouette is trapezoidal, with two thirds of its bulk to the left and one third to the right of the midline (fig 2). The right side of the trapezoid is more-or-less straight, and is positioned just to the right of the sternum. The left side is pointed, and extends out to the apex, which is located in the left mid-clavicular line in the normal individual. The short upper, and long lower, borders are both horizontal. The lower border lies on the diaphragm, while the upper border is at the sternal angle.

Arrangement of the cardiac chambers and valves

The biggest problem to be overcome in understanding cardiac anatomy is to appreciate that the adjectives "right" and "left" are used inappropriately when describing the cardiac chambers. In reality, the so-called "right" chambers are more-or-less anterior to their purported left sided counterparts, while the atria are essentially to the right of their respective ventricles. Thus, in the frontal silhouette, it is the right atrium and right ventricle which occupy most of the cardiac surface (fig 3). Viewing the heart from its apex, corresponding to the left anterior oblique angiographic projection (fig 4), then reveals the crucial interrelation of the cardiac valves. The pulmonary trunk is the most superior valve, with the leaflets supported on the free standing muscular infundibulum. The tricuspid valve is the most anterior valve, but is also the most inferior. The aortic valve forms the centrepiece of the heart, and is located directly in front of, and just above, the mitral valve.[3] The leaflets of the aortic and mitral valves are in fibrous continuity, a feature of

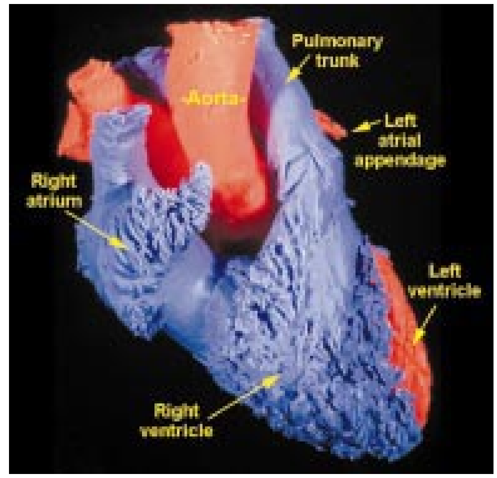

Figure 3. The heart has been prepared by making casts of its "right" and "left" sides, shown in blue and red, respectively. When viewed from the front, it can be seen that the so-called "right heart" chambers are really anterior to the "left" sided counterparts.

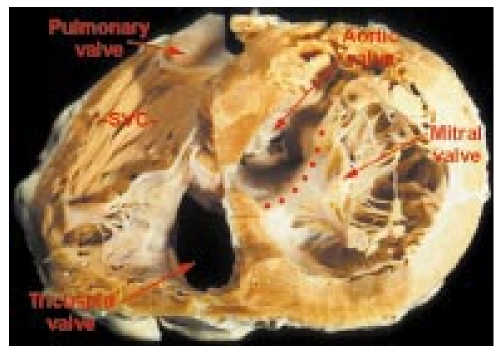

Figure 4. A cross-section of the ventricular mass is shown as viewed in left anterior oblique orientation. The right ventricle is anterior to the circular left ventricle, to the left hand as viewed in the section. Note the fibrous continuity of the valvar leaflets in the roof of the left ventricle (dotted line), in contrast to the situation in the right ventricle where the supraventricular crest (SVC) separates the leaflets of the tricuspid and pulmonary valves.

crucial importance in understanding the complications of endocarditis of the aortic root. Via the substance of the membranous part of the septum, the aortic valvar leaflets are also in continuity with those of the tricuspid valve. When seen in the frontal silhouette, only a thin strip of left ventricle projects to the cardiac margin, and only the appendage of the left atrium is visible. This is important information for the echocardiographer, since it means that, if approached anteriorly, it is necessary to traverse the cavities of the right atrium or ventricle before it becomes possible to interrogate the left sided structures.

