An Evaluation of the Left Atrial/Aortic Root Ratio in Children with Ventricular Septal Defect

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SUMMARY Echocardiograms were performed in 80 infants and children with isolated ventricular septal defect (VSD) who underwent cardiac catheterization. The pulmonary-to-systemic flow ratio (Qp/Qs) was correlated with the echocardiographic left atrial-to-aortic root diameter ratio (LA/Ao), and a relatively poor correlation (r = 0.62) was found.

The end-systolic diameters of the left atrium and aorta at the level of the aortic root, obtained from lateral cineangiograms of 55 of the 80 patients, were compared with the corresponding echocardiographic dimensions. To assess the possible effect of transducer beam angulation upon the echocardiographic determinations, the angiographic measurements were made at 0° position (perpendicular to the frontal plane) and at angles of 5°, 10°, 15°, and 20° from zero, using the aortic root center as the point of intersection. The echocardiographic and angiographic aortic root measurements were comparable (r = 0.95), and the angiographically derived aortic diameter did not vary with different angle projections. However, the left atrial angiographic dimensions were significantly influenced by the angle of projection. We conclude that the echocardiographic LA/Ao ratio cannot reliably estimate the severity of the shunt flow in VSD.

THE INCREASED pulmonary blood flow resulting from ventricular septal defect (VSD) promotes enlargement of the left atrium and the left and right ventricles, but not of the aorta. The size of the left atrium relative to that of the aorta may, therefore, reflect the magnitude of the left-to-right shunt. Assessment of left atrial (LA) size by echocardiography has been carried out by Hirata in adults and, more recently, by Yabek et al. in children in whom the LA echocardiographic dimensions correlated well with the angiographically derived LA volumes. However, Hirata and later Brown et al. reported considerable overlap of the echocardiographic LA dimensions between normal subjects and patients with LA enlargement. They observed a wide range of normal values that improved somewhat after “normalization” of the echocardiographic measurements for body surface area. Brown et al. consequently proposed relating the echocardiographic LA diameter to that of the relatively nondistensible fibrous aortic root (Ao), as a ratio of LA to Ao dimension (LA/Ao ratio). The latter was found to be more sensitive than LA dimension alone for identifying LA enlargement.

The usefulness of “normalized” echocardiographic LA dimensions in the form of LA/Ao ratio or LA dimension/m² for predicting the severity of left-to-right shunting, particularly for serial measurements, has been investigated by a number of workers over the past 5 years, with various results. Some have shown good correlation between echocardiographic LA/Ao ratio and Qp/Qs obtained at catheterization. In our experience, however, this correlation has not been consistent; it was excellent in some patients but quite poor in others. This study was carried out to determine the factors responsible for these observations and, in particular, to investigate the effect of LA geometry and transducer beam angulation on the echocardiographic LA and LA/Ao measurements.

Materials and Methods

Echocardiograms were obtained from 80 consecutive patients with isolated VSD, age 0.02–19.5 years (mean 4.8 years) and body surface area 0.18–1.8 m², admitted for hemodynamic evaluation. Six had repeat echocardiographic and catheterization studies 6 months to 2 years later. The echocardiograms were generally taken within 48 hours of catheterization
(within 24 hours in 50 patients). Twenty-eight of the 80 patients were under treatment for congestive heart failure, but all were clinically stable at the time of the studies. No other cardiac lesions were present. Pulmonary hypertension (pulmonary artery systolic pressure > 30 mm Hg) was present in 24 patients. None had right-to-left shunts. Patients who had had cardiac surgery were not included in this study.

