1. Introduction (2'34")

The purpose of our video is to discuss the normal echocardiographic examination, and to introduce its anatomic foundations. This booklet is designed to supplement, and to expand, the material demonstrated in the video. Thus, the illustrations are still frames taken from the video. The time codes of the various sections refer to their position within the tape. We have taken the opportunity when writing the booklet, nonetheless, to add additional snippets of information. We might have neglected to mention these aspects when narrating our tape, or else we were prevented from including them because of constraints of time.

There can be no question but that, with the continuing development of the hardware, cross-sectional echocardiography is now an immensely powerful clinical tool. It permits accurate assessment of the structure and function of the cardiac valves. At the same time, it readily establishes the structure, function, and size of the two ventricles. It permits the demonstration of many other features. For the purposes of this video, it is the valves and the ventricles which are the focus of our attention. In order properly to access all the potential information provided by the interrogating sound beam, the starting point is to understand the location of the heart within the body.

2. Landmarks of the Heart (3'54")

We start our exploration by demonstrating the essential landmarks which permit the echocardiographer to locate the heart within the body. The first structure to be identified is the sternal angle, the prominent ridge felt just below the suprasternal notch where the manubrium meets the body of the sternum. The second costal cartilages articulate with the sternum at this level, so the intercostal space palpated just below the angle is the second space. This space, on the left side, marks the upper extent of the left border of the heart. The border itself then slopes laterally and outwards to the apex beat. This can readily be palpated during the

echocardiographic examination. In the normal individual it lies in the fifth or sixth intercostal space at the midclavicular line, although obviously it can be displaced markedly should the heart be enlarged. From the apex beat, the inferior surface of the heart is marked by a vertical line drawn to the right edge of the sternum. The right border of the heart then extends upwards and vertically to the level of the third intercostal space to the right of the sternum. Joining together these points produces the surface silhouette of the cardiac borders (Fig. 1).

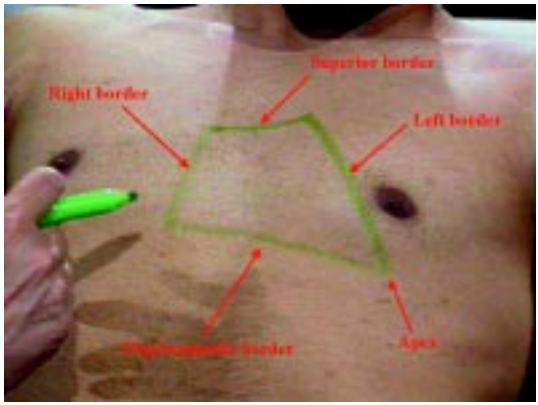

Figure 1. The cardiac silhouette has been drawn on the chest wall.

3. The Heart within the Chest (5’34”)

Having established the location of the heart relative to the landmarks of the thorax, it is then essential that the various components of the heart be understood as they relate to each other, but within the context of the heart itself being described as it lies within the chest during life (Fig. 2). It is of no advantage for the clinician if the heart is described as it might be seen when removed from the body subsequent to an autopsy examination.

4. Attitudinal Descriptions (6’11”)

The process of studying the heart anatomically as it is positioned in the heart during life is called attitudinal description. Although the anatomist in our team (RHA) has,

Figure 2. The cast of the heart is demonstrated as it lies in the chest.

for quite some time, expressed the intention always to use attitudinally correct descriptions, not always has this principle been followed. It is also the case that, conventionally, many terms currently used to describe various parts of the heart are attitudinally incorrect. Irrespective of such current failings, it is our belief that the echocardiographic interrogation is greatly facilitated if the investigator has an appreciation of the proper attitudinal arrangement. All structures in the body, irrespective of the posture of the individual being examined, are described using the framework of the so-called anatomical position. To adopt this position, the subject stands upright, facing the observer, and extends the arms slightly from the side with the palms directed forward and the thumbs out (Fig. 3). Structures are then described

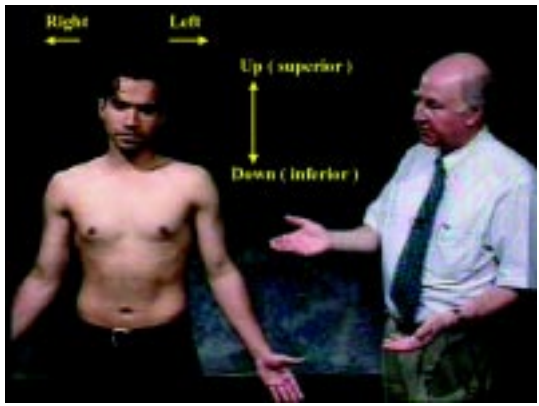

Figure 3. The subject is in the anatomical position.

relative to this position even if the subject is lying down during the examination, as is usually the case during the echocardiographic study. Thus, even though the subject will be lying supine during the study, the head is still considered to be up, or superior, whilst the feet are down, or inferior. The right and left sides are indicated by the positions of the hands. Turning the subject to the side (Fig. 4) the sternum is seen to the front, or anterior, whilst the spine is to the back, or posterior. The various components of the heart are then related to these coordinates, and described within the framework of the anatomical position. In this respect, it must then be remembered that the heart is located within the mediastinum with most of its bulk to the left of the midline. More importantly, its long axis is markedly skewed relative to the long axis of the body itself (Fig. 5).

