Contrast M-Mode Echocardiography in Diagnosis of Atrial Septal Defect in Acyanotic Patients

GERHARD KRONIK, M.D., JÖRG SLANY, M.D., AND HERBERT MOESSLACHER, M.D.

SUMMARY Contrast echocardiograms during normal quiet respiration and during the Valsalva maneuver were performed in 15 patients with atrial septal defect (ASD) by injecting saline solution into an antecubital vein. Contrast shunting (the appearance of contrast echoes in the left heart) was observed not only in four patients with severe pulmonary hypertension (group 2), but also in 11 patients with uncomplicated ASD (group 1). Contrast shunting was prominent in all group 2 patients. In group 1, contrast shunting was sometimes subtle and difficult to recognize, but at other times was very obvious and similar to the findings in group 2. Contrast shunting was generally more pronounced during the Valsalva maneuver than during normal respiration, although there were exceptions. The amount of contrast appearing in the left heart did not correlate with the size of the defect. Small right-to-left shunts which are clinically insignificant but detectable by contrast echocardiography are present, or can be provoked by the Valsalva maneuver, in most patients with ASD. Contrast echocardiography is a useful, noninvasive method to detect interatrial communication, even in acyanotic patients.

CONTRAST ECHOCARDIOGRAPHY is a very sensitive method to detect right-to-left (R-L) shunts, but it is usually considered of little value in patients with left-to-right (L-R) shunts. Patients with atrial septal defect (ASD) may be an exception to this rule and contrast echocardiography may be successfully used to detect interatrial communications even in the absence of pulmonary vascular disease and severe pulmonary hypertension.

Patients and Methods

We examined 15 patients with ASD by contrast echocardiography. The presence of ASD was documented by standard cardiac catheterization. The 11 patients in group 1 had normal pulmonary vascular resistance, normal to moderately elevated pulmonary artery pressure, and no oxymetric evidence of a R-L shunt. The four patients with clinically obvious R-L shunts (group 2) had high pulmonary arteriolar resistance and severe pulmonary hypertension documented at cardiac catheterization. The most important clinical and hemodynamic data of both groups are presented in table 1.

After a complete M-mode echocardiographic study had been obtained, an antecubital vein was punctured and a plastic cannula with a luminal diameter of 1 mm

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CONTRAST ECHO IN ASD/Kronik et al.

Table 1. Hemodynamic, Echocardiographic and Contrast Echocardiographic Findings in 15 Patients With ASD

<table>
<thead>
<tr>
<th>Pt no</th>
<th>PAP (syst/diast/mean) (mm Hg)</th>
<th>PAR (dyn-sec-cm⁻¹)</th>
<th>R-L</th>
<th>L-R</th>
<th>Echocardiography</th>
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<tbody>
<tr>
<td></td>
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<td>M-mode</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>RV</td>
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<tr>
<td>1</td>
<td>18/6/11</td>
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<td>(-)</td>
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<td>53%</td>
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<tr>
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<td>(-)</td>
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<td></td>
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<td>(-)</td>
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<td>30%</td>
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<td>(-)</td>
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</tr>
<tr>
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<td>(-)</td>
<td></td>
<td>63%</td>
</tr>
<tr>
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<td>9</td>
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<td>87</td>
<td>(-)</td>
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<td>57%</td>
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<tr>
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<td>23/9/14</td>
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Group 2

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<tr>
<th>Pt no</th>
<th>PAP (syst/diast/mean) (mm Hg)</th>
<th>PAR (dyn-sec-cm⁻¹)</th>
<th>R-L</th>
<th>L-R</th>
<th>Echocardiography</th>
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<td>M-mode</td>
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<td></td>
<td></td>
<td>RV</td>
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<tr>
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<td>17%</td>
<td></td>
<td>53%</td>
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<td>11%</td>
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<td>115/60/90</td>
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<td>dil</td>
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<tr>
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<td>90/35/45</td>
<td>774</td>
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<td>44%</td>
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Discrepancies between the blind and the open evaluations occurred in patients 3, 5, and 9 during normal respiration and in patient 7 during the Valsalva maneuver.

*ASD with anomalous pulmonary venous connection.
†Small VSD present in addition to a very small ASD.
‡Catheterized in another hospital; R-L shunt not given.

