ESSENTIALS OF ECHOCARDIOGRAPHY #1

Two-Dimensional Echocardiography in the Normal Heart

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Introduction

Echocardiography is a unique noninvasive method for imaging the living heart. It is based on detection of echoes produced by a beam of ultrasound (very high frequency sound) pulses transmitted into the heart.

From its introduction in 1954 to the mid 1970's, most echocardiographic studies employed a technique called M-mode, in which the ultrasound beam is aimed manually at selected cardiac structures to give a graphic recording of their positions and movements. M-mode recordings permit measurement of cardiac dimensions and detailed analysis of complex motion patterns depending on transducer angulation. They also facilitate analysis of time relationships with other physiological variables such as ECG, heart sounds, and pulse tracings, which can be recorded simultaneously.

A more recent development uses electromechanical or electronic techniques to scan the ultrasound beam rapidly across the heart to produce two-dimensional tomographic images of selected cardiac sections. This gives more information than M-mode about the shape of the heart and also shows the spatial relationships of its structures during the cardiac cycle.

A comprehensive echocardiographic examination, utilizing both M-mode and two dimensional recordings, therefore provides a great deal of information about cardiac anatomy and physiology, the clinical value of which has established echocardiography as a major diagnostic tool.

This unit covers the principles of two-dimensional echocardiography in more detail; it explains the normal two-dimensional recordings in terms of the anatomy of the cardiac sections scanned by the ultrasound beam. Some supplementary M-mode recordings are included. Subsequent units will discuss applications of both M-mode and two-dimensional echocardiography in acquired and congenital disease.

Two-Dimensional Scanning

Mechanical Sector Scanners

In the M-mode technique, all the ultrasonic pulses are propagated along the same axis and different parts of the heart are studied by changing the direction of the beam manually. An M-mode echocardiogram is not a "picture" of the heart, but rather a diagram that shows how the positions of its structures change during the course of the cardiac cycle. It is an admirable method for studying a structure like a heart valve, but it does not provide information about the spatial relationships of different parts of the heart to each other. However, this can be accomplished by scanning the ultrasound beam rapidly back and forth across a section of the heart.

Because access to the heart afforded by the ribs and lungs is very limited, almost all cardiac scanners are of the sector type. A mechanical sector scanner can use either an oscillating or rotating scan head. In the rotating type **(Fig. 1)**, several transducers spin inside a small dome filled with liquid. As each one passes over the heart, it transmits pulses and receives echoes. The next element then takes over, like a succession of beams from a lighthouse scanning over the sea. The echo signals are displayed in B-mode form. Signals from the scan head are used to steer the oscilloscope beam in the same manner as the ultrasound beam. The result is a tomographic image of the heart, showing the structures in the selected scan plane and their motion patterns.

Electronically Steered or Phased Array Sector Scanners

The ultrasound beam can also be steered electronically, without moving the transducer. Electronically steered, or “phased array” systems **(Figs. 2 to 4)** typically comprise 96 to 128 small elements (only a few are shown), which are pulsed in a very rapid, precisely controlled sequence. The top element is pulsed first **(Fig. 2);** because it is very small, the ultrasound wave it generates is circular. Very soon afterwards, the second element is pulsed, and so on. The individual wavelets combine to make one compound wave that, because of the pulsing sequence, travels at an angle to the axis of the transducer array. Returning echoes do not reach all the transducer elements simultaneously; electronic circuits delay the signals from those arriving first, allowing the remainder to catch up **(Fig. 4)**. Continuously changing the pulsing sequence scans the ultrasound beam in a manner similar to a mechanical scanner. Despite the necessary complexity of the electronic circuitry the phased array technique offers methods for reading the effective beam width not possible with mechanical systems. This is a very important factor in improving image quality. Focusing can be achieved by fitting a plastic lens over the face of the transducer. Phased array systems can provide additional focusing electronically; a lens works by delaying portions of the wavefront and a phased array can achieve the same effect electronically by further modifying the pulsing sequence **(Fig. 3)**. A phased array system can also employ a technique called “dynamic focusing” **(Fig. 4)**. If a pulse is transmitted across two interfaces, A and B, the echo from A returns first. Its curved wavefront reaches the center transducer elements before those at the edges. The electrical signals from the central elements are delayed to allow those from the edges to catch up. All the signals are then added together (A1). A few microseconds later, echoes from B arrive. This wavefront is less curved, so the delay pattern is altered. In this way the receiver changes its focal distance as echoes from more distant structures arrive, just as a pair of binoculars can be adjusted to keep an airplane in focus as it flies past. This technique rejects off-axis echoes that reduce effective beam width.

