Visualization of Ventricular Septal Defects by Cardiac Ultrasonography

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SUMMARY
Anatomically true cross-sectional ultrasonic images of the heart have demonstrated ventricular septal defects in 25 patients with this lesion as an isolated anomaly or in conjunction with other defects. In two additional patients a defect was visualized but confirmation was not obtained. Ventricular septal defects were not demonstrated in 13 other patients in whom this lesion was identified by other techniques. In these instances the lesion was not sought for, was inaccessible, or was too small to image. Defects were manifested by the septum overriding the posterior great artery, septal discontinuity immediately below the posterior semilunar valve, or a discontinuity caudal to the posterior semilunar valve. It appears that cardiac ultrasonography may be able to demonstrate most of the common larger ventricular septal defects occurring in the infracristal region of the septum.

Additional Indexing Words:
Heart, ultrasound
Congenital heart disease, ultrasound diagnosis
Ultrasound, cardiovascular diagnosis

A NATOMICALLY TRUE CROSS-SECTIONAL ultrasonic (B-scan) representations of the heart have been made by a stop-action technique utilizing a modified compound contact scanner. This application of ultrasound is called cardiac ultrasonography. An application of this technique for calculating left ventricular volumes by the area-length method has been described. More recently, it has been used to demonstrate the characteristic anatomic features of transposition of the great arteries. In the course of examining these and other patients with congenital heart disease it was frequently possible to demonstrate the presence of ventricular septal defects. This paper describes the ultrasonographic appearance of ventricular septal defects and the modifications of the technique used for their visualization. The anatomy of the septum is conducive to ultrasonographic demonstrations of defects. The septum presents a curvilinear surface convex anteriorly and to the right. The conus and infracristal portions of the septum lie in various positions left of the sternum. The right, cephalad margin of the conal and infracristal septum is indicated by the aortic root and valve echoes, structures regularly recorded by the ultrasound beam. Thus, a significant portion of the ventricular septum is accessible to cross-sectional imaging leftward and caudal from the aortic valve. When right ventricular enlargement occurs, the septum rotates leftward to a position more parallel to the chest wall presenting an even larger surface to the ultrasound beam. It is in these accessible areas that most of the common, larger ventricular septal defects occur (fig. 1).

Method
The stop-action technique for cardiac ultrasonography utilizes an ultrasonic compound contact scanner modified by the addition of an electrocardiogram and a QRS-trigger circuit. The recording oscilloscope is synchronized with the electrocardiogram so that echoes from various points in the heart are recorded during identical segments of a series of heart cycles. Echocardiography is used as an initial step in an examination to locate the aortic root, mitral valve, and cardiac apex. The cardiac apex is indicated by the most leftward and caudal point on the anterior chest wall at which the sound beam can record cardiac motion. The plane of the ultrasonic scanner is adjusted to pass antero-posteriorly through these structures. In nongated
Figure 1

Right ventricular aspect of the interventricular septum. Most ventricular septal defects lie caudal and leftward from the aortic root toward the cardiac apex in a region accessible to the ultrasound beam. The aortic root defines the right, cephalad margin of the septum. The latter may be localized by recording the anterior root echo at the level of the aortic valve. (Figure redrawn from Spach MS, Boineau JP, Canent RV Jr: Defects of the Ventricular Septum. In Heart Disease in Infants, Children and Adolescents, ed. by Moss AJ, Adams FH. Baltimore, Williams & Wilkins Co., 1968. Reprinted with permission.)

(continuous motion) mode of operation, the moving echoes of the aortic root and mitral valve are observed on the recording oscilloscope of the scanner. In this manner, the origin of various echoes is confirmed and the scanning plane is adjusted to produce the desired image. After switching to stop-action mode, an unblurred cross-sectional image of the heart is produced at a preselected phase of the cardiac cycle (fig. 3). The image represents an “en face” view of the heart from the left, as if it had been sectioned through the scanning plane. The anterior and posterior walls of the aortic root appear as parallel lines of echoes. Posterior to the aortic root lies the left atrium. The ventricular septum is represented by a thick band of echoes extending from the anterior aortic root wall at the level of the aortic valve caudally and anteriorly to the anterior heart wall. Anterior to it lies the oval cross-section of the right ventricular outflow tract. Posterior to the septum lies the triangular outline of the left ventricle. When the scanning plane passes through the cardiac apex the latter appears as a sharp angle in the cardiac outline.

