Echocardiographic Pattern of Right Ventricular Diastolic Volume Overload in Children

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SUMMARY
Echocardiograms were performed on 20 children who were 1–14 years old. Ten children had secundum atrial septal defects (ASD 2°); four had partial and two had complete atrioventricular canal defects (AVC); and three had partial and one had total anomalous pulmonary venous connection (APVC). Twenty-eight normal children were also examined. Echocardiograms of nine patients with ASD 2° revealed increased right ventricular dimension index (RVDI) and abnormal (paradoxic) ventricular septal (VS) motion. The remaining patient with ASD 2°, who had a Qp/Qs of 1.2 (smallest in the series), had a normal echocardiogram. All four patients with APVC had increased RVDI, and three had abnormal VS motion. The patient with normal septal motion had associated mild aortic stenosis, but he too had a small left-to-right shunt (19%). The echocardiograms of two patients with partial AVC revealed features similar to ASD 2°, but in the third patient who had significant mitral regurgitation (MR) the VS motion was normal, indicating that the degree of associated MR influences the VS motion in this anomaly. The septal motion was normal in both patients with complete AVC. Three patients in the series had abnormal systolic anterior motion of mitral valve. Postoperative echocardiograms revealed persistence of increased RVDI and “paradoxic” VS motion.

Additional Indexing Words:
Ultrasound cardiology
Anomalous pulmonary venous connection
Idiopathic hypertrophic subaortic stenosis
Mitral regurgitation

Atrial septal defect
Atrioventricular canal
Congenital heart disease

The role of echocardiography in the diagnosis and evaluation of various forms of heart disease has been well established in adults.1–13 The purpose of the present study was to evaluate the usefulness of this noninvasive technic in children with congenital heart defects. To date, echocardiography has been performed on 150 children whose ages ranged from 4 months to 14 years. The initial experience with the conditions leading to right ventricular diastolic volume overload is reported in this paper; the features of other congenital cardiac defects will be published separately.

Methods
Echocardiography was performed on 20 children, using a commercially available machine (Ekoline 20) that had a 1.91-cm (0.75-in), 2.25-mHz transducer with a repetition rate of 1000/sec. The technic has been well described in previous communications on this subject.1, 14, 15 All patients were studied while in the recumbent position; a water-soluble gel (Aquasonic) was used to ensure airless contact between the transducer and the skin. The transducer was placed at the third, fourth, or fifth left interspace, near the sternal edge; the placement site depended on the size of the patient and his heart. The characteristic echo of the anterior mitral leaflet was first located; then, by rotating the transducer inferolaterally and by adjusting the near and coarse gains, echoes from the right...
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ventricular cavity, the interventricular septum, and the left ventricular posterior wall could be identified. Permanent records of these echoes were obtained on a film (Polaroid) in the "B-mode" presentation.

Three groups of patients were studied: Group 1 consisted of 10 patients (ages 2½–13 years) with ostium secundum atrial septal defects (ASD 2°). Group 2 consisted of four patients (ages 1–14 years) with anomalous pulmonary venous connection (APVC). Three of the four had the partial form of this anomaly, and one of these had in addition mild aortic stenosis. The fourth patient had total anomalous pulmonary venous connection to coronary sinus. All four patients had associated atrial septal defects. Group 3 consisted of six patients (ages 3–9 years) with atrioventricular canal (AVC). Four of the six had the partial form, and two had the complete form.

All but two patients in the series underwent surgical correction of their respective congenital cardiac defects. Preoperative cardiac catheterization was performed on 15 patients. Echocardiography was repeated on eight patients between the fourth and the eighth postoperative day. All preoperative echocardiograms except one were satisfactory for measurement of cardiac chambers and for evaluation of septal motion. The unsatisfactory echocardiogram in a patient with partial AVC was excluded from the series. Two of eight postoperative echocardiograms were unsatisfactory.