The echocardiographic windows

Access to the heart is limited because the sound beam emitted by the echocardiographic transducer does not readily pass through either bone or the pulmonary parenchyma. There are, therefore, strictly limited windows through which the heart can be interrogated transthoracically. Two of these windows permit the

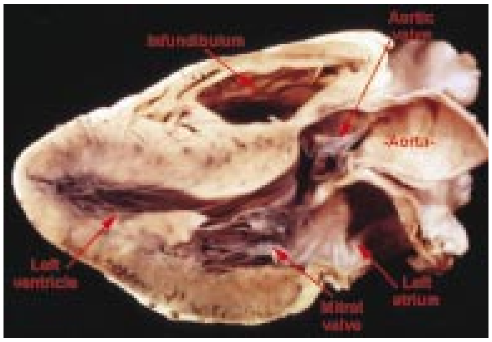

Figure 5. The heart has been sectioned to simulate the parasternal long axis plane. This is shown with the cardiac apex to the left hand of the observer. The anterior surface is to the top of the panel.

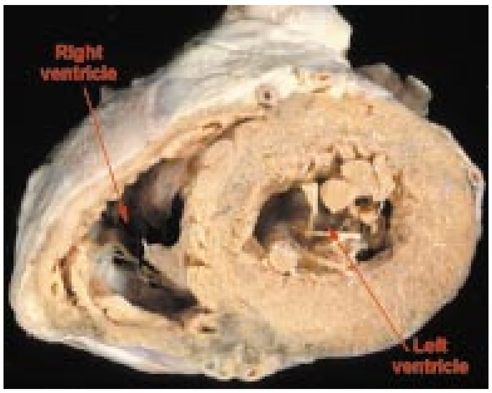

Figure 6. This is a short axis cut across the middle of the ventricular mass—compare with the section shown in fig 4.

heart to be cut along its own long or short axes. From each window, the heart can be cut in only two of the orthogonal planes, albeit that multiple intermediate planes can be obtained. Once again, nonetheless, it is knowledge of the images obtained in the orthogonal planes which provides the key to understanding. The parasternal windows, usually obtained from the third or fourth interspaces, permit the heart to be cut from front to back, and also in short axis. Traditionally, the slices from front to back are orientated as they would be seen in lateral projection, with the cardiac apex pointing to the left hand of the observer (fig 5). The short axis slices are orientated as they would be seen from inferiorly (fig 6). The long axis slice from front to back can also be obtained from the cardiac apex, but the apical window provides the crucial slice in which the heart is cut from side to side, giving the so-called four chamber section (fig 7). In fact, because of the deeply wedged location of the aortic root, most sections obtained from the cardiac apex which slice the heart from right to left also cut through the aorta, giving the so-called "five chamber" cut (fig 8). These cuts show well the arrangement of the septal components, particularly the membranous septum, which forms an integral part of the aortic root. For traditional reasons, it is customary for echocardiographers dealing with adult subjects to display these "four chamber" sections as though the patients are standing on their head. There seems no logical reason to continue this

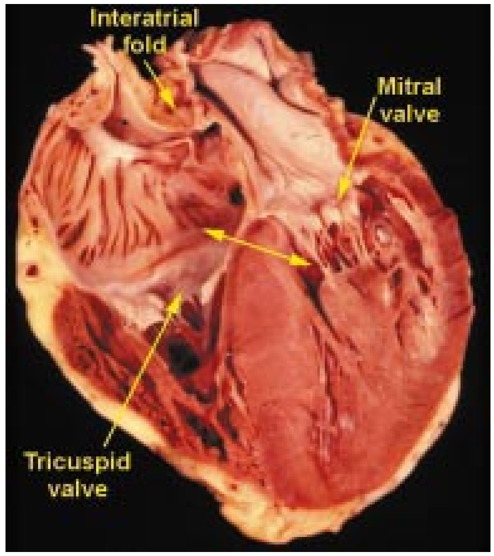

Figure 7. This section, taken to replicate the so-called "four chamber cut", is orientated in attitudinally correct position. It makes little sense to show this slice in upside down orientation. Note the off-setting of the septal hinges of the tricuspid and mitral valves (yellow double headed arrow). Note also the superior interatrial fold (shown again in fig 9).

practice, other than familiarity, since echocardiographic machines permit the operator to produce the images in whatever orientation is desired. Correlations with other imaging modalities, and with anatomy itself, are surely facilitated if the images are shown in attitudinally appropriate fashion.