Abbreviations: PAP = pulmonary artery pressure; PAR = pulmonary arteriolar resistance; R-L = right-to-left shunt; L-R = left-to-right shunt; (-) = no oxymetric evidence for L-R shunt; RV = right ventricle; SM = septal motion; dil = dilated; nl = normal; abnl = abnormal; Echo CS = maximal contrast shunting; NR = normal respiration; VM = Valsalva maneuver; +++ = massive; ++ = strong; + = weak; (±) = questionable; 0 = no contrast shunting; o = open analysis; b = blind analysis; NP = not performed; Pt no = patient number.

was inserted. Then the mitral valve was located and the gain controls of the Picker Echoview 80 C echocardiograph were carefully adjusted using as much gain and as little damping and reject as possible. Great care was taken to eliminate background noise.

Multiple 10 ml samples of saline solution were then rapidly injected through the intravenous line. All contrast injections were continuously recorded without changing transducer position or gain controls. The last five to 10 cardiac cycles immediately preceding the appearance of saline solution in the right ventricle were included in the recording and used for comparison. In 12 patients, saline solution was not only injected during normal quiet respiration, but also during the Valsalva maneuver. In three patients, contrast studies were done under basal conditions only.

Contrast echoes were defined as strong linear echoes with a motion pattern different from that of any other intracardiac structure and which were clearly distinguishable from background noise. Contrast shunting was defined as the appearance of contrast echoes in the left heart semiquantitatively graded according to the following criteria: massive contrast shunting (+++): the mitral funnel is filled with contrast echoes (figs. 1, 2, and 3); strong contrast shunting (++): many contrast echoes on the left side of the septum (fig. 4); weak but definite contrast shunt-

![Figure 1](http://circ.ahajournals.org/Downloaded from http://circ.ahajournals.org by guest on April 14, 2017)

Figure 1. Massive (+++) contrast shunting in a cyanotic patient with atrial septal defect (case 15).
FIGURE 2. Massive contrast shunting during normal quiet respiration in patient 6. In this patient contrast shunting varied markedly with respiration, and massive contrast shunting is in fact visible during one diastole only.

FIGURE 4. Strong (++) contrast shunting during the release phase of the Valsalva maneuver in patient 9.

In order to prevent biased interpretation of the contrast echocardiograms and to test for false positive results, all echocardiograms of patients with ASD who received no saline injection and all contrast echocardiograms were coded and read blindly by one of us, while the echoes of the right ventricle and the septum were covered. Thus, the investigator looking for contrast echoes in the left heart did not know if and when saline solution had been injected. All tracings were then decoded and reanalyzed. Although there were no gross discrepancies between these two evaluations, in a few borderline cases contrast shunting had been somewhat underestimated by the blind analysis. To guarantee uniform interpretation of the tracings, we used the results of the second analysis.

FIGURE 3. Contrast echocardiogram during the Valsalva maneuver in patient 11. Massive contrast shunting occurs only during the early release phase (R). S = strain phase.
Results

Conventional M-mode echocardiography revealed the typical combination of a dilated right ventricle and abnormal septal motion in only eight of our 15 ASD patients (table 1). Septal motion was essentially normal in seven cases and patient 10, who had a very small ASD in addition to a small ventricular septal defect, had a normal right ventricular diameter and normal septal motion.

The results of the contrast echocardiographic studies during normal respiration and during the Valsalva maneuver are summarized in table 1. Massive or strong contrast shunting during normal respiration was found in all group 2 patients, as expected, since clinically manifest R-L shunts were present in all these patients. However, diagnostic contrast shunting either during normal respiration or during the Valsalva maneuver could also be demonstrated in all group 1 patients, who were considered uncomplicated cases of ASD with pure L-R shunts (table 1). Under basal conditions, contrast shunting was absent, questionable, or weak in the majority of group 1

Figure 5. A) Weak (+) contrast shunting during the Valsalva maneuver in patient 2. The white arrow marks the end of the strain phase. A cluster of four contrast echoes and another single typical contrast echo are marked by small arrows in the tracing. B) A close-up view of the early release phase and contrast shunting. These five contrast echoes represent the minimum required for the diagnosis of weak but definite contrast shunting.

