Echocardiographic Determination of Left Atrial Volumes in Children with Congenital Heart Disease

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SUMMARY The feasibility of determining left atrial volumes (LAV) from LA echo dimensions was assessed in 36 children (group I) with normal cineangiographically determined LAV and 16 children (group II) with LAV overload. Conventional LA echo dimensions, obtained within 24 hours of cardiac catheterization, were compared to the angiographic LA anterior-posterior minor axes (LAmA) and LAV. There was excellent correlation between the LA echo dimensions and the LAmA. In all patients, the LA echo < LAmA, the differences being more pronounced in group II. Good correlations were found between the LAV and the LA echo, and were expressed by the equations LAV = 7.5 LA echo1.8 (r = .85) and LAV = 8.1 LA echo1.9 (r = .86) for groups I and II, respectively. Changes in LA configuration with volume overload were shown to cause a disproportionate increase in LAmA compared to the other LA dimensions and the LA echo dimension, thus necessitating the separate regression equations. Echo LA to aortic ratios were 0.86 ± 0.11 and 1.21 ± 0.23 (mean ± SD) for groups I and II, respectively. This method of estimating LAV can be useful in the management of left-to-right intracardiac shunts and mitral regurgitation in infants and children.

ULTRASONOGRAPHY as a noninvasive technique has been used to evaluate cardiac function in adults,1-3 and more recently in children.4 In these studies the echocardiographically measured left ventricular dimension correlated well with left ventricular volume. Recently, emphasis has been placed on the left atrial (LA) echo dimension as a means of identifying infants and children with large left-to-right ventricular and ductal shunts.5-7 These studies, however, have relied on the absolute LA dimension and the ratio of LA to aortic root diameter. Previous studies have shown that left atrial maximal volume correlates well with the magnitude of left-to-right aortic or ventricular shunts,8 and with the severity of mitral regurgitation.9 Thus, estimating LA volume by a noninvasive method could be a useful tool in patient management. To our knowledge, no study in children or adults has correlated the LA echo dimension with the cineangiographically determined LA volume.

The purpose of this study was to determine the feasibility and accuracy of determining LA volume from the echocardiographic LA dimension in children with both normal and increased LA size. In addition, the ability to recognize patients with LA volume overload from the LA to aortic root diameter (LA/Ao) ratio was evaluated.

Materials and Methods

Diagnostic echocardiograms and biplane cineangiograms were obtained in patients undergoing cardiac catheterization after obtaining informed consent. Fifty-two patients (ages 8 months to 18 years) with good quality echocardiograms and cineangiograms were included in the study, and were divided according to LA volume into two groups. Group I consisted of 36 patients with normal left atrial volumes, defined as being within the range of the normal predicted value ± 2 SD (63% to 137% of normal predicted volumes).10 Group II consisted of 16 patients with large left atrial volumes, defined as being greater than 137% of predicted normal values. The patients selected had a wide variety of congenital cardiac lesions (table I). The majority of patients in group II had either mitral regurgitation or large left-to-right ventricular shunts.

All echocardiograms were obtained within 24 hours of cardiac catheterization using a Smith Kline Ekoline 20 ultrasonoscope. Patients were examined in the supine position utilizing transducers with frequencies of 2.25 MHz (½ inch diameter), 3.5 MHz (½ inch diameter) or 5 MHz (¾ inch diameter). After obtaining the mitral valve echogram from the third or fourth left intercostal space at the left sternal border, the transducer was directed medially and superiorly until echoes from the aortic root and valve cusps were identified, with care taken to insure that the transducer was perpendicular to the chest wall. Gains were then adjusted to obtain the clearest possible echoes from the aortic root and the posterior left atrial wall. Echocardiograms were recorded on Polaroid film or strip chart. The LA dimensions were measured at the end of ventricular systole from the posterior edge of the posterior aortic wall to the endocardial surface of the left atrial posterior wall. The aortic root diameter was measured from the anterior edge of the anterior aortic wall to the anterior edge of the posterior aortic wall at ventricular end systole (fig. 1). Three consecutive cycles were measured and the average values utilized for analysis. The LA/Ao ratio was calculated for each patient.

All LA volume data were obtained from biplane cineangiograms filmed during diagnostic cardiac catheterization with the patients sedated with meperidine (1 mg/kg), chlorpromazine (½ mg/kg) and promethazine (½ mg/kg). Biplane cineangiograms were exposed at 60 frames/sec in the posterior-anterior and lateral projections following the injection of 1.0 to 1.25 ml/kg of Renografin-76 into the right ventricle or main pulmonary artery. Maximum LA volumes (at ventricular end systole) were calculated during the initial beats of the levogram according
to the area-length method of Dodge et al.11 The atrial appendage was excluded from the calculations and all ectopic beats were excluded. All values obtained were corrected for magnification. The left atrial anterior-posterior minor axes (LAMAp) were calculated using the LA area and longest length on the lateral projection. In addition, both minor axes and the longest lengths were directly measured from the cineangiograms (fig. 2). Normal predicted LA volumes were

