Prospective Identification of Ventricular Septal Defects in Infancy Using Subxiphoid Two-dimensional Echocardiography

FREDICK Z. BIERMAN, M.D., KENNETH FELLows, M.D., and ROBERTA G. WILLIAMS, M.D.

SUMMARY The objective of this study was to establish a dependable technique for imaging the interventricular septum and ventricular septal defects in infants. Subxiphoid two-dimensional echocardiograms were performed on 81 infants who were 1 day to 12 months (median 43 days) old and weighed 1.6–8.6 kg (median 3.4 kg). A short-focus, 5-MHz crystal with a 13-mm active element diameter was used in all studies. The interventricular septum was visualized in 80 of 81 infants. Defects in the membranous, atrioventricular canal, conoventricular and muscular segments of the septum were identified using three standard transverse subxiphoid projections. All defects in the membranous and atrioventricular canal segments, as well as malalignment type conoventricular communications, were correctly identified when compared with selective angled cineangiography. Only two of the three subpulmonic and four of 11 muscular defects were identified successfully. Limitations in imaging defects in the muscular septum reflected the varied morphology of these interventricular communications and the tangential orientation of the echo beam to the extreme apical and anterior segments of the muscular septum.

THE INTERVENTRICULAR SEPTUM (IVS) is a complex curvilinear structure of varied thickness and spatial orientation. Ventricular septal defects (VSDs) occur in five classic positions: membranous, atrioventricular canal (AVC), intracristal, conoventricular and muscular. Two-dimensional echocardiographic imaging of the IVS and VSD requires direct visualization of all segments and exceptional axial and lateral resolution. Two-dimensional imaging of the IVS has been performed using a variety of precordial and subxiphoid transducer positions with low-frequency, wide-angle or high-frequency, narrow-angle transducer systems. Silverman and Schiller demonstrated large membranous, AVC-type and malalignment defects using an apical precordial projection. Lange et al. demonstrated aneurysms of the membranous septum and defects of the AVC using subxiphoid visualization. A comprehensive technique for visualization of all segments of the IVS in infants by two-dimensional echocardiography has not been reported. This approach requires differentiation of contiguous structures and verification using selected angled cineangiograms. We have previously reported on the utility of subxiphoid projections for displaying atrial septal anatomy and great vessel relationships. The objective of this study was to establish a subxiphoid technique for identifying and localizing VSDs in infants.

Material and Methods

Subxiphoid two-dimensional echocardiography (S2DE) was performed and interpreted before cardiac catheterization of 81 infants with suspected congenital heart disease. The patients were 1 day to 12 months old (median 43 days) and weighed 1.6–8.6 kg (median 3.4 kg). Studies were performed with the patient supine using a Picker 80 CI Echoview system with a mechanical sector scanner. The intracardiac structures were displayed with a 45–60° sector angle at an image rate of 45 frames/sec and a variable line density. All studies were performed using a 5-MHz, short-focus crystal with a 13-mm active element diameter (AED). The beam width of the crystal was 1.0–2.0 mm at 3.8 cm between −6 db and −20 db. The useful zone (i.e., lateral resolution two times the minimum beam width) extended from 2.5–7.5 mm from the crystal. The axial resolution was 0.5 mm at −20 db (Harris D: personal communication). Modification of the sector display with inversion of the format has been reported. All studies were recorded on ½-inch video cassette tapes. Stop-frame imaging permitted still photographs on 1700 or 084 Polaroid film using a Tektronics C-50/C-70 series land-pack camera.

Technique

The transducer was placed in a midline subxiphoid position perpendicular to the frontal plane and parallel to the sagittal plane of the trunk. The hepatic vein was visualized, and, with 50° of cranial angulation, the confluence of the right atrium with the inferior vena cava and superior vena cava, the left atrium and the right pulmonary artery were simultaneously displayed (fig. 1). The IVS was visualized using three projections (fig. 2) obtained with lateral angulation of the transducer from the reference position. Clockwise angulation of the transducer from the reference position to the left sternoclavicular joint

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(fig. 2, projection A) simultaneously displayed the membranous and AVC segments of the IVS (fig. 3). Further angulation of the transducer toward the medial third of the clavicle (fig. 2, projection B) displayed the conoventricular septum (fig. 4). Directing the transducer at the midclavicle (fig. 2, projection C) completed the transverse 2DE examination of the IVS with visualization of the muscular septum (fig. 5).

Cineangiography

Selected angled views were used to localize defects in the ventricular septum. The long axial oblique
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produced extreme leftward deviation of the mediastinum and interposition of air-filled lung between the heart and the subxiphoid transducer.

The separation between the IVS and the transducer varied with age and projection. The distance between the transducer and the inferior IVS was 3–4 cm. Septal height varied from base to apex, and the maximum distance between the superior septum and the transducer was 5–7 cm.