Quality of Two-Dimensional Images

A single two-dimensional scan comprises a number of radial lines, each displaying echoes in B-mode format. For accurate images both the echoes shown on each B-mode line should accurately reflect the structures encountered by the ultrasound beam, and the two-dimensional image should contain the maximum possible number of lines. Because the ultrasound beam is not a fine, laser-like line, objects that lie off-axis are detected and generate artifactual multiple echoes **(Fig. 5)**. This greatly impairs lateral resolution, the major limiting factor in B-mode image accuracy. Reduction of beam width by focusing techniques is therefore necessary to make the beam as narrow as possible. The number of B-mode lines available to form a two-dimensional image is determined by the velocity of ultrasound in the body **(Fig. 6)**. For a 20 cm depth the maximum pulse rate is 3750 per second. Also, the structures being imaged must not move significantly during the period of the scan. A cardiac scan must therefore be completed in $1/60^{th}$ of a second or less depending on power supply characteristics to 'freeze' valve motions, and a succession of such images made for each cardiac cycle (1 second) to show the motion patterns. If 60 images are made each second, only 75 lines gives 2.5 lines per degree, but if increased to 90 degrees, there is less than one line per degree. Sector scanning systems must therefore compromise between scans per second, scan angle, and line density. **Fig. 7** summarizes two beams. With poor lateral resolution, multiple images are formed of A and some echoes from B are also detected. (2) Increasing line density without improving lateral resolution simply gives more multiple images. (3) If resolution is improved but line density remains low, a clear image is made of A but B disappears. There must be both high line density and good resolution for high-quality images of both objects.

Recording a Two-Dimensional Display

The simplest method of recording a two-dimensional display is to focus a TV camera on the oscilloscope image and record it on a standard video tape recorder. However, this does not give very good image quality, partly because of the double conversion from electrical to visible image, then back to electrical before obtaining the final visible image, and also because of interaction between the radial scan lines forming the sector image and the parallel lines used for TV. Another possibility is to use a movie camera, but film is expensive and processing it takes time. Furthermore, unless the movie camera shutter is synchronized to the oscilloscope scan rate, there will be unsightly flickering or blank bars across the picture.

A much better method is to change the sector image into a TV format by means of a digital scan converter **(Fig. 9)**. This comprises a matrix of electronic memory cells (typically 512 x 512 elements). The image intensity at each point on the waveform is assigned a specific number by which is it expressed in digital form on a scale of 0-64 grey levels and its value stored in the appropriate memory cell. The memory matrix can then be "read" in any sequence, for example as a series of horizontal lines to form a TV image, or as vertical lines to enable it to be printed by a fiberoptics strip chart recorder. Digitizing the image also permits a certain amount of manipulation, for example addition of alphanumeric characters, changing contrast, or elimination of low-level "noise".

Images from a scan converter can be transferred directly onto videotape. For quantitative analysis, selected scans can be photographed or measured directly from the oscilloscope screen.

It is sometimes useful to be able to record M-mode and two-dimensional images simultaneously. This makes it possible, for example, to analyze in detail the motions of structures whose precise spatial orientation is defined by a two-dimensional image. An electronic cursor superimposed on the display is adjusted to the desired position and the appropriate B-mode lines are printed on an M-mode strip-chart recorder. Unfortunately, with a mechanical sector scanner only one such line is available for each two-dimensional scan field (typically 60 per second) and the resulting M-mode recording quality is poor. With an electronically steered system, however, the beam direction can be changed in any desired sequence. For example, it is thus possible to allocate 500 pulses a second for transmission along a selected axis to form a good quality M-mode recording, alternating these with pulses whose direction is changed sequentially to form the two-dimensional image **(Fig. 8)**.

Access to the Heart for Echocardiography

In a normal subject of average build, the position of the heart can be defined from the rib cage **(Fig. 10)**. The cardiac outline extends from the junction of the second left costal cartilage with the sternum at the sternal angle to the apex beat, usually in the fifth intercostal space on the midclavicular line. From the apex, the inferior surface of the heart runs across to a point in the right fifth intercostal space about 1 cm from the sternal edge, then it parallels the sternum to a point 1 cm to the right of its junction with the third right costal cartilage. The base of the heart is marked by a line joining the right third costal cartilage and the left second costal cartilage.

Most of the heart is covered anteriorly by bony structures, the sternum and ribs, or by the lungs within their pleural membranes, and these tissues are virtually impenetrable to ultrasound. However, as shown in **Fig. 11**, the left lung does not cover the heart completely and in most individuals beneath the third, fourth and fifth intercostal spaces, for 2 or 3 cm to the left of the sternal border, the pericardium lies directly beneath the chest wall and pleural membranes. This region, termed the left parasternal area, provides the best access for echocardiography. Moreover, it lies over the center of the heart, and the distance from the chest wall to the furthest part of the normal heart is only about 12 cm.

