Detection and Exclusion of Interatrial Shunts by Two-dimensional Echocardiography and Peripheral Venous Injection

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SUMMARY Two-dimensional echocardiography (2-D echo) was used with peripherally injected contrast material to detect interatrial shunts in 33 patients. Group 1 consisted of 11 patients having classic clinical findings of atrial septal defect. Group 2 consisted of 12 patients with problems requiring that atrial shunting be excluded. Group 3 (control group) consisted of 10 patients undergoing cardiac catheterization for chest pain. Confirmation of the 2-D echo findings was provided by cardiac catheterization in 32 patients and postmortem examination in one.

Right-to-left atrial shunts were detected in all 11 patients in group 1, although seven had no right-to-left shunt calculable by oximetry. Four patients in Group 2 had right-to-left atrial shunts. None of the patients in Group 3 had atrial shunts. In the 15 patients with atrial shunts, the degree of right-to-left shunting could be qualitatively assessed as small, moderate, or large. There were no false-negative or false-positive results by contrast 2-D echo.

RECENT REPORTS have demonstrated the use of contrast M-mode echocardiography in identifying and localizing significant right-to-left intracardiac shunts at the atrial level using peripherally injected contrast material.1,2 Seward7 has shown that small amounts of right-to-left shunting3 are not always detected by contrast M-mode echocardiography in patients with secundum atrial septal defect when there is predominant left-to-right shunt.

Two-dimensional echocardiography should improve the probability of detecting right-to-left shunt at the atrial level because it provides greater spatial information and allows simultaneous examination of the right atrium, left atrium, and interatrial septum. This report describes the use of two-dimensional echocardiography (2-D echo) to detect the spectrum of atrial level right-to-left shunts using peripheral venous injection of contrast material.

Patients and Methods

Twenty-three consecutive patients 15–68 years old were referred to the Duke Clinical Cardiology Laboratory between June 1977 and February 1978 for contrast 2-D echo to investigate possible intracardiac shunting, and assigned to one of two groups. The 11 patients in Group 1 had clinical and radiographic findings that suggested atrial septal defect, including fixed splitting of the second heart sound, right ventricular lift, pulmonic flow murmur, and hyperemic lungs.

Group 2 consisted of 12 patients with various problems requiring that interatrial shunting be excluded, including unexplained right ventricular enlargement, arterial desaturation, and possible paradoxical embolization. Group 3, consisting of 10 patients undergoing diagnostic cardiac catheterization for suspected coronary or valvular heart disease, was the control group.

All of the patients in this series had catheterization or anatomic verification of the echocardiographic findings. Twenty-nine of the 33 patients underwent diagnostic catheterization within 2 months of the echocardiographic examination, while three patients had remote cardiac catheterization. The remaining patient did not undergo cardiac catheterization but subsequently died and underwent postmortem examination.

Echocardiographic Methods

Two-dimensional echocardiograms were obtained in real-time using a previously described® or commercially available focused, phased-array imaging system. High resolution images of cardiac structures were produced in a circular sector format, 70, 80, or 90 degrees in azimuth, and stored on videotape for playback and analysis.

Two-dimensional images were obtained in standard cross-sectional planes of the heart as previously described.® In addition, the simultaneous visualization of all four cardiac chambers, the septa, and both atrioventricular valves was obtained by placing the transducer over the cardiac apex and aiming toward the base with the plane of view kept perpendicular to the plane of the atrioventricular valve rings and the plane of the ventricular septum (fig. 1).7

Echocardiographic contrast was produced by rapid injection of 10 ml of normal saline through an 18 gauge needle placed in a superficial arm vein. The resonance characteristics of the resultant micro-
cavitations, or tiny gas bubbles, make them suitable echocardiographic targets for contrast studies. This technique, used since 1968, has been shown to be safe and effective. The microcavitations can be visualized best when the controls of the echo system are set at low reject and high gain.