The other echocardiographic windows permit the heart to be cut in the orthogonal planes of the body. Thus, from subcostal position the heart can be sliced in paracoronal and parasagittal fashion. Similar slices, and intermediate planes, can be obtained from the suprasternal

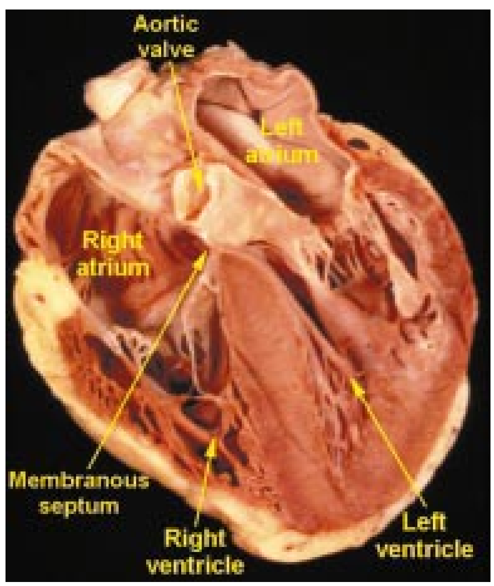

Figure 8. This four chamber section comes from the same heart as the one shown in fig 7, but is cut more anteriorly. It shows how the subaortic outflow tract is interposed between the leaflets of the mitral valve and the septum, with the so-called membranous septum forming an integral part of the aortic root, separating the outflow tract from the right-sided chambers.

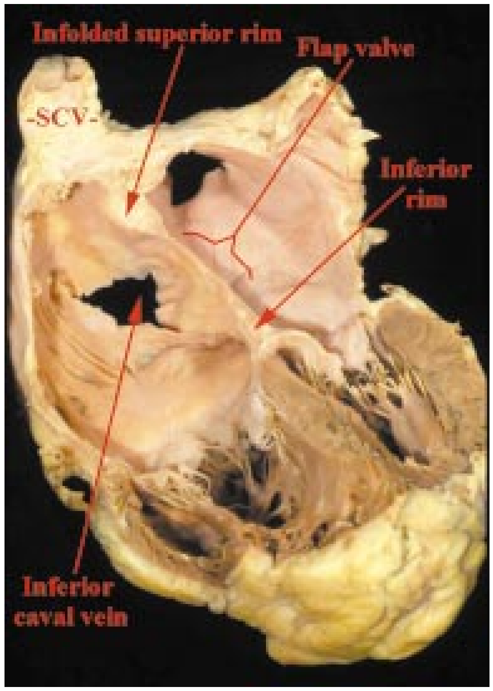

Figure 9. When studied with prior knowledge, the echocardiographer should be in a position to demonstrate all the features shown in this angled four chamber section. Thus, it should be possible to confirm that the so-called "septum secundum" is no more than a deep infolding between the venous attachments to the right and left atria. The true atrial septum is the flap valve, anchored on the muscular inferior rim.

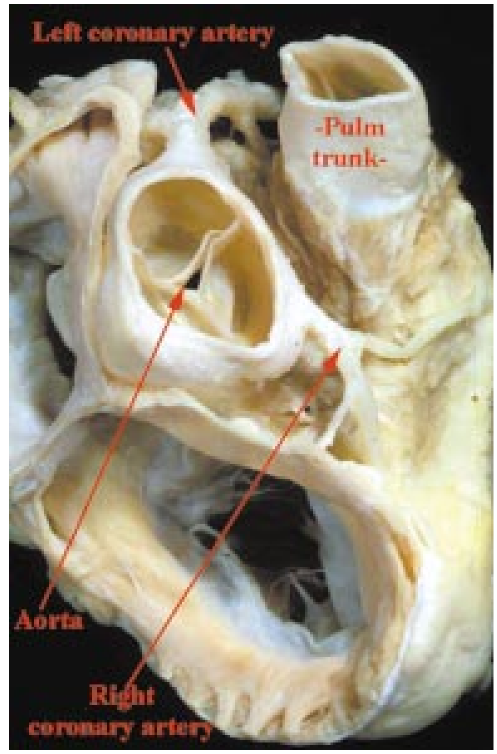

Figure 10. With modern day equipment, particularly when combined with Doppler interrogation, it should be possible to show all the details of coronary arterial origin from the aortic root, illustrated here in the right posterior oblique projection.

