Echocardiographic Visualization of Ventricular Septal Defect in Infants and Assessment of Hemodynamic Status Using a Contrast Technique

Comparison of M-mode and Two-dimensional Imaging

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SUMMARY Twenty-seven patients with ventricular septal defect (VSD), ages 2 months to 2 years, were evaluated by both M-mode and two-dimensional echocardiography (2-D echo) with the aid of a peripheral venous contrast technique. M-mode echocardiography was unreliable for imaging VSD. Using 2-D echo, defects in the interventricular septum were visualized in all patients examined; defects in the membranous portion (24 patients) were visualized by the subcostal frontal approach and defects in the supracristal portion (three patients) by the subcostal sagittal approach.

The 2-D echo contrast study revealed negative contrast jets appearing through the defect in the right ventricle in 22 patients with a pulmonary-to-systemic blood flow ratio greater than 2.0, and positive contrast jets appearing through the defect in the left ventricle in 13 patients with a right-to-left ventricular peak pressure ratio greater than 0.71.

We conclude that 2-D echo with peripheral contrast technique confirmed the anatomic location of VSD and indicated the approximate right-to-left ventricular peak pressure ratio, showing the contrast material shunting through the defect itself.

VENTRICULAR SEPTAL DEFECT (VSD) is one of the most common cardiac diseases in the pediatric population. The M-mode echocardiographic features of VSD are left ventricular enlargement, left atrial dilatation, and hyperdynamic motion of both the interventricular septum and the left ventricular posterior wall. These features are characteristic of VSD, but can be mimicked by other conditions, such as patent ductus arteriosus or mitral regurgitation. The interruption of septal echoes on M-mode scan from the aorta to the left ventricle is unreliable for the diagnosis of VSD because of the high incidence of both false-positive and false-negative results. Recently, M-mode contrast echocardiography has been used to identify VSD indirectly by revealing the right-to-left shunt at the ventricular level and to estimate the right ventricular pressure.

Two-dimensional echocardiographic visualization of VSD seems to be the most accurate means of diagnosis. Aziz et al.7 reported that two-dimensional echocardiography (2-D echo) in a parasternal long-axis view of the left ventricle shows a supracristal-type defect as a clear space between the top of the ventricular septum and the anterior portion of the aortic root. However, this sign is absent in the majority of patients with membranous-type defects, the most common type of VSD, which limits the value of this technique.2

In this report, we show that 2-D echo can reveal the presence and anatomic location of interventricular septal defects in the subcostal view. We also estimated the hemodynamic status of the right ventricle using M-mode and two-dimensional contrast technique, and compared the reliability of these techniques.

Methods

We studied 27 patients, ages 2 months to 2 years, in whom a VSD was diagnosed by cardiac catheterization and angiography. Twenty-two patients had iso-
lated VSDs, and five patients had a VSD and an atrial septal defect. Peripheral vein injections were made through a 20F Teflon venous sheath positioned in a superficial vein of the foot or hand. One to 2 ml of indocyanine green dye were forcefully injected by hand through the venous line.

M-mode contrast echocardiography was performed with the M-mode beam in the plane of the posterior mitral valve leaflet along with the recording of the right ventricle, interventricular septum, left ventricular outflow tract and mitral valve orifice. The echocardiograms were obtained with an Aloka SSD 110 echocardiograph with a 3.0-MHz nonfocused transducer, and were recorded with a Honeywell strip-chart recorder.

We obtained 2-D echocardiograms using a real-time mechanical sector scanner (Aloka SSD 1000 with ASU 25 hand scanner and USM 6B amplifier). The scanner probe contained a 3.0-MHz transducer focused at 7.5 cm and was mechanically driven through a variable angle (from 30°-80°) at a rate of 10-30 frames/sec. We usually operated this system at a rate of 30 frames/sec, which yielded a line density of approximately 110 lines/frame. A camera photographed the 2-D echo images, which were displayed as phase-selected single frames directly from the oscilloscope screen. Contrast studies were recorded with a 16-mm cinecamera and subsequently analyzed in real-time, slow-motion and single-frame formats.