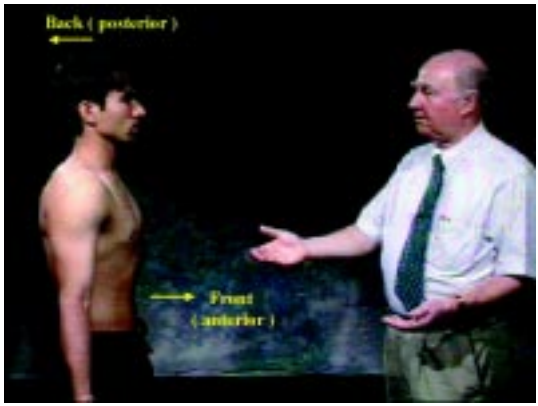

Figure 4. Turning to the side reveals the anterior and posterior surfaces of the body.

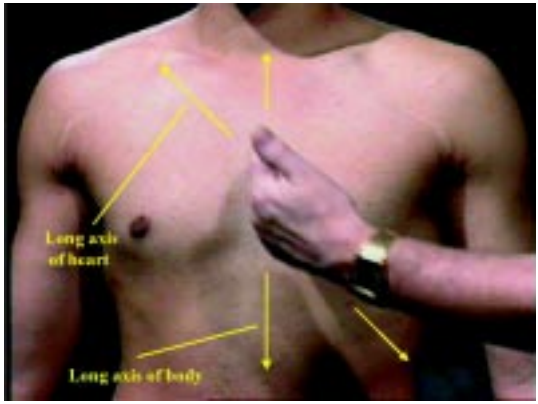

Figure 5. The long axis of the heart is malaligned relative to the bodily long axis.

5. Structure of the Heart (8’09”)

Having established the rules for description of the heart, and assessed its position within the thorax (Fig. 5), we are now in position to return to our cast showing the internal structure of the heart (Fig. 2). We can then describe the attitudinally correct relationships of its constituent parts. The cast itself has been made by taking a normal human heart and filling the so-called right heart chambers with blue silastic, and the allegedly left-sided chambers with red silastic. When the heart is positioned as it normally lies within the chest (Fig. 6), it can immediately be seen that, in reality, the purported right-sided chambers are in front of, or anterior to, their allegedly left-sided counterparts. This discrepancy between the arrangement during life, and the terms conventionally used for description, is one of the legacies of the old habit of removing the heart from the body and positioning it on its apex prior to description. Be that is it may, the old names will not be discarded. We need, therefore, to appreciate the proper positions of the so-called right and left-sided chambers. All that is seen of the left ventricle when viewed frontally is a small strip running down the sloping left lateral cardiac border. The aorta, however, is prominent as it sweeps upward from the middle of the cardiac mass. The larger part of the borders of the cardiac silhouette is made up of the right atrium and right ventricle. The right atrium occupies the entirety of the right border, with the superior and inferior caval veins entering at its upper and lower margins. The right ventricle is then found to the left of the atrium, with the plane of the tricuspid valve almost

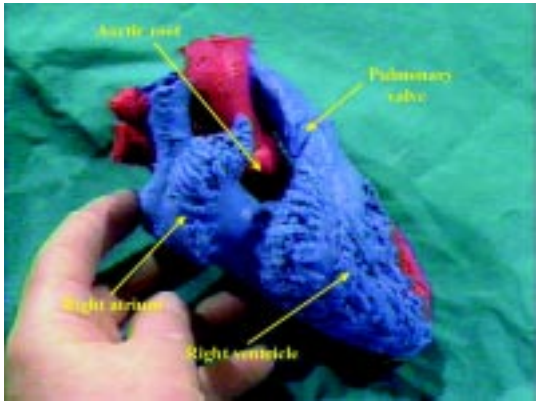

Figure 6. The cast of the heart demonstrated as it lies in the chest (See Fig. 2).

vertical. The inferior margin of the cardiac mass is formed exclusively by the right ventricle, which swings upwards and leftwards around the aorta to the pulmonary valve. The pulmonary valve, supported on its muscular infundibulum, occupies the leftward and superior margin of the silhouette. There is a space in the middle of the heart between the tricuspid and pulmonary valves. This is the site of the supraventricular crest of the right ventricle.