notch. Information obtained from these windows supplements that obtained using the parasternal and apical windows, and is particularly valuable for the echocardiographer examining neonates and infants with congenitally malformed hearts. The basic knowledge concerning the overall cardiac structure, nonetheless, is usually obtained from the classical windows. Using these limited points, it is usually possible to obtain information concerning not only the dimensions and structure of the chambers and valves, along with the outflow tracts and the arterial trunks, but also the origins and patency of the proximal coronary arteries. By combining cross-sectional examination with Doppler interrogation, it is also possible to reveal the patterns of the flow of blood throughout the heart. With the advent of harmonic and contrast imaging, the patterns of contraction of the ventricles can be determined, permitting recognition of subtle abnormalities of wall motion.

The clinical echocardiographer must be versatile and opportunist. Not all views will be optimal, or even obtainable, in all patients. In most patients, nonetheless, all the necessary information can be obtained. The parasternal long axis views are particularly useful for displaying the left atrium, the mitral valve, the inflow and outflow tracts of the left ventricle, and the aortic valve. The apex of the left ventricle is often amputated in the parasternal long axis cut, but is well shown by an apical "two chamber" view. This latter view should always be interrogated in patients with poor parasternal windows. The parasternal short axis views show to best effect any abnormalities of ventricular wall motion, and are invaluable in determining overall ventricular function. The central location, and precise anatomy, of the aortic valve is best appreciated from this approach. The apical four chamber view is the "cardiologist's friend". It is the view most readily interpreted without much knowledge of cardiac anatomy! The information would be the more amenable if the images were orientated in attitudinal fashion. This view is essential for the Doppler assessment of flow across the aortic and mitral valves. When combined with harmonic and contrast imaging, it is used for identification of abnormalities of wall motion during stress echo.

Echocardiography, without doubt, is an immensely and increasingly powerful tool. To take full advantage, it helps if the investigator is fully conversant with the detailed structure of the heart, particularly such features as the precise arrangement of the atrial septum (fig 9), the origin and proximal course of the coronary arteries (fig 10), and the structure of the aortic root.[3] Detailed descriptions of these features are beyond the scope of this brief review, but the structure of the atrial septum will be addressed in a subsequent article in this series of anatomic reviews. The simple rules as set out here, nonetheless, should provide the information needed to display the echocardiographic manifestations of clinically significant cardiac structure.

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1. **Silverman NH, Hunter S, Anderson RH,** *et al***.** Anatomical basis of cross-sectional echocardiography. *Br Heart J* 1983;**50**:421–31.
- *This review, now nearly 20 years old, sets out the philosophy summarised in the current article. Nothing has changed in the meantime, except that the echocardiographic machines are now much more powerful, and demonstrate the anatomy in even greater detail.*

2. **Cosio FC, Anderson RH, Kuck K,** *et al***.** Living anatomy of the atrioventricular junctions. A guide to electrophysiological mapping. A consensus statement from the Cardiac Nomenclature Study Group, Working Group of Arrhythmias, European Society of Cardiology, and the Task Force on Cardiac Nomenclature from NASPE. *Circulation* 1999;**100**:e31–7; *Eur Heart J* 1999;**20**:1068–75; *J Cardiovasc Electrophysiol* 1999;**10**;1162–70.
- *This article sets out the obvious, but highlights a problem that we had ignored even though, for many years, we had professed to illustrate the heart as seen by the clinician. We had failed to observe that the terms used to describe the heart reflects its position as standing on its apex, rather than its true position within the thorax. This means that there is, in general, a deficiency of almost a right angle in current descriptions. Those structures presently said to be "anterior" are, in reality, superior, and so on. The article emphasises the deficiencies of the current approach for the electrophysiologist, but they are equally applicable to description of the coronary arteries.*

3. **Anderson RH.** Clinical anatomy of the aortic root. *Heart* 2000;**84**:670–3.
- *This review was the forerunner to this article in our contributions to "Education in Heart". We discussed the structure of the aortic root, emphasising clinical features, and pointing to problems in defining the enigmatic "annulus".*