To diagnose the anatomic position of the VSD, we used two cross-sectional planes: a subcostal frontal plane (fig. 1) and a subcostal sagittal plane (fig. 2). For the subcostal frontal view, the scanner probe was placed on the subcostal region, and the sector beam was directed through the heart on a plane parallel to a line between the patient’s shoulders, which allowed simultaneous visualization of the left ventricular cavity, left ventricular outflow tract and aortic root. This subcostal view showed defects in the membranous part of the interventricular septum. For the subcostal sagittal view, the two-dimensional section was positioned parallel to a plane cutting both the long axis of the sternum and the spinal column. The subcostal sagittal view showed the right ventricular outflow tract, pulmonary valves and main pulmonary artery, and helped visualize defects in the conus septum.

Two-dimensional contrast technique was used on both subcostal frontal and sagittal planes in all patients. Right-to-left shunts were detected by the passage of the contrast echoes into the left ventricular outflow tract through the defect; left-to-right shunts were detected as negative contrast jets appearing in the echo-filled right ventricle. A technically acceptable image was one in which the contrast echo completely filled the right ventricular cavity and outlined the surrounding solid intracardiac structures, such as the interventricular septum. Images were discarded when contrast echoes obliterated the delineating walls of the intracardiac structures.

Hemodynamic data were obtained at routine cardiovascular catheterizations performed under sedation with sodium pentobarbital and hydroxyazine pamoate. Using the method of Bargeron et al., properly angled selective left ventricular angiography was performed for precise diagnosis of the anatomic location of the VSD. A flow-directed balloon catheter was inserted through the patent foramen ovale or atrial septal defect into the left ventricle in all patients. Pressure data were obtained with a fluid-filled catheter system before angiography. Left and right ventricular pressures were measured with the same catheter system by quick pull back across the patent foramen ovale or atrial septal defect from the left ventricle into the right ventricle. All blood samples were obtained in rapid succession before angiography. Both right-to-left and left-to-right shunts were evaluated by Fick’s method and cineangiography.

All patients underwent both M-mode and 2-D echo with peripheral injection contrast studies within 24 hours before cardiac catheterization. The echocardiograms and contrast studies were independently

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**Figure 1.** (A) The position of the subcostal frontal plane. (B) A diagrammatic representation of the area encompassed by this two-dimensional section, including the left ventricle (LV), the right ventricle (RV), the interventricular septum (IVS) and the aortic root (AO). The membranous portion is the upper part of the IVS just below the aortic valves. S = superior; I = inferior; R = right; L = left.

**Figure 2.** (A) The position of the subcostal sagittal plane. (B) A diagrammatic representation of the area encompassed by this two-dimensional section, including the right ventricle (RV), the left ventricle (LV), the interventricular septum (IVS) and the main pulmonary artery (PA). The conus septum is the upper part of the interventricular septum immediately below the pulmonary valves. S = superior; I = inferior; A = anterior; P = posterior.
reviewed by three of the authors; the cardiac catheterization and analysis of its data were performed by another of the authors.

Results

Three groups of patients were defined by M-mode contrast echocardiography. Group 1 consisted of 13 patients in whom right-to-left shunts were not identified. Group 2 consisted of nine patients in whom right-to-left shunts at the ventricular level were identified. Group 3 consisted of five patients in whom right-to-left shunts at both the atrial and ventricular levels were identified.

The results of the contrast echocardiographic studies and hemodynamic data of cardiac catheterization are summarized in table 1.

