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Two-Dimensional Real-Time Ultrasonic Imaging of the Heart and Great Vessels

Technique, Image Orientation, Structure Identification, and Validation

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Conventional M-mode echocardiography has become established as a diagnostic tool for noninvasive evaluation of cardiovascular diseases. Now the advent of two-dimensional real-time echocardiography has opened a new era of investigation. This paper describes in detail the technique of a complete two-dimensional ultrasonic examination of the heart and great vessels. Four transducer locations were commonly utilized—namely, parasternal, apical, subxiphoid, and suprasternal notch positions. The tomographic sections of the heart obtained along the long and short axes of the heart and great vessels by utilizing the above positions were validated by detailed anatomic and contrast echocardiographic techniques.

During the past decade, M-mode echocardiography has gained increasing popularity, and this technique is currently regarded as an essential diagnostic tool for the practice of cardiology. This popularity is due to the fact that ultrasonic examination is entirely noninvasive, can be readily performed at the bedside, and provides accurate and reproducible information at no known risk to the patient. M-mode echocardiography provides a one-dimensional ("ice pick") view of the heart, and this represents the major limitation of the technique. It displays the cardiac structures in an unfamiliar format that bears no resemblance to the cardiac anatomy. Moreover, M-mode echocardiography is limited in its ability to provide information regarding the spatial orientation of cardiac structures. To overcome these disadvantages, two-dimensional ultrasonic imaging of the heart has been perfected over the past few years.

The initial work in two-dimensional imaging appeared in the late 1960s and early 1970s.[1-6] However, only in the past few years has there been accelerated development in the clinical application of two-dimensional echocardiography.[7-28] At present, there are three different approaches to two-dimensional real-time ultrasonic imaging. These include (1) mechanical sector scanner, (2) multi-element linear array (multiscan), and (3) electronic sector scanner or phased-array system. The mechanical scanner consists of a single crystal transducer that is made to oscillate rapidly by means of an electric motor through a 30° to 60° arc. This system is relatively inexpensive and provides good-quality images. However, its disadvantages are a narrow angle, noise, and a vibrating sensation that is occasionally irritating to the patient. More recently, wide-angle (80° to 90°) mechanical sector scanners utilizing multiple rotating crystals have been developed which may overcome most of these limitations.

In the original model of the multi-element linear-array system (multiscan), the transducer comprised 20 separate crystals that were arranged linearly. The resultant head of the transducer was relatively large, measuring approximately 8 cm in length. Each crystal was pulsed sequentially and the image was displayed as a series of single-line reflections. The large transducer size, low line density, and wide beam size resulted in overall poor resolution and discontinuity of images from the underlying ribs.

Electronic steering of the ultrasonic beam by phased element excitation has been the most recent development in the real-time two-dimensional imaging of the heart. Instantaneous and continuous pictures of the beating heart can be obtained with the stationary transducer by the use of high-speed electronic sector scanning as has been utilized in radar technology. The commercial model utilized in this study is manufactured by Varian and Associates (Varian 3000). The transducer, with a frequency of 2.25 MHz, measures 12 by 13 mm. The external diameter of the transducer measures 24 mm at the skin contact. There are 32 piezoelectric crystals arranged in linear array. An external acoustic lens is utilized for focusing the ultrasound beam. A groove on the handle of the transducer (Fig. 1) indicates the direction of the sector beam (long axis of groove is parallel to scanning beam). The ultrasound beam is steered through an arc of 80° by excitation of the crystals almost simultaneously but slightly out of phase so that the crystal on one end of the transducer is excited slightly before the next one, and so on. In this way, the resultant beam is transmitted at an angle to the face of the transducer, and the angle can be changed by introducing variable delays in the excitation sequence.

The 80° sector scan of the heart is obtained at a scan rate of 30 frames per second. The number of lines per frame varies, depending on the depth scale utilized. At a depth range of 21 cm, there are 85 lines

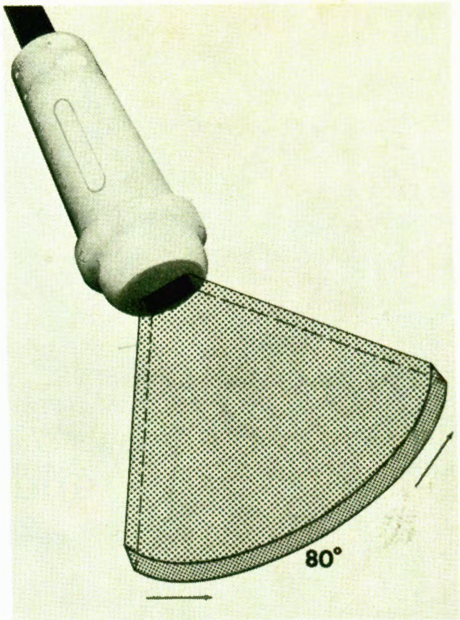


Fig. 1. Transducer with schematic drawing of beam fan. Note groove on handle of transducer, long axis of which is parallel to direction of beam.

per frame and 120 lines at the 15-cm range. Images are represented in real time and the sector images or frames (30 per second) are recorded on a 1-inch video tape at 30 frames or 60 fields per second. Hard copy is obtained by electrocardiogram-gated or still-frame photography utilizing a Polaroid or 90-mm x-ray camera attachment. Still frames of the sector scans published in this article, however, were all made by means of a 35-mm camera assembly. The desired single frame image was displayed on the oscilloscope in stop-frame mode and photographed directly. An enlargement of 8 by 10 inches was obtained, structures were labeled, and then the picture was rephotographed. Since each videotape frame consists of two fields and the stop-frame mode consists only of a single field (half of the information), significant degradation of image quality in the stop-frame mode results. Furthermore, the still frame presentation also results in loss of the visual appreciation of motion which accompanies real-time recordings and playback. This sector scanner also has the capability of recording a simultaneous M-mode echogram along any selected line in the sector arc (Fig. 2). In most of the examinations, a simultaneous electrocardiogram was also recorded.

Patients were examined supine or turned into a partial left lateral decubitus position. Demographic data (patient and operator identification, date, and time of examination) were entered before each study,

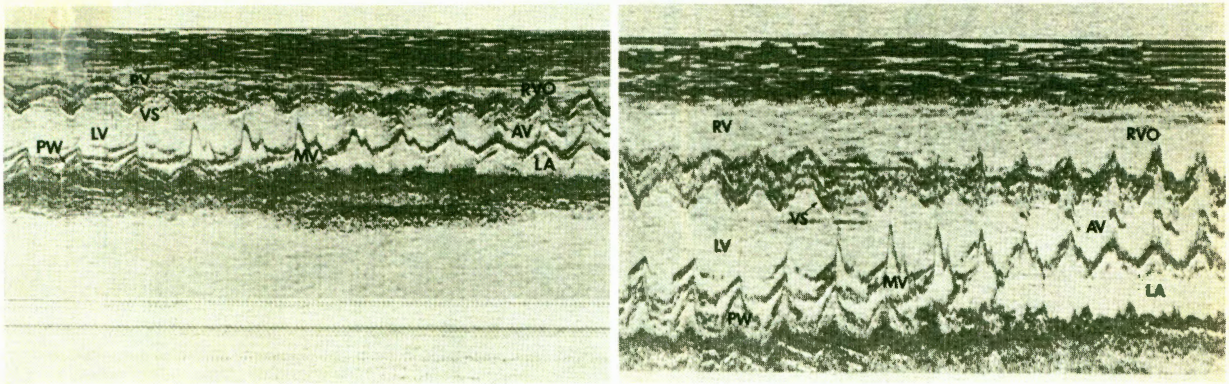


Fig. 2. Apex-to-base M-mode scan obtained while long-axis sector scan of left ventricle was being recorded: *Left,* Depth scale of 21 cm. *Right,* Depth scale of 15 cm. On left of figure, left ventricular cavity at chordae tendineae level is recorded. As cursor line was moved gradually from left to right, continuous scan from body of left ventricle to base of heart was recorded, as shown in this figure. *PW* = posterior wall; *RV* = right ventricle; *RVO* = right ventricular outflow tract; *VS* = ventricular septum; *MV* = mitral valve; *LV* = left ventricle; *AV* = aortic valve; *LA* = left atrium.

and this information appears on each videoframe that was recorded. The brightness was adjusted so that the sector scan was only dimly visible on the oscilloscope. The contrast (black-white scale) was appropriately adjusted so that the resultant images were pleasing to the eye of the operator. For the majority of the examinations, we utilized high-transmit and low-reject settings. The gain controls were adjusted individually for each patient in order to record the best possible image. A water-soluble gel was utilized as an interface to provide an airless contact between the transducer and the skin. The instantaneous cross-sectional views (tomograms) of the heart were obtained by placing the transducer in different positions and utilizing various transducer angulations. In practice, four positions were commonly utilized—parasternal, apical, subxiphoid, and suprasternal notch (Fig. 3). Tomographic sections of the heart relative to its long and short axes can be obtained from each of the first three transducer positions and those of the great vessels (aorta, pulmonary artery, and superior vena cava), from the suprasternal notch position (Table 1).

With the advent of two-dimensional imaging of the heart, and especially with the various tomographic sections obtained from different positions along the long and short axes of the heart and great arteries, it has become necessary to validate the anatomy of these unique views. The cardiac images obtained from various planes are not readily comprehended by physicians, for the majority of these views bear little similarity to routine angiographic images or commonly utilized pathologic sections. For the purpose of identification of structures and validation, we employed two methods. First, pressure-perfusion-fixed cadaver hearts were sectioned in the presumed planes of the ultrasound tomographic sections. The sections were photographed with the same orientation as the ultrasound images. For purposes of labeling, drawings of these same representative sections of the heart tissue were made by our medical art department. Secondly, with the use of contrast echocardiography at the time of scheduled cardiac catheterization, selective injections of echo-producing agents (indocyanine green and saline) into various cardiac chambers aided in the identification and confirmation of the ultrasonic anatomy.[29]

The purpose of this paper, therefore, was (1) to describe the technique of complete two-dimensional imaging of the heart and great vessels based on the authors' experience of more than 500 such examinations, (2) to describe the image orientation of various tomographic sections, and (3) to provide detailed validation of sector images by utilizing anatomic and two-dimensional contrast echocardiographic techniques.

PARASTERNAL POSITION

Examination is begun by placing the transducer in the left parasternal region, usually in the third or fourth left intercostal space. From this position, a sector image of the heart along its long and short axes can be obtained.

LONG-AXIS VIEWS

Long-Axis View of Left Ventricle (Figure 4, Section 1).—The long-axis view of the left ventricle is recorded with the transducer groove facing toward the patient's

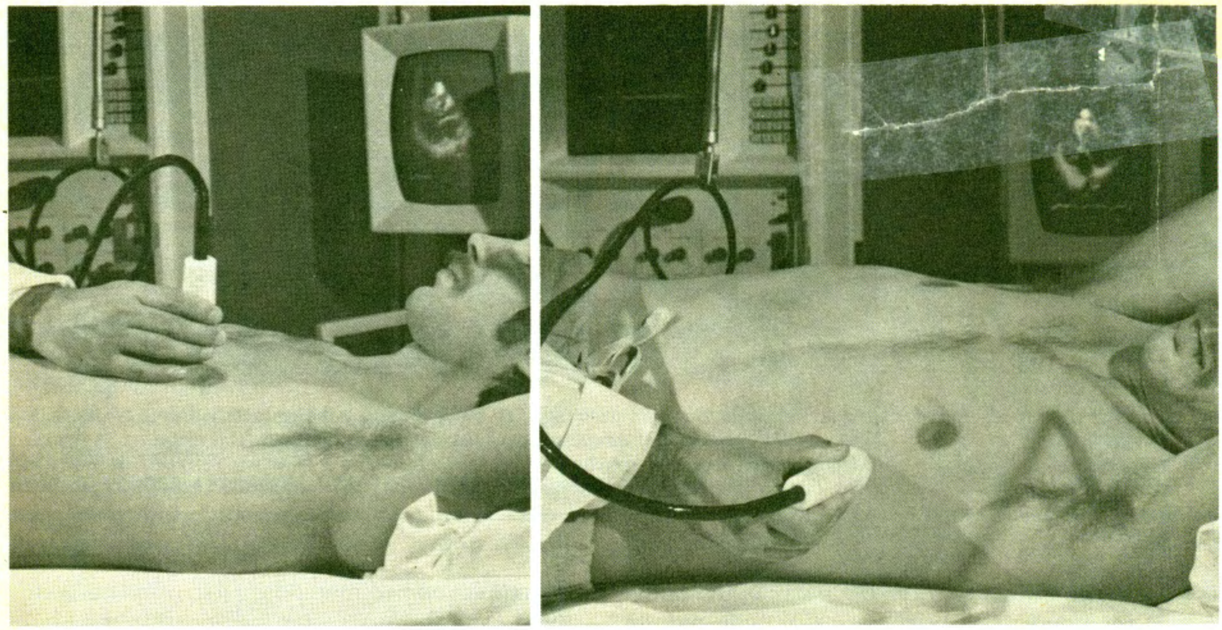
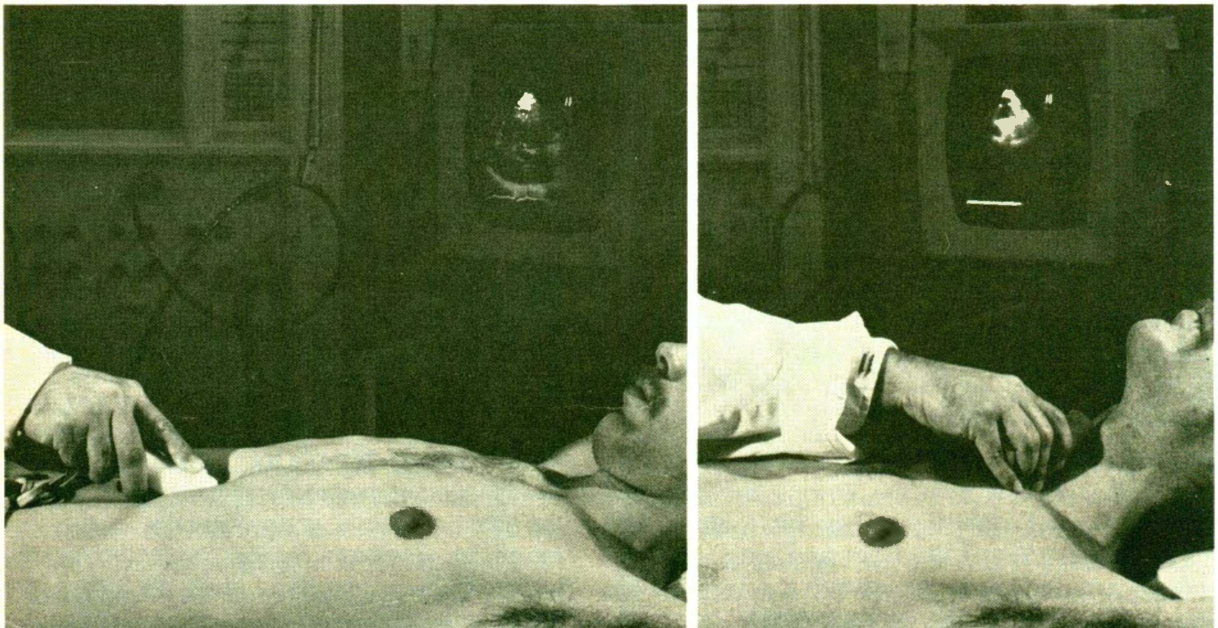


Fig. 3. Technique of examination utilizing the four standard transducer positions. *Upper Left,* Parasternal. Location is usually in third or fourth left intercostal space. *Upper Right,* Apical. Patient is turned in left semilateral decubitus position and transducer is placed directly over or in close proximity to point of maximum impulse and is tilted toward patient's right scapula.



Lower Left, Subxiphoid. Transducer is placed in subxiphoid region and is tilted superiorly toward patient's left supraclavicular fossa to obtain cross-sectional view of heart. *Lower Right,* Suprasternal notch. Transducer is placed directly in suprasternal notch and pointed inferiorly and somewhat posteriorly to record great vessels in their long and short axes.

Table 1.—**Transducer Positions and Corresponding Cardiac Tomographic Sections**

Position		View	Tomographic section
Parasternal	Long axis	Left ventricle	1
		Right ventricular inflow	2
		Right ventricular outflow	3
		Right ventricular and left ventricular inflow	4
	Short axis	Left ventricular apex	5
		Papillary muscles	6
		Mitral leaflets	7
		Left ventricular outflow	8
		Great arteries	9
		Pulmonary trunk bifurcation	10
Apical		Four-chamber view	11
		Four-chamber and aortic valve	12
		Right anterior oblique equivalent	13
Subxiphoid		Inferior vena cava and hepatic vein	14
		Right ventricular and left ventricular inflow	15
		Left ventricle-aorta	16
		Right ventricular outflow	17
Suprasternal notch		Long axis aorta, short axis right pulmonary artery	18
		Short axis aorta, long axis right pulmonary artery	19
		Long axis aorta and superior vena cava	20

right flank and the transducer so positioned in the third or fourth left interspace that the ultrasound beam is parallel to a line joining the right shoulder to the left flank (Fig. 4, section 1). The image thus obtained represents a section through the long axis of the left ventricle. The image is oriented so that the aorta is displayed on the right, cardiac apex to the left, chest wall and right ventricle anteriorly, and posterior structures (left ventricle and left atrial posterior walls) posteriorly on the image (Fig. 5). Therefore, the long-axis view of the left ventricle is displayed as a sagittal section of the heart viewed from the left side of the supine patient.[9] Figure 6 *left* represents an anatomic section through the long axis of the left ventricle in the plane of the ultrasonic section 1. The structures traversed are illustrated in the accompanying schematic drawing (Fig. 6 *right*). Figure 7 is a still frame of the long-axis view of the left ventricle, with injection of contrast medium into the left ventricle. Note that the contrast medium fills and opacifies the left ventricle and outlines the boundaries.

The long-axis view of the left ventricle allows visualization of the aortic root and aortic valve leaflets. The aortic valve leaflets appear thin and they coapt during diastole in the midline of the aortic root. With the onset of systole, the leaflets open abruptly and come to lie nearly parallel to the aortic walls. The right ventricular outflow tract is anterior to the aortic root. The chamber behind the aortic root is the left atrial cavity. Immediately posterior to the lower part of the left atrium, the left inferior pulmonary vein, appearing as a round structure, can also usually be seen. The long-axis view allows good visualization of the anterior and posterior leaflets of the mitral valve along with their chordal and papillary muscle attachments. The anterior leaflet appears longer and larger than the posterior leaflet. Both are thin and usually produce uniform echoes. With the onset of diastole, the distal third of the anterior mitral leaflet approximates the left ventricular septal surface, moves posteriorly to lie in a mid-open position during mid diastole, and reopens with atrial systole. The posterior leaflet demonstrates a similar although oppositely directed (mirror image) motion and has a much smaller excursion compared with the anterior leaflet.