To determine the presence of right-to-left shunting, multiple boluses of saline were injected rapidly while the transducer was positioned in standard views and in the apical four-chamber view. In patients without right-to-left shunts, microcavitations appeared in the right atrium and passed through the tricuspid valve into the right ventricle without appearing in left heart chambers. Atrial level right-to-left shunts caused microcavitations to cross the atrial septum or to appear simultaneously in both atria. Microcavitations are normally cleared completely by the pulmonary capillary bed. The presence of one or more discreet, rapidly moving microcavitations in the left atrium, agreed upon by at least two independent observers unaware of the clinical findings, warranted the diagnosis of right-to-left shunt.

The degree of right-to-left shunting was qualitatively assessed as small, moderate or large. After multiple injections, an occasional microcavitation indicated small right-to-left shunting (fig. 2); numerous microcavitations in the left atrium indicated moderate right-to-left shunting (fig. 3); and equal opacification of both atria indicated large right-to-left shunting (fig. 4).

Catheterization Methods

Right and left heart catheterizations were performed from the right groin by standard percuta-
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Figure 3. A moderate right-to-left atrial level shunt (patient 10, group 1) using the apical four-chamber view in a patient with an atrial septal defect. The arrow indicates a small, dense cloud of microcavitations just as they appear in the left atrium. Orientation is the same as in figure 1.

Figure 4. A large right-to-left shunt (patient 11, group 1) in the long axis view of the left ventricle. Panel A and the accompanying schematic diagram in panel B show equal opacification of the left and right ventricles in this patient with an atrial septal defect and pulmonary hypertension. AoR = Aortic root; RV = right ventricle; LV = left ventricle; LA = left atrium.

Results

The hemodynamic, angiographic, and echocardiographic findings in all patients are given in table 1. All patients in this series had adequate echocardiographic examinations. We recognized the echo targets from injected microcavitations easily, even in subjects with poor overall target definition.

In this series of 33 patients who underwent either cardiac catheterization or anatomic examination, use of contrast 2-D echo showed no false-positive or false-negative diagnoses of atrial-level communications.

Group 1

Seven patients in this group had atrial septal defects with right-to-left shunting undetected by oximetry or indicator dilution curves at catheterization. In each...
case a small right-to-left shunt was seen by contrast 2-D echo. A negative contrast effect was visible in three of these patients as blood without microcavitations streamed from the left atrium into the right atrium (fig. 5). Two patients with predominant left-to-right shunt and right-to-left shunt calculable by oximetry had moderate right-to-left shunts estimated by contrast 2-D echo. In the only patient with pulmonary hypertension and predominant right-to-left shunt at catheterization, equal echocardiographic opacification of both atria with microcavitations after peripheral injection indicated a large right-to-left shunt (fig. 4).

**Group 2**

Four patients in this group had atrial level shunting demonstrated by contrast 2-D echo and confirmed at cardiac catheterization. Two of these patients had residual shunts after repair of an atrial septal defect and two patients had patent foramen ovale. In eight patients with clinical histories that suggested atrial-level shunting, the use of contrast 2-D echo detected no right-to-left shunt, which was confirmed in seven cases by cardiac catheterization and in one by postmortem exam. Although atrial-level shunting was ex-

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**Table 1. Hemodynamic, Angiographic, and Echocardiographic Findings**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Clinical diagnosis</th>
<th>Catheterization diagnosis</th>
<th>PA pressure (mm Hg)</th>
<th>Calculation of shunt by oximetry size (1/min)</th>
<th>Estimate of R→L shunt by echo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>L→R</td>
<td>R→L</td>
<td></td>
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<tr>
<td>Group 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>ASD</td>
<td>Secundum ASD</td>
<td>24/8</td>
<td>10.0</td>
<td>small</td>
</tr>
<tr>
<td>2</td>
<td>ASD</td>
<td>Secundum ASD</td>
<td>20/5</td>
<td>28.1</td>
<td>small</td>
</tr>
<tr>
<td>3</td>
<td>ASD</td>
<td>Secundum ASD</td>
<td>28/15</td>
<td>6.3</td>
<td>small*</td>
</tr>
<tr>
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<td>24/7</td>
<td>3.1</td>
<td>small*</td>
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<td>24/9</td>
<td>3.4</td>
<td>small*</td>
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<td>20/9</td>
<td>4.1</td>
<td>small*</td>
</tr>
<tr>
<td>7</td>
<td>ASD</td>
<td>Primum ASD</td>
<td>26/6</td>
<td>8.6</td>
<td>small*</td>
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<tr>
<td>8</td>
<td>ASD</td>
<td>Primum ASD</td>
<td>NA</td>
<td>NA</td>
<td>small*</td>
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<td>Ebstein's anomaly, ASD</td>
<td>10/3</td>
<td>2.2</td>
<td>moderate</td>
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<td>Ebstein's anomaly</td>
<td>Ebstein's anomaly, ASD</td>
<td>15/5</td>
<td>1.3</td>
<td>moderate</td>
</tr>
<tr>
<td>11</td>
<td>ASD, cyanosis</td>
<td>Secundum ASD, pulmonary hypertension</td>
<td>56/28</td>
<td>0.9</td>
<td>2.2</td>
</tr>
</tbody>
</table>