Additional access **(Fig. 12)**, important particularly for two-dimensional echocardiography, can usually be obtained from the cardiac apex and by a subcostal route, with the transducer placed near the xiphisternum.

The great arteries and the base of the heart can also be visualized from the suprasternal notch.

The approaches described above are available, to a greater or lesser degree, in most adults. In young children, the ribs and lungs do not attenuate the ultrasound beam so severely, and in neonates the transducer can be placed almost anywhere on the precordium. By contrast, in adults with “barrel” chests, or who have hyper inflated lungs, for example as a result of chronic emphysema, it can be almost impossible to obtain any echocardiographic images. Lack of adequate access to the heart is the greatest limitation to echocardiography and a large proportion of the technical skill required to perform the examination lies in being able to find a transducer site from which clear images can be obtained.

Standard Planes for Two-Dimensional Echocardiography

Even with the limited access to the heart afforded by the left parasternal, apical, and subcostal transducer positions, it is possible to direct an ultrasound beam at most cardiac structures. For M-mode, it is relatively simple to describe the beam orientation in terms of the structures encountered, but for two-dimensional recordings it is possible to obtain an almost infinite variety of cross-sectional images of the heart. It is therefore desirable to standardize on a limited number of views that cover the majority of applications, and that can be described readily in terms of transducer orientation and anatomical features.

To this end, it has been agreed that two-dimensional echocardiographic images should be based on three orthogonal planes, as shown in **Fig. 13**. The *long-axis* plane transects the heart from the aortic root to the left ventricular apex and includes the aortic and mitral valves. On the surface of the body, it is almost perpendicular to the plane of the sternum and runs approximately from the subject's right shoulder to the left kidney. The *short axis* approximates to the plane of the atrioventricular junction. On the surface of the body, it is at right angles to the plane of the sternum and runs from the left midclavicle to the right hip. The *four-chamber* plane is at right angles to both the long and short axes. It runs from the apex to the base of the heart and is approximately perpendicular to both the posterior interventricular septum and the interatrial septum. As its name implies, it includes parts of each of the four cardiac chambers. On the surface, it is parallel to the plane of the sternum, and includes both the apex and the right shoulder.

As can be appreciated from **Fig. 13**, the three best echocardiographic approaches to the heart correspond approximately to the points at which the three standard planes intersect. Thus, from the left parasternal transducer position, it is possible to examine the long-axis and short-axis planes. From the apical position, the long-axis and four-chamber planes can be visualized, and from the subcostal position, the four-chamber and short-axis planes.

Two-Dimensional Recording Technique

Transducer Manipulation

Much of the skill needed to perform an echocardiographic examination lies in being able to direct the ultrasound beam at cardiac structures of interest in such a way that echoes from them can be detected. The principles of cardiac anatomy and recording technique relevant to M-mode apply equally to two-dimensional echocardiography. The stationary ultrasound beam used for M-mode can be thought of as a flashlight, illuminating only a small area of the heart at a time; a two-dimensional transducer is like a circular saw, rotating around the point where it rests on the chest, with the blade aligned with the index mark on the transducer **(Fig. 16)**. The side of the transducer with the index mark corresponds to the right-hand side of the display.

When performing a two-dimensional examination, therefore, more complex maneuvers are necessary to order to align the scan plane with the desire anatomic axis of the heart. Manipulation of the transducer can be described as follows **(Fig. 16)**. *Rotating* the transducer pivots the scan plane about the transducer axis. Rotation through 90 degrees is used, for example, to change from the parasternal long axis to the short axis. *Tilting* the transducer displaces the scan to form a series of radial planes, like the faces of the segments of an orange. *Angling* the transducer moves its axis in the plane of the scan, for example to bring an object at one edge into the center of the field of view.

Parasternal Views

To obtain parasternal views, the subject is inclined slightly toward the left lateral position. The transducer is placed over the intercostal space as for an M-mode examination **(Fig. 17)**. For the long-axis view, the scan plane is aligned from the right shoulder to the left kidney, with the transducer index mark toward the shoulder so the aorta will appear on the right-hand side of the display. From this position, the transducer is rotated clockwise through 90 degrees to obtain short-axis views (the index mark should now point toward the left midclavicle). Since the right-hand side of the short-axis scan tends to be obscured by lung, the transducer should be positioned as close to the sternal border as possible. It may help to turn the subject more toward the left, and to record during forced exhalation. In difficult subjects, such maneuvers may be necessary even to obtain minimal visualization of cardiac structures.