During systole, the mitral valve leaflets coapt at a point inferior (toward the left ventricular apex) to the left atrioventricular groove. The coronary sinus, appearing as a small, circular echo-free structure, can usually be recorded in the region of the posterior atrioventricular groove. The left ventricular outflow tract, bounded by the ventricular septum anteriorly and the anterior leaflet of the mitral valve posteriorly, is well seen and is normally widely patent during systole. The ventricular septum can usually be

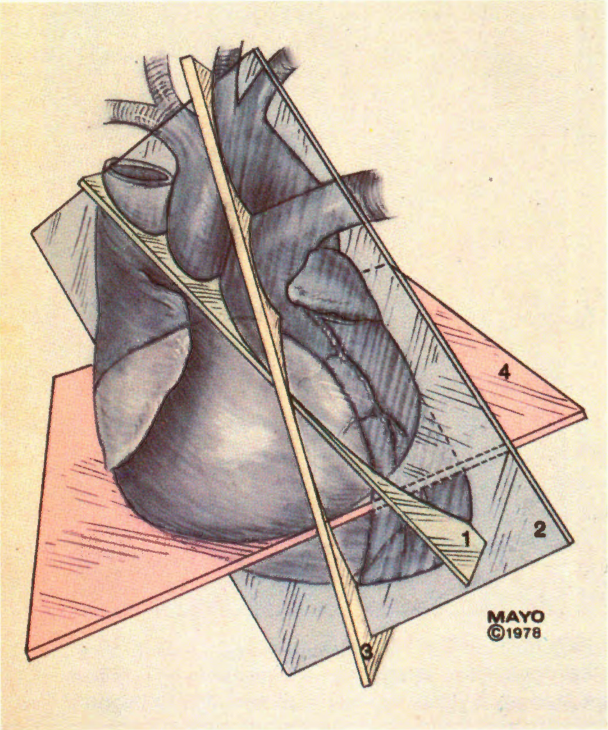


Fig. 4. Drawing of heart demonstrates the four ultrasonic tomographic planes utilized for obtaining long-axis views of heart. Section 1: Beam is parallel to a line joining patient's right shoulder to left flank and records long axis of left ventricle. Section 2: Transducer is rotated slightly clockwise and is tilted inferomedially so that long-axis view of right ventricular inflow tract is recorded. Section 3: Beam is almost parallel to true sagittal plane and transducer is tilted somewhat superiorly so that beam transects right ventricular outflow tract in its long axis and left ventricle in oblique section. Section 4: This section is best recorded usually from fourth left intercostal space. Transducer is rotated further clockwise and tilted somewhat superiorly so that beam passes through both ventricles and atria and records a foreshortened four-chamber view in which inflow tracts of both ventricles can be clearly identified.

visualized in its entirety, and its motion characteristics at different levels can readily be appreciated. In normals, the septum moves posteriorly during systole. The normal anatomic relationships of septal-aortic and mitral-aortic continuity are best evaluated in this view. This view also allows good visualization of the left ventricular cavity in the long axis throughout various phases of the cardiac cycle.

Usefulness of Long-Axis View of Left Ventricle (Section 1).—1. Evaluating aortic root pathology (enlargement, dissection)

2. Evaluating aortic valvular pathology (calcification, stenosis, vegetations, bicuspid valve)

3. Evaluating subvalvular left ventricular outflow obstruction (muscular or membranous stenosis)

4. Evaluating left ventricular chamber dimensions and performance

5. Determining ventricular septal and posterior wall motion, excursion, thickness, and function

6. Visualizing ventricular septal defect and septal aneurysm

7. Evaluating ventricular septal-to-aortic continuity or discontinuity

8. Determining mitral-to-aortic fibrous continuity

9. Evaluating structural and motion abnormalities of mitral valve and of its supporting structures (chordae and papillary muscles), such as stenosis; subvalvular, valvular, or annulus calcification; prolapse; flail leaflets; vegetations; diastolic flutter; and systolic anterior motion

10. Evaluating enlargement of coronary sinus as seen in patients with anomalous systemic venous or pulmonary venous connection to coronary sinus

11. Evaluating left atrial dimension and detecting intra-atrial masses (thrombus, myxoma) or membrane (cor triatriatum)

Long-Axis View of Right Ventricular Inflow (Figure 4, Section 2).—With the transducer in the same interspace (third or fourth) and with inferomedial

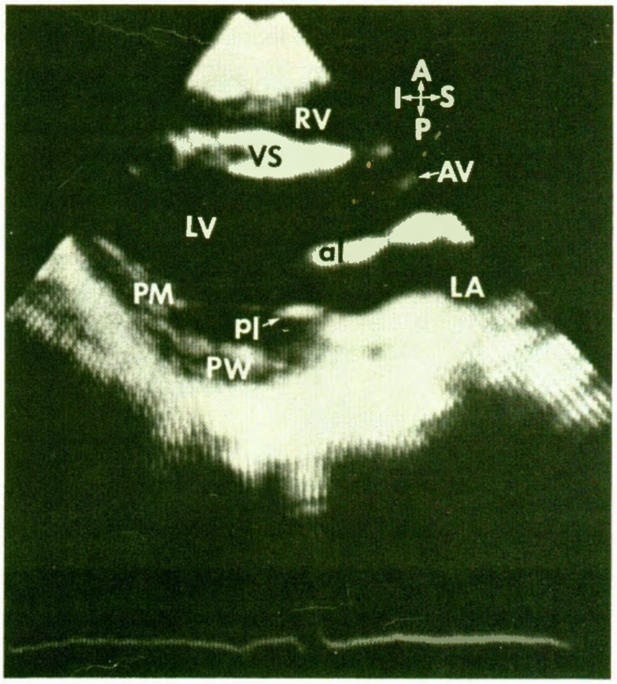


Fig. 5. Long-axis view of left ventricle of normal subject. Aorta is to right and apex of left ventricle is to left of image. Right ventricle is anterior and left atrium is posterior. Anterior (*al*) and posterior (*pl*) leaflets of mitral valve and posteromedial papillary muscle (*PM*) are seen. *A* and *P* = anterior and posterior, *I* and *S* = inferior and superior; *AV* = aortic valve; other abbreviations as before.

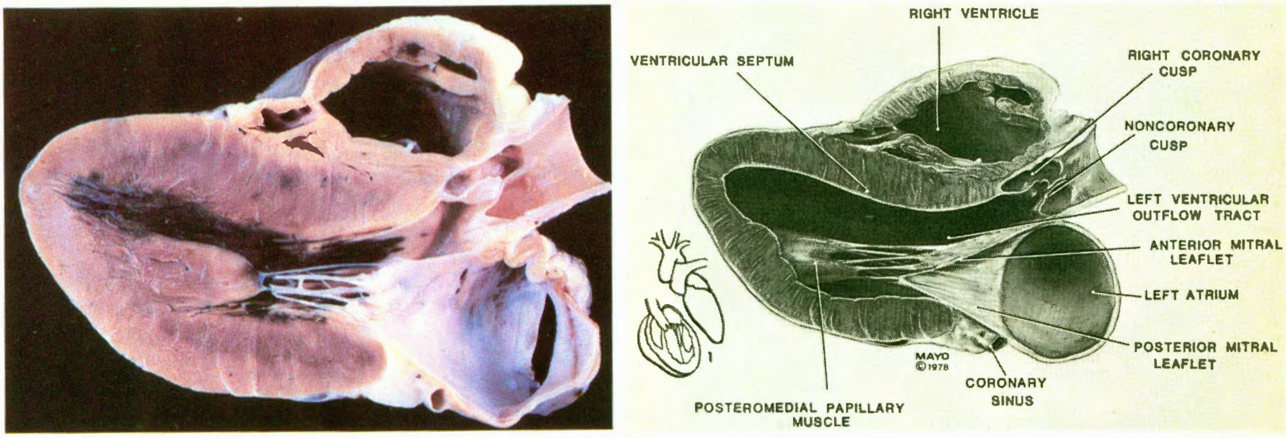


Fig. 6. *Left*, Anatomic section of heart obtained in presumed plane of long axis of left ventricle as shown in Figure 4, section 1. *Right*, Drawing of this section with identification of structures.

tilt and slight clockwise rotation of the transducer, a long-axis view of the right ventricle and right atrium is obtained, as shown in Figure 8. The image orientation of this view is such that the chest wall is anterior, the right atrium is on the right and posterior, and the right ventricular apex is anterior and to the left of the image. Figure 9 is a schematic drawing of a presumed section obtained in the ultrasound direction as shown in section 2. These views allow visualization of the right atrial cavity, the tricuspid valve, and the right ventricular inflow up to the apex of the right ventricle. The position and motion of the tricuspid leaflets are usually well demonstrated in this view. As with the anterior leaflet of the mitral valve, the anterior leaflet of the tricuspid valve is a relatively larger and longer structure when compared with the posterior and septal components of this valve. The excursion of the anterior leaflet is large during diastole, whereas there is comparatively less excursion of the posterior and septal leaflets.

Long-Axis View of Right Ventricular Outflow Tract (Figure 4, Section 3).—The long axis of the right ventricular outflow tract can be recorded with the transducer in the same parasternal location but with further clockwise rotation and slight superior tilting of the transducer (notch facing right midchest) so that the beam is now nearly parallel to the true sagittal plane. The tomographic section of the heart thus obtained is shown in Figure 10. The image orientation of this view is similar to that of section 1 in that the right ventricle is anterior and the left ventricle is posterior. In this section, the pulmonary valve is recorded to the right of the image, with the right ventricular outflow tract anteriorly and an oblique

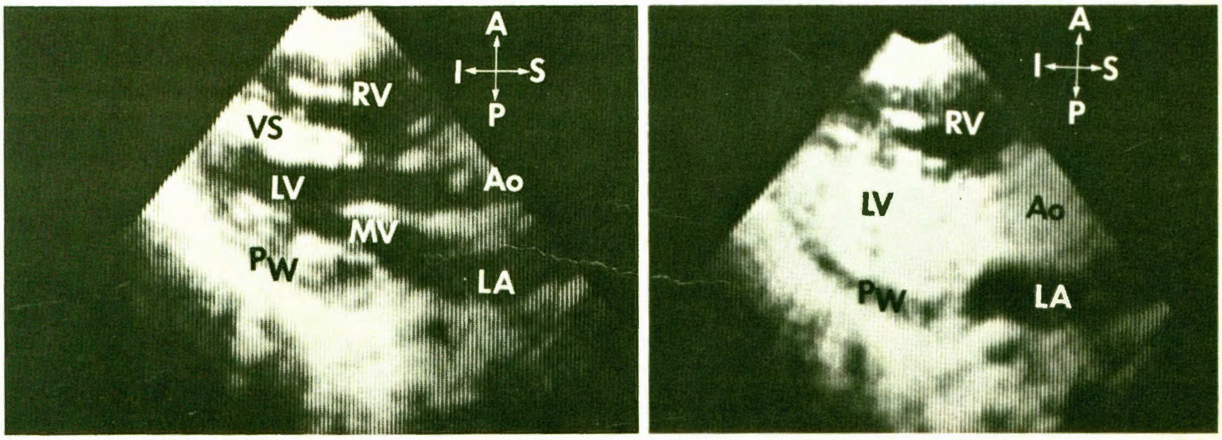


Fig. 7. *Left*, Long-axis view of left ventricle. *A* and *P* = anterior and posterior, *I* and *S* = inferior and superior. *Right*, After injection of indocyanine green and saline in left ventricle, echoes fill left ventricular cavity and outline its boundaries. Contrast medium is also seen to fill aortic root (*Ao*). Left atrium and right ventricle remain echo free. Endocardial surface of left ventricular posterior wall is clearly outlined by dye in left ventricle. Abbreviations as before.

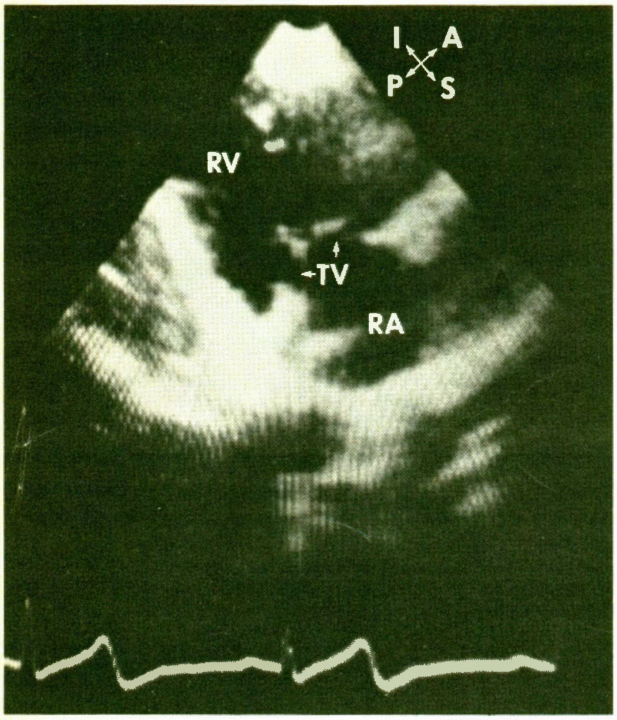


Fig. 8. Sector scan of normal subject obtained in plane of tomographic section 2. This outlines right atrium (*RA*) and right ventricle and defines right ventricular inflow tract. Tricuspid valve (*TV*) along with its tensor apparatus is well seen.

section of the left ventricle posteriorly. Figure 11 *left* is an anatomic section made in the plane of section 3, and Figure 11 *right* represents a drawing of the same section. This section allows good visualization of the entire right ventricular outflow region and

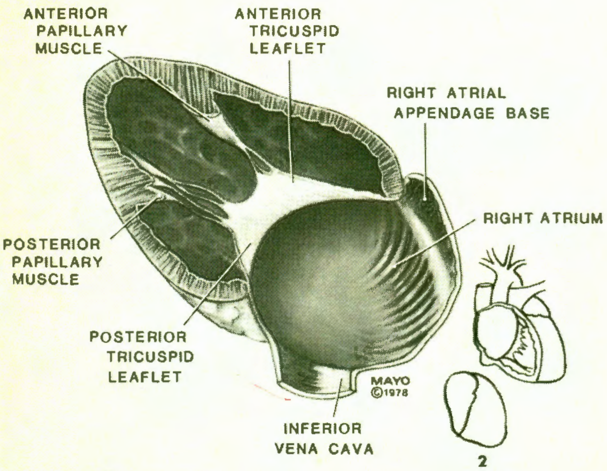


Fig. 9. Schematic drawing of a section made along presumed plane of tomographic section 2. Note that section is through right atrium and right ventricle and allows good visualization of right ventricular inflow tract.

of the pulmonary valve and the proximal main pulmonary artery.

Usefulness of Long-Axis Views of Right Ventricular Inflow and Outflow Tracts (Sections 2 and 3).—1. Evaluating right atrial and right ventricular enlargement

2. Detecting mass lesions in the right atrium and ventricle

3. Evaluating right ventricular outflow tract

4. Evaluating tricuspid valvular abnormalities (prolapse, ruptured chordae, stenosis, vegetations)

5. Evaluating tricuspid atresia

6. Diagnosing Ebstein's anomaly

7. Evaluating pulmonary valvular pathology

Long-Axis View of Right and Left Ventricular Inflow Tracts (Figure 4, Section 4).—This view is best recorded with the transducer usually in the fourth interspace in the parasternal region and often slightly more laterally placed. The groove on the transducer is pointed down, and the transducer is tilted slightly superiorly. This view records the four chambers of the heart (both atria and both ventricles). Both ventricles appear slightly foreshortened, but the inflow tracts of both ventricles are readily seen. The image thus obtained is shown in Figure 12, and Figure 13 is a drawing of the same section. The image is oriented so that the atria are displayed on the right and posterior, and the ventricles are on the left and slightly anterior. The right atrium and right ventricle are anterior, closer to the transducer, whereas the left atrium and left ventricle are posterior. In this view, the comparative dimensions of both atrial chambers can usually be easily delineated. The long axis of the atrial septum can be visualized, with occasional dropout or thinning in the region of the fossa ovalis.

The motion characteristics of the atrial septum can also be evaluated. Normally, the atrial septum bulges toward the right atrium during ventricular systole. In patients with tricuspid regurgitation, a reversal of the atrial septal motion can be seen—that is, with ventricular systole, the atrial septum bulges toward the left atrium. The anatomic interrelationships of the anterior leaflet of the mitral valve and the septal leaflets of the tricuspid valve can be well outlined in this view. Details of this relationship and the usefulness of this view will be discussed under the apical view. Figure 14 is a four-chamber view obtained in the manner described above in a patient with a large atrial septal defect. An injection of contrast medium was made in the left atrium which resulted in opacification of the left atrium as well as of the right atrium and indicated a large left-to-right

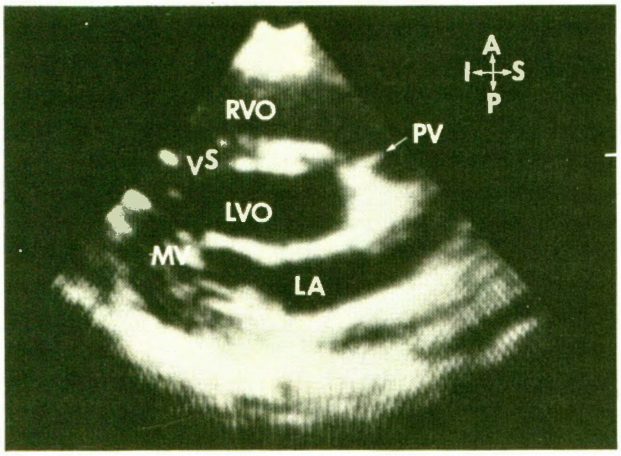


Fig. 10. Still frame of sector scan obtained with transducer nearly parallel to true sagittal plane (tomographic section 3). Long-axis view of right ventricular outflow tract is recorded, along with pulmonic valve (*PV*). Posteriorly, left ventricular outflow tract (*LVO*), mitral leaflets (*MV*), and left atrium are recorded. Abbreviations as before.

shunt. With subsequent ventricular diastole, the right and left ventricles became opacified and the dye outlined the boundaries of all four cardiac chambers visualized in this view.

SHORT-AXIS VIEWS

Short-Axis Views (Figure 15, Sections 5 Through 10). —With the transducer placed in the parasternal position (third or fourth left intercostal space), the short-axis view of the heart is obtained by rotating the transducer clockwise so that the plane of the ultrasound beam is approximately perpendicular to the plane of the long axis of the left ventricle. The groove on the transducer is pointed superiorly facing the right supraclavicular fossa, and the beam is roughly parallel to a line joining the left shoulder to the right flank. With the transducer pointed directly posteriorly, a cross section of the left ventricle at the level of the mitral leaflets is obtained (section 7). From this position, the transducer is tilted inferiorly toward the left ventricular apex so that a transverse section of the ventricular apex is obtained. The images are displayed as if being viewed from below (looking from the apex of the heart up toward the base).[9] In this format, the cross-sectional view of the left ventricle is displayed posteriorly and to the right of the image and the right ventricle is displayed anteriorly and to the left.

Figure 16 represents a sector scan of the ventricular apex along the plane of tomographic section 5 obtained from a normal volunteer. Note the small ventricular cavity, which diminishes further in size during systole. Figure 17 *left* represents an anatomic section through the apex of the heart, and Figure 17 *right* is a drawing of the same section. A cross section of the cardiac apex can also be obtained by placing the transducer directly over the point of maximum (apical) impulse. As the ultrasound beam is tilted superiorly from section 5, the cross section at the level of the papillary muscles (section 6) is obtained (Fig. 18 and 19). The papillary muscles, namely, anterolateral and posteromedial, project in the left ventricular cavity at approximately the 3 and 8 o'clock positions, respectively. In this and the subsequent section (7), the left ventricle appears circular and its cavity dimension, wall thickness, and motion during various phases of the cardiac cycle can be clearly delineated. With further superior tilting of the transducer so that it is nearly perpendicular to the chest wall, the ultrasound beam transects the body of the left ventricle at the level of the mitral leaflets. In this view, the mitral anterior and posterior leaflets are transected in cross section and appear like a fish mouth during diastole (Fig. 20). Portions of the right ventricle, tricuspid valvular apparatus, ventricular septum, and left ventricular

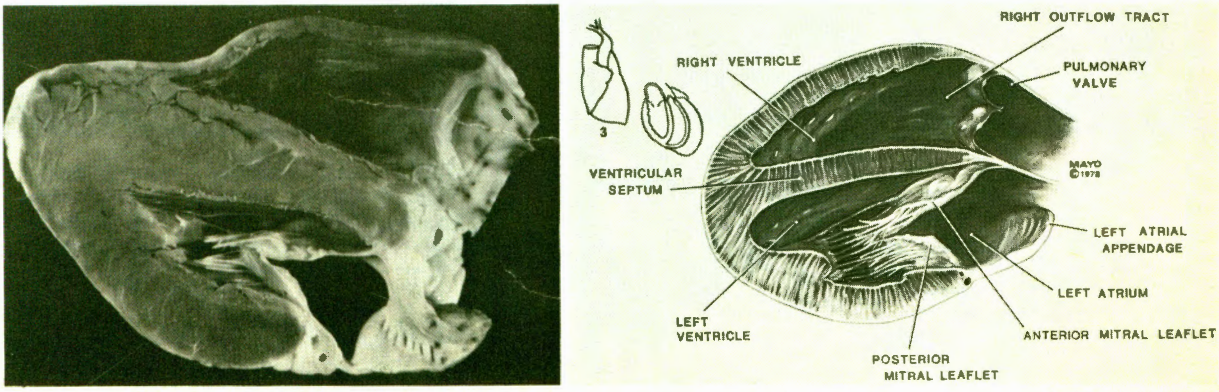


Fig. 11. *Left*, Anatomic section of heart in plane parallel to true sagittal plane at level of right ventricular outflow tract. *Right*, Drawing of this section with identification of structures.