Removing the blue cast of the right heart chambers reveals the structure of the posteriorly located left atrium and ventricle (Fig. 7). The aorta, springing from the middle of the cardiac mass, is positioned in front of the body of the left ventricle. The left atrium is the most posterior of all the cardiac chambers. Its appendage swings upwards and outwards from its leftward and superior border. This is the only part of the left atrium which forms part of the frontal cardiac silhouette. The right pulmonary veins enter the right side of the left atrium, although in life they lie directly behind the right atrium. The cast shows the important adjacency of the aortic and mitral valves. As we will see, the continuity between the leaflets of these valves is an important landmark for the echocardiographer interrogating the left heart chambers, and is an important difference in structure between the right and left sides of the heart.

So as to cement these various relationships, we can review and revise them using diagrammatic depictions. The first diagram (Fig. 8) shows the anatomical position. Fully to describe structures in this position, we need to take note of three orthogonal planes. Two of these planes are in the long axis. The so-called coronal plane cuts the body from side to side, whereas the sagittal plane runs from front to back. The third orthogonal plane is then in the short axis, and is at right angles to both the frontal and the sagittal planes. The second diagram (Fig. 9) shows the overall position of the heart within the body. Although part of the medisatinum, the heart is normally positioned with two-thirds of its bulk to the left of the midline. Significantly, its own long axis is markedly malaligned relative to the long axis of the body.

If we then confirm the location of the cardiac chambers within the frontal silhouette (Fig. 10), we see that the so-called right chambers are, in reality, anterior, with the atrium basically to the right of the ventricle. All that is seen of the posterior left chambers is the tip of the left atrial appendage, along with a strip of left ventricle extending down to the cardiac apex. We can then superimpose the cardiac valves within this cardiac silhouette (Fig. 11). The valves of the right side are

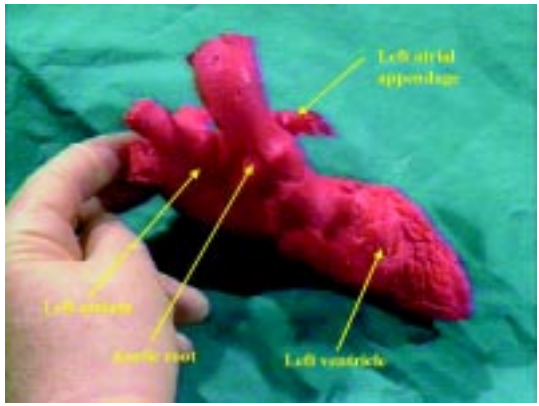

Figure 7. The right side of the heart has been removed, revealing the posterior location of the left heart chambers.

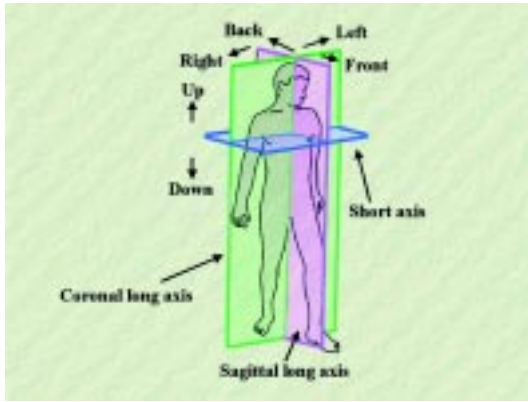

Figure 8. The planes of the body are described relative to the anatomic position (See Fig. 3).

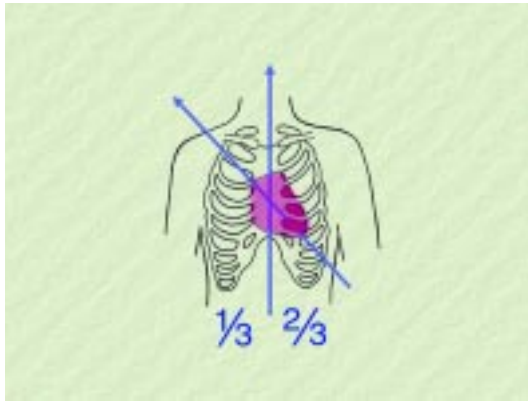

Figure 9. The location of the heart within the chest (See Fig. 5).

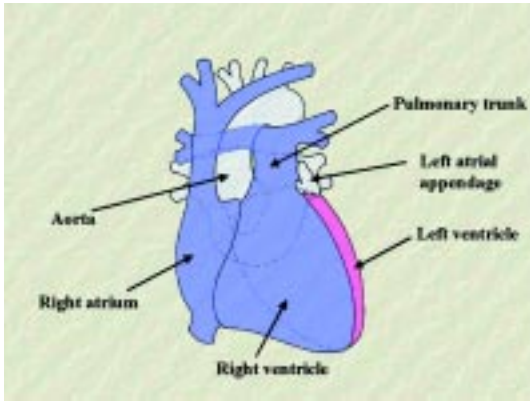

Figure 10. The location of the cardiac chambers within the cardiac silhouette (See Fig. 6).