The echocardiograms were obtained by means of a Unirad series 100 ultrasonoscope interfaced with a Tektronix model 174 strip chart recorder modified for use with Kodak Linograph light-sensitive paper. Infants and children 5 years of age or younger were examined by means of an Aerotech 5 MHz nonfocused transducer. In the older children, an Aerotech 3.5 MHz nonfocused, or a 2.25 MHz 0.5-inch diameter transducer focused at 3-6 cm was used. All patients were studied in the supine position and without sedation. The transducer was positioned at the third or fourth intercostal space to the left of the sternal border. Full recording was made of the right and left ventricles at the mitral valve level, and the transducer was directed superiorly and to the right in a continuous sweep to the Ao and LA level. Care was taken to record optimally the aortic valve echoes, and the gain was adjusted to obtain sharp images of the anterior and posterior walls of the Ao, as well as the posterior LA wall. This was usually accomplished with the transducer held at the third left parasternal interspace, almost perpendicular to the chest wall at the superoinferior axis, although its angulation sometimes varied slightly, depending upon chest con-

The Ao dimension was measured from the outer edge of the anterior wall to the outer edge of the posterior wall at end-diastole, identified as the beginning of the QRS complex.11 Because similar measurements have been obtained at end-systole by others, particularly by Lewis and Takahashi,9 the end-diastolic and end-systolic dimensions were compared. The LA dimension was measured at end-systole, from the outer edge of the posterior aortic wall to the endocardial surface of the posterior LA wall (fig. 1). When identification of the atrial posterior wall was in question, e.g., in the presence of multiple, ill-defined echoes, the pericardial line from behind the left ventri-

Cardiac catheterization was performed in the usual manner, with the patients sedated by oral chloral

**Figure 1.** Typical left atrial-aortic root echo tracing showing the aortic dimensions in end-diastole (Ao_d) and in end-systole (Ao_s) for comparison. The left atrial diameter (LA) was obtained in end-systole.
hydrate (150 mg/10 lb). Children weighing more than 5 kg were also given Demerol and Vistaril intramuscularly (1.5-1.8 mg/kg up to 50 mg) for premedication. Pulmonary and systemic blood flows were determined using the Fick principle and an assumed normal oxygen consumption. The degree of left-to-right shunting was expressed by the pulmonary-to-systemic blood flow ratio (Qp/Qs). Selective left ventriculograms in the oblique projections and right-heart angiograms in the frontal and lateral projections were obtained in all patients by means of Phillips biplane, dual-mode, 5- and 9-inch cesium iodide image-intensifier tubes with fixed tube-to-film distances of 81 cm in the frontal and 89 cm in the lateral projections. In 55 patients, the right-sided angiograms were suitable for LA and Ao diameter measurements in the lateral view of the levophase. These were obtained at the 0° position perpendicular to the frontal plane, with the anterior margin of the cineframe as the frontal reference line. Similar

**Figure 2.** Schematic diagram of the aortic root (Ao) (upper tracing) showing theoretical pathways of the echo beams. Traversal of this structure may be central (solid arrow) or eccentric (dotted arrows). The lower pictures are actual tracings of the lateral angiocardiograms in ventricular end-systole of two patients with ventricular septal defect showing the difference in left atrial geometry and the likely influence of echo transducer angulation upon the echocardiographic dimensions. Qp/Qs = pulmonary-to-systemic flow; LA = left atrium; LV = left ventricle.

**Figure 3.** Left atrial-aortic root dimension (LA/Ao) ratio with aortic diameter in end-systole compared with the LA/Ao ratio with aortic diameter in end-diastole. The regression line (solid) and the line of identity (dotted) are shown.
measurements were made at 5°, 10°, 15° and 20° angles below 0°, with the Ao center as the point of intersection (fig. 2). All measurements were corrected for x-ray magnification, as previously described.13 The angiographic LA and Ao measurements and the corresponding LA/Ao ratios were compared with the respective echocardiographic measurements.

Results

The heart rates at the time of echocardiography (mean 111 ± 4.4 beats/min [SEM]) were slightly lower (p < 0.01) than those at the time of right-heart angiography (mean 120 ± 4.2 beats/min). The echocardiographic Ao dimensions obtained at end-diastole were generally similar to those measured at end-systole. There was, accordingly, no difference between the LA/Ao ratios using end-systolic or end-diastolic aortic dimensions (r = 0.96; fig. 3). All LA/Ao ratios later referred to in this paper have been obtained with the aortic diameter measured in end-diastole.