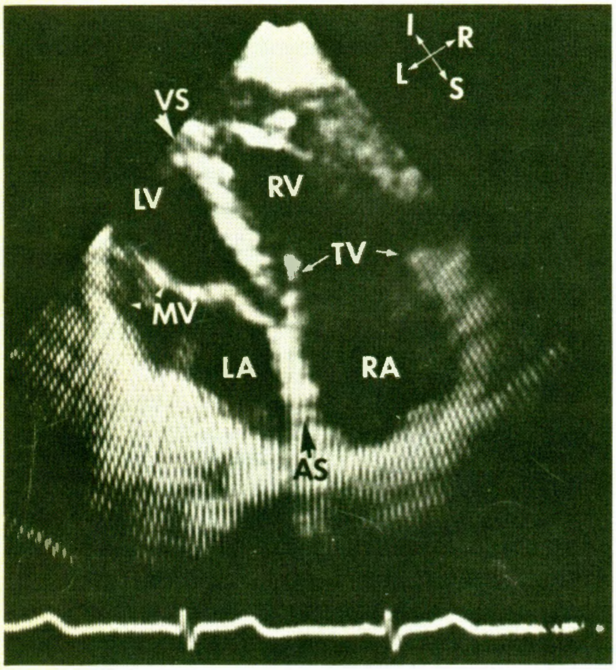


Fig. 12. Sector scan obtained with transducer in fourth left intercostal space in parasternal region and with transducer tilted up so that beam transects four chambers of heart. The left ventricle and left atrium are displayed to left of image (groove facing down). All four chambers of heart are well outlined in this section, including the crux of heart, which represents junction point of the two septa and of right and left atrioventricular anuli. *AS* = atrial septum; other abbreviations as before.

outflow tract are visualized anterior and to the left of the image. The tricuspid valve orifice, when transected in full, has a round-edged triangular shape during diastole. The moderator band and the anterior papillary muscle become readily recognized, especially if the right ventricle is hypertrophied and enlarged. Figure 21 demonstrates the corresponding anatomic section and a schematic drawing, respectively, at this level. Delineation of the right ventricular chamber and of the right side of the ventricular septum by contrast study is demonstrated in Figure 22.

By further superior and slightly medial tilting of the transducer, a section at the level of the left ventricular outflow tract (section 8) is obtained (Fig. 23). This section allows visualization of the anterior mitral leaflet and of the outflow tracts of both ventricles. The boundaries of the left ventricular outflow tract—namely, ventricular septum, anterolateral wall, and anterior mitral leaflet—are clearly visualized. On the left of the image are seen the right atrium and the right ventricle with a portion of the anterior tricuspid leaflet. Interposed between the two atrioventricular valves is part of the ventricular septum; posteriorly, the junction of the ventricular and atrial septa is visualized. The left atrium is seen directly posteriorly. An anatomic section obtained at this level and the drawing of the same section with identification of structures can be seen in Figure 24.

In section 9, obtained by further superior tilting of the transducer, the great arteries are sectioned transversely, as shown in Figures 25 and 26. In normals at this level, the aorta appears as a circle with a trileaflet aortic valve that has the appearance of the letter Y during diastole. The right ventricular outflow tract crosses anterior to the aorta from the left to the right of the image, wrapping around the aorta, and

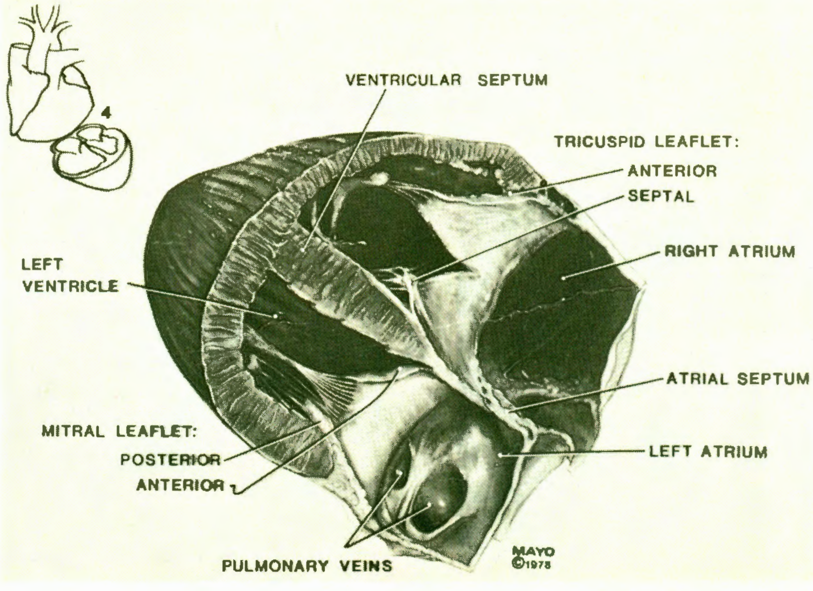


Fig. 13. Drawing of presumed section along plane of tomographic section 4.

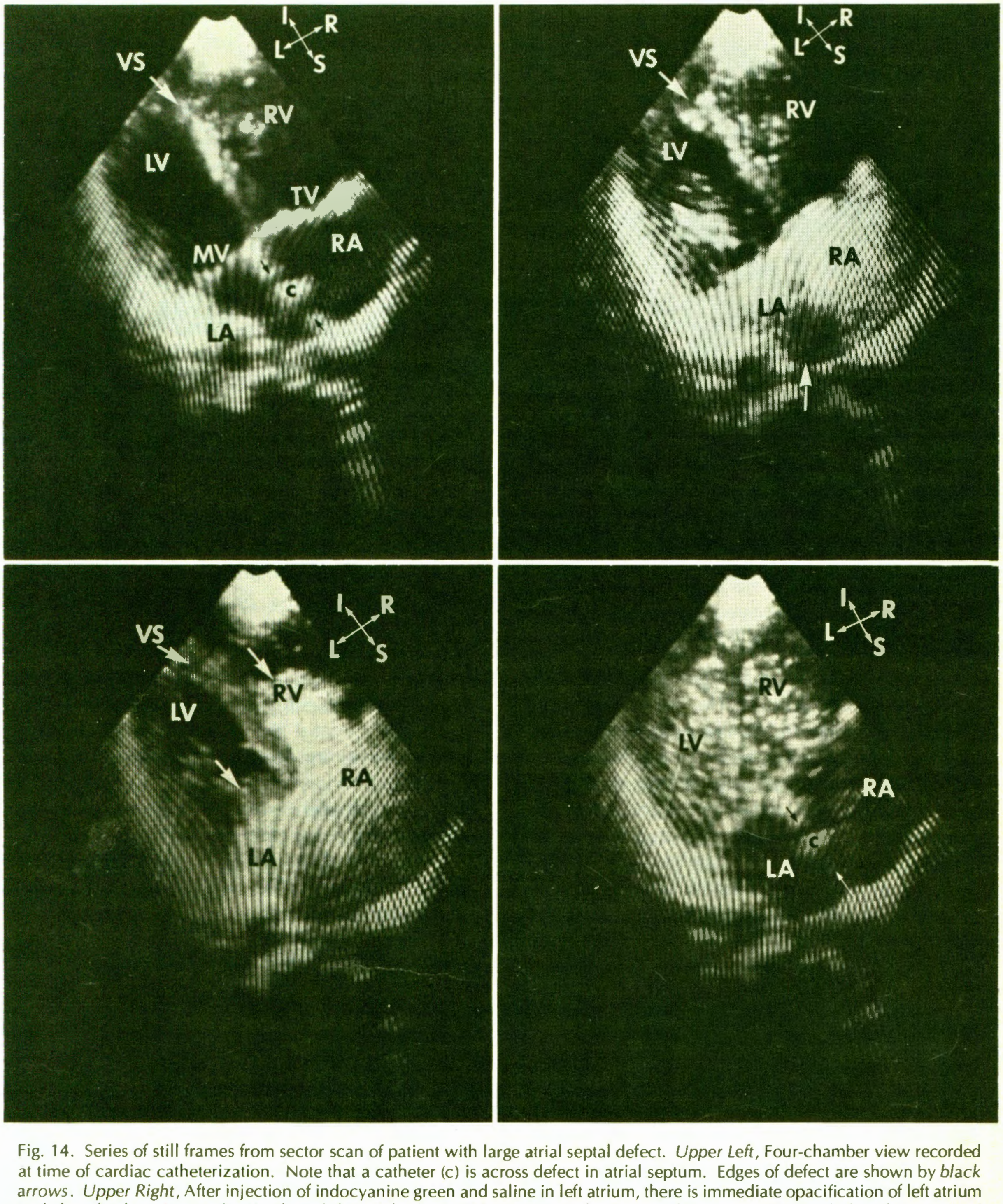


Fig. 14. Series of still frames from sector scan of patient with large atrial septal defect. *Upper Left*, Four-chamber view recorded at time of cardiac catheterization. Note that a catheter (c) is across defect in atrial septum. Edges of defect are shown by *black arrows*. *Upper Right*, After injection of indocyanine green and saline in left atrium, there is immediate opacification of left atrium and also of right atrium, indicating large left-to-right shunt. *White arrow* on lower part of figure is pointing to bolus of unopacified blood entering left atrium from pulmonary veins. In this frame, slight amount of dye has trickled into left ventricle; otherwise, ventricles are essentially free of contrast medium. *Lower Left*, With onset of ventricular diastole, contrast medium in atria enters through their respective atrioventricular valves into right and left ventricular cavities. Note that bolus of dye (*white arrows*) enters right ventricle slightly ahead of left ventricle; this indicates that tricuspid valve opened before mitral valve. *Lower Right*, Contrast material has cleared completely from atrial chambers and is present only in ventricles, where it outlines cavities. c = catheter; *arrows* indicate defect through which catheter passed. This contrast echoangiographic study helps to define and confirm two-dimensional ultrasonic anatomy, delineates boundaries of atrial and ventricular chambers, and defines ventricular and atrial septa and relationship of atrioventricular valves. Abbreviations as before.

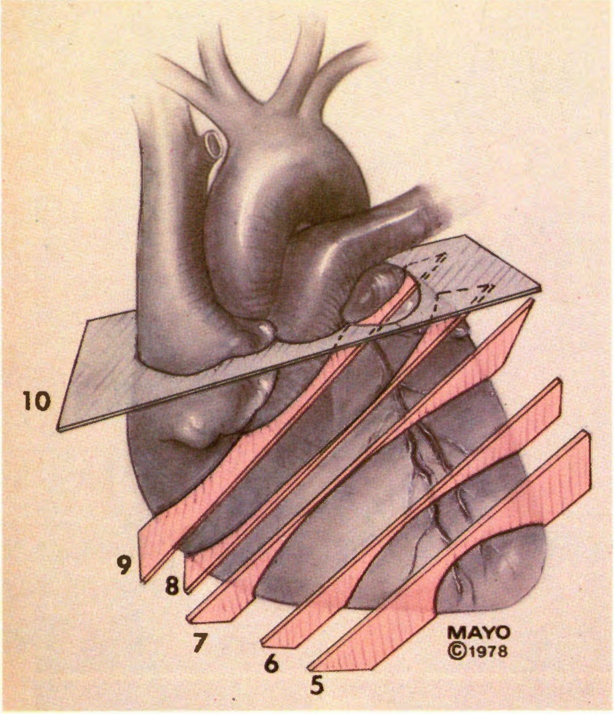


Fig. 15. Six tomographic planes utilized for obtaining various short-axis views of heart and great arteries.

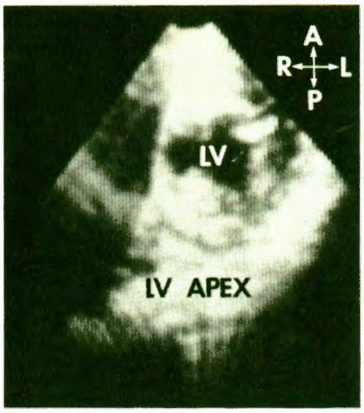
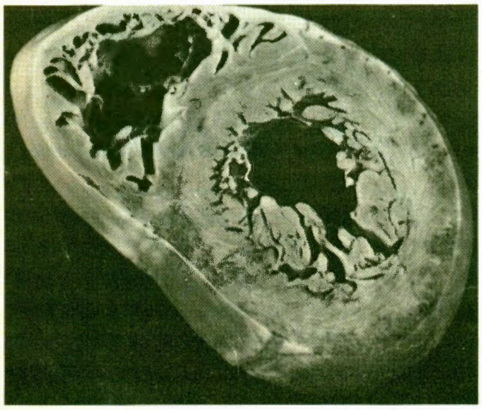


Fig. 16. Sector scan obtained with transducer beam directed in a plane as shown in tomographic section 5. Note that this transects left ventricle near apex, and therefore left ventricular cavity appears small; in real time, considerable reduction in cavity size can be seen during ventricular systole. *R* = right; *L* = left.

in cross section it forms a sausage-like appearance anterior to the circular aorta.[10] The pulmonary valve is observed anterior to and to the right of the aortic valve. The other structures recorded in this section include the left atrium (posterior to the aorta), left atrial appendage (to the right), and right atrium (to the left of the image). The atrial septum is interposed between the left and right atrial chambers. The origins of the right and left main coronary arteries can be seen in this view also. The anterior leaflet of the tricuspid valve can be seen on the left of the image. Occasionally, the inferior vena cava and the coronary sinus can also be seen. Figure 27 shows a cross-sectional view at this level, and the injection of contrast medium is made in the inferior vena cava, with resulting dense opacification sequentially of the right atrium, right ventricular outflow tract, and pulmonary artery. From this position—which records section 9—if the transducer is rotated slightly clockwise (groove facing suprasternal notch) and tilted superiorly beyond the pulmonary valve, the main pulmonary artery and its bifurcation into the right and left pulmonary arteries can be identified, as shown in section 10 and Figure 28. Figure 29 represents a schematic drawing of a section at this level.

Usefulness of Short-Axis Views (Sections 5 Through 10).—1. Determining right and left ventricular chamber dimensions

2. Evaluating global and regional left ventricular performance



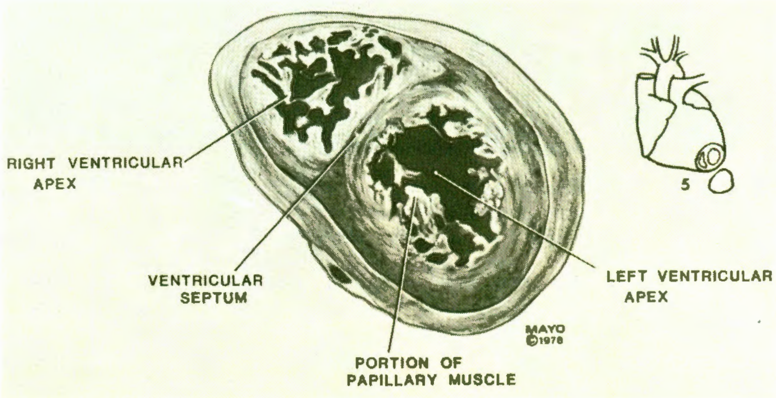


Fig. 17. *Left*, Anatomic section of heart obtained near apex in presumed plane of section 5. *Right*, Drawing of this anatomic section with identification of structures.

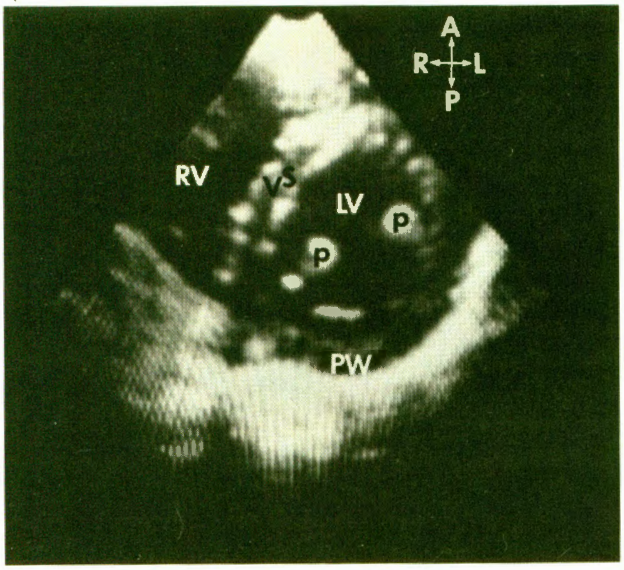


Fig. 18. Sector scan of normal subject recorded with ultrasound beam directed along plane of tomographic section 6, which transects left ventricle at level of papillary muscles. Note that papillary muscles (*p*) project into left ventricular cavity at approximately 3 and 8 o'clock positions. Left ventricle appears circular in this cross section. Portion of right ventricle is also seen anterior and to left. Abbreviations as before.

3. Estimating mitral and tricuspid valve orifice
4. Locating and determining the number of papillary muscles in the left ventricle
5. Evaluating atrial dimensions and detecting intra-atrial masses
6. Evaluating atrial septum for motion and defects
7. Determining spatial orientation of great arteries
8. Evaluating abnormalities of aortic, pulmonic, mitral, and tricuspid valves
9. Visualizing right and left main coronary arteries

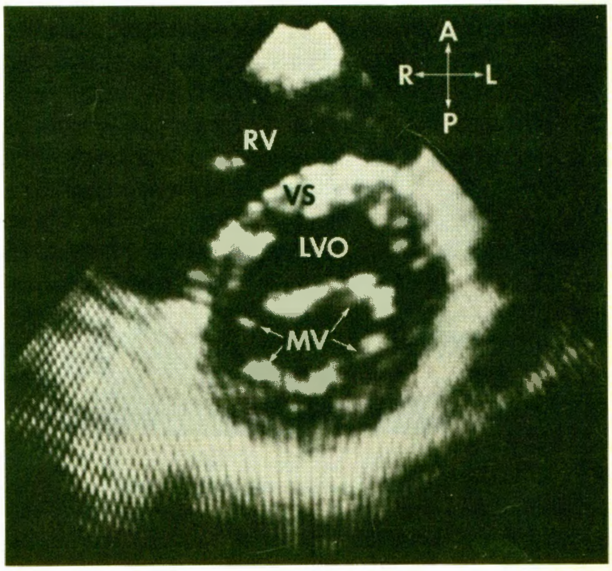
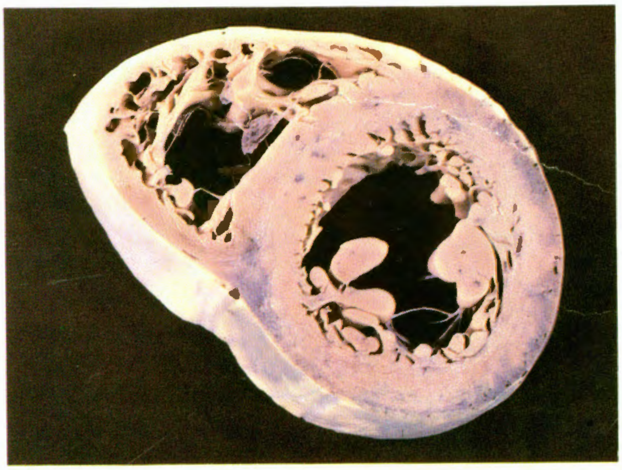


Fig. 20. Still frame of sector scan obtained from normal subject, with transducer pointing posteriorly and beam transecting heart in plane shown in Figure 15, section 7. In this figure, right ventricle is anterior and to left; left ventricle appears circular and is located posteriorly. Anterior and posterior leaflets of mitral valve have fish-mouth appearance during diastole. Portions of tricuspid valvular apparatus can also be seen in this section. Septum, free wall, and posterior wall of left ventricular cavity are clearly delineated. Abbreviations as before.