Echocardiograms were also performed on 28 normal children (ages 1 month to 14 years) in order to obtain the normal dimensions of different cardiac chambers for control purposes. The measurements of the heart chambers were performed using the landmarks described by Popp and associates.14

Results

Normal Group

In children with body surface area of less than 1.0 m², the mean right ventricular dimension (RVD) was 0.8 cm (range 0.4 to 1.4 cm). The mean right ventricular dimension index (RVDI) was 1.3 cm/m² (range 0.5 to 2.0 cm/m²). It is noteworthy that, although

![Figure 1](http://circ.ahajournals.org/)

**Figure 1**

Case 1. (Left) Echocardiogram reveals increased RVD and abnormal (paradoxic) ventricular septal motion; that is, both the septal echo and the LPW echo move in the same direction during cardiac cycle. (Right) Arrows point to abnormal (exaggerated) systolic anterior motion of mitral valve. Abbreviations for figures: CW = chest wall; RV = right ventricular wall; RVC right ventricular cavity; IVS = interventricular septum; LVC = left ventricular cavity; AML = anterior mitral leaflet; LPW = left ventricular posterior wall; and LAW = left atrial wall.

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the mean RVD is less in the control group than in an adult group (as expected), the calculated mean RV DI was greater than that of adults.14, 15 The excursion of anterior mitral leaflet in this group was between 1.0 and 2.3 cm, and the speed of diastolic closure slope varied between 70 and 160 mm/sec. In children with body surface area of 1.0 m² and greater, the mean RVD was 1.0 cm (range 0.7 to 1.4 cm). The mean RV DI was 0.8 cm/m² (range 0.5 to 1.1 cm/m²). The mean RV DI and the mitral valve excursion of the group with body surface of 1 m² and greater resembled more closely the corresponding measurements in adults.3, 15 The ventricular septal motion was normal in all patients in this group; that is, both the septal echo and the left ventricular posterior wall echo moved in opposite directions during each cardiac cycle.

**Group 1**

Nine of the 10 patients with ASD 2° had abnormal or “paradoxic” ventricular septal motion (fig. 1); that is, both the left ventricular posterior wall echo and the septal echo moved in the same direction during the cardiac cycle, a paradox of normal motion. All patients had increased RV DI (mean 3.3 cm/m² and range 1.7 to 4.6 cm/m² (table 1). One patient (case 10) had an RV DI that was at the upper limit of normal and was associated with normal septal motion. These two findings (increased RV DI and paradoxic ventricular septal motion) constitute the echocardiographic hallmarks of right ventricular diastolic volume overload.

**Group 2**

Three patients (cases 11, 12, and 14) had echocardiographic features of right ventricular volume overload. In these three, RV DI was increased (mean 4.5 cm/m² and range 3.3 to 6.3 cm/m²), and the ventricular septal motion was paradoxic (table 2). The fourth patient (case 13) had normal septal motion in the presence of increased RV DI (fig. 2). In

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**Table 1**

Patients with Ostium Secundum Atrial Septal Defects

<table>
<thead>
<tr>
<th>Case</th>
<th>Sex &amp; age (yr)</th>
<th>RV dimension</th>
<th>Mitral valve motion</th>
<th>Qp/Qs</th>
<th>Rp/Rs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Size (cm)</td>
<td>Index (cm/m²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>F 4½</td>
<td>2.8</td>
<td>3.5</td>
<td>A</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Postop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>M 5</td>
<td>3.1</td>
<td>4.6</td>
<td>A</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Postop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>F 4</td>
<td>3.0</td>
<td>4.1</td>
<td>A</td>
<td>3.9</td>
</tr>
<tr>
<td>4</td>
<td>F 6</td>
<td>2.9</td>
<td>3.9</td>
<td>A</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Postop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>F 8</td>
<td>1.8</td>
<td>1.7</td>
<td>A</td>
<td>1.3</td>
</tr>
<tr>
<td>6</td>
<td>M 10</td>
<td>3.2</td>
<td>2.8</td>
<td>A</td>
<td>—</td>
</tr>
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<td></td>
<td></td>
<td>Postop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>F 2½</td>
<td>2.2</td>
<td>3.8</td>
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<td>8</td>
<td>F 13</td>
<td>2.7</td>
<td>2.4</td>
<td>A</td>
<td>1.4</td>
</tr>
<tr>
<td>9</td>
<td>F 4</td>
<td>1.9</td>
<td>3.3</td>
<td>A</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Postop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>F 4½</td>
<td>1.5</td>
<td>2.0</td>
<td>Normal</td>
<td>1.2</td>
</tr>
</tbody>
</table>