The relatively poor linear correlation (r = 0.59) between the Qp/Qs ratio and the echocardiographic LA/Ao ratio improved somewhat (r = 0.62) when the data were treated by an exponential function analysis, using the basic equation: \( Y = a e^{bX} \), where \( Y \) is the Qp/Qs ratio, and \( X \) the LA/Ao ratio. In both, there was wide distribution of the data points, suggesting poor sensitivity of the LA/Ao ratio for predicting the Qp/Qs ratio (fig. 4).

To account for the above observations, we evaluated several factors or possible sources of error related to the echocardiographic examination. First, we considered the possibility that the transducer beam might have failed to traverse the Ao centrally, despite the presence of aortic valve echoes. This could result in fortuitously small aortic echocardiographic dimensions (fig. 2). The angiographically derived Ao diameters at 0° projection correlated well with the echocardiographic aortic diameters (r = 0.95); the regression line did not deviate much from the line of identity (fig. 5). In addition, the angiographic Ao measurements at 0°, 5°, 10°, 15° and 20° angle projections were comparable, varying by only ± 10% of the mean of the five values (lower graph, fig. 5).

Second, we investigated the possibility that the echocardiographic LA dimension did not reflect the degree of LA enlargement, taking into consideration LA geometry and transducer beam angulation, which are illustrated in figure 2, where sketches were traced from the lateral angiograms in ventricular end-systole of two patients with different shunt flows. The tracing on the left is from a 4.9-year-old child with a trivial VSD shunt shown only in the left ventricular angiogram (Qp/Qs = 1.0). The tracing on the right is from a 1.5-year-old infant with a Qp/Qs of 1.8. The echocardiographic LA/Ao ratios were similar (1.4 and 1.5, respectively) despite the difference in shunt flows.

Comparison of the angiographic LA diameter at 0° projection with the echocardiographic LA dimension of 55 patients showed a relatively poor correlation (r = 0.38), although the regression line was situated close to the line of identity (fig. 6). Because of the wide distribution of the data points, the echocardiographic

Figure 4. Correlation between pulmonary-to-systemic flow (Qp/Qs) and left atrial-aortic root dimension (LA/Ao) ratios, analyzed by linear function (solid line) and by exponential function (dotted line); the corresponding t values are shown.
dimensions inconsistently underestimated or overestimated the LA angiographic diameters. Similar plots of angiographic LA diameters obtained at projection angles of 5°, 10°, 15° and 20° showed progressive reduction of the correlation coefficients and further deviation of the regression lines from identity (table 1).

Comparison of the echocardiographic LA/Ao and the angiographically derived LA/Ao ratios at projection angle of 0° revealed only fair correlation ($r = 0.62$). At increasing angles of projection in the angiographic analysis, $r$ values declined progressively, accompanied by a wider scatter of the individual values: at 5°, $r = 0.52$; at 10°, $r = 0.40$; at 15°, $r = 0.25$; at 20°, $r = 0.38$ (only 51 patients had LA measurements at a 20° angle). A consistent decline of the angiographic LA diameter at each 5° increment of angulation accounted for these observations (table 1).

We also checked the reliability of the echocardiographic LA/Ao ratio for discriminating groups of VSD patients with different shunt flows. Patients in group A, whose LA/Ao ratios were < 1.3, had a mean Qp/Qs of 1.36, which differed significantly from that of patients in groups B and C, who had larger LA/Ao ratios (table 2). However, the LA/Ao in group A did not differ from that of 151 normal infants and children studied in our laboratory (mean $1.15 \pm 0.01$ [SEM]). Also, there was no significant difference between the Qp/Qs of patients in group B, whose LA/Ao ranged from 1.3–1.6, and the Qp/Qs of patients in group C, whose LA/Ao ranged from 1.6–2.7.