10. Evaluating aortic root pathology
11. Evaluating main pulmonary artery and proximal right and left branches for size and presence of clots
12. Evaluating enlargement and drainage of coronary sinus



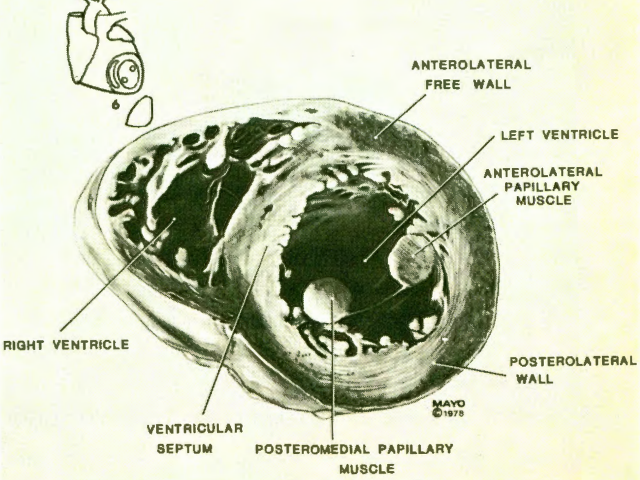
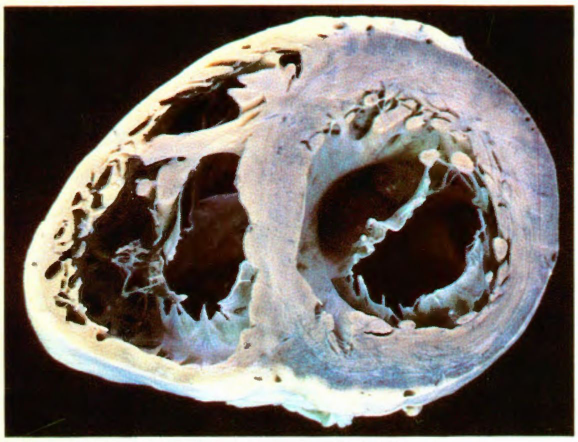


Fig. 19. *Left*, Anatomic section of heart made along plane of ultrasound tomographic section 6. *Right*, Drawing of same section with identification of structures.



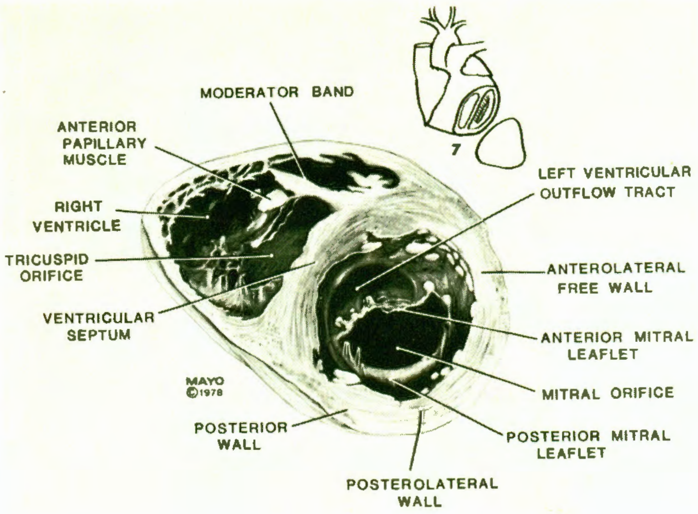


Fig. 21. *Left,* This anatomic section of heart has been obtained along a plane corresponding to ultrasonic tomographic section 7. *Right,* Drawing of same section with identification of structures.

APICAL POSITION (Figure 30, Sections 11 Through 13)

This view is obtained with the patient turned in the left semilateral decubitus position. The apical impulse is localized and the transducer is placed at, or in the immediate vicinity of, the point of maximum impulse. With the apical transducer position, a four-chamber view of the heart or a right anterior oblique equivalent view of the left ventricle is usually recorded.[21,26] The notch on the transducer is placed pointing up or down, depending on whether one wishes to display the left ventricle on the right or on the left of the image, respectively. Since with the apical transducer position the views obtained (sections 11 through 13) represent long-axis views of the heart, in particular of the left ventricle, we believed it would be desirable that the image orientation of these views be similar to that of tomographic section 1, which represents the long-axis view of the left ventricle. For this reason we have chosen to display the apical views with the left ventricle on the left and the right ventricle on the right of the image.

For the four-chamber view, the ultrasound beam is directed superiorly and medially toward the patient's right scapula (section 11). In this position, the beam transects the heart from the apex to the base,

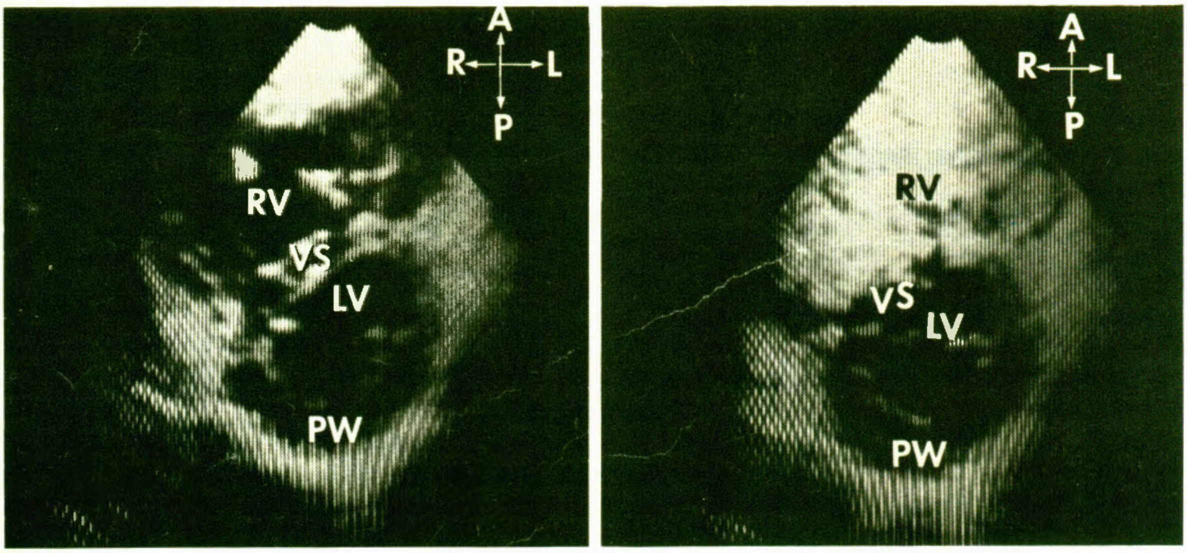


Fig. 22. *Left,* Still frame of sector scan of patient with pulmonary hypertension. Short-axis view of left ventricle and of right ventricle at level of mitral orifice is recorded. Note prominent moderator band in right ventricle. *Right,* After injection of indocyanine green and saline in superior vena cava, dense echoes opacify right ventricular chamber and outline its dimensions and right septal surface. Left ventricular cavity remains echo free. Abbreviations as before.

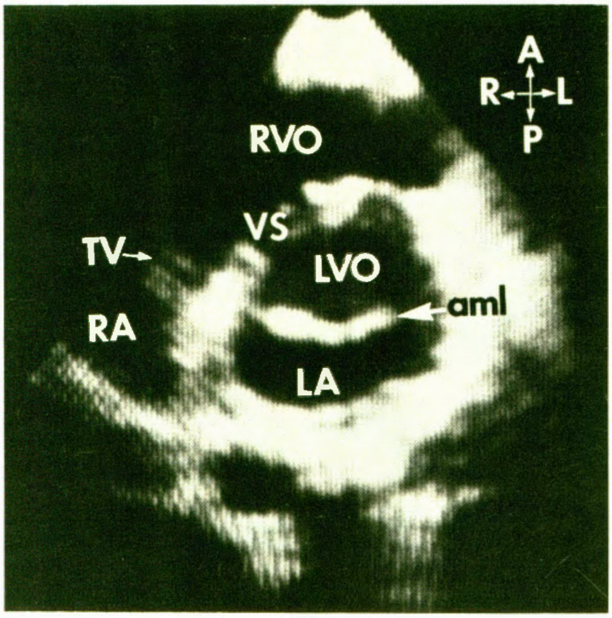


Fig. 23. Still frame of sector scan of normal subject. Transducer is tilted superiorly and slightly medially, and beam is directed in plane of tomographic section 8. In this plane, transverse section of heart across left ventricular outflow tract region is recorded. Basal portion of anterior mitral leaflet (*aml*) is transected, and boundary of left ventricular outflow tract is well delineated. Posterior to mitral leaflet is left atrium and anterior is left ventricular outflow tract. On left of figure (posterior to anterior), right atrium, portion of anterior leaflet of tricuspid valve, and right ventricular outflow tract are recorded. In this plane, junction of ventricular and atrial septa is also noted. Abbreviations as before.

as shown in Figure 31. This view displays all four chambers of the heart, the ventricular and atrial septa, and the crux of the heart. While recording the apical four-chamber view (section 11), we usually tilt the beam in a slightly anterior (11a) and a posterior (11b) direction in order to scan a greater portion of the atrial septum. The image orientation is such that the apex is on the top and the atria are on the bottom. The right atrium and right ventricle are on the right, and the left atrium and left ventricle are on the left of the image, with the groove down. Figure 32 *upper left* and *upper right* shows anatomic sections obtained in the plane of tomographic section 11 (11a and 11b, respectively), and Figure 32 *lower* is a drawing of the same section with identification of structures. This apical four-chamber view allows evaluation of the interrelationships of the ventricular and atrial septa and of both atrioventricular valves. In normals, with this projection the ventricular and atrial septa do not appear to join each other in a straight apex-to-base line. Instead, the atrial septum appears displaced slightly to the left of the ventricular septum. The continuation of the echoes of the ventricular and atrial septa is by means of a membranous connection. The left (mitral) atrioventricular groove is normally slightly higher than the right (tricuspid) atrioventricular groove. The anterior leaflet of the mitral valve inserts in the left atrioventricular sulcus and near the cephalic end of the membranous septum, whereas the septal leaflet of the tricuspid valve inserts near the midportion of the membranous septum. Therefore, the insertion of the septal leaflet of the tricuspid valve is somewhat (5 to 10 mm in the hearts of older children and adults) inferior to the insertion of the anterior mitral leaflet. This is an important anatomic distinction because it can be useful in identifying ventricular chambers.

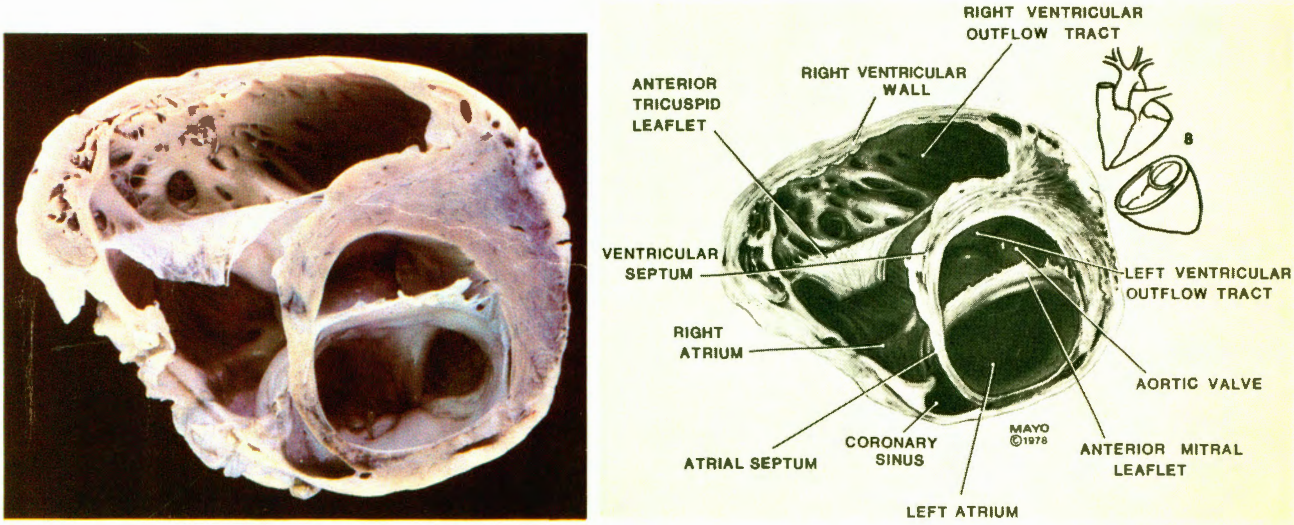


Fig. 24. *Left*, Anatomic section obtained in plane of ultrasonic tomographic section 8. *Right*, Drawing of same section with identification of structures.

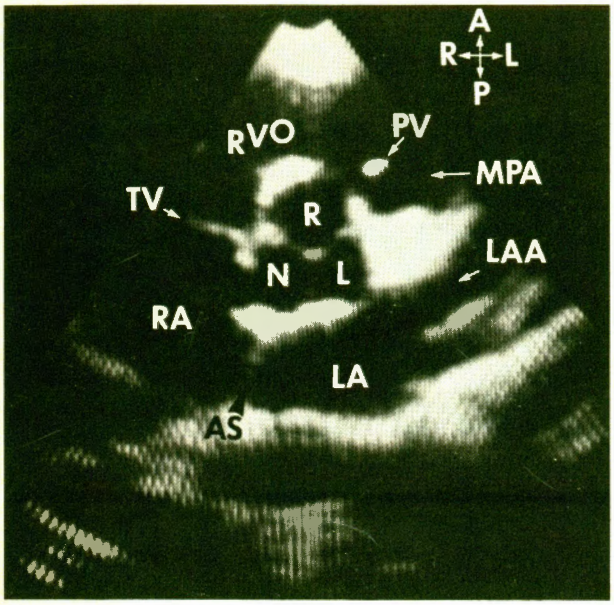


Fig. 25. Still frame of sector scan obtained with further superior and slight medial tilt of transducer so that ultrasound beam transects heart roughly parallel to plane as shown in Figure 15, section 9. This section transects heart at level of great arteries. Aorta appears as circular structure. Aortic valve leaflets in closed position are well seen (left *L*, right *R*, noncoronary *N*). Left atrial cavity is directly posterior to aortic root, and left atrial appendage (*LAA*) is toward right of figure. Right atrium and tricuspid valve are on left of figure and right ventricular outflow tract is anterior. Right ventricular outflow tract curves around circular aorta. Also well recorded is atrial septum. Abbreviations as before.

In this view, the atrial septum can usually be seen in its entirety without any thinning or dropout if the ultrasound beam is directed slightly anteriorly (section 11a, Fig. 32 *upper left*). However, dropout of echoes does occur in its mid portion, which is the region of the fossa ovalis, if the ultrasound beam is directed further posteriorly (section 11b, Fig. 32 *upper right*). This fact needs to be remembered when this view alone is used in the evaluation for atrial septal defects, for there exists potential for both false-positive (section 11b, Fig. 31 and 32 *upper right*) and false-negative (section 11a, Fig. 32 *upper left*) diagnoses of atrial septal defect. Motion of the atrial septum can also be well evaluated, and the atrial septum can be seen to bulge toward the right atrium during ventricular systole. This view also allows visualization of the right and left inferior pulmonary veins emptying into the left atrium (Fig. 31).