(Rp = 2.0 Um²)

* A signifies that both the septal echo and the left ventricular posterior wall echo move in the same direction during cardiac cycle; B indicates flattened septal echo during ventricular ejection.15

Abbreviations: Qp/Qs = pulmonic-to-systemic flow ratio; Rp/Rs = pulmonic-to-systemic resistance ratio; Um² = units meter square.
Table 2

Patients with Anomalous Pulmonary Venous Connection (APVC)

<table>
<thead>
<tr>
<th>Case</th>
<th>Sex &amp; age (yr)</th>
<th>RV dimension (cm)</th>
<th>RV dimension Index (cm/m²)</th>
<th>Septal motion*</th>
<th>Mitral valve motion</th>
<th>Qp/Qs</th>
<th>Rp/Rs</th>
<th>Additional diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 M 8</td>
<td>2.8</td>
<td>3.3</td>
<td>A Normal</td>
<td>—</td>
<td>—</td>
<td>Partial APVC from right upper lobe to superior vena cava</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postop</td>
<td>2.0</td>
<td>2.6</td>
<td>3.9</td>
<td>A Normal</td>
<td>2.6</td>
<td>0.1</td>
<td>Partial APVC from right upper and middle lobes to superior vena cava</td>
<td></td>
</tr>
<tr>
<td>13 M 14</td>
<td>1.9</td>
<td>1.3</td>
<td>Normal</td>
<td>Normal</td>
<td>L-to-R shunt, 19%</td>
<td>—</td>
<td>Partial APVC from right upper lobe to superior vena cava</td>
<td></td>
</tr>
<tr>
<td>14 F 1½</td>
<td>2.2</td>
<td>3.8</td>
<td>A Normal</td>
<td>3.8</td>
<td>0.2</td>
<td>Total APVC to coronary sinus</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*See table 1 for definitions and abbreviations.

addition, this patient had mild aortic stenosis (peak gradient 22 mm Hg).

Group 3

The echocardiograms of two patients (cases 16 and 17), both of whom had partial AVC, revealed increased RVDI and paradoxical ventricular septal motion (table 3 and fig. 3). Both patients had minimal mitral insufficiency, and the ratio of LVMDI to RVDI was 0.5 and 1.05, respectively. The third patient (case 15), who had partial AVC, had significant mitral regurgitation. This patient had a slightly increased RVDI but a normal ventricular septal motion (fig. 4) and a LVMDI-to-RVDI ratio of 2.5. The RVDI was at the upper range of normal in both patients with complete AVC. The septal motion was also normal in both of these patients.

In the series, the mitral valve motion was normal in all except three patients (cases 1, 3, and 15) in whom an abnormal systolic

Figure 2

Case 13. Echocardiogram reveals increased RVD but normal ventricular septal motion; that is, the septal echo and the LPW echo move in the opposite directions during the cardiac cycle.
Table 3

Patients with Atrioventricular Canal (AVC)