It is normal to obtain a series of parasternal short-axis views, from the apex to the pulmonary artery, by tilting the transducer along the line of the long axis. When the transducer is aimed toward the apex, a tomographic section is obtained at the level of the papillary muscles. Progressive tilting up the long axis shifts the section first to the mitral valve, then to the left ventricular outflow tract, the aortic and pulmonary valves, and finally to the main pulmonary artery.

Apical Views

The subject is turned to the left, and the transducer is positioned at the exact point where the maximal apical impulse can be felt, with its axis aimed toward the right shoulder **(Fig. 18)**. To obtain a long-axis view, the transducer is rotated so that the index mark points upward. This is a difficult view to obtain in young, slim subjects, because the scan plane is at a right angle to the direction of the ribs and the latter act as a "venetian blind", that greatly limits the field of view.

If the transducer is rotated 90 degrees clockwise, the index mark points toward the left axilla. The scan plane is now parallel to the intercostal spaces, affording an easier view showing the four cardiac chambers together with the interatrial and interventricular septa.

Subcostal Views

The subject is placed in a supine position, possibly with a pillow under the kidneys to arch the back upward. The transducer is positioned just to the right of the xiphisternum, with its axis pointing toward the left shoulder and the index mark oriented toward the left hip **(Fig. 19)**. It is then pressed down so that the ultrasound beam scans underneath the rib cage in the four-chamber plane. Rotation counterclockwise through 90 degrees, to bring the index mark upward, changes the scan plane to the short axis. Subcostal views are often improved by the subject inhaling; this lowers the diaphragm and pulls the heart down toward the transducer.

Parasternal Long-Axis Plane

The long-axis section is familiar to those who have experience of M-mode echocardiography. As shown in **Fig. 21**, it contains the following structures.

At the top is the outflow portion of the right ventricle, below which the plane cuts across the anterior portion of the interventricular septum. The aortic root is seen at the right, with the right coronary (upper) and noncoronary (lower) cusps of the aortic valve. Below the aortic root is the left atrium. To the left of the section is the apex of the left ventricle, in which the posteromedial papillary muscle can be seen. Separating the left atrium from the left ventricle is the mitral valve. The longer, anterior leaflet arises from the posterior wall of the aortic root, and the shorter, posterior leaflet is attached at the atrioventricular groove; the plane cuts across the coronary sinus at this point.

The ultrasound image **(Figs. 23 and 24)** encompasses the region from the papillary muscles to the aortic valve. It clearly shows the motion of the aortic and mitral valves and permits measurement of the left atrial and aortic root dimensions, as well as those of the left ventricular cacity, interventricular septum, and posterior ventricular wall. This view is used for many purposes, including all types of left ventricular outflow obstruction, mitral and aortic valve vegetations, and mitral valve prolapse. It corresponds approximately to the angiographic right anterior oblique view, but reversed right-to-left. Superior angulation of the transducer allows the scan plane to be extended up to the roof of the left atrium and the proximal part of the ascending aorta, which is useful for detecting atrial masses and for aortic root dissection and aneurysms. However, the parasternal long-axis view cannot normally be used to visualize the apical region of the left ventricle, since attempts to angle the scan toward the apex are thwarted by the presence of lung tissue.

With counterclockwise rotation of the transducer and slight medial angulation, the right atrium, tricuspid valve apparatus, and proximal portion of the right ventricular inlet are encountered. This is termed the right ventricular inlet view **(Figs. 25 and 26)**.

Parasternal Short-Axis Plane

Mitral Valve Level

If the transducer is rotated clockwise through 90 degrees from the parasternal long-axis view, the short-axis view is obtained. Provided the mitral valve was in the center of the sector before rotation, the short-axis section will be at mitral valve level. As shown in **Fig. 29**, the tomographic section of the heart shows the left ventricle, bounded by thick, muscular walls comprising the anterior and posterior portions of the interventricular septum on the left and the lateral free wall to the right. Within the left ventricular cavity are the two leaflets of the mitral valve, the upper being the anterior and the lower the posterior. To the upper left of the left ventricle a portion of the right ventricle is seen as a crescent. The section cuts it between the tricuspid valve and the apex of the right ventricle, below the crista.