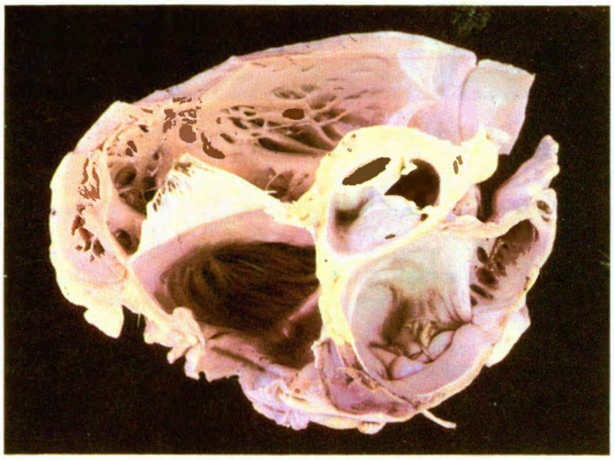
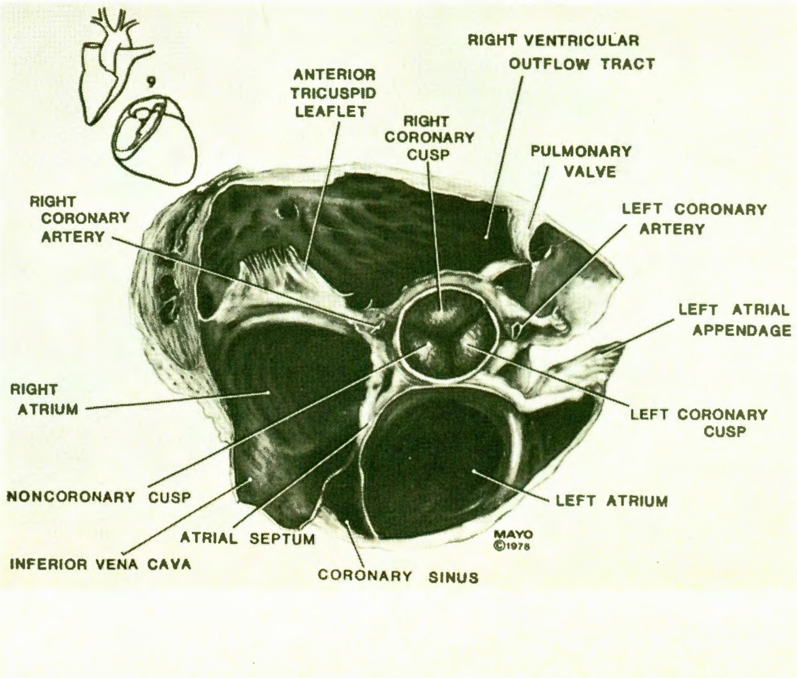
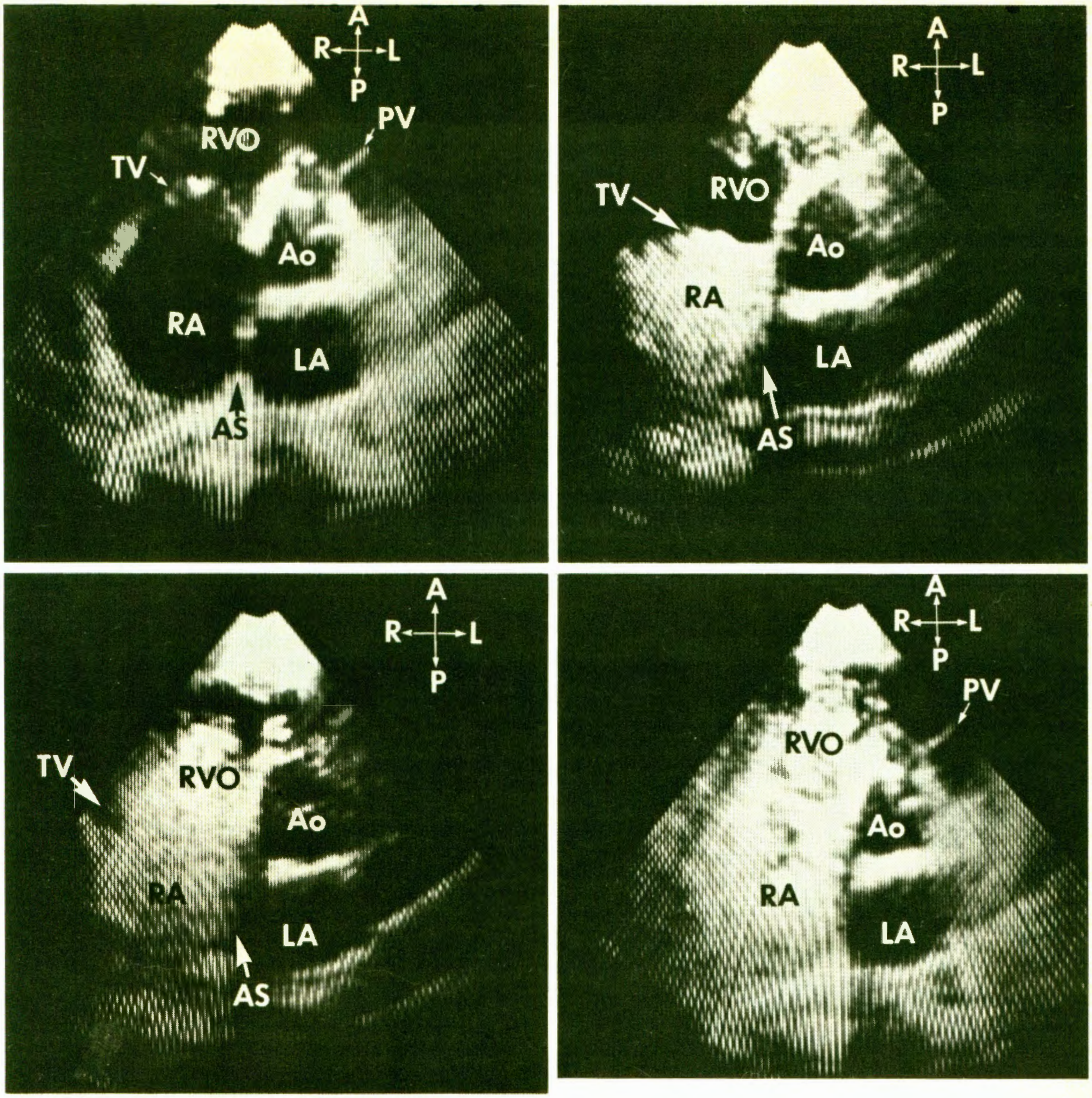


Fig. 26. *Upper*, Anatomic section of heart obtained along presumed ultrasonic tomographic plane 9. *Lower*, Drawing of same section with identification of structures.





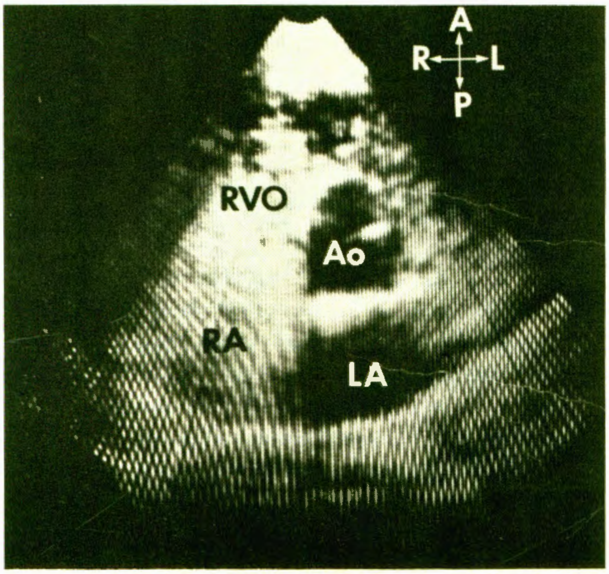
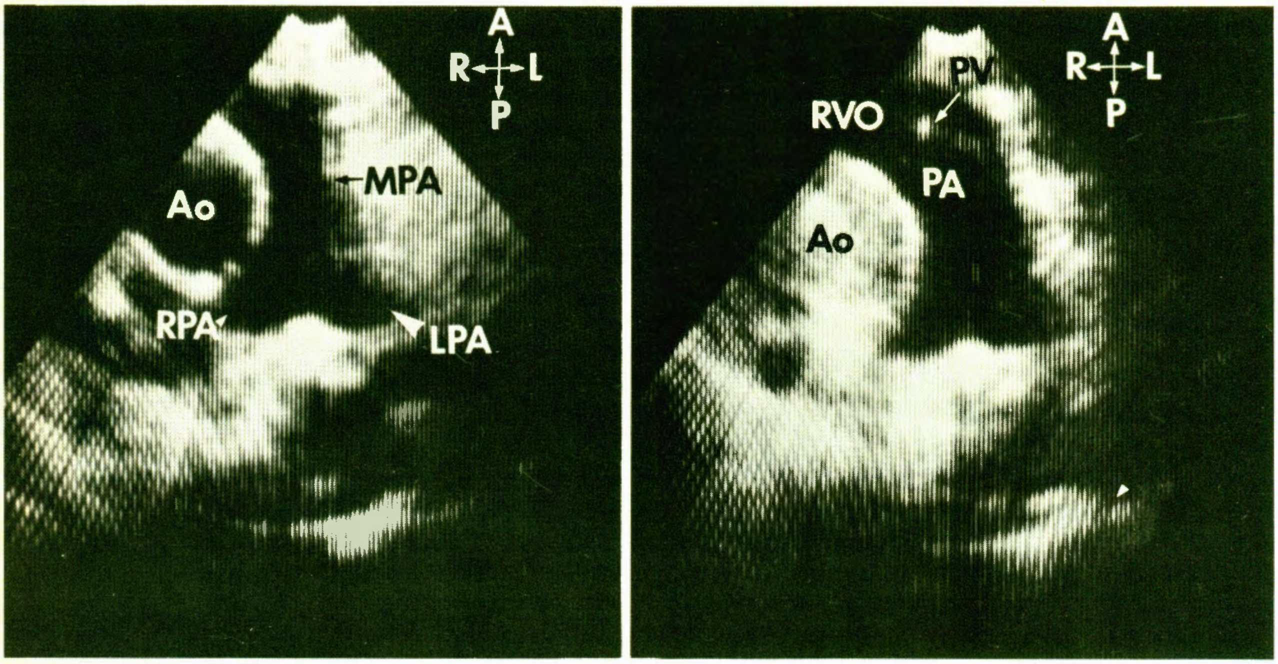


Fig. 27. *Upper Left*, Still frame of sector scan representing tomographic section 9. Structures recorded include aortic root with aortic valve, left atrium, atrial septum, right atrium, tricuspid valve, right ventricular outflow tract, and pulmonary valve. *Upper Right*, With injection of indocyanine green and saline into superior vena cava, dense echoes appear in right atrium and outline this chamber and right side of atrial septum. With subsequent ventricular diastole, contrast medium enters right ventricle and opacifies right ventricular outflow tract (*Middle Left and Right*), and with subsequent ventricular systole, dye opacifies proximal pulmonary artery (*Lower*). Throughout this sequence, left atrial chamber and aortic root remain echo free as contrast medium traverses and outlines right-sided chambers. Abbreviations as before.



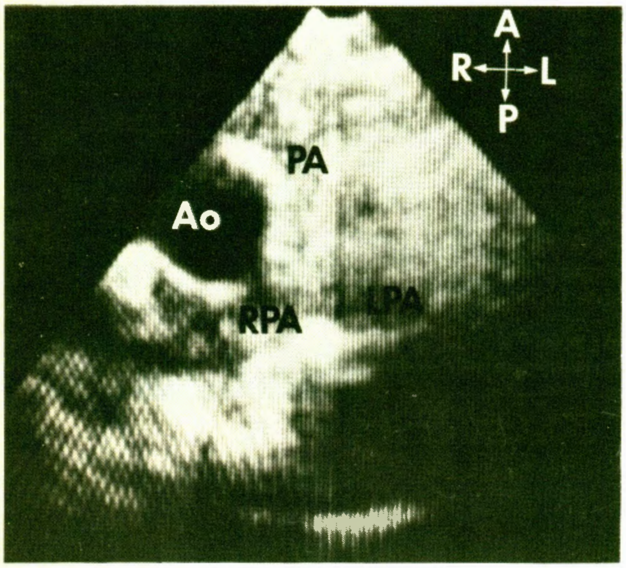


Fig. 28. *Upper Left*, Still frame of sector scan obtained with ultrasound beam directed in plane shown in Figure 15, tomographic section 10. In this section, beam transects main pulmonary artery (*MPA*) through its point of bifurcation into proximal right (*RPA*) and left (*LPA*) pulmonary arteries. This section also passes through aortic root in immediate supravalvular region. *Upper Right*, After injection of indocyanine green and saline into left ventricle, echoes densely opacify aortic root. *Lower*, After similar injection into right ventricle, contrast medium opacifies pulmonary trunk and its branches. These contrast studies aided in confirming ultrasonic anatomy. Abbreviations as before.

With the same apical transducer position, in order to obtain tomographic section 12, the transducer is tilted further anteriorly to record the aortic root and valve in addition to the four chambers (Fig. 33). The aortic root occupies the region where the crux of the heart was recorded in the previous section. Figure 34 *upper* is an anatomic section obtained in the tomographic plane of section 12, and Figure 34 *lower* is a drawing of the same section with identification of structures.

Right Anterior Oblique View of Left Ventricle.— This view is obtained with the transducer placed at the apex and with the groove pointing toward the patient's left. The beam is directed in a plane nearly parallel to the ventricular septum (section 13). In this view, the apex of the left ventricle is displayed at the top right of the projected image, the aorta is at the bottom left, and the left atrium lies directly posterior (Fig. 35). In this view the anterolateral and inferior walls of the left ventricle are imaged, and since this view bears a close resemblance to the left ventricular angiogram obtained in a right anterior oblique position, it has been referred to as the right anterior oblique equivalent view of the left ventricle.[26] A

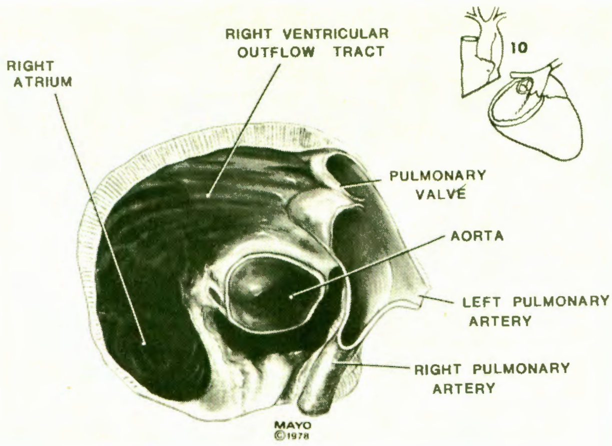


Fig. 29. Drawing of a presumed section obtained along ultrasonic tomographic section 10.

mirror-image right anterior oblique view can be recorded by rotating the transducer head 180° (groove pointing to patient's right). In practice, we prefer to obtain this latter view, primarily for consistency of orientation and therefore ease of comprehension, because it bears a close resemblance to the long-axis view of the left ventricle.

Usefulness of Apical Views (Sections 11 Through 13).—1. Evaluating ventricular and atrial dimensions

2. Detecting and localizing intracardiac masses

3. Evaluating septal defects (atrial and ventricular)

4. Detecting malalignment of atrial and ventricular septa

5. Detecting displacement of atrioventricular valve leaflets and orifice as in Ebstein's anomaly and straddling valve

6. Detecting structural abnormality of the atrioventricular valves and of their tensor apparatus

7. Evaluating left ventricular function

8. Evaluating left ventricular apex and detecting left ventricular aneurysm

9. Determining aortic override of the ventricular septum

10. Visualizing the right and left inferior pulmonary veins draining into the left atrium

SUBXIPHOID POSITION (Figure 36, Sections 14 Through 17)

In certain patients, especially those with chronic obstructive lung disease and emphysema, the usual precordial ultrasonic window may become obliterated because of hyperinflated lungs. This situation necessitated a search for other locations for imaging the heart and led to the discovery of the subxiphoid region as a good ultrasonic window in such patients. The technique and usefulness of M-mode subxiphoid

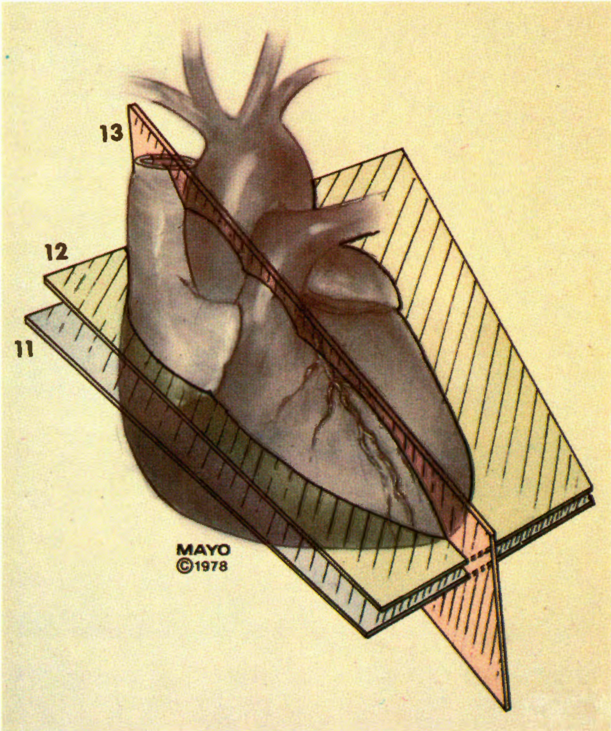


Fig. 30. Drawing of heart demonstrating the three tomographic planes (sections 11 through 13) obtained with transducer placed at apex of heart.

echocardiography have been previously described.[30] With the two-dimensional ultrasound system, we have observed that the subxiphoid position provides good imaging of the heart not only in emphysematous patients but also in the majority of normal (nonemphysematous) adults, children, and infants. Indeed, the views recorded from the subxiphoid position are unique, for they allow better definition of certain structures from this location than can be obtained from the precordial positions. Subxiphoid examination is often facilitated if performed with held inspiration.

We begin the subxiphoid examination by placing the transducer in the midline or slightly to the patient's right, and the transducer groove is pointed down toward the patient's spine. The transducer head is tilted inferiorly and slightly toward the patient's right, and with this position the liver parenchyma, hepatic vessels, and short-axis view of the inferior vena cava are obtained. With slight superior tilt of the transducer, the drainage of the hepatic veins into the inferior vena cava can be identified (Fig. 37 *upper left*). To record the inferior vena cava along its long axis, the transducer is rotated so that the groove points toward the patient's right flank. The hepatic veins

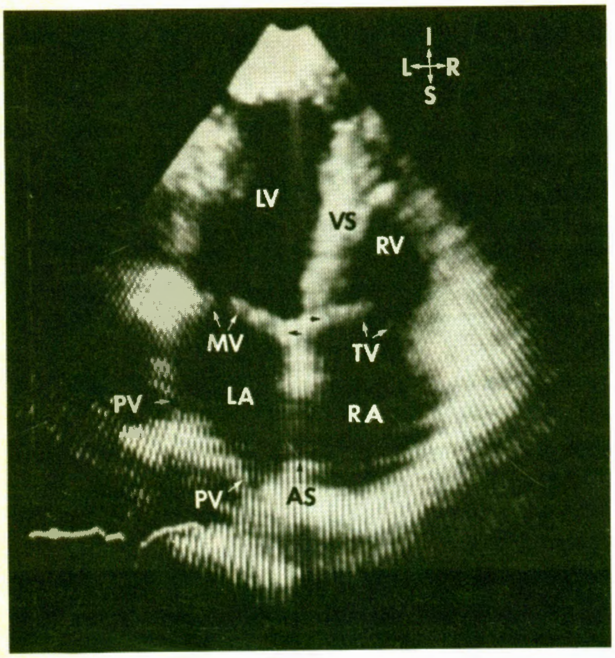


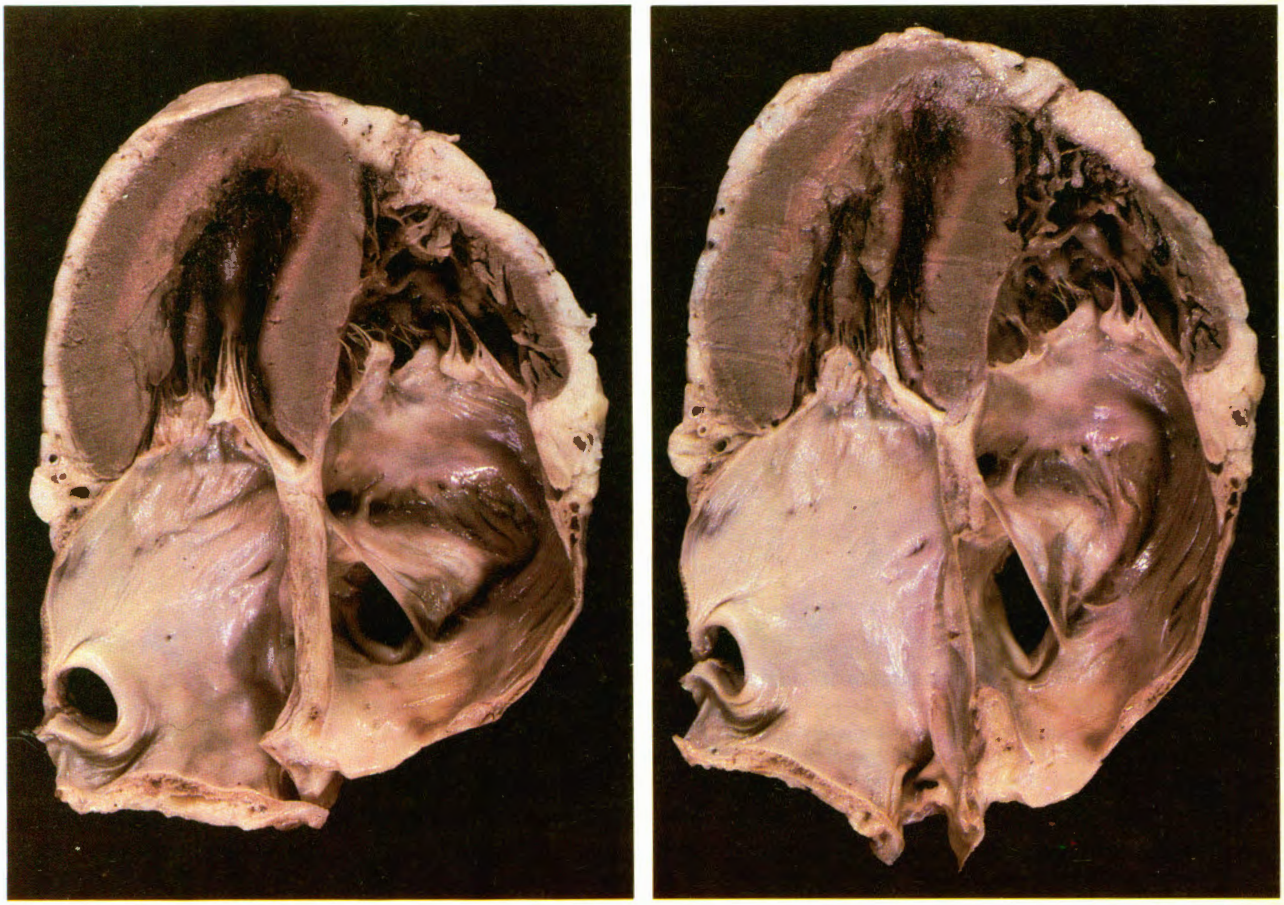
Fig. 31. Still frame of sector scan of normal subject, obtained by placing transducer at apex of heart and recording apical four-chamber view. See text for details. *Black arrows* mark points of attachment of anterior leaflet of mitral valve and of septal leaflet of tricuspid valve. Note that latter is normally situated inferior to mitral valve. Also note some dropout of echoes in the region of the fossa ovalis. Abbreviations as before.

again can be recognized by the fact that they drain into the inferior vena cava, as shown in Figure 37 *upper right*. Figure 37 *lower* demonstrates how injection of contrast medium into the inferior vena cava densely opacifies this structure. The inferior vena cava-to-right atrium communication is also best assessed in this view (tomographic section 14). With the transducer in the epigastric region, other intra-abdominal structures, such as the abdominal aorta and its branches, portal vein, gallbladder, pancreas, and kidneys, can be visualized. However, these will not be discussed any further here.