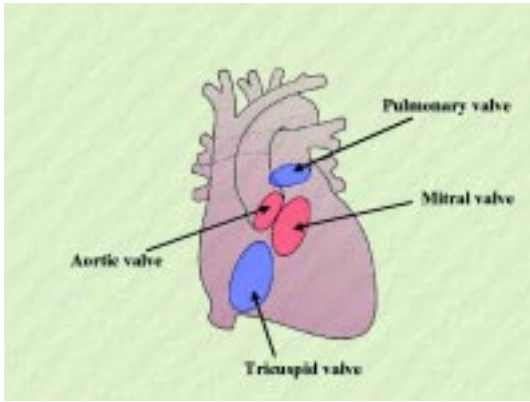

Figure 11. The location of the valves relative to the cardiac silhouette.

separated, with the tricuspid valve the most inferior and rightward, and the pulmonary valve the most superior and leftward. The aortic valve occupies the centre of the heart, being positioned in front of the mitral valve and just above it. Although thus far we have emphasised the orthogonal planes of the body, we must remember that the heart has its own orthogonal planes (Fig. 12). For the most part, these planes correspond with the sections we will see when we examine the echocardiographic images. As long as we make allowances for the discrepancies between the cardiac and bodily axes, it is of great value to describe the planes of the heart itself. Two are in the cardiac long axis, extending from the stomach up towards the right shoulder. One of these cuts the heart from front to back, and is parallel to the larger

part of the ventricular septum. This plane, and the others parallel to it, basically show two of the cardiac chambers, although components of the other side of the heart are almost always included because the two ventricular outflow tracts spiral round each other. The other long axis plane is at right angles to the bulk of the ventricular septum. This is the so-called four chamber plane. As we will see, it can also be scanned so as to incorporate the subaortic outflow tract and the aortic valve. The third series of planes is the short axis collection. These planes are at right angles to both series of planes which cut the heart in its long axis. Although the echocardiographer will use any plane, be it orthogonal or oblique, so as to demonstrate the structures of interest, for the purposes of demonstration we will illustrate the echocardiographic manifestations of only the three orthogonal planes of the heart.

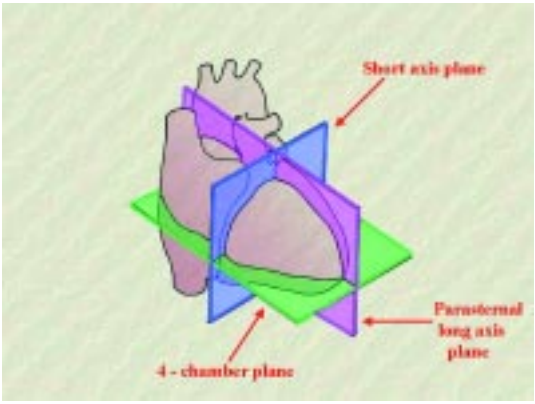

Figure 12. The orthogonal planes of the heart.

6. The Parasternal Long Axis Planes (15'25")

When considering the sectional anatomy of the heart in the context of echocardiography, then probably the most important, and frequently used, plane is the long axis one which cuts the heart from the front to the back (Fig. 13). This plane can be obtained either from the parasternal windows, exploring through the intercostal spaces, or from the apex. The heart is cut from its own apex up through the middle of the aorta. Conventionally, we display the right side of the heart, turning it so that the apex is pointing to our left hand. The sternocostal anterior surface of the heart is then shown as though superior, with the inferior, diaphragmatic,

surface looking downwards (Fig. 14). During the echocardiographic study, the sound beam would enter the heart from the top if interrogation takes place from the parasternal window, or from the left hand side if explored from the apex. The section shows well the interrelationships of the left atrium and ventricle, and shows the antero-superior position of the infundibulum of the right ventricle, transected as it swing upwards and leftwards to the pulmonary valve. The larger part of the ventricular septum is parallel to the section, but the antero-superior septum is transected. The left atrium is the most posterior chamber, and the atrioventricular groove containing the coronary sinus and circumfex artery is well seen. The leaflets of the mitral valve are usually described as being anterior and posterior. This description is mostly correct, but the mitral valve itself is obliquely located within the left ventricle. A better way of describing the leaflets of the mitral valve is to recognise their origin. The anterior leaflet, having considerable depth, is directly continuous with the aortic root. This leaflet, therefore, is better described as the aortic leaflet. The other leaflet, much shallower than the aortic leaflet, is hinged from the inferior atrioventricular junction. This is the mural leaflet. The centrepoint of the parasternal long axis section is the aortic valve. This structure itself has considerable length, extending from the basal attachment of the leaflets to the sinutubular junction with the aorta. The leaflets transected in this section are those supported by the right coronary and non-coronary aortic sinuses. The right coronary leaflet is hinged on the musculature of the ventricular septum, whilst the non-coronary leaflet is in fibrous continuity with the aortic leaflet of the mitral valve.