<table>
<thead>
<tr>
<th>Case</th>
<th>Sex &amp; age (yr)</th>
<th>RV dimension</th>
<th>Mitral valve motion</th>
<th>Qp/Qs</th>
<th>Rp/Rs</th>
<th>Additional diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>F 9</td>
<td>1.4</td>
<td>Normal</td>
<td>2.7</td>
<td>—</td>
<td>Partial AVC with significant mitral regurgitation</td>
</tr>
<tr>
<td>16</td>
<td>F 5</td>
<td>2.8</td>
<td>A</td>
<td>—</td>
<td>—</td>
<td>Partial AVC</td>
</tr>
<tr>
<td>17</td>
<td>F 5</td>
<td>2.6</td>
<td>A</td>
<td>Normal</td>
<td>2.6</td>
<td>Isolated levocardiawith partial AVC</td>
</tr>
<tr>
<td>18</td>
<td>M 7</td>
<td>1.6</td>
<td>Normal</td>
<td>1.9</td>
<td>—</td>
<td>Complete AVC</td>
</tr>
<tr>
<td>19</td>
<td>F 3</td>
<td>1.0</td>
<td>Normal</td>
<td>1.3</td>
<td>0.7</td>
<td>Complete AVC</td>
</tr>
</tbody>
</table>

(Rp = 9.5 Um²)

*See table 1 for definitions and abbreviations.

Comment

In this study, an attempt was made to evaluate the role of echocardiography in the diagnosis of congenital cardiac defects associated with diastolic volume overload of right ventricle in children. The characteristic echocardiographic pattern of such conditions consists of two features: increased RVDI and abnormal (paradoxical) septal motion. Results in general agree with and support the earlier findings of Diamond et al.15 in adults with atrial septal defects (secundum and primum). However, we found normal septal motion in three patients (cases 10, 13, and 15), each one belonging to a separate group.

One patient (case 10) had secundum atrial septal defect; her echocardiogram revealed RVDI of 2.0 cm/m² (upper limit of normal), along with normal ventricular septal motion. Cardiac catheterization data in this case showed a left-to-right shunt of 10%, with a pulmonic-to-systemic flow ratio (Qp/Qs) of 1.2 (smallest in our series). We also have encountered normal septal motion and normal RVDI in an adult patient with secundum atrial septal defect, with left-to-right shunt of 12%, and a Qp/Qs of 1.2 (to be published). These observations suggest that the magnitude of the left-to-right shunt at the atrial level might be the factor for determining both the RVDI and ventricular septal motion and that the diagnostic accuracy of echocardiography may be decreased in patients with atrial septal defects and small left-to-right shunts. Increased RVDI and abnormal septal motion (paradoxical) have been reported previously, however, in a patient with a small left-to-right shunt (Qp/Qs of 1.1).15 Hence, experience with more patients is necessary to define properly the diagnostic value of echocardiography in differentiating patients who have tiny atrial septal defects from normal patients.

Figure 3

Case 17. Echocardiogram reveals increased RVD and abnormal (paradoxical) ventricular septal motion.
One patient (case 15) had partial atrioventricular canal associated with moderately severe mitral regurgitation. Her echocardiogram revealed normal septal motion. Diamond et al. noted abnormal septal motion in all patients with ostium primum defects in their series, regardless of the degree of mitral insufficiency, which varied from none to moderate. The findings in one patient (case 15) in our series suggest that the degree of mitral regurgitation might influence the septal motion. A diastolic volume overload of both ventricles occurs in this situation, and the motion of ventricular septum might be expected to be different from that of isolated right ventricular volume overload. This hypothesis is further supported by similar observations in a 23-year-old woman who had total anomalous pulmonary venous connection from the right lung to the superior vena cava, with an intact interatrial septum (left-to-right shunt of 45%) and associated moderately severe mitral regurgitation. This patient's echocardiogram also revealed normal ventricular septal motion which, in the absence of significant mitral regurgitation, would have been expected to show abnormal (paradoxic) septal motion.

The septal motion was normal in both patients with complete forms of atrioventricular canal, resembling that of patients with uncomplicated ventricular septal defect.