Identification of Patients with VSD

Forty-six of forty-nine patients (94%) with a VSD at cardiac catheterization were prospectively identified using transverse S2DE. Three false-negative studies were reported in patients with a pinhole communication in the muscular septum. An intact septum was correctly predicted in 29 of 32 subjects (91%). Postmortem exams were available for two of the patients with false-positive transverse S2DE reports. In one patient, a trivial membranous VSD predicted by S2DE was not shown angiographically but postmortem examination revealed a 1–2-mm communication between the left ventricle and the right atrium. The postmortem examination of the second patient with an incorrect transverse S2DE report of a muscular VSD revealed a fissure-like trabeculation of the left septal surface extending to, but not penetrating, the right septal surface. The remaining false-positive report was a small membranous VSD. No direct observation was made either by postmortem or intraoperative examination.

Recognition and Localization of VSDs

Fifty-three patients with VSDs, including four patients with multiple defects, were found on angiography. All but two of the lesions were localized angiographically to either the membranous, AVC, conoventricular or muscular segments of the septum. Table 1 summarizes the prospective recognition and

Data Analysis

Subxiphoid two-dimensional echocardiograms were interpreted by the echocardiographer before cardiac catheterization. Cineangiograms were reported by the cardiac radiologist. The plain chest x-ray, arterial blood gas and the ECG were available to both examiners before their respective reports.

Results

Transverse S2DE projections A, B and C were successfully performed in 80 of 81 infants. These projections were inadequately displayed in one infant, who had an absent pulmonary valve and obstruction of the right mainstem bronchus, and air trapping projection was used to display malalignment (conoventricular), posterior or apical muscular and membranous defects. Intracristal (i.e., subpulmonic and anterior) muscular defects were displayed by right anterior oblique projections. The four-chamber, hepatocavicular projection best demonstrated AVC, communications and deficiency of the posterior septum.

Table 1. Recognition and Localization of Ventricular Septal Defects

<table>
<thead>
<tr>
<th>Cineangiography</th>
<th>S2DE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Defect recognized*</td>
</tr>
<tr>
<td>Membranous</td>
<td>16</td>
</tr>
<tr>
<td>Complete AVC</td>
<td>13</td>
</tr>
<tr>
<td>Conoventricular</td>
<td></td>
</tr>
<tr>
<td>Malalignment</td>
<td>8</td>
</tr>
<tr>
<td>Subpulmonic</td>
<td>3</td>
</tr>
<tr>
<td>Muscular</td>
<td>11</td>
</tr>
<tr>
<td>Other†</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
</tr>
</tbody>
</table>

*S2DE present regardless of identity.
†VSDs seen by cineangiography but not localized.

Abbreviations: AVC = atrioventricular canal; S2DE = subxiphoid two-dimensional echocardiography.

FIGURE 2. Standard transverse subxiphoid two-dimensional projections and ventricular septal defect locations. (A) Atrioventricular canal (1) and membranous (2); (B) malalignment (3) and subpulmonic (intracristal) (4); (C) muscular (5).
localization of these defects by transverse S2DE.

All defects of the membranous13 and AVC segments13 were recognized and correctly identified using transverse S2DE projection A. The most superior membranous communications were subaortic, adjacent to the septal tricuspid leaflet and superior to the AVC segment (fig. 6). The proximity of the tricuspid septal leaflet to the membranous defect varied with the cardiac cycle. The defect could be obscured by diastolic apposition of the septal tricuspid leaflet with the ventricular septum. Aneurysm of the membranous septum was not a frequent finding in this series. When present, however, the appearance was that of a defect in the membranous septum with thickening of the adjacent septal tricuspid leaflet. The proximity of the tricuspid valve to the location of a true aneurysm, as well as similarity of their motion with the cardiac cycle, precluded their differentiation. The VSD of a complete AVC (CAVC) was bordered superiorly by the membranous septum. The inferior boundary of the defect varied with the size of the communication. The inferior margin of smaller defects was formed by the remnant of posterior septum. In large defects, this posterior segment of septum was absent and the inferior border was formed by the diaphragmatic segment of the ventricular free wall.
These defects were crossed by either the chordae of the atroventricular valves, i.e., septally attached anterior common leaflet (Rastelli type A), or by a sail-like, anterior common leaflet not attached to the septum (Rastelli Type C)\(^4\) (fig. 7). There was no false-positive report of a CAVC among patients with primum atrial septal defect (ASD). Defects in the conoventricular septum were identified by transverse S2DE projection B as intracristal (i.e., subpulmonic) or typical malalignment communications. Neither the malalignment nor the intracristal subpulmonic defects varied in appearance with the cardiac cycle. All eight malalignment defects were recognized and correctly localized. Projection B displayed the anteriorly displaced parietal band and resultant subpulmonic narrowing in patients with this VSD as part of a tetralogy of Fallot complex (fig. 8). Three intracristal, subpulmonic defects were recognized using projection B, although one was incorrectly localized to the membranous septum. The correctly identified defects were immediately below the pulmonary valve and anterior to the right coronary cusp of the aorta (fig. 9). The error in localization occurred in a patient with double outlet right ventricle.