All this anatomy is readily demonstrated by the echocardiographer. To obtain the necessary image, the transducer is placed in the third or fourth intercostal space just to the left side of the sternum, and is pointed so that the dot on the transducer is aimed at the right shoulder (Fig. 15). With the sound beam then approaching from the anterior chest wall, it cuts first the free wall of the right ventricle before extending across the cavity of the right ventricle to pass across the ventricular septum. It then shows the cavities of left ventricle and atrium, the aortic and mural leaflets of the mitral valve, and the right coronary and non-coronary leaflets of the aortic valve (Fig. 16). Minimal angulation of the transducer superiorly then permits the echocardiographer to visualise the pulmonary valve on its infundibulum (Fig. 17). Downwards and lateral angulation reveals the tricuspid valve interposed between the right atrium and ventricle (Fig. 18).

Figure 13. The heart has been sliced along its own long axis.

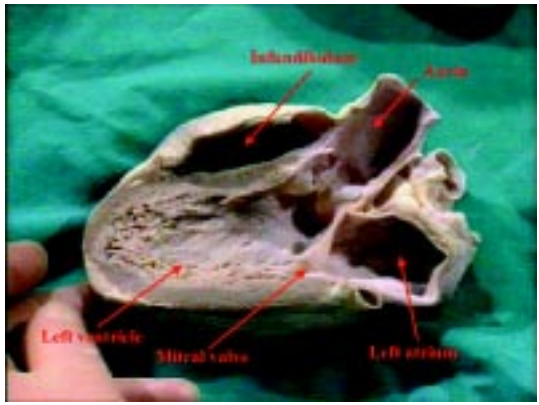

Figure 14. The orientation of the parasternal long axis slice through the heart.

Figure 15. Dr Brecker is demonstrating the ridge on the transducer, which is directed towards the right shoulder so as to obtain the parasternal long axis section.

Figure 16. The echocardiographic parasternal long axis image. The inset shows the position of the transducer.

Figure 17. The transducer has been angled to the left from the position demonstrating the long axis section of the left ventricle (See Fig. 16) to show the pulmonary valve.

Figure 18. Angulation of the transducer to the right (compare with Fig. 16) reveals the right atrium and the right ventricle in their own long axis.

7. The Parasternal Short Axis Planes (21'42")

This series of planes is typically obtained from the parasternal window, hence their name, but very similar images can be produced from the subcostal window (see Section 9). Because of constraints of time, we illustrate them in the video only as obtained from the parasternal approach. Although any number of short axis planes can be cut along the ventricular mass, for the sake of simplicity we illustrate only three. The most apical of these illustrative planes is taken across the papillary muscles of the mitral valve. The section (Fig. 19) is orientated as though viewed from beneath, and is attitudinally correct. The left ventricle has an obvious circular profile, and the papillary muscles of the mitral valve are obliquely positioned supero-posteriorly and infero-anteriorly within the ventricular cross section. The inferior muscle is much closer to the ventricular septum. The middle slice across the ventricle confirms the oblique orientation of the papillary muscle (Fig. 20). The most superior anatomic slice shows well the relationship of the cardiac valves within the cardiac short axis (Fig. 21). The aortic valve takes centre stage, interposing between the mitral valve and the septum. Sections close to the atrioventricular junction transect the area of aortic-to-mitral fibrous continuity. The tricuspid valve is positioned inferiorly, with its three leaflets located inferiorly, antero-superiorly, and septally. Unlike as in the left ventricle, the septal leaflet is directly adjacent to the septum. The short axis section shows well how the right ventricle wraps itself in banana-like fashion around the circular left ventricle as its outflow tract extends up to the superior and leftwardly located pulmonary valve. The muscular supraventricular crest forms the roof of the ventricle between the hinges of the tricuspid and pulmonary valves.

To obtain these short axis sections echocardiographically, the transducer is first positioned so as to obtain the long axis parasternal section, and is then rotated through 90 degrees towards the left shoulder (Fig. 22). The standard section then shows the arrangement of the papillary muscles of the mitral valve (Fig. 23), a view which can be reinforced by angulation towards the apex. Much more information is obtained by superior angulation of the transducer. The short axis sections then show well the "fish-mouth" arrangement of the leaflets of the mitral valve, with their oblique positioning in the left ventricle (Fig. 24). It is these sections which are typically used to asses the motion of the walls of the left ventricle, and to identify any areas of asynchronous contraction. Continued upward angulation (Fig. 25) then

Figure 19. The apical short axis slice across the ventricular mass.