### Table 1. Catheterization and Echocardiographic Data

<table>
<thead>
<tr>
<th>Pt</th>
<th>Age</th>
<th>RV/LV</th>
<th>LV-RV (mm Hg)</th>
<th>Qp/Qs</th>
<th>Rp/Rs</th>
<th>Two-dimensional contrast study</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(mm Hg)</td>
<td></td>
<td></td>
<td>Positive jets</td>
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<td>AO</td>
<td>4 mo</td>
<td>0.30</td>
<td>82</td>
<td>2.9</td>
<td>0.09</td>
<td>No</td>
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<tr>
<td>MY</td>
<td>2 yr</td>
<td>0.30</td>
<td>80</td>
<td>3.1</td>
<td>0.08</td>
<td>No</td>
</tr>
<tr>
<td>TK</td>
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<td>0.30</td>
<td>78</td>
<td>1.6</td>
<td>0.14</td>
<td>No</td>
</tr>
<tr>
<td>NS</td>
<td>8 mo</td>
<td>0.31</td>
<td>82</td>
<td>1.2</td>
<td>0.21</td>
<td>No</td>
</tr>
<tr>
<td>EN</td>
<td>8 mo</td>
<td>0.41</td>
<td>59</td>
<td>2.3</td>
<td>0.14</td>
<td>No</td>
</tr>
<tr>
<td>YM</td>
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<td>0.45</td>
<td>60</td>
<td>3.6</td>
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<tr>
<td>KT</td>
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<td>0.47</td>
<td>49</td>
<td>2.2</td>
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<tr>
<td>RA</td>
<td>2 yr</td>
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<td>55</td>
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<td>No</td>
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<tr>
<td>HF</td>
<td>8 mo</td>
<td>0.50</td>
<td>50</td>
<td>2.0</td>
<td>0.13</td>
<td>No</td>
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<tr>
<td>MO</td>
<td>3 mo</td>
<td>0.50</td>
<td>56</td>
<td>2.1</td>
<td>0.11</td>
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<tr>
<td>KR*</td>
<td>1 yr</td>
<td>0.59</td>
<td>50</td>
<td>2.4</td>
<td>0.18</td>
<td>No</td>
</tr>
<tr>
<td>SF</td>
<td>6 mo</td>
<td>0.51</td>
<td>50</td>
<td>2.7</td>
<td>0.07</td>
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<tr>
<td>HH</td>
<td>4 mo</td>
<td>0.55</td>
<td>39</td>
<td>1.3</td>
<td>0.28</td>
<td>No</td>
</tr>
<tr>
<td>HI</td>
<td>6 mo</td>
<td>0.60</td>
<td>38</td>
<td>4.4</td>
<td>0.08</td>
<td>No</td>
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<tr>
<td>YN</td>
<td>4 mo</td>
<td>0.71</td>
<td>34</td>
<td>4.1</td>
<td>0.12</td>
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<tr>
<td>TF*</td>
<td>3 mo</td>
<td>0.80</td>
<td>16</td>
<td>3.8</td>
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<tr>
<td>YA</td>
<td>11 mo</td>
<td>0.82</td>
<td>18</td>
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<tr>
<td>KY</td>
<td>4 mo</td>
<td>0.82</td>
<td>30</td>
<td>2.9</td>
<td>0.27</td>
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<tr>
<td>AR</td>
<td>7 mo</td>
<td>0.83</td>
<td>17</td>
<td>5.0</td>
<td>0.05</td>
<td>Yes</td>
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<tr>
<td>TM</td>
<td>3 mo</td>
<td>0.89</td>
<td>14</td>
<td>3.0</td>
<td>0.22</td>
<td>Yes</td>
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<tr>
<td>HM*</td>
<td>5 mo</td>
<td>0.90</td>
<td>8</td>
<td>2.4</td>
<td>0.33</td>
<td>Yes</td>
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<tr>
<td>HT</td>
<td>5 mo</td>
<td>0.92</td>
<td>10</td>
<td>2.0</td>
<td>0.38</td>
<td>Yes</td>
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<tr>
<td>MH</td>
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<td>0.74</td>
<td>15</td>
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<td>0.23</td>
<td>Yes</td>
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<tr>
<td>YM</td>
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<td>0.82</td>
<td>21</td>
<td>5.4</td>
<td>0.09</td>
<td>Yes</td>
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<tr>
<td>SI</td>
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<td>18</td>
<td>2.8</td>
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<td>Yes</td>
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<tr>
<td>HO</td>
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<td>0.98</td>
<td>2</td>
<td>2.3</td>
<td>0.39</td>
<td>Yes</td>
</tr>
<tr>
<td>KN</td>
<td>3 mo</td>
<td>1.00</td>
<td>0</td>
<td>0.9</td>
<td>1.08</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Patients with supracristal-type ventricular septal defect. The others had membranous-type defects.

Abbreviations: RV/LV = ratio of right to left ventricular peak pressure; LV-RV = peak systolic pressure gradient between the left and right ventricles; Qp/Qs = ratio of pulmonary to systemic blood flow; Rp/Rs = ratio of pulmonary to systemic vascular resistance.

M-mode Contrast Echocardiography

**Group 1**

The appearance of the echo-dense material was found only in the right ventricular cavity in patients in group 1. These patients had either small or moderate isolated VSDs. The right-to-left ventricular peak pressure ratio was 0.30–0.55 and the systolic pressure gradient between the ventricles was 39–82 mm Hg. Cardiac catheterization revealed no evidence of a right-to-left shunt in any patient in group 1.