Figure 6. A) Questionable contrast shunting under basal conditions in patient 9 (compare with figure 4). Two probable contrast echoes are seen in the left ventricle (arrows). Similar echoes are absent before the appearance of contrast within the right ventricle. A magnification of the respective cardiac cycles is given in panels B and C.
patients, but two patients showed strong and one patient massive contrast shunting during normal respiration, which was similar to the findings in group 2 (fig. 2).

During the Valsalva maneuver, contrast shunting was less obvious in only two patients, unchanged in three, and distinctly increased in six, including three patients in whom no diagnostic contrast shunting had been evident under basal conditions. Thus, contrast shunting was definitely more pronounced during the Valsalva maneuver than during normal respiration.

There was no correlation between the amount of contrast passing the septum and the size of the defect as determined by cardiac catheterization. In fact, some of the strongly positive contrast studies, particularly during the Valsalva maneuver, were from patients with small ASDs.

The findings of the blind and the open analyses were the same in most instances. Even when the tracings were read without the interpreter knowing if and when saline solution had been injected, diagnostic (+, ++ or ++++) contrast shunting was never diagnosed in any of the control recordings, and whenever contrast echoes were found in the left heart, they were also present in the right heart. On four occasions, contrast shunting was underestimated by the blind analysis (table 1) and graded as questionable instead of weak (two patients) or as weak instead of strong (two patients). However, even during the blind analysis, diagnostic contrast shunting either at rest or during the Valsalva maneuver could be positively diagnosed in as many as 10 of 11 group 1 patients (91%). We recognized weak but definite contrast shunting in patient 2 at rest, but graded it questionable during the blind evaluation.

Discussion

A dilated right ventricle and abnormal septal motion, the conventional M-mode echocardiographic criteria for the diagnosis of ASD, are not specific indicators of right ventricular volume overload and do not prove the presence of an interatrial communication.6-7 Furthermore, these signs may be absent in patients with small leaks and septal motion may be normal, even when the shunt is large6 (table 1).

Two-dimensional echocardiography can be used to visualize the interatrial septum. Defects in the lower part of the atrial septum seem to indicate a septum primum defect.6,9 However, the upper part of the interatrial septum cannot be seen in many normal patients, so the absence of an upper atrial septum cannot be used to diagnose secundum type ASD.6,9 Weyman et al. described an elegant method to diagnose ASD using two-dimensional contrast echocardiography.10 When injecting indocyanine into a peripheral vein, they saw the jet of contrast-free left atrial blood enter the contrast-filled right atrium. We confirmed Weyman’s observations in the few patients in whom we did cross-sectional contrast echocardiograms (fig. 8).

M-mode contrast echocardiography may also be useful to prove the presence of a suspected ASD, even in patients without severe pulmonary hypertension and cyanosis. Clinically insignificant R-L shunts detectable by contrast echocardiography seem to be present at rest or can be provoked by the Valsalva maneuver in most patients with uncomplicated ASD. These patients with uncomplicated ASD are usually considered to have pure L-R shunts; however, because the pressure difference between the atria is small, and turbulent rather than laminar blood flow is present within the right atrium, and the inflow of left atrial blood decreases with inspiration,19 small amounts of right atrial blood may sometimes escape into the left atrium, even when the shunt is purely L-R from a clinical standpoint.

When the patient performs the Valsalva maneuver, the heart continues to pump blood into the major cir-
culation, but the venous return is significantly impeded during the strain phase by the increased intra-thoracic pressure. Upon release, the engorged peripheral veins rapidly empty into the right atrium, which floods, while the left atrium receives little blood from the pulmonary veins. In this situation some R-L shunt may occur in patients with ASD irrespective of the presence or absence of severe pulmonary hypertension. This transient shunt reversal can be seen directly by two-dimensional echocardiography (fig. 8).

When sensitive methods for shunt detection are used, small R-L shunts in patients with uncomplicated ASD can also be demonstrated at cardiac catheterization. During the Valsalva maneuver even an open foramen ovale seems to be sufficient to allow some transient R-L shunt. Whether or not patients with a patent foramen ovale may also have positive contrast studies during the Valsalva maneuver is not clear, but strong contrast shunting could be provoked by the Valsalva maneuver even in patient 10, who had a combined atrial and ventricular L-R shunt of only 18%, normal septal motion, and a normal right ventricular diameter, indicating that his ASD was indeed very small.