The major feature of the ultrasound image **(Figs. 30 and 31)** is the motion of the mitral valve leaflets that form a shape like the mouth of a goldfish, viewed head-on. The large, curved upper leaflet, and the flatter lower leaflets separate and come together as blood flow through the orifice varies. In early diastole, they separate widely during rapid ventricular filling, then partially come together in mid-diastole as the filling rate falls. With the advent of atrial systole, they again separate, before closing completely at the beginning of systole, where they remain until the beginning of the subsequent diastole.

It is possible from this view to estimate mitral valve orifice area, a measurement that has been shown to correlate well with the actual area assessed at surgery. It therefore forms probably the best echocardiographic method for determining the severity of mitral stenosis. However, considerable care needs to be taken to obtain accurate measurements.

Parasternal Short-Axis Plane

Papillary Muscle Level

If the transducer is tilted toward the apex, the ultrasound beam scans a lower plane, as indicated in **Figs. 32-35**. At this level, the left ventricle is sectioned across the middle of its two papillary muscle groups. These are normally easy to visualize and they form a reliable means of identifying ventricular morphology, since the right ventricle has only one prominent papillary muscle. The right boundary of the left ventricle is formed by the lateral free wall and the bottom of the section by the inferior wall. To the left is the muscular interventricular septum. This section cuts the right ventricle very close to its apex. The deep trabeculation in this region may be apparent.

In addition to identification of ventricular situs, this view is useful for segmental analysis of wall motion in patients with ventricular disease. For this purpose, the ventricular wall is divided into a number of segments, typically 10 to 15, and the motion and thickening of each is assessed independently. For example, the short-axis views at mitral valve and papillary muscle levels might be divided into five segments each, with an additional four segments derived from the apical long-axis and short-axis views. This provides a disciplined approach to analysis of ischemic disease, but as with all echocardiographic methods, it frequently fails due to technical difficulty in visualizing all the segments adequately.

Parasternal Short-Axis Plane

Aortic Valve Level

Further tilting of the transducer toward the subject's right shoulder, combined with slight rotation clockwise, brings the scan plane above the level of the mitral valve annulus, so that it transects the two atria **(Fig. 37)**. In the center is the aorta, with its three cusps visible. Below the aorta is the left atrium, with the interatrial septum running diagonally downward and to the left, dividing it from the right atrium. The plane of the section passes diagonally across the tricuspid valve annulus, above the posteroseptal leaflet, part of which is still visible. Above the tricuspid valve is the crista supraventricularis and part of its parietal band. The outflow tract of the right ventricle arches over the top of the aorta toward the pulmonary valve, the posterior cusp of which is seen.

These features are depicted on the echocardiographic image **(Fig. 39)**. There is usually some "dropout" in the atrial septum in the region of the fossa ovalis where it is very thin. While lack of continuity of the atrial septum on the echo display is therefore not diagnostic of an atrial septal defect, this view can be used in conjunction with echocardiographic contrast studies to demonstrate interatrial shunts. Microbubbles, generated by rapid injection of fluid into a peripheral vein, enter the right atrium. Even where the dominant shunt is left to right, there is usually a small amount of flow from right to left at the onset of systole, and this is indicated by passage of a few microbubbles across the interatrial septum into the left atrium.

Tilting the transducer slightly further moves the scan plane above the level of the aortic valve. In this position, it is possible to visualize the ostium of the left coronary artery in a substantial proportion of subjects, and that of the right coronary artery in rather less. With further refinements in instrument resolution, it may become possible to detect major stenosis of the proximal coronary arteries with acceptable reliability.

Further counterclockwise rotation aligns the scan plane along the main pulmonary artery, seen running posteriorly to the right of the aorta. It is frequently possible to visualize this vessel as far as the bifurcation into right and left pulmonary arteries, with the right seen turning behind the heart and the left in the opposite direction **(Fig. 40)**. Finding the bifurcation is positive identification of the pulmonary artery, and thus is valuable in congenital heart disease.

Apical Long-Axis Plane

By moving the transducer to an apical position, the portions of the long-axis plane, which are generally inaccessible from the parasternal position, can be seen. The anatomy of the scan plane is identical to that described earlier, except that the section is oriented with the apex uppermost **(Fig. 43)**.

This view is, however, not always easy to obtain, particularly in tall, slim subjects. The direction of the scan is at right angles to the intercostal spaces, and since the transducer axis has to be aimed fairly strongly superiorly, the effect is like looking through a nearly closed venetian flind. It is frequently necessary to position the transducer one intercostal space above the apex, which retains the view of the apical area but tends to obscure the more anterior structures, such as the aortic valve.

The ultrasound image is illustrated in **Fig. 44**, which shows the apical region of the left ventricle and also the aortic and mitral valves. Both mitral leaflets are seen. The aortic valve in this view presents a similar target to the pulmonary valve when seen from the parasternal position. When the valve is closed, echoes are detected, but as it opens, the cusps fold away parallel to the aorta and no echoes return to the transducer.