In congenital heart disease, the relationship of intracardiac landmarks frequently deviates from the normal. As a result, the difficulty of establishing the imaging plane is often increased. This is overcome by trial-and-error adjustment of the position and angulation of the scanner while observing the intracardiac echoes in nongated mode of operation. When seeking to demonstrate a ventricular septal defect, the plane of the scanner is set along the extreme left lateral heart border diagonal to the sagittal plane. The anterior aortic root echo is identified and followed in nongated mode as far as possible toward the cardiac apex. The anterior aortic root echo is continuous with and becomes the interventricular septal echo below the level of the aortic valve. If a ventricular septal defect is not demonstrated, the procedure is repeated after medial adjustment of the plane of the scan. In this manner the plane of the scanner will be swung through an arc based on the aortic root until all of the available surface of the ventricular septum has been examined (fig. 2). The tilt or angulation of the scanning plane is also adjusted during this sequence to permit the sound beam to strike the surface of the ventricular septum as nearly perpendicular as possible. When a discontinuity in the interventricular septum is seen, the scanner is switched to a stop-action mode of operation and an unblurred cross-section is made.

Patients examined in this series were suspected of having congenital heart disease and had undergone or were soon to undergo cardiac catheterization. They ranged in age from six weeks to 22 years.
septal defect was demonstrated by ultrasonography when repeated cross-sections demonstrated a definite echo-free discontinuity in the interventricular septum. For valid demonstration of a defect upper and lower edges of the defect had to be clearly apparent and echoes had to be recorded from structures posterior to the ventricular septal defect while the sound beam was passing through the echo-free discontinuity representing the defect. It was also required that there be no major change of position or angulation of the transducer while scanning across the defect; that is, the angle of incidence of the sound beam was as nearly the same as possible on one edge of the defect as on the other. Ultrasonographic demonstration of a ventricular septal defect was considered to have been confirmed when catheterization data and/or angiocardiography indicated the presence of a ventricular septal defect.

**Results**

Ventricular septal defects were visualized by cardiac ultrasonography in 25 patients with this lesion as an isolated anomaly or in conjunction with other defects. In 22 patients, catheterization data, angiocardiography, or surgical visualization indicated the presence of a large defect. In the remaining three confirmed cases, a ventricular septal defect was definitely present but was thought to be comparatively small since there was little or no elevation of right ventricular pressure. Two additional patients with defects visualized by ultrasonography remain unconfirmed. In one, a patent ductus arteriosus was demonstrated at cardiac catheterization. A left ventricular angiocardiogram was not done however to exclude the possibility of a supracristal defect that the findings by cardiac ultrasonogram suggested. The second patient was examined after attempted repair of a single ventricle. There was thought to have been a persistent defect in the reconstructed septum. He has not yet been restudied by cardiac catheterization.

Ventricular septal defects were not demon-
strated in 13 additional patients shown by other studies to have this lesion. In some instances this lesion was not sought for during cardiac ultrasonography, a fact which probably explains why the technique failed to visualize it. In other instances, either the small size or inaccessible location of the defects was probably responsible for nonvisualization.

No attempt was made to record or measure the maximum size or dimensions of the defect seen ultrasonographically. In cross-section, the defects appear to be one of three types: a) defects manifested by overriding of the septum by the posterior great artery (fig. 4), b) defects immediately below the semilunar valve of the posterior great artery with normal alignment of the anterior aortic wall and the upper septum (fig. 5), and c) defects removed from the level of the posterior semilunar valve in a caudal direction (fig. 6).

Discussion

The presence of a ventricular septal defect is often readily suspected on clinical grounds and may be documented by cardiac catheterization. Its size and location often may only be inferred. With precise positioning, selective right or left ventricular angiocardiography may demonstrate the approximate size and location of the defect as contrast material is shunted through it. Cardiac ultrasonography is an alternative means of visualizing the size and location of a ventricular septal defect. Our accumulating experience suggests that it can directly visualize ventricular septal defects in a significant number of patients, particularly those with larger defects. In addition, it appears that in so doing, it may also provide an approximation of the size or diameter of the defect as well as its location relative to the level of the semilunar valve of the posterior great artery. This should improve the selection of patients for cardiac catheterization.

Visualization of a ventricular septal defect depends upon demonstration of a discontinuity in the pattern of echoes arising from the ventricular septum, or conversely, upon positive identification of the edges of the defect. Recognition of the significance of an absent echo signal in a given location requires a thorough understanding of cardiac anatomy and the physical and technical

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**Figure 4**

A long axis cross-section of a patient with Tetralogy of Fallot. The aortic root diameter is comparatively large and overrides the ventricular septum producing a discontinuity between the anterior aortic wall echo and the upper septum. The right ventricular outflow tract appears comparatively small in this patient who had infundibular stenosis. Ao = aorta. See figure 3 for other abbreviations.