For tomographic section 15, the transducer (groove pointing toward the patient's spine) is tilted further superiorly so that it points roughly between the patient's suprasternal notch and the left supraclavicular fossa. A tomographic view of the heart is thus obtained which is nearly similar to the four-chamber view obtained from the parasternal position, section 4, except that in this view the apices of the two ventricles can be visualized by tilting the transducer head slightly toward the patient's left. In this section, the two atria and especially the atrial septum are best visualized. Whereas dropout of echoes of the atrial septum in the region of the fossa ovalis may be noted from parasternal and apical transducer positions (sections 4, 9, and 11), the atrial septum can be seen in its entirety from the subxiphoid position and it appears intact in almost every examination without any persistent dropout. Atrial septal motion can again be well evaluated in this view. For image orientation of this view, we have followed the same format as that for the similar view from the parasternal position (tomographic section 4), so that the atria are displayed to the right and the cardiac apex is seen to the left of the image. The right atrium and right ventricle are displayed as anterior chambers closer to the transducer, and the left atrium and left ventricle are displayed posteriorly (Fig. 38). A portion of the hepatic parenchyma is interposed between the transducer and the cardiac silhouette. Figure 39 represents an anatomic section and a drawing of the cardiac section obtained in the tomographic section of plane 15. In Figure 40 *left*, a subxiphoid view of the atria and of the atrial septum is demonstrated. In Figure 40 *right*, contrast medium has been injected into the superior vena cava and the dye is seen to fill the right atrial cavity densely and outline its boundaries, including the atrial septum. The left atrial cavity remains echo free.

From this position, the transducer is rotated clockwise and tilted slightly superiorly to visualize the posterior great artery (aorta) and its relationship to the mitral valve and left ventricle (Fig. 41). In this tomographic section, number 16, a foreshortened view of the left ventricular long axis is recorded. Both leaflets of the mitral valve and the aortic leaflets, as well as the left ventricular outflow tract, can usually be well visualized. The tricuspid valve can usually be seen directly anterior in this view. Since this view bears a close resemblance to tomographic section 1, we have followed the same format for image orientation—namely, aorta to the right, cardiac apex to the left, right ventricle anteriorly, and left ventricle posteriorly.

Tomographic section 17 is obtained by further clockwise rotation and superior tilting of the transducer which results in a cardiac cross section as shown in Figure 42. In this view, the left ventricle is visualized in the short axis with portions of the mitral valve in its cavity. More importantly, this view is utilized to show the long axis of the entire right ventricular outflow tract. The tricuspid valve orifice usually appears directly end on. On the video monitor, the heart appears upside down, with the right ventricular inflow and outflow tracts along the right of the image, the cross section of the left ventricle to



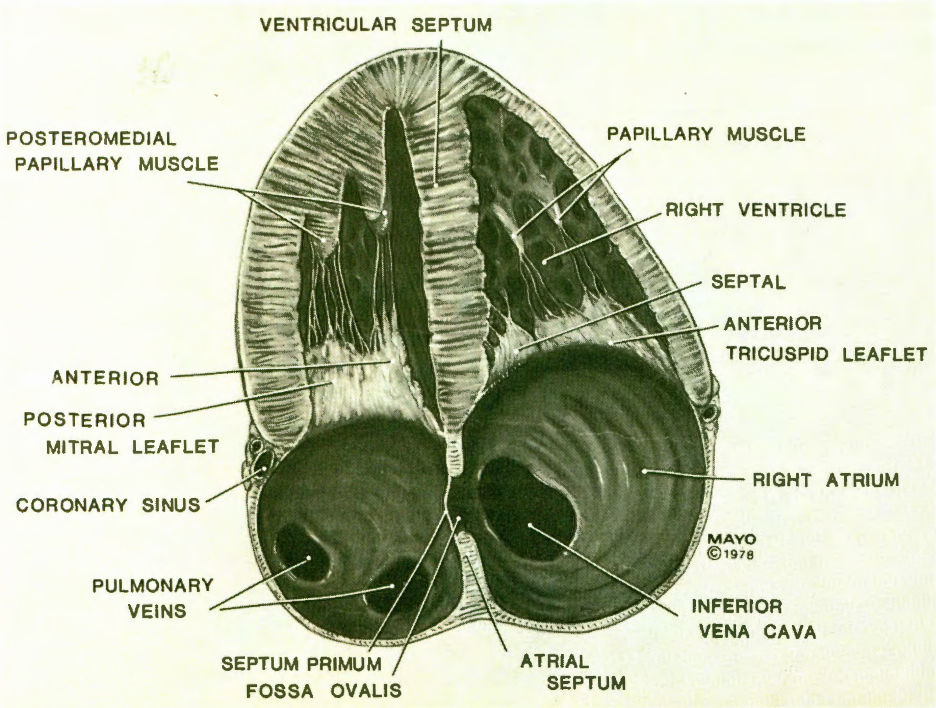


Fig. 32. *Upper Left*, Anatomic section along presumed plane of ultrasonic tomographic section 11. *Upper Right*, Section along same plane but slightly more posterior. *Lower*, Drawing of same section with identification of structures. Note insertion of anterior leaflet of mitral valve and its relationship to septal leaflet of tricuspid valve. Also, it is important to note that atrial septal dropout may occur (in region of fossa ovalis) when beam is slightly more posteriorly directed, as evident in *Upper Right* and in Figure 31.

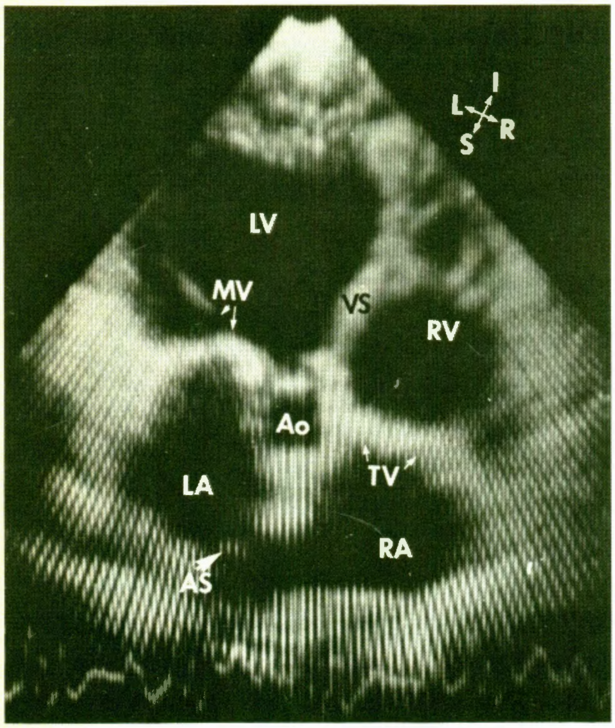


Fig. 33. Still frame of sector scan obtained with transducer at apex of heart with beam tilted slightly superiorly from recording plane of section 11. In this section, number 12, therefore, in addition to demonstrating four chambers of heart, beam now transects left ventricular outflow tract and aortic root and valve. Aorta *(Ao)* appears to occupy region previously occupied by crux of heart, as noted in Figure 31. Abbreviations as before.

the left, hepatic tissue anterior, and pulmonary valve inferior (posterior). Figure 43 *left* is an anatomic section obtained in the plane of the ultrasonic tomographic section 17, and Figure 43 *right* is a drawing of this section with identification of structures.

Usefulness of Subxiphoid Views (Sections 14 Through 17).—1. Evaluating hepatic veins and detecting dilatation or obstruction of the inferior vena cava

2. Determining inferior vena cava-to-atrium connections

3. Determining visceral and atrial situs

4. Evaluating atrial dimensions and detecting atrial masses

5. Evaluating atrial septal motion

6. Detecting and locating atrial septal defects

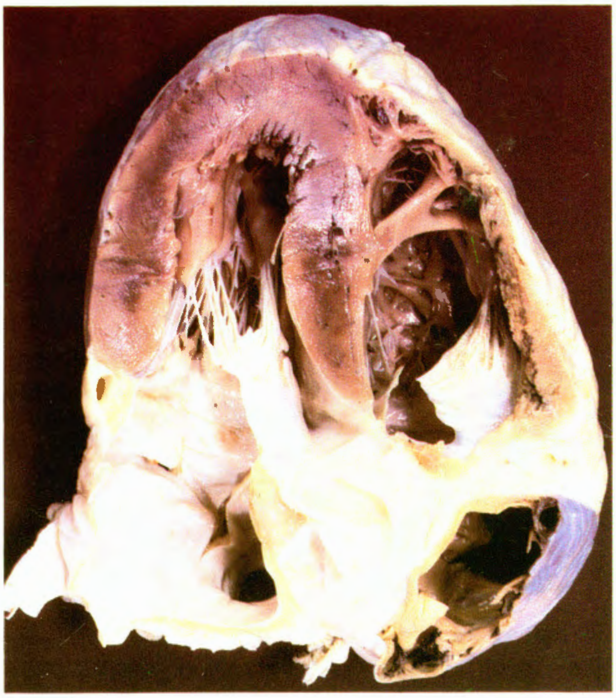
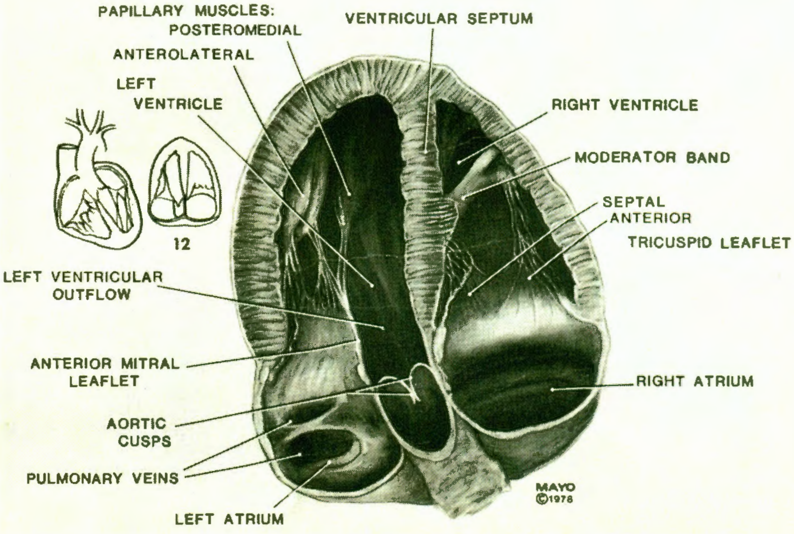


Fig. 34. Anatomic section *(Upper)* and drawing *(Lower)* of sector scan along presumed plane of tomographic section 12.



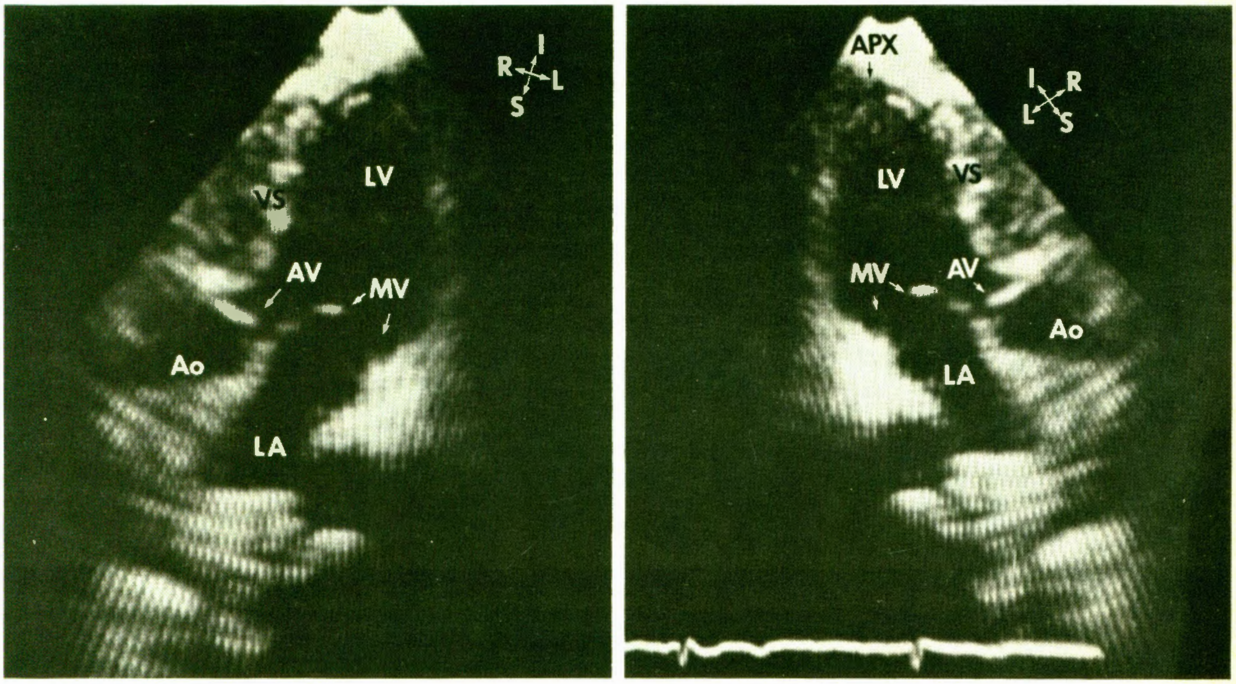


Fig. 35. *Left*, Still frame of sector scan recorded with transducer at apex of heart (tomographic section 13); beam is parallel to plane of ventricular septum and therefore right anterior oblique equivalent view of left ventricle is recorded. *Right*, Mirror-image of right anterior oblique view. *APX* = apex.

7. Detecting right and left atrioventricular valve abnormalities
8. Detecting pulmonary valvular abnormalities
9. Determining right ventricular wall thickness
10. Evaluating right ventricular apex and outflow tract
11. Determining number, origin, and spatial relationship of the great arteries
12. Evaluating left ventricular size, shape, performance, and wall dynamics
13. Evaluating ventricular septum for thickness, dynamics, and defects

SUPRASTERNAL NOTCH POSITION (Figure 44, Sections 18 Through 20)

With the M-mode transducer placed in the suprasternal notch, echoes of the aortic arch, right pulmonary artery, and left atrium have been recorded.[31,32] We therefore utilized the phased-array scanner to describe the cross-sectional anatomy of the great vessels as visualized from the suprasternal notch position. For visualization of the left aortic arch in the long axis (tomographic section 18), the transducer head is positioned in the suprasternal notch, with the long axis of the transducer to the left and parallel to the trachea and the groove directed toward the right supraclavicular region. With this transducer position, the ascending aorta, aortic arch, origin of the brachiocephalic vessels, and descending thoracic aorta are visualized (Fig. 45). Occasionally, leaflets of the aortic valve can also be seen in the aortic root. The orientation of the image of this view is similar to that seen with a lateral view of an angiogram; thus, the ascending aorta is on the left of the figure and the descending aorta is along the right. Posterior to the ascending aorta and beneath the aortic arch, the

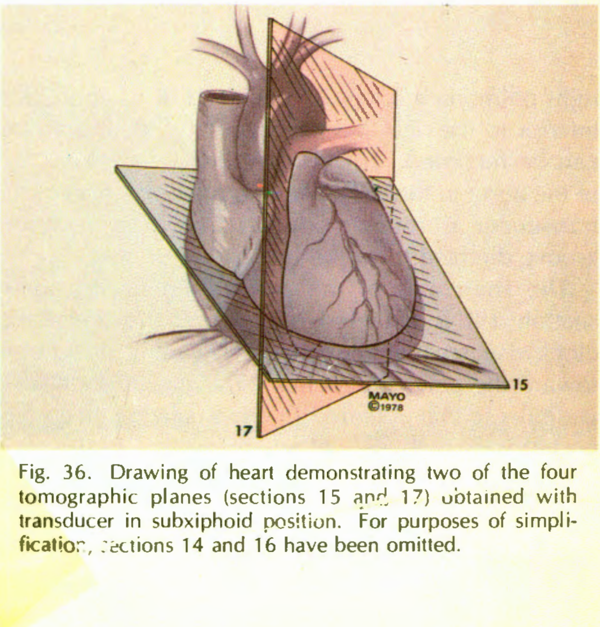
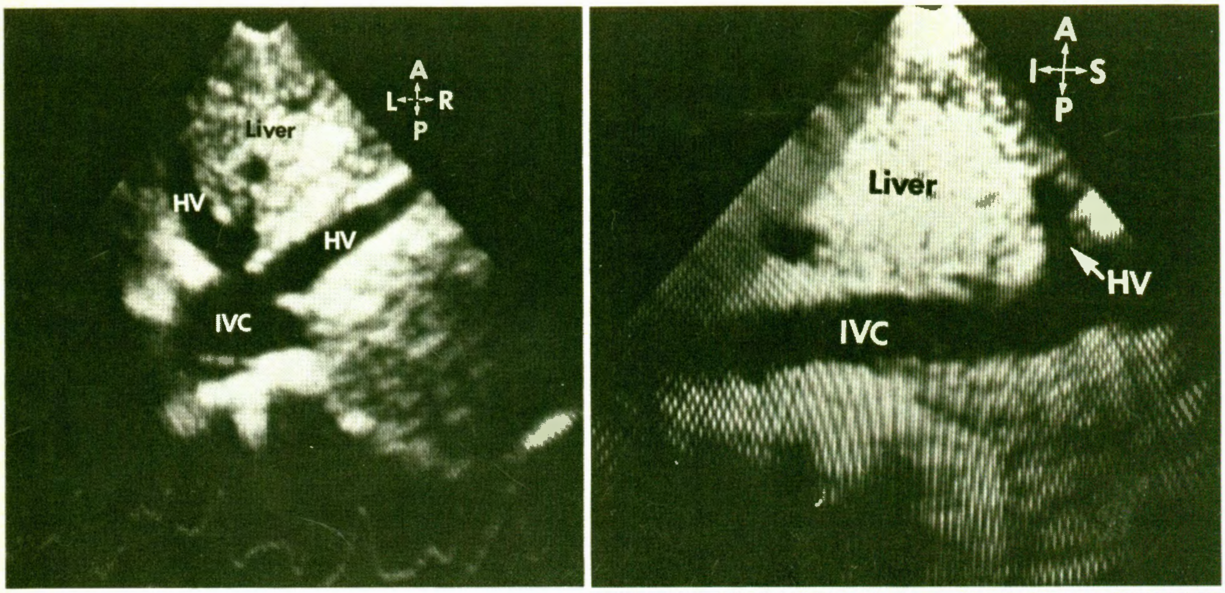


Fig. 36. Drawing of heart demonstrating two of the four tomographic planes (sections 15 and 17) obtained with transducer in subxiphoid position. For purposes of simplification, sections 14 and 16 have been omitted.