| Group 2 |                   |                           |                     |                                             |                           |
| 1       | Cyanosis, RVH     | PS, patent foramen        | 10/5                | 0                                           | 0.7                       | moderate                  |
| 2       | Cyanosis          | Patent foramen            | NA                  | NA                                          | NA                        | moderate                  |
| 3       | Repaired ASD,     | ASD patch leak            | 55/23               | 0                                           | 0.9                       | small                     |
|         | Cyanosis          | ASD patch leak            | 62/33               | 0                                           | 0.9                       | small                     |
| 4       | Repaired ASD,     | Normal                    | 24/13               | No shunt                                    | none                      | none                      |
|         | RVE               |                           |                     |                                             |                           |
| 5       | Repaired ASD      | ASD                       | 20/8                | No atrial shunt                             | none                      | none                      |
|         | RVE               | ASD                       | 19/10               | No atrial shunt                             | none                      | none                      |
| 6       | RVE               | Small VSD                 | 26/16               | No shunt                                    | none                      | none                      |
| 7       | RVE               | Small VSD                 | 16/9                | No atrial shunt                             | none                      | none                      |
| 8       | Systemic emboli   | Aortic SBE                | 22/12               | No shunt                                    | none                      | none                      |
| 9       | Systemic emboli   | Aortic SBE                | 15/6                | No shunt                                    | none                      | none                      |
| 10      | Systemic emboli   | Mitral valve endocarditis | 15/6                | No shunt                                    | none                      | none                      |
| 11      | Ebstein's anomaly | Ebstein's anomaly, ASD    | 10/3                | 2.2                                         | moderate                  |
| 12      | Systemic emboli   | Mitral valve endocarditis | 10/3                | 2.2                                         | moderate                  |

*Denotes patients having negative contrast effect.

Abbreviations: ASD = atrial septal defect; NA = data not available; RVH = right ventricular hypertrophy; PS = pulmonic stenosis; RVE = right ventricular enlargement; VSD = ventricular septal defect; PDA = patent ductus arteriosus; SBE = subacute bacterial endocarditis; CAD = coronary artery disease; AI = aortic insufficiency; MS = mitral stenosis; PA = pulmonary artery; R→L = right-to-left; L→R = left-to-right.
cluded in two patients with ventricular septal defect, we did not observe right-to-left ventricular-level shunt or a negative contrast effect of left-to-right shunt.

Group 3

The 10 patients in this group showed no evidence of shunt through use of either contrast 2-D echo or oximetry and indocyanine green dye curves at cardiac catheterization.

Discussion

Slight degrees of right-to-left shunt flow are present in atrial septal defects, even when the predominant shunt is left-to-right. Levin\(^3\) demonstrated this by angiographic techniques in children with uncomplicated ostium secundum atrial septal defects. Further evidence substantiating this point was reported by Swan,\(^15\) who used indicator dilution methods. Alexander\(^4\) created atrial septal defects in dogs and was able to measure directly the phasic shunt flow (including transient right-to-left shunting) during the cardiac cycle.