The primary application of this view is in assessing the function of the apical region of the left ventricle, since it is the region most prone to development of an aneurysm following infarction associated with occlusion of the left anterior descending coronary artery.

Apical Four-chamber Plane

Rotation of the transducer through 90 degrees clockwise from the apical long-axis position turns the scan plane so that it is approximately parallel to the precordium and it passes through all four chambers of the heart **(Fig. 47)**. The section shows the interventricular and interatrial septa running down the center, with the left ventricle and atrium to the right, and the right ventricle and atrium to the left. The part of the interventricular septum seen is the posterior septum, whereas the anterior part is seen in the long-axis view.

A particularly valuable contribution of echocardiography in the diagnosis of complex congenital heart disease is the ability to identify the cardiac chambers and great vessels. This view is particularly helpful for identification of the two ventricles.

In a normal subject, the left ventricle has much thicker walls, but in abnormal hearts this may not be the case, and it is necessary to look for other clues to ventricular morphology. One of these has already been mentioned – the presence in the left ventricle of two distinct papillary muscle groups. Additional features that potentially provide positive identification of the ventricles are seen in this section.

It can clearly be seen in **Fig. 47** that the tricuspid valve joins the septum above (i.e., nearer to the apex, and thus below in the body) the mitral. This is because the mitral valve is positioned so that its annulus joins to the septum above the membranous septum, whereas the annulus of the tricuspid valve crosses the membranous septum. Since the right and left atrioventricular valves are invariably associated with the corresponding ventricles, this provides firm identification of the two ventricles. Further evidence can be obtained from the presence in the right ventricle of the moderator band, and by the more extensive and deeper trabeculation in the right ventricle.

The features described can be seen on the ultrasound image **(Fig. 49)**.

The relative position of the two atrioventricular valves to the septum is apparent, with the membranous septum deviating to the right of the picture between them. It is apparent from this image how it is possible to have a communication between the left ventricle and right atrium (Gerbode defect).

Prolapse most commonly affects the posterior mitral leaflet, which occupies two-thirds of the annulus, and is divided into three "mini-cusps". It is most frequently observed in the central of the three, presumably because it is less well supported by the chordae tendinae that arise from the papillary muscles beneath the leaflet commissure. This part is readily visualized from the parasternal position, either by M-mode or two-dimensional echocardiography. However, there are cases in which prolapse is confined to one of the lateral portions.

The left ventricular outflow tract and proximal portions of the aorta may also be interrogated from the apical approach. With superior angulation of the scan plane from the apical four-chamber view, these structures usually come into view **(Fig. 50)**.

Subcostal Four-Chamber Plane

The anatomy of the four-chamber plane seen from the subcostal views is identical to that already described in the apical view, but with orientation as shown in **Fig. 52**. In the body, the inferior surface of the right ventricle, seen at the top **(Fig. 52)**, rests on the diaphragm, and the ultrasound beam approaches the heart through a corner of the liver and across the diaphragm.

The echocardiographic image of the subcostal four-chamber plane is shown in **Fig. 54**. Although the apical region is not seen as well as from the apex, more of the atria are visualized. In addition, clearer echoes are generated by the interatrial and interventricular septa because the ultrasound beam approaches them more nearly at right angles. Thus, while dropout of the echo signals from the septa in the apical view is most likely to be artifactual, consistent absence of echoes from a region of either the interatrial or interventricular septum in the subcostal view suggests the presence of a defect. Two-dimensional echocardiography is helpful for diagnosing these lesions and, in the case of the interatrial septum, it is usually possible to differentiate a defect in the area of the fossa ovalis (secundum type) from a low defect extending down to the mitral annulus (primum) or a sinus venous defect high in the roof of the atria.

The subcostal four-chamber view is the only satisfactory way to visualize the right atrium, and it also affords the best view of the right ventricle, since these chambers like nearest to the transducer. Right atrial morphology can be confirmed by tilting the scan plane inferiorly so that the entrance of the inferior vena cava is seen. In addition to the identification of the atrioventricular valves by their relative levels of attachment to the septum, it is frequently possible to determine ventricular morphology by locating the moderator band within the right ventricle. To a certain extent it is also possible to assess the thickness of the right ventricular walls, and in some patients to diagnose right ventricular hypertrophy.

If a pericardial effusion is present, its extent and the degree of separation of the heart from the pericardium should be determined in the subcostal view if pericardiocentesis is contemplated.