**Table 1.** Echocardiographic vs Angiographic Left Atrial Dimensions at Various Angle Projections in Lateral Angiograms ($n = 55$)

<table>
<thead>
<tr>
<th>Angle</th>
<th>$r$ value</th>
<th>Regression equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>0.58</td>
<td>$Y = 0.87X + 0.39$</td>
</tr>
<tr>
<td>5°</td>
<td>0.54</td>
<td>$Y = 0.81X + 0.42$</td>
</tr>
<tr>
<td>10°</td>
<td>0.50</td>
<td>$Y = 0.78X + 0.38$</td>
</tr>
<tr>
<td>15°</td>
<td>0.43</td>
<td>$Y = 0.69X + 0.42$</td>
</tr>
<tr>
<td>20°</td>
<td>0.40</td>
<td>$Y = 0.60X + 0.51$</td>
</tr>
</tbody>
</table>

* $Y = aX + b$, where $Y$ is the angiographic left atrial dimension, and $X$ is the echocardiographic left atrial dimension.
The changes in the echocardiographic LA/Ao and Qp/Qs ratios in the six patients subjected to a second cardiac catheterization were also analyzed. The values obtained at the second study were expressed as a percent of the initial observation; there was no correlation between the change in LA/Ao ratio and that in the Qp/Qs ratio (r = 0.12).

**Discussion**

The ability to assess the shunt size in VSD or related lesions using a noninvasive, readily repeatable procedure is invaluable. Previous studies on patients with VSD, or premature infants with patent ductus arteriosus have suggested that this is possible with echocardiography, using the echocardiographically obtained LA dimension or LA/Ao ratio to indicate the extent of LA enlargement from the volume overload. In a study of 20 patients with isolated VSD, Lewis and Takahashi reported excellent correlation between the Qp/Qs obtained at cardiac catheterization and the echocardiographic LA/Ao ratio (r = 0.96). Good correlation (r = 0.85) was also observed between Qp/Qs and the echocardiographic LA dimension “corrected” for body surface area (LA/m²), although there was a wider scatter of the data points.

In the present study of 80 patients, the correlation coefficient between Qp/Qs and echocardiographic LA/Ao using exponential regression analysis was much lower (r = 0.62). There was wide scatter of the data points, with a large standard error of the estimate. Thus, if one were to estimate the Qp/Qs from the LA/Ao ratio, the calculated error range (± 2 see) would be 41–245% of the estimate. The correlation by linear regression analysis was even poorer (r = 0.59), and the standard error of the estimate larger. We do not know why our results differed from those of the above investigators. Our measuring technique for echocardiographic aortic diameter differed only slightly from that of Lewis and Takahashi; our measurements included the thickness of the anterior and posterior aortic walls, whereas theirs extended from the outer surface of the anterior wall to the endothelial surface of the posterior wall, i.e., excluded the posterior wall thickness in the measurement. They also used the end-systolic aortic diameters in the LA/Ao ratios, not the end-diastolic aortic diameters that we used. However, we have failed to show signifi-

**TABLE 2.** Group Analysis of Left Atrial-Aortic Root (LA/Ao) and Pulmonary-to-Systemic Flow (Qp/Qs) Ratios in Ventricular Septal Defect

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>LA/Ao Mean ± SEM</th>
<th>p value</th>
<th>Qp/Qs Mean ± SEM</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A*</td>
<td>41</td>
<td>1.16 ± 0.015</td>
<td>&lt;0.001</td>
<td>1.36 ± 0.07</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>B†</td>
<td>27</td>
<td>1.42 ± 0.015</td>
<td></td>
<td>2.78 ± 0.31</td>
<td></td>
</tr>
<tr>
<td>C‡</td>
<td>18</td>
<td>1.89 ± 0.069</td>
<td>&lt;0.001</td>
<td>3.51 ± 0.39</td>
<td>NS</td>
</tr>
</tbody>
</table>

*LA/Ao < 1.3.
†LA/Ao 1.3–1.6.
‡LA/Ao > 1.6.
significant differences between the end-systolic or end-diastolic Ao dimensions; the LA/Ao ratios using aortic diameters in end-systole or in end-diastole were practically identical (fig. 3).