Gramiak,\(^11,\ 12\) Feigenbaum\(^13\) and others\(^14-16\) have used indocyanine green dye to identify and validate intracardiac structures with M-mode echocardiography. The contrast effect of injected indocyanine green, saline, dextrose in water, or blood is thought to be caused by the microcavitations produced by rapid injection of any gas-containing solution through a small-bore orifice. Following the Bernoulli principle, the pressure drop at the orifice tip allows dissolved gases to come out of solution; the resonance characteristics of these gases, or microcavitations, make them excellent echo targets.\(^8-10\) The contrast effect lasts for several cardiac cycles and the microcavitations are subsequently cleared by any capillary bed.

Peripheral contrast echocardiography involves injecting 10 ml of fluid from a peripheral vein and obviates the need for intracardiac catheters. Valdes-Cruz\(^1\) and Seward\(^16\) have used this technique to detect predominant right-to-left intracardiac shunts in children. Lieppe\(^17\) has applied the contrast technique to two-dimensional echocardiography for detection of tricuspid regurgitation.

Although small degrees of right-to-left shunting exist in many patients with atrial septal defect, M-mode echocardiography, presumably because of its narrow field of view, has failed to demonstrate this phenomenon except in a few cases.\(^1\) Two-dimensional echocardiography overcomes this limitation by providing a wide field of view and spatial orientation of cardiac target information.
Two-dimensional echocardiography, combined with contrast techniques, provides a means of detecting even small degrees of right-to-left flow that accompany atrial-level shunting. In our series of 33 patients there were no false-positive or false-negative results when contrast 2-D echo was compared with data obtained by cardiac catheterization. Most importantly, the small amount of right-to-left shunting present in seven patients in group I missed by oximetry and indocyanine green dye dilution was detected by contrast 2-D echo. Because contrast 2-D echo can document the presence or absence of an atrial-level communication without the need for cardiac catheterization, it is very important in the clinical management of the patients. In all 12 patients in Group 2, for example, clinical suspicion of an atrial-level communication was strong; but, using contrast 2-D echo, we detected atrial shunts in only four of them.

In three patients who had proven atrial-level communications, we observed the negative contrast effect wherein blood from the left atrium without microcavitations can be seen to disrupt the opacification of the right atrium. The negative contrast effect did not, however, predict the presence of a large left-to-right shunt, nor have we had success in identifying ventricular septal defects by contrast 2-D echo unless there is pulmonary hypertension and right-to-left shunt. The negative contrast effect may be useful in diagnosing ventricular septal defects when there is exclusively left-to-right shunt, though we have encountered only a few patients with this finding.

The echocardiographer should use this method prudently. Other cardiac abnormalities may be present in patients with atrial septal defect, necessitating cardiac catheterization. Some patients have poor sound transmission characteristics due to obstructive lung disease, obesity, or anterior chest wall abnormalities, so the diagnostic certainty of the ultrasonic information may, in itself, be questionable. Right-to-left atrial shunts may also be more difficult to demonstrate by contrast 2-D echo at faster heart rates, as is frequently the case in children. The negative contrast effect is best seen at slow heart rates and only when the right atrium is completely opacified by contrast material. Patients with predominant left-to-right atrial shunts do not always have microcavitations in the left atrium on the first injection; multiple views of the atria with several bolus injections during each view may be required to prove or exclude the presence of an atrial level defect.

Twice, we have seen microcavitations appear in the left atrium or ventricle without any peripheral injection of fluid and without any other obvious source. One patient had a prosthetic mitral valve and the microcavitations appeared to be closely associated with the valve ring. We are unable to explain these findings.

We described previously the 2-D echo features of patients with atrial septal defects, including right ventricular enlargement, flattening of the left ventricle in short axis, and mitral valve prolapse, especially of the anterior leaflet. These findings in the patients in the present study were similar to those previously reported; and although characteristic of atrial septal defects, they are not specific and could be mimicked by other conditions. The addition of the peripheral venous contrast technique permits diagnosing atrial septal defect with greater certainty and estimating the degree of right-to-left shunting. The ability to detect intracardiac shunting at the atrial level, combined with diagnostic information concerning chamber size, septal motion, and valvular abnormalities, makes a more specific diagnosis possible.

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References

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