Subcostal Short-Axis Views

Short-axis views, similar to those seen from the parasternal position but with the right ventricle or right atrium in the foreground, can be obtained from the subcostal position. However, it is often difficult to produce clear recordings because the transducer must be pressed down in order to scan under the rib cage. In addition, the angle formed by the right and left sixth ribs at the xiphisternum limits transducer mobility. The main application of the subcostal short-axis views is therefore to obtain short-axis images in subjects with hyperinflated lungs where the parasternal approach is impossible. In such patients the diaphragm is usually low, and this facilitates a subcostal approach. In contrast, it is very difficult to get adequate recordings by this method in young normal subjects, even during deep inspiration.

Visualizing cardiac structures from the subcostal approach can also be utilized for M-mode recordings in difficult subjects **(Fig. 55)**. The smaller transducer is easier to position beneath the rib cage and with practice most cardiac structures can be visualized. The closest valve to the transducer is the tricuspid, which is seen by aiming the ultrasound beam almost straight up the center line of the sternum. Beyond it is the aortic valve. Slight angulation toward the midclavicular line should reveal the mitral valve. The same direction with the transducer pressed down to align the beam almost parallel with the underside of the rib cage brings the pulmonary valve, farthest from this position, into view.

Additional Subcostal Views

Further views, useful for studying the right side of the heart, can be obtained from the subcostal position. With the transducer placed a little to the right of the xiphoid process and directed posteriorly, with the scan in a caudocranial plane, the inferior vena cava (IVC) can be seen passing behind the liver, crossing the diaphragm, and entering the right atrium **(Fig. 56)**. At this level, the IVC is lateral and anterior to the descending aorta. If in doubt, the two can be distinguished by the pulsation of the aorta or by asking the subject to inhale deeply, which sucks blood into the chest and causes the IVC to collapse. Angling the scan plane toward the head shows more of the right atrium. With careful manipulation it is sometimes possible to align the scan to show the IVC, right atium, tricuspid valve, pulmonary valve, and proximal pulmonary artery simultaneously **(Fig. 58)**.

Rotating the transducer through 90 degrees and directing it posteriorly shows the IVC in cross-section. Caudal tilt moves the section down into the liver, where hepatic vessels can be seen joining the IVC. In cases of right heart failure, the hepatic veins will be engorged and echo contrast agent injected into a peripheral vein can be seen carried down into the liver.

It is also possible to visualize the IVC by M-mode in almost all subjects. Although this is sometimes more difficult than by two-dimensional echocardiography, it can be helped by obtaining a two-dimensional image first, and then performing the respiratory maneuver described above. M-mode shows precise timing relationships, thereby increasing the specificity of the echo-contrast technique in the diagnosis of tricuspid regurgitation. An M-mode recording of the IVC is made with the ECG during a contrast injection. If initial arrival of contrast in the IVC is during systole, tricuspid regurgitation is most likely present, if in diastole, it merely indicates high right-sided pressures.

Suprasternal Views

Echocardiographic images of the great arteries can often be obtained by positioning the transducer in the suprasternal notch. As shown in **Fig. 60**, the subject lies supine, with the head tilted back over a pillow. If the transducer is positioned so that the scan plane is aligned with the aortic arch, it may be possible to see the ascending aorta passing posteriorly and turning downward, with some of the arteries that supply the head and arms arising from it **(Figs. 61 to 63)**. Within the loop of the aortic arch, the right pulmonary artery may be seen as a pulsating circular structure.

If the scan plane is rotated through 90 degrees, the aorta will be seen in cross-section, with the right pulmonary artery forming two parallel lines below it. Slight adjustments in scan direction may reveal part of the roof of the left atrium and, if sufficient depth range is available, the mitral valve annulus.

Recordings of the aortic arch can be used to diagnose coarctation and to determine both the site of the stricture relative to the subclavian artery and its approximate extent. In patients whose parasternal recordings reveal aortic root aneurysms, knowing whether the enlarged region extends to the origins of the arterial branches can be very helpful as an adjunct to angiography in assessing suitability for surgery.

Although it is not always easy to identify the relevant structures on M-mode recordings, the smaller transducer size and greater depth of penetration allow tracings showing the aorta, right pulmonary artery, and part of the left atrium to be made in the majority of subjects. These are useful in congenital disease for showing the relative sizes of the vessels as a means of assessing severity of shunts, and also in conjunction with contrast injections for identifying the great vessels in patients in whom the combination of transposition and a shunt makes identification from the parasternal position difficult.

Two-Dimensional Echo in Normal Heart (Figure Legends)

Fig. 1 Diagram showing the principle of a mechanical sector scanner.