Of the two echocardiographic measurements analyzed (LA and Ao dimensions), the LA measurement is the more troublesome and likely to cause erroneous Qp/Qs estimation. The geometry of this chamber, particularly of its cephalad portion, which adjoins the Ao posteriorly, may vary. In some patients, the posterosuperior wall is inclined more vertically than in others (fig. 2). The position of the echo transducer relative to the plane of the chest wall is not always constant, though optimal Ao echoes are generally recorded with the transducer held at an angle of 70–90° along the superoinferior axis. The direction of the echo beam as it traverses the central Ao and left atrium could, therefore, also affect the measured LA dimension, which may be longer if the echo beam is almost perpendicular to the superoinferior axis, and shorter if it is directed cephalad at a more acute angle. The evidence for this assumption is indirect, and is based on the decreasing LA dimensions at more acute angles of projection in the lateral angiogram. Echocardiographic measurements at comparable transducer angulations were actually not obtained. Ours was a retrospective study, and it was, therefore, not possible to compare the atrial diameters at various angles of projection by the angiographic and echocardiographic methods.

**TABLE 3.** Correlations Between Pulmonary-to-Systemic Flow Ratio and Left Atrial-Aortic Root Dimension Ratio or Left Atrial Dimension Corrected for Body Surface Area in Subgroups of Ventricular Septal Defect

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>n</th>
<th>Mean Qp/Qs</th>
<th>r</th>
<th>Regression equation*</th>
<th>95% confidence range</th>
<th>Independent variable: LA/Ao</th>
<th>r</th>
<th>Regression equation†</th>
<th>95% confidence range</th>
</tr>
</thead>
<tbody>
<tr>
<td>I†</td>
<td>18</td>
<td>3.89</td>
<td>0.17</td>
<td>Qp/Qs = 2.292e^0.190X</td>
<td>42–237%</td>
<td>0.65 Qp/Qs = 0.608e^0.314X</td>
<td>51–194%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II§</td>
<td>25</td>
<td>2.44</td>
<td>0.60</td>
<td>Qp/Qs = 0.575e^0.493X</td>
<td>49–206%</td>
<td>0.59 Qp/Qs = 0.625e^0.291X</td>
<td>48–206%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>III¶</td>
<td>26</td>
<td>1.67</td>
<td>0.64</td>
<td>Qp/Qs = 0.593e^0.491X</td>
<td>54–187%</td>
<td>0.58 Qp/Qs = 0.694e^0.119X</td>
<td>52–193%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV**</td>
<td>17</td>
<td>1.15</td>
<td>0.62</td>
<td>Qp/Qs = 0.307e^1.144X</td>
<td>71–140%</td>
<td>0.02 Qp/Qs = 1.102e^0.0444X</td>
<td>65–154%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*X = LA/Ao.
†X = LA/m².
§BSA = 0.18–0.30 m².
¶BSA = 0.31–0.50 m².
§BSA = 0.51–1.0 m².
**BSA = > 1.0.

Abbreviations: Qp/Qs = pulmonary-to-systemic flow ratio; LA/Ao left atrial-aortic root dimension ratio; LA/m² = left atrial dimension corrected for body surface area (BSA).
Nevertheless, a potential source of error is shown. The echocardiographic tracings (fig. 7) illustrate this point. We believe that both factors (LA geometry and transducer angulation) are closely interrelated and that both play critical roles in the determination of LA dimension by current methods of M-mode echocardiography.

Yabek et al.\textsuperscript{3} have shown that estimation of LA volume from echocardiographic LA measurement is feasible in children with congenital heart disease. However, the echocardiographic dimensions were less representative of the angiographic anteroposterior minor axis in LA volume overload. In the latter situation, the anteroposterior minor axis increased by an average of 16.5\% over the anteroposterior major axis or inferosuperior minor axis of the enlarged left atrium. Thus, as the dilated left atrium becomes relatively more globular, the estimation of its volume based on this single linear measurement can be faulty, even if one wrongly assumes that the echo beam traverses this chamber at identical sites and trajectories in all patients. An additional echocardiographic dimension obtained at a separate projection plane, such as by the suprasternal approach,\textsuperscript{14} is helpful.