Theoretically, the R-L shunt should always be more pronounced during the Valsalva maneuver than during normal respiration. Nevertheless, contrast shunting was in fact less obvious during the Valsalva maneuver in two patients. Contrast shunting not only reflects the magnitude of the R-L shunt, but also depends on the amount of contrast echoes in the right heart. Therefore, one cannot expect to find a strict correlation between contrast shunting and the magnitude of the R-L shunt.

Patient 6 had massive contrast shunting without provocative maneuvers, despite his normal pulmonary artery pressure and resistance. This patient had anomalous pulmonary venous connection and a small ASD at surgery. Part of his pulmonary circulation drained into the right atrium rather than the left atrium, which probably decreased the L-R shunt at the site of the defect and facilitated the occurrence of some R-L shunt. However, the high oxygen content of his right atrial blood, which contained admixtures of

**FIGURE 8.** Cross-sectional contrast echocardiogram in a patient with atrial septal defect. At rest (A) a contrast-free stream of left atrial blood can be seen to enter the contrast-filled right atrium. During the release phase of the Valsalva maneuver (B) there is a transient reversal of the shunt direction and a bolus of contrast-stained right atrial blood is visible in the left atrium.
pulmonary venous blood, made the oxymetric recognition of the R-L shunt particularly difficult.

The diagnosis of an uncomplicated ASD by contrast echocardiography is technically more difficult than the demonstration of R-L shunts in patients with cyanotic heart disease, and certain technical aspects deserve mention. First, the right heart should be densely filled with contrast echoes, otherwise the small amounts of right atrial blood which cross the interatrial septum may not contain enough contrast to be recognized. Second, multiple injections should be given under basal conditions as well as during the Valsalva maneuver because individual injections may result in variable contrast production, and because contrast injections of seemingly equal quality may or may not result in contrast shunting. This reflects spontaneous variations in the magnitude of the R-L shunt during normal respiration and variations in the quality of the Valsalva maneuvers. Another explanation may be that saline solution which enters the left ventricle is undetected because it is not evenly distributed and misses the sampling site of the M-mode beam. Third, while contrast shunting is immediately apparent in patients with clinically manifest R-L shunts (fig. 1), it is often subtle in patients with uncomplicated ASD and must be searched for carefully. Finally, when obtaining contrast echocardiograms during the Valsalva maneuver, careful instruction of the patient and excellent patient cooperation are necessary, which precludes the use of the technique in young children. Although contrast shunting may become evident during the strain phase, this part of the tracing is often technically unsatisfactory and difficult to interpret. The most important moment is usually the first diastole following Valsalva release (fig. 3). If the patient takes a deep breath at this time, intervening lung echoes will obscure the echocardiogram and contrast shunting may be missed. Sometimes it is tedious and time-consuming to record several adequately filled contrast echocardiograms during the release phase.

Since contrast shunting is weak in some patients with uncomplicated ASD, one of our major concerns was to see if these few echoes could be reliably differentiated from artifacts, background noise, and incomplete mitral echoes. Our blind analysis indicates that this is possible. When only diagnostic (massive, strong, or weak) contrast shunting was considered, there were no false positives. On four occasions when control tracings were recorded shortly after contrast studies had been done, we saw single, typical contrast echoes in the left heart which met our criteria for questionable contrast shunting. In each instance, small residual amounts of contrast were still present in the right heart at that time. Therefore, these examples of seemingly false positive questionable contrast shunting may have been true positives.

The sensitivity of the proposed technique must be determined in a larger group of patients. We encountered one patient with typical clinical, radiological, electrocardiographic, and echocardiographic findings of an ASD in whom contrast studies at rest and during the Valsalva maneuver were not diagnostic. In another six clinically diagnosed acyanotic cases who refused catheterization, the ASD could be as readily documented by contrast echocardiography as in our 11 catheterized patients. Thus, the sensitivity of the technique seems to be satisfactory but probably not 100%.

In summary, small R-L shunts which are clinically insignificant but detectable by contrast echocardiography are present or can be provoked by the Valsalva maneuver in most patients with ASD. Contrast echocardiography can be used to prove the presence of a suspected interatrial defect noninvasively, even in acyanotic patients with normal pulmonary arteriolar resistance. Positive contrast studies do not allow any conclusions concerning the size of the defect and should not be taken as proof of severe, inoperable pulmonary hypertension. Negative contrast studies do not exclude the possibility of an ASD.

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References

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