One patient (case 13) had partial APVC from the right upper lobe to the superior vena cava (left-to-right shunt of 19%), with associated mild aortic stenosis. The RVDI was slightly increased, while the septal motion was normal on echocardiographic examination. The small left-to-right shunt in this patient further amplifies the importance of the magnitude of the shunt in determining the septal motion. Whether associated mild aortic stenosis helps prevent the septal motion from becoming abnormal is not known. All other patients with partial and total anomalous pulmonary venous connections had increased RVDI and "paradoxic" septal motions.
The echocardiographic findings of right ventricular volume overload are nonspecific and should be considered with the clinical findings in order to arrive at an accurate diagnosis.

In the acyanotic children suspected of having large left-to-right shunts, the echocardiographic findings of right ventricular volume overload help locate the site of the shunt at the right atrial level or proximal to it. However, such overload would not differentiate further between ASD 2\(^\circ\) and partial APVC, because both of these entities have similar clinical, electrocardiographic, and echocardiographic features.

When the echocardiographic pattern of right ventricular volume overload is seen in a cyanosed patient, two diagnostic possibilities are suggested: total APVC and common atrium. In such a patient, a clockwise frontal-plane QRS axis on the electrocardiogram would strongly suggest the diagnosis of total APVC, whereas a counterclockwise frontal-plane QRS axis would favor the diagnosis of common atrium.\(^{16}\) All other patients with cyanotic congenital heart disease accompanied by right ventricular decompensation, whom we have studied, have had normal ventricular septal motion. These include patients with tetralogy of Fallot, truncus arteriosus, tricuspid atresia, transposition of the great vessels with ventricular septal defect, double-outlet right ventricle, and severe pulmonary stenosis with atrial septal defect. However, it should be emphasized that abnormal (paradoxical) ventricular septal motion has been noted in tricuspid regurgitation, which also leads to volume overload of right ventricle.\(^{15}\)

In three patients (cases 1, 3, and 15), the echo of the anterior mitral leaflet revealed systolic anterior motion similar to that seen in patients with idiopathic hypertrophic subaortic stenosis (IHSS). Such abnormal motion was first noted by Popp and Harrison\(^{11}\) in a patient with secundum atrial septal defect (pseudo-IHSS pattern). They attributed it to an exaggerated anterior movement of whole mitral valve structure secondary to large volume change in the right heart during ejection. This mechanism could be operative in these patients with secundum atrial septal defect, as both had large shunts. The systolic anterior motion as seen in these patients occurred gradually and did not show a posterior motion during the isometric relaxation phase. In idiopathic hypertrophic subaortic stenosis, the systolic anterior motion occurs abruptly during systole and characteristically shows a posterior motion prior to the diastolic reopening of the valve,\(^{17}\) distinctly different from that seen in atrial septal defect. The two other possible features that differentiate pseudo from true idiopathic hypertrophic subaortic stenosis patterns are that in the pseudo form the left ventricular internal dimension is usually normal or slightly decreased and the diastolic closure slope of the mitral valve is normal. In idiopathic hypertrophic subaortic stenosis, the left ventricular internal dimension is usually considerably decreased and the diastolic closure slope of the mitral valve is slow, resembling that seen in mitral stenosis.\(^{17}\)

The systolic anterior motion seen in case 15 could be due to abnormal attachment of the mitral valve, which is often present in this condition. A similar false-positive idiopathic hypertrophic subaortic stenosis pattern recently was observed by Shah et al.\(^{18}\) in three patients: one patient with ostium primum defect and a left mitral valve (similar to our case 15) and two patients with nonobstructive cardiomyopathy.

After surgical closure of the defect and abolition of the left-to-right shunt, the septal motion continued to remain paradoxical during the postoperative period (4–8 days) in six patients in whom satisfactory echocardiograms were obtained. The first time this observation was made in a patient after closure of secundum atrial septal defect, incomplete closure of the defect was considered. Subsequent assurance from the surgeon and repeated experience with other patients indicate that in almost all patients, pediatric as well as adult, paradoxical septal motion remains early after closure of the defect. The RV DI also remained increased (except in case 4) but
was decreased from the preoperative measurement. It is not yet known how long the increased RVDI and the abnormal ventricular septal motion will remain before the normal pattern returns.

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References
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