**Group 2**

In the nine patients in group 2, who had large isolated VSDs, right-to-left shunts were identified by M-mode contrast studies. The echocardiograms initially
showed contrast material in the right ventricular cavity. During the next ventricular diastole after the appearance of the contrast echoes in the right ventricle, these echoes entered the left ventricular outflow area on the ventricular surface of the anterior mitral leaflet at the time of the mitral opening. The shunting echoes from the right ventricle into the left ventricle were strong and linear, passing from the upper left to the lower right on the M-mode echocardiograms (fig. 3). Because the motion pattern of the shunting echoes was different from that of any other intracardiac structure, even a few echoes of right-to-left shunts were easily distinguished. The right-to-left ventricular peak pressure ratios were 0.60–0.92 and the systolic pressure gradient between the ventricles was 10–30 mm Hg.

**Group 3**

The five patients in group 3 had atrial septal defects as well as VSDs; all had moderate-to-severe pulmonary hypertension and right-to-left shunts at both the atrial and ventricular levels in the cardiac catheterization studies. From the echocardiograms, however, we could not detect right-to-left shunts at the ventricular level, for the left ventricular cavity was filled by large contrast echoes shunted at the atrial level (fig. 4).

**Two-dimensional Echocardiography with Contrast Study**

Two-dimensional echocardiographic detection and exact localization of defects in the interventricular septum was successfully achieved in all patients in this study; 24 patients had defects of the membranous septum and three had supracristal-type defects.

**Membranous-type VSD**

The defects of the membranous part were clearly shown by the subcostal frontal approach as an interruption of the septal echo, just below the aortic valves (fig. 5). The defects could be verified by passage of the contrast material from the right ventricular cavity directly through the defect into the left ventricular cavity.
outflow tract (fig. 6A). Negative contrast jets were produced in the echo-filled right ventricle by the passage of non-dye-containing blood from the left ventricle through the defect, displacing the dye-containing blood. The negative jets pointed toward the body of the right ventricle (fig. 6B). In figure 6C, positive contrast jets in the left ventricular outflow tract and negative contrast jets in the dye-filled right ventricle were recorded simultaneously in one frame. The subcostal sagittal imaging did not show these negative jets.

In five patients of group 3, M-mode contrast echocardiography failed to diagnose the presence of VSD due to large right-to-left shunts at the atrial level, whereas 2-D echo in the subcostal frontal view diagnosed the presence of VSD by visualizing the defect itself and showing the bolus of contrast material entering the left ventricular cavity through the defect. In two patients in group 3, negative contrast jets were not produced, for both left and right ventricular cavities became opaque simultaneously due to large right-to-left shunts at the atrial level. In the other three patients who had smaller right-to-left shunts at the atrial level, negative jets were observed.

**Supracristal-type VSD**

The subcostal frontal approach failed to show the defect, but on the subcostal sagittal section the defect was shown immediately below the pulmonic valve echoes (fig. 7A). This position of the defect was thought to be the subpulmonic part of the interventricular septum. Injection of contrast material into a peripheral vein showed that negative jets ran from the dye-filled right ventricular outflow tract through the defect toward the pulmonary artery in systole (fig. 7B); in diastole, the contrast material entered the left
ventricle through the defect. In the subcostal frontal view, however, the negative jets could not be seen.

Positive contrast jets were found in 13 patients who had pulmonary hypertension and a right-to-left ven-

tricular peak pressure ratio greater than 0.71. Negative contrast jets were visualized in 22 patients who had large left-to-right shunts and a ratio of pulmonary-to-systemic blood flow greater than 2.0.

In one group 2 patient (HI) who had a right-to-left ventricular peak pressure ratio of 0.60, we found a small amount of contrast material shunted in the left ventricular cavity on the M-mode contrast echocardiogram; however, we could not find contrast material in the left ventricular cavity on the two-dimensional echocardiogram.

In patient HO (group 3), the defect shown by 2-D echo to be in the membranous portion of the inter-
ventricular septum was found at surgery to be an atrioventricular canal-type defect that was very large and extended to the membranous portion of the inter-
ventricular septum.