Fig. 2 The principle of an electronically steered sector scanner. Sequential pulsing of the elements results in wave propagation at an angle to the transducer axis.

Fig. 3 Electronic focusing. Modifying the pulsing sequence changes the relationship of the subsidiary wavelets causing the compound wave to focus.

Fig. 4 Dynamic focusing. Differential delay of electrical signals allows the receiver to change its focal distance as echoes from more distant structures arrive.

Fig. 5 Lateral resolution. Because the ultrasound beam is wide, echoes are generated by off-axis structures.

Fig. 6 Time, distance, and velocity relationships in ultrasound.

Fig. 7 Effect of lateral resolution and line density on 2-D image quality.

Fig. 8 2-D image with M-mode corresponding to cursor line position.

Fig. 9 Schematic representation of the recording and display of the 2-D image.

Fig. 10 The position of the cardiac outline relative to the thoracic skeleton.

Fig. 11 Access to the hear from the left parasternal area.

Fig. 12 Echocardiographic approaches to the heart.

Fig. 13 Standard planes of the heart for 2-D echocardiography.

Fig. 14 The echocardiographic examination with the transducer in the parasternal long-axis position.

Fig. 15 Diagram to show the relationship between the transducer position relative to the hear and the orientation of the image displayed. The part of the heart nearest the transducer always appears at the top of the displayed image. (a) the parasternal long axis view. (b) the parasternal short axis view. (c) the apical four chamber view.

Fig. 16 Diagram to illustrate the terminology of transducer manipulation.

Fig. 17 Transducer in the parasternal position.

Fig. 18 Transducer in the apical position.

Fig. 19 Transducer in the subcostal position.

Fig. 20 The long-axis plane with the parasternal transducer position indicated.

Fig. 21 Anatomical section through the long axis – parasternal orientation.

Fig. 22 Diagram of the parasternal long-axis image: systole key to Fig.24.

Fig. 23 Echocardiographic image: diastole.

Fig. 24 Echocardiographic image: systole.

Fig. 25 Diagram of the left parasternal right ventricular inlet view.

Fig. 26 Echocardiographic image in the right ventricular inlet view.

Fig. 27 The short-axis plane at mitral valve level with parasternal transducer position indicated.

Fig. 28 Diagram of the parasternal short-axis image at mitral valve level: diastole. Key to Fig.30

Fig. 29 Anatomical section through the short axis at mitral valve level – parasternal orientation.

Fig. 30 Echocardiographic image: diastole.

Fig. 31 Echocardiographic image: systole.

Fig. 32 The short axis plane at papillary muscle level with the parasternal transducer position indicated.

Fig. 33 Anatomical section through the short axis at papillary muscle level-parasternal orientation.

Fig. 34 Key to Fig.35

Fig. 35 Echocardiographic image.

Fig. 36 The short axis plane at aortic valve level with parasternal transducer position indicated.

Fig. 37 Anatomical section through the short axis at aortic valve level – parasternal orientation.

Fig. 38 Diagram of the parasternal short-axis image at aortic valve level: diastole.

Fig. 39 Echocardiographic image: diastole.

Fig. 40 Key to Fig.41.

Fig. 41 2-D image of the pulmonary artery bifurcation from the parasternal position.

Fig. 42 The long axis plane with the apical transducer position indicated.

Fig. 43 Anatomical section through the long-axis – apical orientation.

Fig. 44 Echocardiographic image: diastole.

Fig. 45 Diagram of the apical long-axis image: diastole. Key to Fig.44

Fig. 46 The four-chamber plane with the apical transducer position indicated.

Fig. 47 Diagram of the apical four chamber plane image: systole. Key to Fig.49.

Fig. 48 Anatomical section through the four-chamber plane-apical orientation.

Fig. 49 Echocardiographic image: systole.

Fig. 50 With superior angulation, the left ventricular outflow tract and proximal aortic root can be seen from the apical view.

Fig. 51 The four-chamber plane with the subcostal transducer position indicated.

Fig. 52 Anatomical section through the four-chamber plane – subcostal orientation.

Fig. 53 Diagram of the subcostal four-chamber plane image: systole. Key to Fig.54.

Fig. 54 Echocardiographic imager: systole.

Fig. 55 M-mode scan from subcostal transducer position showing relative positions of the four cardiac valves.

Fig. 56 Echocardiographic image showing the inferior vena cava entering the right atrium with hepatic vasculature: systole.

Fig. 57 Key to Fig.56.

Fig. 58 Echocardiographic image of the right heart: diastole.

Fig. 59 Key to Fig.58

Fig. 60 Transducer in the suprasternal position.