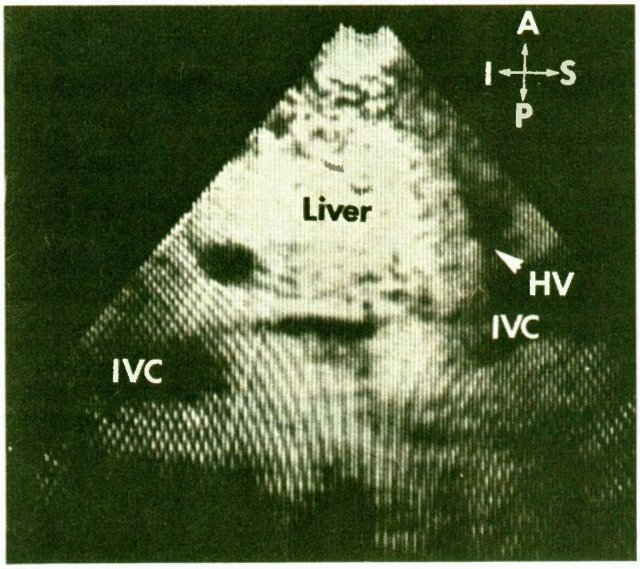


Fig. 37. *Upper Left*, With ultrasound beam in horizontal plane, transverse section of inferior vena cava (*IVC*) is recorded, anterior to which is hepatic tissue with hepatic veins (*HV*) that can be identified as draining into inferior vena cava. By changing beam direction by 90°, long-axis view of inferior vena cava can be readily recorded (*Upper Right*). Again, hepatic parenchyma is recorded anteriorly and hepatic vein can be seen draining into upper portion of inferior vena cava. *Lower*, Injection of indocyanine green and saline into inferior vena cava resulted in dense echoes that filled and opacified this vessel and confirmed ultrasonic anatomy.

right pulmonary artery is visualized in its short axis. Inferior to the right pulmonary artery, the left atrium can be recorded. For visualization of the long axis of the aorta in the presence of a right aortic arch, the transducer is rotated counterclockwise, with the groove directed toward the right breast.

The short axis of the aortic arch (tomographic section 19) is obtained by rotating the transducer clockwise so that the groove is facing posteriorly toward the patient's trachea. The image orientation is similar to that obtained when visualizing an anteroposterior (frontal) view of an angiogram. In this view the cross section of the ascending aorta appears superior and the right pulmonary artery in its long axis appears inferior, as shown in Figure 46. Occasionally, the first bifurcation of the right pulmonary artery can be visualized to the left of the image. With slight clockwise rotation of the transducer and by tilting it toward the patient's left and slightly anteriorly, the distal main pulmonary artery can be visualized. From this position, with tilting of the transducer posteriorly and to the left, the left pulmonary artery may occasionally be seen.

Inferior to the pulmonary artery, the left atrial cavity is seen. Immediately beneath the distal part of the right pulmonary artery, the right superior pulmonary vein connecting to the left atrium can be seen. Furthermore, in this view the superior vena cava can also be recorded, appearing as an echo-free space alongside the aorta on the left of the image. The left

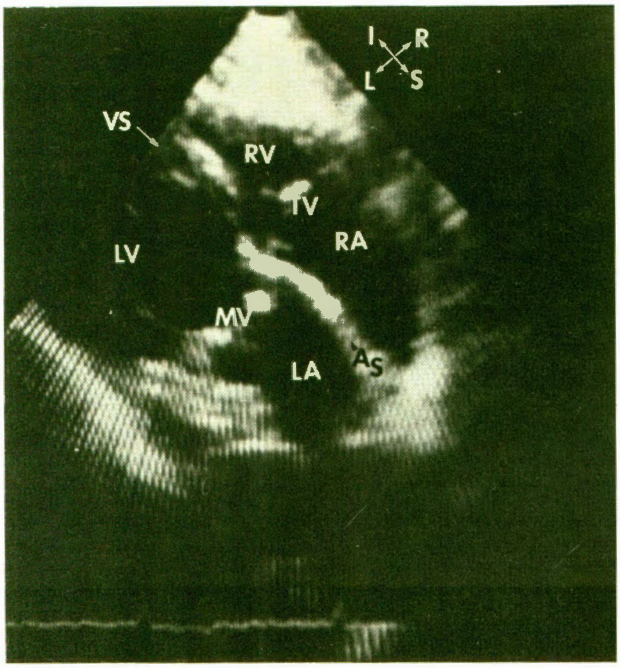


Fig. 38. Still frame of sector scan obtained with transducer positioned in subxiphoid region. Ultrasound beam transects small portions of both ventricles in this patient; however, major portion of bodies of both atria is transected along with atrial septum. Abbreviations as before.

innominate vein can also be visualized traversing superior to the aorta to its junction with the superior vena cava. The right innominate vein can be equally well visualized joining the superior vena cava. With slight counterclockwise rotation and anterior tilt of the transducer, the long axis of the superior vena cava can be recorded alongside the long axis of the ascending aorta (tomographic section 20). In this view the superior vena cava can be scanned to its junction with the right atrium (Fig. 47). This same view of the superior vena cava can occasionally also be obtained with the transducer placed along the upper right sternal border.

Usefulness of Suprasternal Notch Position (Sections 18 Through 20).—1. Determining the dimensions of various parts of the aorta and detecting dissection of the aorta

2. Evaluating arch abnormalities
3. Detecting and localizing coarctation of the aorta

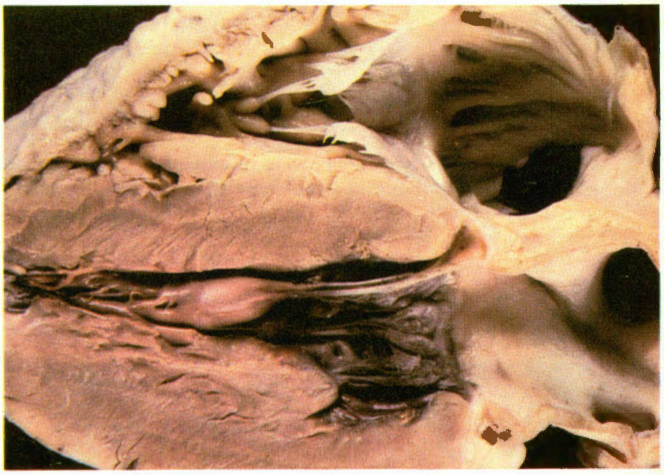
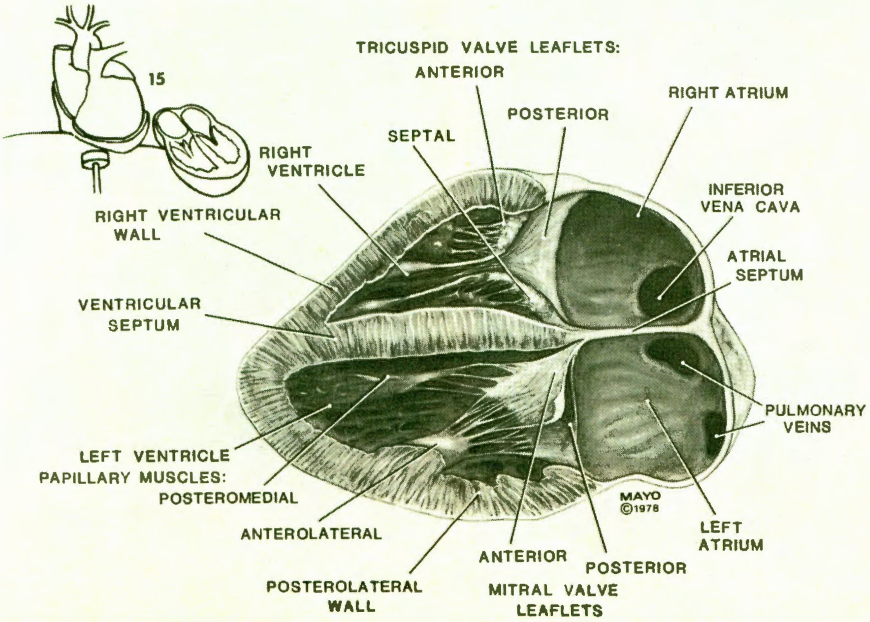


Fig. 39. *Upper*, Anatomic section of heart along presumed plane of tomographic section 15. *Lower*, Drawing of same anatomic section with identification of structures.



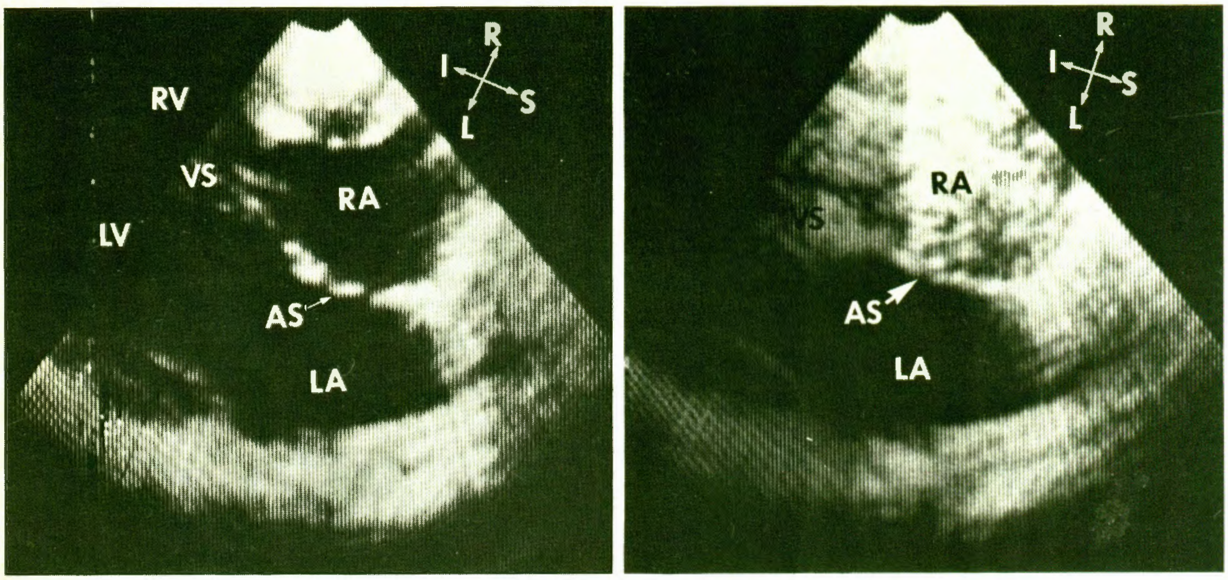


Fig. 40. *Left*, Sector scan obtained from subxiphoid region, demonstrating structures as shown in Figure 38. *Right*, After superior vena caval injection of indocyanine green and saline, dense echoes opacified right atrial chamber, right side of atrial septum, and inflow of right ventricle. This further confirmed ultrasonic anatomy. Abbreviations as before.

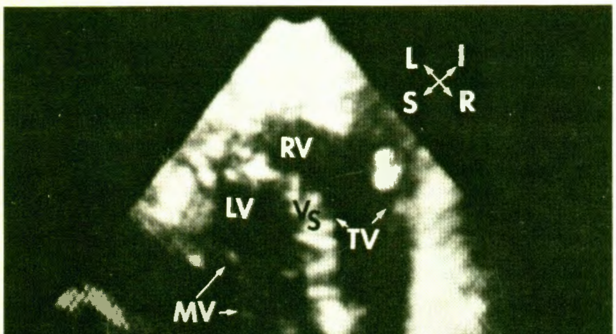


Fig. 41. Still frame of sector scan obtained from a patient with congestive heart failure along plane of tomographic section 16. Left ventricle is transected obliquely. Aorta and aortic valve are recorded inferiorly. Tricuspid valve, anteriorly, and right ventricular outflow tract, along right of image, are also recorded. Abbreviations as before.

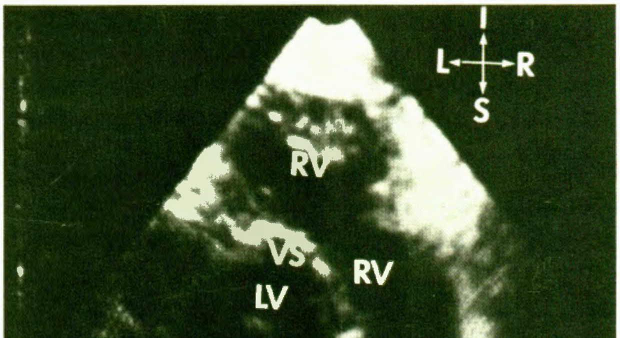


Fig. 42. Still frame of sector scan obtained with transducer in subxiphoid position and ultrasound beam directed as in section 17. Heart image appears upside down. Right ventricular outflow tract can be seen in its entirety along right side of image; left ventricle appears in cross section with portions of mitral valve in its middle. Abbreviations as before.

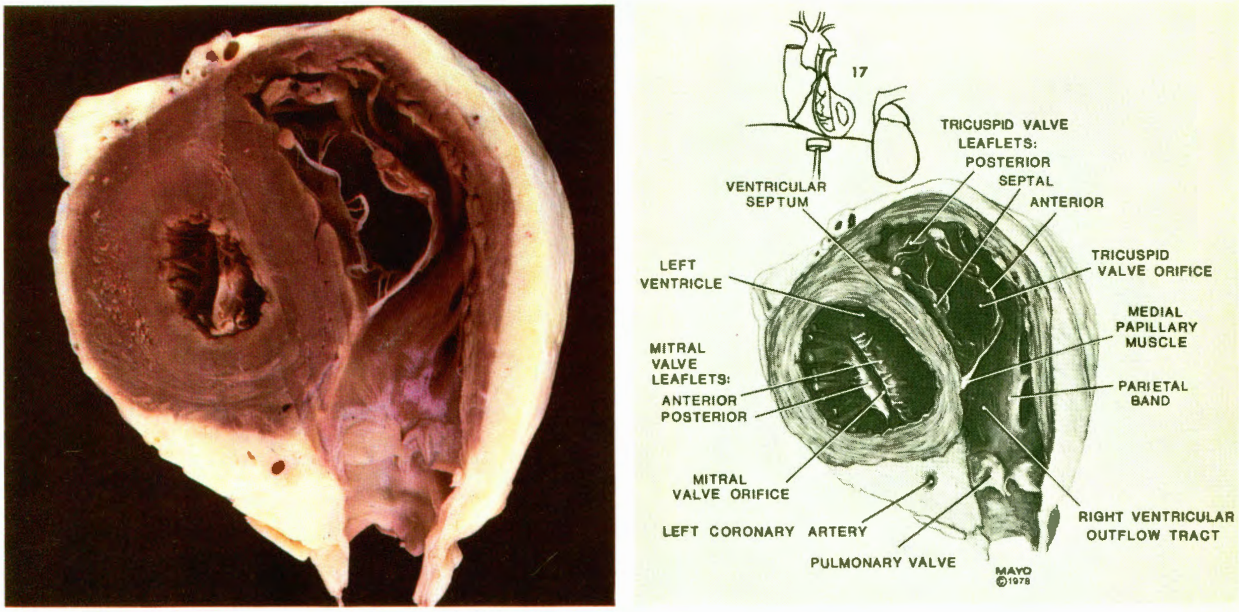


Fig. 43. Anatomic section (*Left*) and drawing (*Right*) of section obtained in plane of ultrasonic tomographic section 17.

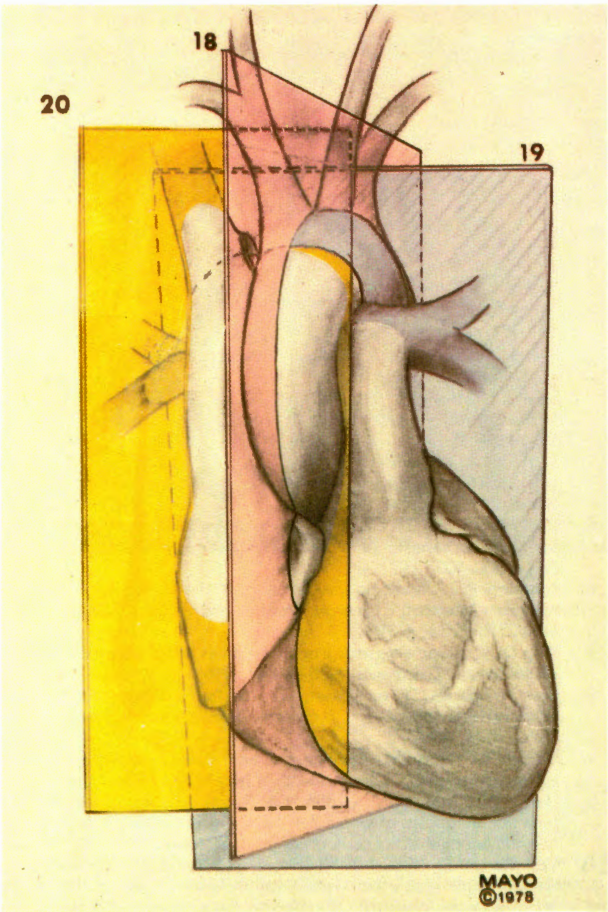


Fig. 44. Drawing of heart and great vessels demonstrating the three tomographic planes (sections 18 through 20) obtained with transducer in suprasternal notch position.

4. Determining the size of the right, main, and, occasionally, left pulmonary arteries
5. Evaluating superior vena caval abnormalities
6. Evaluating the Waterston (ascending aorta to right pulmonary artery) and Glenn (superior vena cava to right pulmonary artery) anastomoses

COMMENT

Real-time, wide-angle, two-dimensional echocardiography is an exciting development and has opened a new era in noninvasive cardiologic investigation. The detailed anatomic and functional information provided by this technique has hitherto been unavailable either with standard M-mode echocardiography or with invasive angiographic techniques. In this paper, we have provided detailed information regarding the technique of obtaining various tomographic sections of the heart by means of an 80° phased-array sector scanner and their validation by anatomic sections and by selective contrast echocardiographic studies. Furthermore, we have presented a simple but unified concept of image orientation so that all long-axis and short-axis views of the heart and great vessels, irrespective of the transducer position from which they are recorded, are oriented with similar right-left, anterior-posterior, and superior-inferior orientation (Fig. 48 and 49).