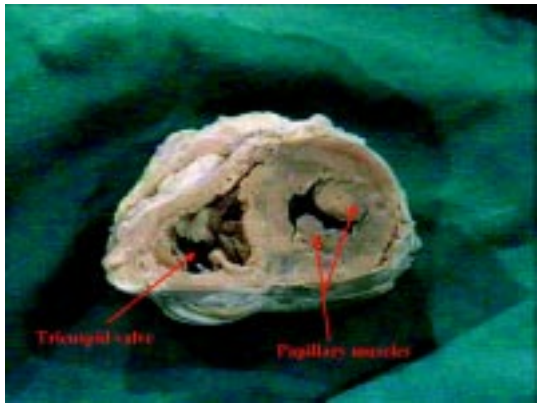

Figure 20. The middle short axis section of the ventricles reveals the papillary muscles of the mitral valve.

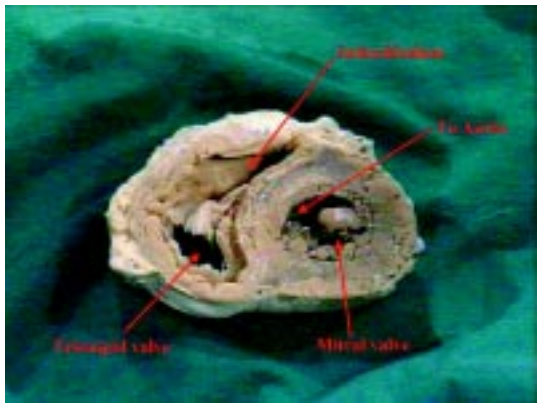

Figure 21. The basal short axis section shows the different orientation of the inlet and outlet valves in the two ventricles.

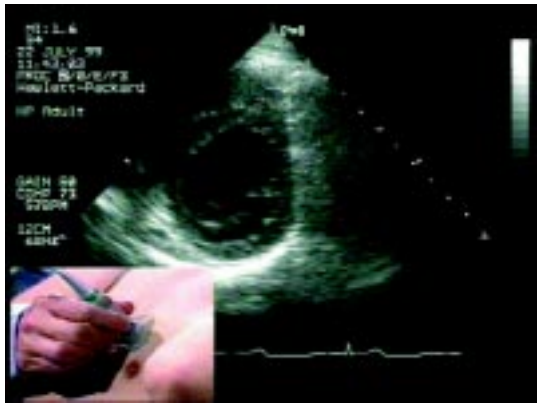

Figure 22. The position of the transducer required to obtain short axis cuts through the ventricles from the parasternal window.

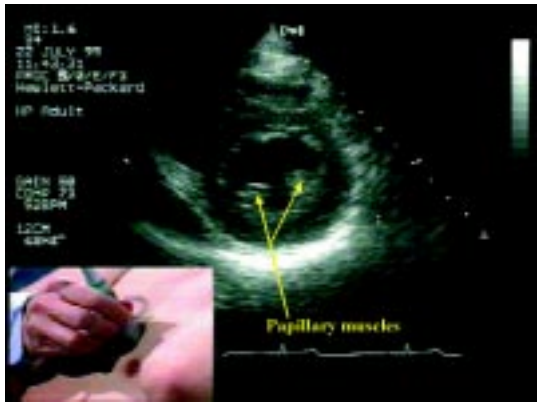

Figure 23. The short axis cut showing the papillary muscles of the mitral valve (Compare with Fig. 20).

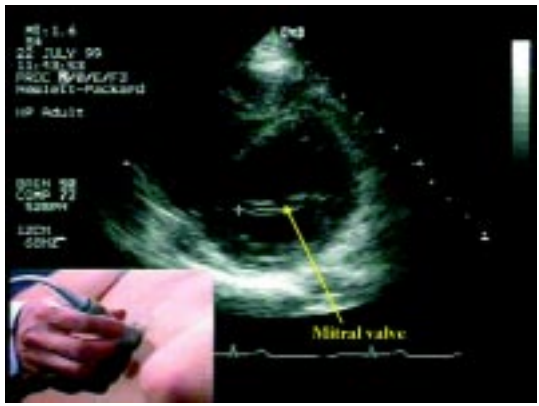

Figure 24. The short axis cut showing the "fish mouth" arrangement of the leaflets of the mitral valve.

reveals the trifoliate arrangement of the aortic valve. If present, this view will obviously demonstrate an aortic valve with only two leaflets. The echocardiographic sections at this level also demonstrate the structure of the atrial septum, with the flap valve adherent to the infolded rims of the oval fossa. Further interrogation reveals the right ventricular outlet and the bifurcation of the pulmonary trunk (Fig. 26).

Figure 25. The basal short axis cut shows the trifoliate pattern of the aortic valve and its relations to the subpulmonary infundibulum and the pulmonary valve.

Figure 26. Further angulation shows the full length of the subpulmonary muscular infundibulum.