In contrast to that of the left atrium, the echocardiographic measurement of the Ao appears to be valid and reproducible.\textsuperscript{13,14} Our echocardiographic and angiographic studies, showing comparable Ao dimensions ($r = 0.95$), support this contention. By taking many Ao recordings, the possibility of the echo beam not traversing the Ao centrally and causing fortuitously small echocardiographic dimensions is minimized. Unlike the LA dimension, the Ao dimension may not be significantly altered by changes in transducer angulation along the superoinferior axis. Francis et al.\textsuperscript{13} also showed good correlation between the echocardiographic Ao dimension and the aortic annulus diameter observed at surgery in 31 adult patients undergoing aortic valve replacement ($r = 0.70$). Gramiak\textsuperscript{17} reported slight and variable alterations in Ao diameter during systole, and recommended measurement of this parameter in enddiastole.

The appropriateness of "normalizing" the echocardiographic LA dimension with body surface area deserves comment. A high correlation coefficient ($r = 0.82$) between Qp/Qs and LA/m\textsuperscript{2} was observed in our patients, and similar findings have been reported by others.\textsuperscript{7,9} These observations may indicate that this echocardiographic parameter can be used for estimating the Qp/Qs ratio. However, scrutiny of our data and those of Lewis and Takahashi\textsuperscript{8} revealed that the functional size of the VSD was also fortuitously related to body surface area or age: In patients subjected to cardiac catheterization, the older subjects generally had small shunts and the younger ones larger shunts. The coincidence could account for the good correlation between Qp/Qs and LA/m\textsuperscript{2}. Thus, repeat analysis of our data revealed much lower correlation coefficients for these two parameters (range 0.02–0.65) when the analysis was carried out in separate groups of patients with comparable body sizes (table 3). There was, however, no significant change in the $r$ value for Qp/Qs vs LA/Ao, except in the very young subjects. Also, when the LA dimensions were expressed as a percent of the predicted normal\textsuperscript{8} and related to the Qp/Qs ratio, the correlation coefficient ($r = 0.64$) was

\begin{figure}

\centering
\includegraphics[width=\textwidth]{figure8}
\caption{Pulmonary-to-systemic flow ($Qp/Qs$) plotted against left atrial (LA) dimension expressed as a percent of the predicted normal (LA/PN $\times 100$) and plotted against LA dimension corrected for body surface area (LA/m\textsuperscript{2}). The respective regression lines are shown.}
\end{figure}

\textsuperscript{*}Based on 151 normal children, using the predicting equation: $Y = 0.697X^{0.04} + 2.40$, where $Y$ is the predicted LA dimension (cm), and $X$ is the body surface area (m\textsuperscript{2}).
much lower than when LA/m² was the independent variable (fig. 8).

Our findings, then, suggest that the usefulness of the echocardiographic LA or LA/Ao dimensions for estimating the magnitude of the left-to-right shunt in VSD is limited. Other factors aside from the limitations of M-mode echocardiography may be responsible, but these will only be briefly mentioned, as it is not our purpose to analyze these other considerations in detail. For example, the quantitation of shunt flow by the Fick method may also be inaccurate, especially in small children, in whom a steady state during the diagnostic run cannot always be maintained. Moreover, there is also the possibility that the LA enlargement, especially in an older patient, may be secondary to a previously large left-to-right VSD shunt no longer reflected by the current Qp/Qs ratio. Our study included 34 children with Qp/Qs ≤ 1.5, many of whom were in the older age group. It is conceivable that the elevated LA/Ao ratios in some of these subjects with trivial shunts could be related to a previously larger VSD now undergoing closure. This process is well documented in natural history studies of VSD.

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