Defects in the muscular septum were reported at angiography in 11 patients but predicted in only four by transverse S2DE, projection C. The four recognized by transverse S2DE were correctly localized to the muscular septum (fig. 10). Four of the defects not visualized by transverse S2DE were pinhole communications. The three defects not diagnosed by S2DE were either extreme apical, anterior (between the septal band and ventricular free wall) or fistulous communications. Seventeen of the 49 patients who had a VSD were evaluated by transverse S2DE, angiography and intraoperative observations. Surgical findings corroborated transverse S2DE and angiographic findings in 13 patients. In two patients, surgical and angiographic findings agreed, but differed from transverse S2DE predictions. In two patients, similar transverse S2DE and cineangiographic findings differed from surgical observations.

**Discussion**

Imaging of the IVS in infants by transverse S2DE was facilitated by a broad acoustical window and the physical characteristics of the high-frequency, short-focus, wide AED transducer. Interposition of an air-filled lung resulted in an incomplete transverse S2DE examination in one patient.

Imaging of the IVS was enhanced by the frequency, useful zone and axial resolution of the transducer. The distance of the IVS from transducer artifact (3-8 cm) capitalized on the transducer useful zone. The vertical orientation of the IVS with lateral resolution of 2 mm and axial resolution of 0.5 mm enhanced definition of right and left septal surfaces and minimized artifactual dropout.

The appearance of the conoventricular defects was unrelated to the cardiac cycle. This finding was due to their anterosuperior position in the IVS and resulting separation from the atroventricular valves. In con-
The appearance of membranous defects varied with the systolic and diastolic position of the tricuspid septal leaflet. The communication was apparent during systole; however, diastolic apposition of the tricuspid leaflet against the septum simulated an intact membranous segment. Aneurysm formation was not frequent in this series. When an aneurysm was present angiographically, projection A revealed a defect in the membranous septum with thickening of the adjacent septal tricuspid leaflet. These findings and those reported by others, may not be specific for true aneurysm of the membranous septum. Structurally, aneurysms are difficult to define and tricuspid valve anomalies associated with a VSD may be mistaken for...
true aneurysms. This distinction may be difficult even at autopsy.\textsuperscript{13, 15} Our current policy is to report a defect of the membranous septum regardless of the morphology of contiguous structures. This approach may change as our experience with this technique grows and as it is coupled with pulsed Doppler echocardiography.\textsuperscript{16}

Despite similarities, there were no false-positive reports of CAVC among cases of primum ASD. The morphology of the primum ASD is similar to that of a Rastelli type A CAVC, but there is no VSD. Shortening of the left ventricular inflow\textsuperscript{17} with denser chordal attachments to the septal crest and more redundant endocardial cushion tissue\textsuperscript{14} contribute to

**FIGURE 5.** Muscular septum (projection C). (A) Cross section showing right ventricle (RV), interventricular septum (IVS) and left ventricle (LV). (B) Subxiphoid two-dimensional echocardiogram showing IVS with intact right (center arrow) and left (right arrow) septal surfaces.
closure of the IVS. In primum ASD, projection A displays an intact IVS with a superior and inferior margin bridged by an echo-dense matrix of irregular tissue in the AVC segments. In a lesion with a variable IVS morphology, as in primum ASD, transitional forms not encountered in this study may occur. Alternative S2DE* and apical precordial projections1 may be necessary to differentiate these lesions from type A Rastelli AVC complexes.

The muscular septum displayed by projection C corresponds to the trabecular zone of the ventricles. Limitations in imaging defects in this portion of the
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Figure 7. Atrioventricular canal type ventricular septal defect (VSD) (projection A). (A) VSD (two-headed arrow) bordered superiorly by membranous septum and inferiorly by residual endocardial cushion tissue. In larger defects, the inferior border of the VSD would be the inferior ventricular free wall (small single arrow). (B) VSD crossed by atrioventricular (A-V) valve elements in systole. MPA = main pulmonary artery; RV = right ventricle; LV = left ventricle; AoV = aortic valve; RVOT = right ventricular outflow tract.

Septum reflect the varied morphology of these communications. They may be apical, anterior or posterior to the trabecular septomarginalis. Difficulty in subxiphoid imaging of the apical defects is due in part to the oblique orientation of the echo beam in projection C to the septal plane. Due to beam angulation, a defect on the right septal surface may not be simultaneously displayed with its left-sided compo-

inent. This problem may be minimized by sliding the transducer leftward, provided that the air-filled stomach is avoided. The other limitation in visualization of a VSD in the muscular septum is not particular to S2DE. Unlike the “direct” communications of the membranous, endocardial cushion and conoventricular segments, defects in the trabecular septum were sometimes tortuous or masked on the right sep-
tal surface by coarse trabeculations. Successful prospective diagnosis of these elusive defects will probably require combined S2DE and gated pulsed Doppler echocardiography.

Conclusion

Transverse S2DE in infants using a wide AED, high-frequency crystal allows direct visualization of the interventricular septum. This technique accurately
predicted and localized defects in the membranous, AVC and conoventricular segments of the septum. Defects in the muscular septum were not consistently visualized, but when seen in projection C, they were accurately localized. Limitations in imaging these lesions reflects their varied anatomy and the tangential orientation of the echo beam to the muscular segment.

References

Figure 10. Large midmuscular ventricular septal defect (curved arrow). RV = right ventricle; LV = left ventricle.
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