**Figure 5**

Long axis cross-section in a two-year-old male demonstrating a defect of the ventricular septum in the common infra-ostial location immediately below the aortic valve. Although there is a discontinuity between the anterior aortic root echoes and the septal echoes, a normal alignment of these structures appears to be present. See figure 3 for abbreviations.
principles of ultrasonic imaging. Fortunately, the anatomic relationships of the ventricular septum facilitate its visualization in most cases, particularly in those with enlarged hearts. Most larger ventricular septal defects occur in the septum immediately below the posterior semilunar valve, the portion of the septum most easily visualized by cardiac ultrasonography. The posterior semilunar valve and its corresponding anterior and posterior wall echoes (the aortic valve and root, except in cases of transposition) are quite characteristic in their location and pattern of motion and are easily identified in almost all patients.

Some of the more posterior defects of the septum may not be demonstrable. This may be due to an oblique position of the septum which makes it less perpendicular to the sound beam. Because the sound beam must be approximately perpendicular to a tissue plane, both upper and lower edges of a defect must be recorded with as little change in direction of the sound beam as possible. Preferably, the sound beam should be perpendicular to the plane of the defect as the beam is moved across from the upper edge to the lower edge. Recording from the septum at angles significantly different from perpendicular may result in a spurious absence of echoes. False negative examinations may therefore result from insufficient examination of the accessible septal surface, from location of a defect in an inaccessible area, and also from incorrect adjustment of the gain characteristics of the ultrasound amplifier.

The sensitivity and swept-gain (time-varied gain) controls of the amplifier must be adjusted to an optimum setting for recording the septal echoes. In general, the optimum setting is the least amount of amplification which will consistently record septal echoes on the display oscilloscope. Excessive amplification degrades lateral resolution by broadening the diameter of the effective sound beam, that diameter over which echoes of a given strength will be recorded. In this way, excessive amplification may artifactiously obscure small defects less than the effective diameter of the sound beam in size. Conversely, decreasing amplification narrows the diameter of the effective beam over which an echo of given strength will be recorded. (The sound beam itself is not altered, only the minimum amplitude or signal strength at which an echo will be recorded.) By decreasing amplification to the point where septal echoes are just recorded, the effective sound beam is narrowed to a minimum at the depth of the septum. The size of defect that can then be resolved is equivalent to the effective diameter of the sound beam. In our experience this appears to be less than one centimeter, using a standard 2 MHz, 13 mm diameter, unfocused transducer. Clearly, many ventricular septal defects will be smaller than the resolving power of the ultrasound beam and will not be visualized. In the future, technical improvements such as the use of focused beams may further narrow the effective diameter of the sound beam and improve lateral resolution.

In the past, it has not generally been possible to demonstrate ventricular septal defects by echocardiography because the method lacks a two-dimensional spatial orientation of the echo signals. In conventional echocardiography, the operator may gain a subjective appreciation of anatomic relationships by coordination of his visual time-motion record with his proprioceptive sense of the direction of the ultrasound beam. This subjective evaluation can be very useful but remains limited in comparison to the spatial orientation achieved by two-dimensional recording techniques. Cross-sectional ultrasonic imaging of the heart utilizing the
stop-action technique (cardiac ultrasonography) has the advantage of being able to integrate in a static image the echoes from a great many different intracardiac structures in their anatomically correct spatial relationships. Thus, the current technique of cardiac ultrasonography achieves a greater density of spatial information at the sacrifice of temporal or dynamic information. While compensation for the latter can be made by making a series of cross-sectional images at different phases of the cardiac cycle, it is probably not essential for the diagnosis of most morphologic abnormalities such as ventricular septal defects.

The current cross-sectional imaging technique is comparatively slow, requiring 30 to 60 min for a thorough examination. As a result a high level of skill and patience is required. This may be diminished to some extent in the future by development of real-time or rapid sequence cardiac scanners. A new generation of cardiac scanners would ideally combine the best features of echocardiography and cardiac ultrasonography, preserving the spatial orientation achieved in current compound scanners while demonstrating cardiac motion. The advantages of such a scanner would be a) visualization of dynamic events in cross-section and b) a more rapid image acquisition or sampling rate. The latter advantage would greatly facilitate selection of imaging planes appropriate for demonstration of morphologic abnormalities. In addition, a new generation of cardiac scanners might also incorporate a “C-scan,” or depth-gated image display. In this technique, an image is created from echoes arising in a plane perpendicular to the sound beam at a predetermined depth. By this means, an “en face” view of ventricular septal defects might also be obtained.

References

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