**Discussion**

Levin et al., in their angiographic study of VSDs, reported that right-to-left shunts occurred when the interventricular systolic pressure gradient was less than 30 mm Hg. Our contrast echocardiographic observations coincide with their angiographic data. Serwer et al. described in detail the relationship between right ventricular pressure and the right-to-left shunting patterns of the contrast echoes on M-mode echocardiograms. In analysis of the appearance time of the echo-dense material in the left ventricle, M-
mode echocardiography is indispensable. The right-to-left shunt echoes were more easily observed by M-
mode contrast echocardiography than by 2-D echo, perhaps because of the different recording systems, i.e., a strip-chart recorder and 16-mm cinecamera. In patients with associated atrial septal defect, we could not detect right-to-left shunts at the ventricular level with M-mode contrast echocardiography, for the left ventricular cavity was filled by large contrast echoes shunted at the atrial level. The VSD was directly visualized by 2-D echo and we saw contrast echoes enter into the left ventricle from right ventricle through the defect as positive jets by 2-D contrast echo. In these patients, 2-D echo was necessary for both the diagnosis of VSD and the assessment of pulmonary hypertension.

The ability to visualize the defect by 2-D echo depends on a variety of factors. The depth of the focal zone of the transducer used in this study may have been optimal for visualizing septal defects in in-
fants, and the subcostal view may be suitable to ex-
hibit these focus characteristics and produce a proper angle for the ultrasound beam to pass through the

**FIGURE 7.** Two-dimensional echocardiograms in the sub-
costal sagittal view from patient TF in group 2. (A) A defect (arrow) of the interventricular septum is shown immedi-
ately below the pulmonic valve (PV) echoes. (B) After injec-
tion of contrast material, a negative contrast jet (arrow) is produced in the contrast-filled right ventricular outflow tract, running through the defect toward the pulmonary artery (PA). RV = right ventricle; LV = left ventricle.
defect. The number of lines of information per degree can be increased by narrowing the sector angle as much as possible for the purpose of imaging the defect.

Precise knowledge of the location of the VSD allows the surgeon to make a more informed decision on the optimal surgical approach. At present, selective left ventricular angiography is the most reliable clinical means of identifying the site of the defect. In this work, we demonstrated that the anatomic locations of defects can be diagnosed by 2-D echo. The subcostal frontal plane was useful for visualizing defects of the membranous type; the usual plane of examination, such as a parasternal long-axis view of the left ventricle or an apical four-chamber view, appears to be less useful. Many times, the defect could not be visualized in the parasternal long-axis view of the left ventricle, probably as a result of the anatomic location of the defect. In the apical four-chamber view, the interventricular septum was parallel to the ultrasound beam, which resulted in the possibility of false positives due to the dropout of the echo of the interventricular septum.

Although the number of patients with a supracristal-type VSD was too small to make a firm conclusion, the subcostal sagittal plane seemed to be valuable in visualizing such defects. In the subcostal sagittal view, the conus septum was parallel to the ultrasound beam, which makes possible a false-positive diagnosis due to the dropout of the septal echo. In such patients, the contrast technique seemed to be necessary to demonstrate positive or negative contrast jets passing through the defect. A parasternal sagittal plane cutting both the right ventricle and main pulmonary artery might avoid dropout of septal echoes.

Left ventricular angiographic studies have shown that the contrast jets of left-to-right shunts are directed toward the body of the right ventricle in the majority of membranous-type VSDs and toward the subpulmonic region of the right ventricle in supracristal VSDs. Our echocardiographic study corroborates these findings: Left-to-right shunts were seen as negative jets in the contrast-filled right ventricle on 2-D echo, and the directions of the negative jets were different for membranous-type VSDs and supracristal-type VSDs. These signs might be helpful in determining the anatomic position of the defects.

Two-dimensional echocardiography allowed diagnosis of VSD by visualization of the defect itself. The addition of peripheral venous contrast technique confirmed the anatomic position by showing the contrast material passing through the defect itself. Although the contrast study indicated the approximate right ventricular pressure, it could not estimate the pulmonary vascular resistance. The use of 2-D echo to visualize defects of the interventricular septum and to estimate the right ventricular pressure state by the contrast technique made possible a more specific diagnosis of VSD.

References

Echocardiographic visualization of ventricular septal defect in infants and assessment of hemodynamic status using a contrast technique. Comparison of M-mode and two-dimensional imaging.

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