8. The Apical Planes (26'21")

From the apex, the echocardiographer is able to obtain the plane running parallel to the larger part of the ventricular septum as already revealed from the parasternal window. The more important apical plane, however, is the one which cuts across the postero-inferior part of the ventricular septum. When sliced close to the postero-inferior surface of the heart (Fig. 27), this reveals all of the cardiac chambers, so not unexpectedly it is usually called the four chamber plane. The major anatomic feature of this section is the off-setting of the hinges of the tricuspid and mitral valves in the centre of the section. The structure of the atrial septum is also well seen, with the flap valve adherent to the infolded superior rim of the oval fossa. Although often described as the "septum secundum", the sections show well that this superior rim is no more than the infolded atrial wall between the superior caval vein and the right pulmonary veins. The adult echocardiographer, however, does not typically display this section attitudinally as shown in Fig. 27. Instead, the heart is usually displayed with the apex pointing upwards. The anatomist is able to replicate this view by showing the anterior half of the heart (Fig. 28). This section then reveals nicely how the subaortic outflow tract "lifts" the mitral valve away from the septum. At the union of the aortic root with the muscular ventricular septum, the fibrous membranous septum interposes between the left and right-sided chambers. The anatomic section also shows well the fine criss-crossing apical trabeculations of the left ventricle, which should be contrasted with the much coarser right ventricular apical trabeculations.

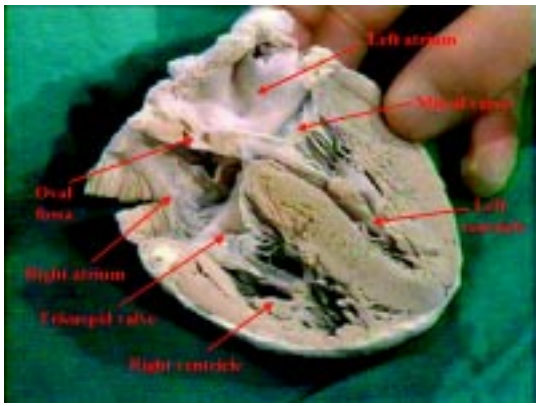

Figure 27. The four chamber cut shown in attitudianally correct orientation.

The echocardiographer obtains the four chamber plane by placing the transducer at the apex, or one interspace below (Fig. 29). As already explained, it is traditional to show the image in non-attitudinal position, with the apex to the top of the screen (Fig. 30). Usually the operator tries to get the ventricular septum positioned vertically. The section then reveals well the two ventricles, usually with the moderator band being seen in the right ventricle. The off-set hinges of the tricuspid and mitral valves dominate the centre of the image. Posterior angulation reveals the coronary sinus running in the postero-inferior atrioventricular groove (Fig. 31), whilst upwards angulation brings into prominence the subaortic outlet and the aortic valve (Fig. 32). This section is particularly important for doppler assessment of flow

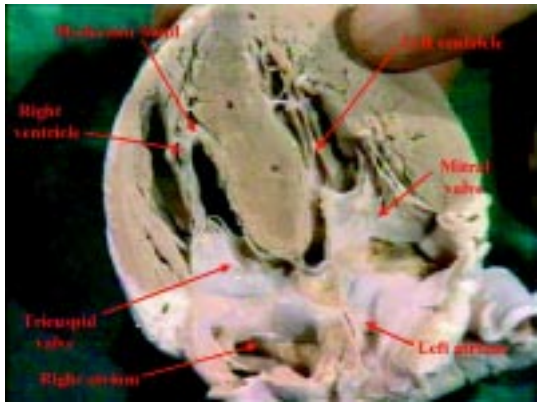

Figure 28. The reciprocal half of the heart shown with apex upward.

Figure 29. The position of the transducer to reveal the apical four chamber cut.

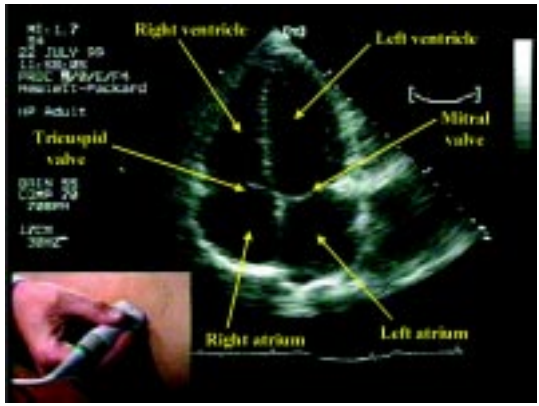

Figure 30. The classical apical four chamber cut of the heart.

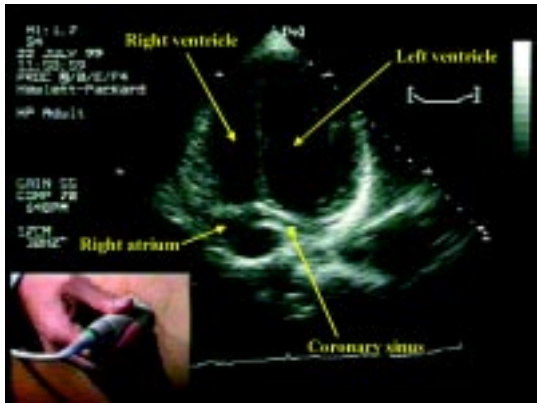

Figure 31. Posterior angulation of the transducer shows the coronary sinus in the left atrioventricular groove.