It should be noted that because of the different chest wall configurations and variability of size, shape, and position of the heart in the chest, the above-described transducer positions and angulations may have to be modified accordingly in order to

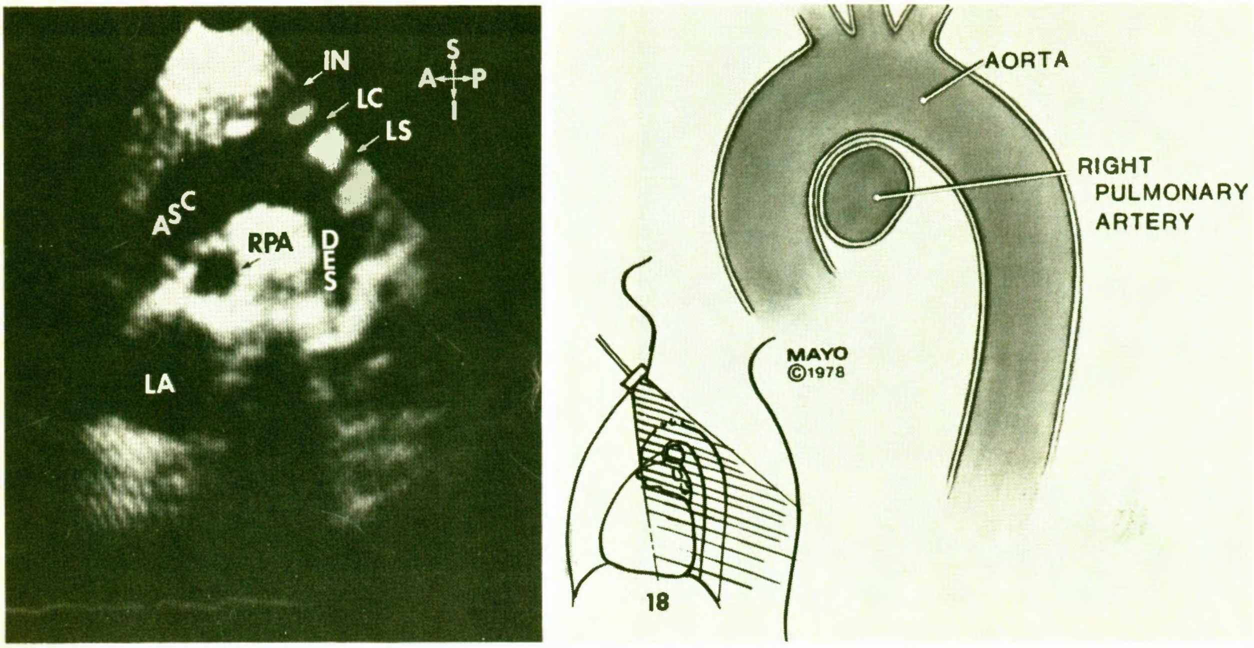


Fig. 45. *Left*, Still frame of sector scan obtained with transducer in suprasternal notch position and directed inferiorly and slightly posteriorly. Ascending aorta is on left and descending aorta is on right. Origins of brachiocephalic vessels can also be seen. Inferior to aortic arch, right pulmonary artery in short-axis cross section is seen. *IN* = innominate artery; *LC* = left common carotid artery; *LS* = left subclavian artery; *ASC* = ascending aorta; *DES* = descending aorta; other abbreviations as before. *Right*, Drawing of section along tomographic plane 18.

obtain the desired sections in an individual patient. It should also be remembered that all 20 tomographic sections are not obtainable in every patient. However, it is important to obtain as many tomographic sections as possible in every patient because only then can one get complete insight into an anatomic and functional derangement. Furthermore, by obtaining many different tomographic sections from different positions, one of the disadvantages of the phased-array system, namely limited view of the objects nearer the transducer, can be overcome. It is expected that with widespread use of this technique, further tomographic sections of the heart and great vessels will be developed. *See Editorial, p 339.*

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SUGGESTED READING

Readers interested in studying the heart in various anatomic sections in addition to those shown herein are referred to the comprehensive atlas by McAlpine (McAlpine WA: Heart and Coronary Arteries: An Anatomical Atlas for Radiological Diagnosis and Surgical Treatment. New York, Springer-Verlag, 1975).

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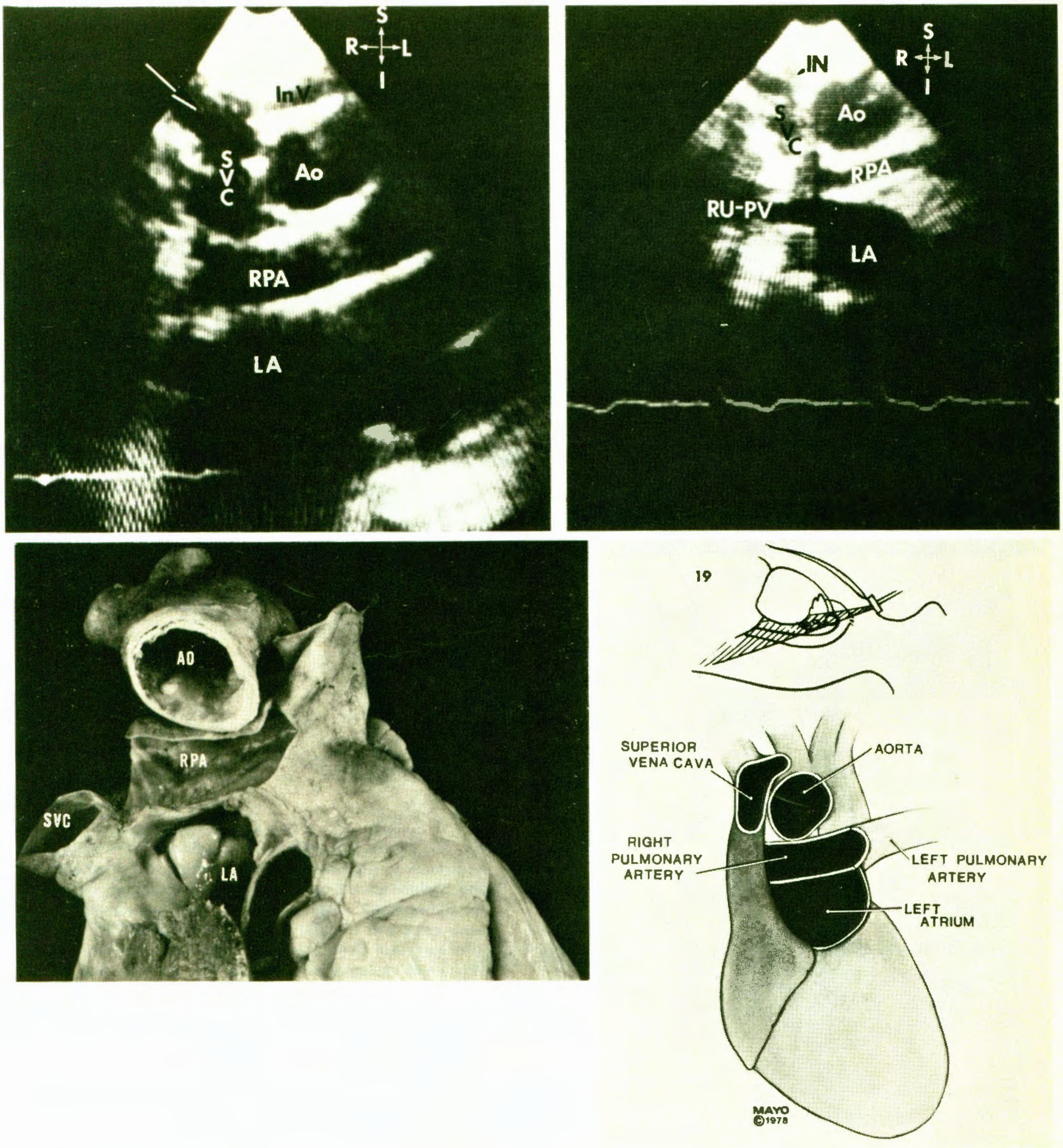
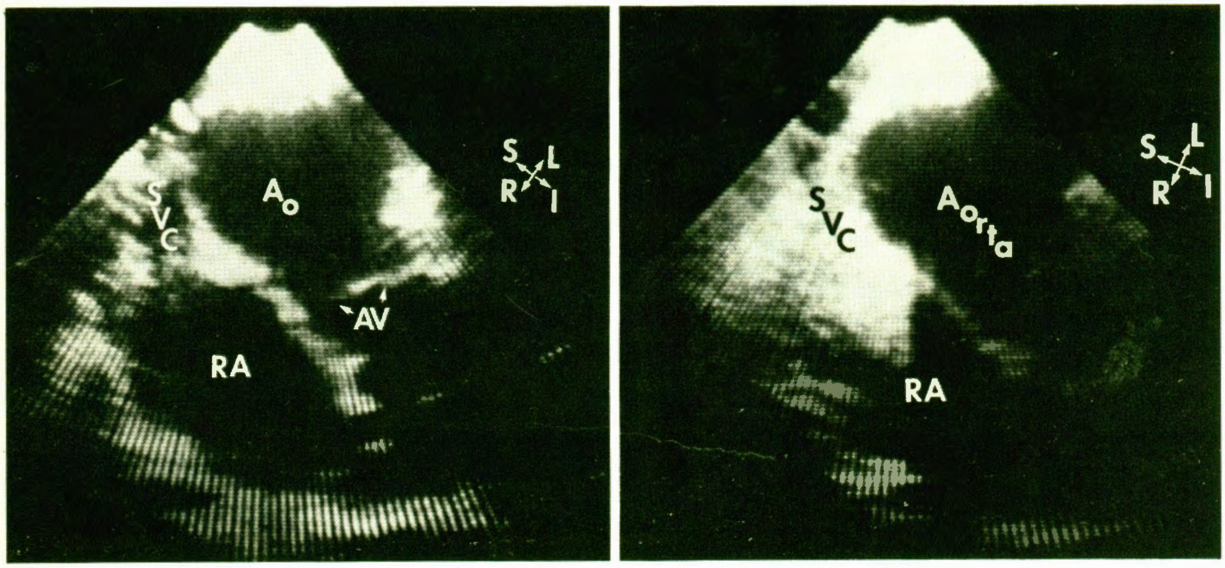


Fig. 46. *Upper Left,* Still frame of sector scan obtained with transducer in suprasternal notch position and ultrasound beam directed inferoposteriorly parallel to frontal plane (tomographic section 19). Aortic arch is transected and appears as round echo-free structure; long axis of right pulmonary artery is recorded inferiorly and upper portion of superior vena cava *(SVC)* on left of image. Left innominate vein *(InV)* can be seen to join superior vena cava coursing superior to transected portion of arch. Right innominate vein (*arrow*) is also clearly seen. Left atrium is recorded inferior to right pulmonary artery. *Upper Right* (from a different patient), In addition to above structures, right upper pulmonary vein *(RU-PV)* entering left atrium can be clearly seen. *Lower Left,* Anatomic section along tomographic plane 19. *Lower Right,* Drawing of same section with identification of structures. Abbreviations as before.



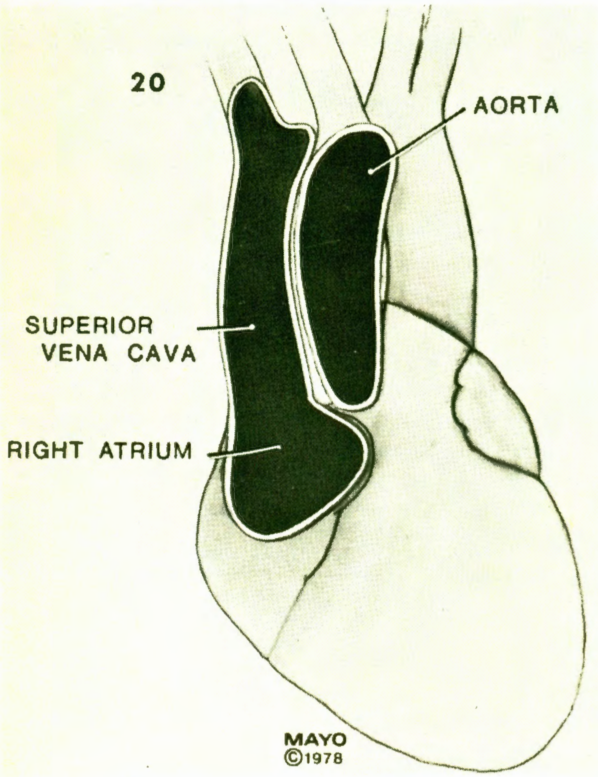


Fig. 47. *Upper Left*, Still frame of sector scan obtained with transducer in suprasternal notch position and tilted anteriorly and slightly toward patient's right (tomographic section 20). Ascending aorta, aortic valve, and long-axis view of superior vena cava and of right atrium are recorded. *Upper Right*, After injection of indocyanine green and saline into superior vena cava, dense echoes opacify this structure and are seen to enter right atrium and confirm ultrasonic anatomy. Abbreviations as before. *Lower*, Drawing of section along tomographic plane 20.

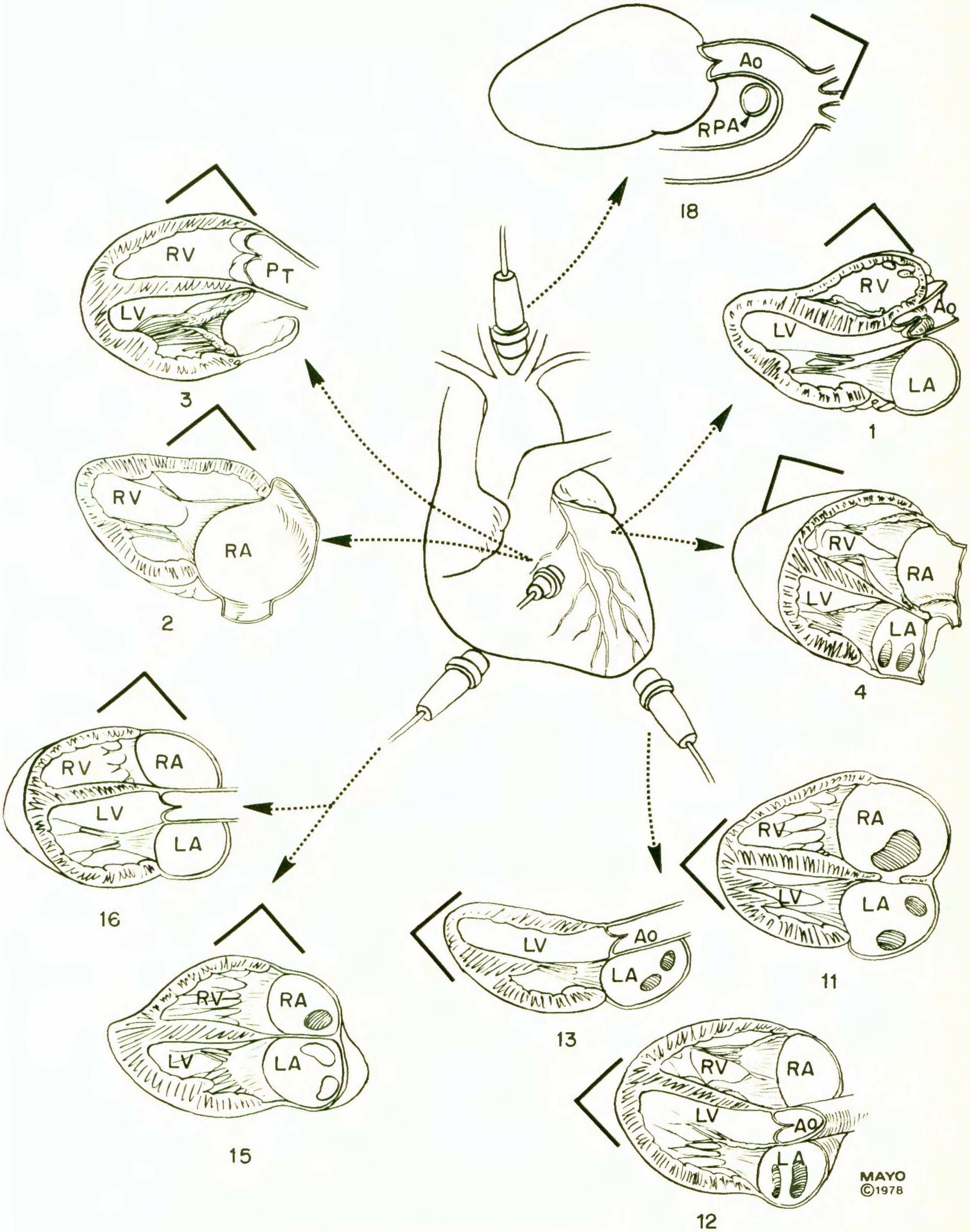


Fig. 48. Long-axis group orientation.

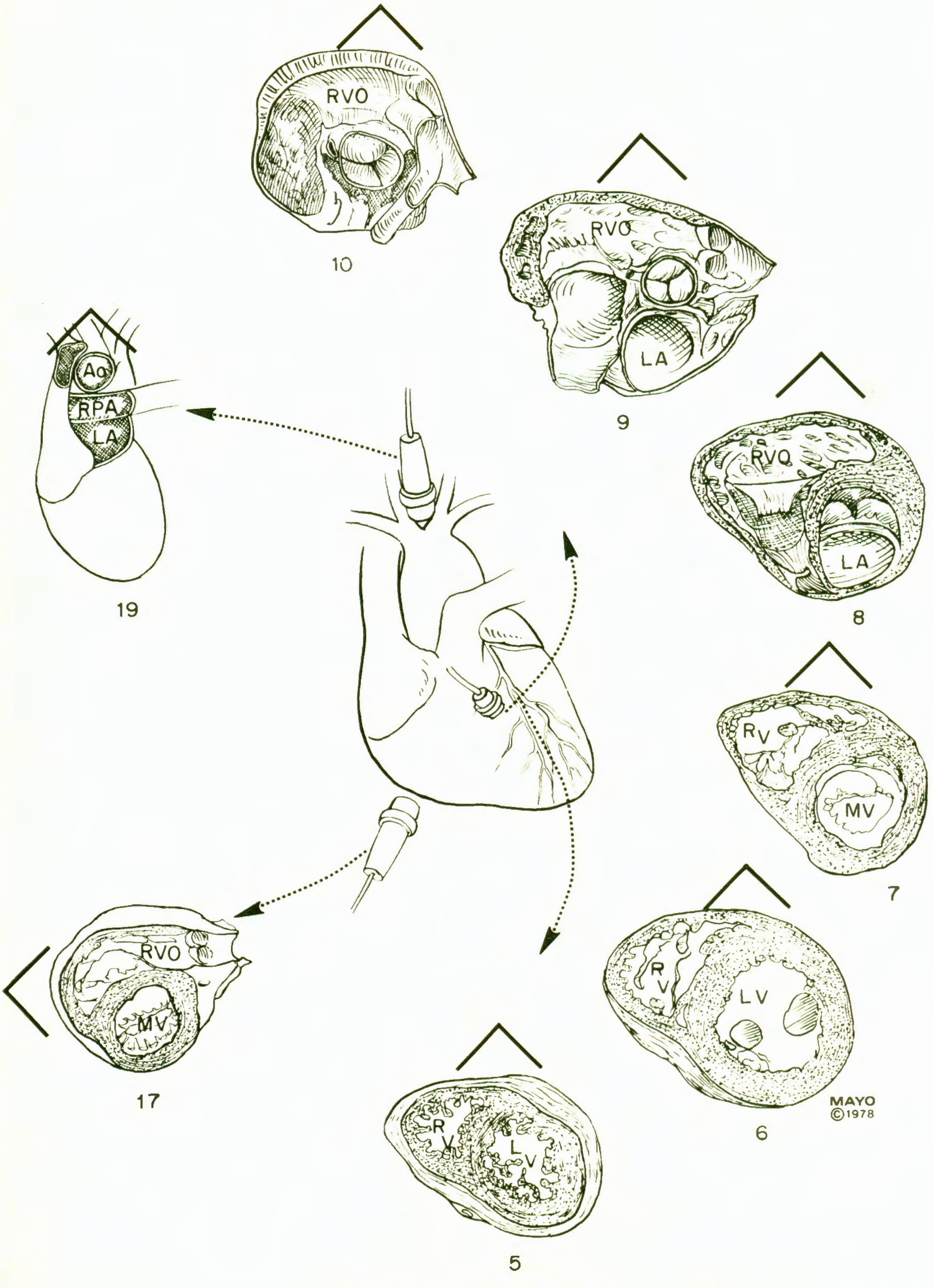


Fig. 49. Short-axis group orientation.

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