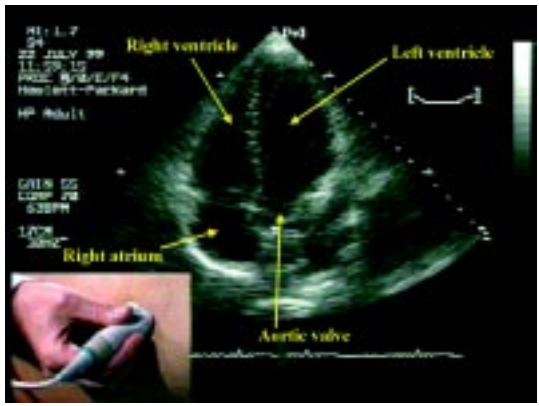

Figure 32. Anterior angulation reveals the aortic root.

across the left ventricular outflow tract. So as to demonstrate the section comparable to the parasternal long axis msection, the transducer is simply rotated through 90 degrees (Fig. 33). The heart is then shown once more with the apex pointing upward. The septum is seen to the right side of the screen, and the diaphragmatic surface of the heart to the left.

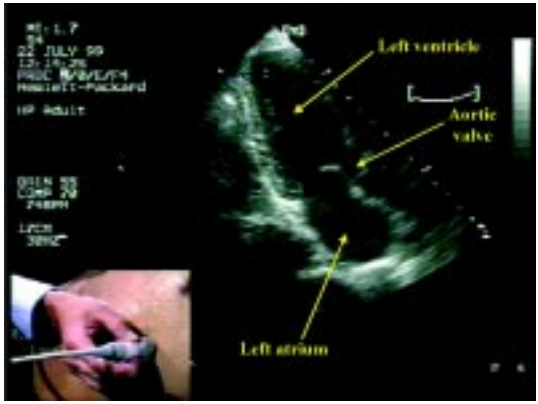

Figure 33. Rotation of the transducer demonstarted the apical long axis section of the left ventricle.

9. The Subcostal Window (31'50")

This approach is particularly valuable for the paediatric echocardiographer, but is also used by the adult echocardiographer when the apical approach proves non-echogenic. The transducer is placed under the xiphisternum, having asked the subject to lie flat and to try and relax the abdominal muscles. Then, with the dot on the transducer to the patient's left, the transducer is angled superiorly and to the left (Fig. 34). The sections are produced so as to replicate the apical four chamber section, but are seen with the liver to the top of the screen (Fig. 35). All the landmarks of the right and left ventricles are well seen, including the moderator band. The cuts provide a particularly good view of the atrial septum.

Figure 34. The position of the transducer to access the subcostal portal.

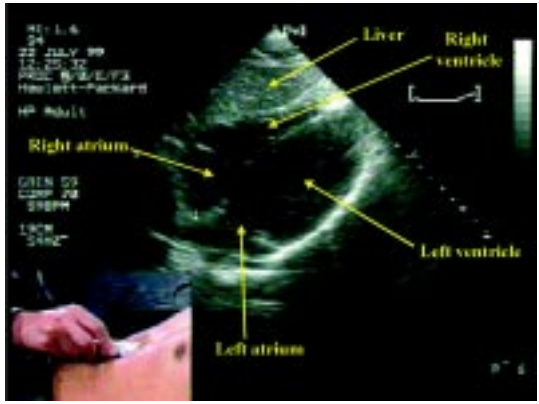

Figure 35. The subcostal four chamber cut of the heart.

10. Conclusions (33'24")

Although limited by the constraints of time, our aspirations in constructing the video, supplemented by this booklet, were to demonstrate the anatomic correlates of cross-sectional echocardiography. Many aspects have not received any coverage, such as M-mode interrogation, the value of Doppler and colour Doppler, the use of stress testing or contrast investigations, and the particularly important topic of transesophageal investigation. We hope to explore this in a subsequent videotape. We have tried, nonetheless, to review the basics of the transthoracic approach to the

normal echocardiographic examination. We have illustrated the crucial parasternal long axis section, and the three basic short axis section across the ventricular mass. We have then demonstrated the apical and subcostal images, with their anatomic counterparts. Through all of these demonstrations, we have concentrated on the cardiac valves, which guard the entrances to, and the exits from, the tripartite ventricles. The key to the echocardiographic study is to recognise that, in the left ventricle, the inlet and outlet valves are directly adjacent while, in the right ventricle, they are separated in the ventricular roof by the muscular supraventricular crest. If any one feature is worthy of special emphasis, it is the central location of the aortic valve. What the videotape demonstrates beyond question is that the echocardiographer will become tomorrow's cardiac anatomist, since all the features seen with the heart in one's hand are demonstrated with equal facility by the ultrasonic beam.