<table>
<thead>
<tr>
<th>Patient</th>
<th>Diagnosis</th>
<th>Age (yr)</th>
<th>BSA (m²)</th>
<th>Cardiac Output (mL/min/m²)</th>
<th>LA Volume Predicted (mL)</th>
<th>LA Volume Actual (mL)</th>
</tr>
</thead>
</table>

Table 1. Summary of Cineangiographic and Echocardiographic Data in 52 Patients

**Group I — Normal LA Volumes**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Diagnosis</th>
<th>Age (yr)</th>
<th>BSA (m²)</th>
<th>Cardiac Output (mL/min/m²)</th>
<th>LA Volume Predicted (mL)</th>
<th>LA Volume Actual (mL)</th>
</tr>
</thead>
</table>

**Group II — Large LA Volumes**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Diagnosis</th>
<th>Age (yr)</th>
<th>BSA (m²)</th>
<th>Cardiac Output (mL/min/m²)</th>
<th>LA Volume Predicted (mL)</th>
<th>LA Volume Actual (mL)</th>
</tr>
</thead>
</table>

Abbreviations: Ao = aorta; AI = aortic insufficiency; AS = aortic stenosis; ASD = atrial septal defect; band = pulmonary artery band; BSA = body surface area; mA = cineangiographic left atrial anterior-posterior minor axis; Coarc. = coarctation of the thoracic aorta; DORV = double outlet right ventricle; echo = echocardiographic dimension; MI = mitral insufficiency; PA/V = pulmonary artery volume; PS = patent ductus arteriosus; RAV = right atrial volume; VSD = ventricular septal defect; vol = volume; shunt = Waterston anastomosis.
Points used for left atrial (LA) and aortic root (Ao) dimensional measurements.

calculated for each patient based on body height, weight and age according to the equations of Graham et al. All volume values, expressed as a percentage of predicted normal, served as the basis for patient group selection.

**Results**

The diagnoses, ages, and body surface areas together with the cineangiographic and echocardiographic data of all patients are shown in table 1. The LA echo dimensions normalized for patient size (LA echo/BSA) averaged 2.5 ± 0.67 cm/m² and 3.8 ± 1.5 cm/m² (mean ± sd) for groups I and II, respectively. Despite the significant difference (P < 0.01) between the two groups, a great amount of overlap existed. All but one patient, however, with a LA echo greater than 3.4 cm/m² had increased LA volumes (>137% predicted) while all patients with a LA echo less than 2.5 cm/m² had normal LA volumes.

The LA/Ao ratio in group I averaged 0.86 ± 0.11 with a maximum ratio of 1.07. The ratio in group II averaged 1.21 ± 0.23 with three patients having values less than 1.07. These three patients, however, had lesions predisposing to aortic root dilatation (tetralogy of Fallot in two, aortic stenosis in one), thereby reducing the LA/Ao ratio despite an angiographically determined increase in LA volume.

The calculated LAmA was almost identical to the actual cineangiographically measured anterior-posterior dimension in all patients (r = .99). The calculated value will, therefore, be used to represent this dimension. There were excellent correlations between the angiographically determined LAmA (y) and the LA volume (x) in both groups (r = .88; .96) allowing volume calculation from this single angiographic dimension (fig. 3). The two equations were almost identical thus indicating a similar overall relationship between the LAmA and the LA volume in both groups of patients. There were good linear correlations (r = .87) between the LA echo dimension (y) and the LAmA (x) in the two groups (fig. 4). The relationships, however, were expressed by equations having significantly different slopes (P < .05). In every patient, the LA echo dimension was less than or equal to the angiographically determined LAmA.

The correlation between LA volume and LA echo dimension for the two groups combined was good (LA volume = 8.16 LA echo0.81; r = .81). The correlation for each of the two groups individually was improved in terms of correlation coefficients and standard errors (fig. 5). They are LA volume = 7.5 LA echo0.8 (r = .85) for patients in group I, and LA volume = 8.1 LA echo0.81 (r = .86) for patients in group II.

**Discussion**

The echocardiographic assessment of left atrial size was first attempted by Hirata et al. who found good correlation between the LA echo dimension and the LA area measured.
cineangiographically from the right anterior oblique projection. To the best of our knowledge, no study has attempted to correlate the cineangiographically determined LA volume with the LA echo dimension.

Studies on adults \(^1\) have shown the volume of the left ventricle to be a function of the left ventricular echo dimension to the third power. In children with left ventricular echo dimensions less than 5 cm, the relationship is a linear one as described by Meyer et al. \(^4\). Our results indicate a power curve relationship (\(y = ax^3\)) as providing the best correlation between the LA echo dimension and LA volume.

The correlation between the LA echo and the angiographic LAmA was not as good as expected (\(r = .87\)), suggesting an inconstant relationship between the position of the echo beam and the cineangiographic anterior-posterior minor axis. This may be due in part to variation in location of the aortic cusps in relation to the LAmA, or to variation in left atrial morphology. In all patients, however, the LA echo dimension was smaller than or, in two cases, equal to the LAmA.

By drawing the course of the echocardiographic beam onto the projected lateral angio image, we showed that the beam traverses the left atrium obliquely through its superior pole. This resulted in echo dimensions which were consistently less than the actual LAmA. In addition, the obliquity of the echo beam resulting from medial angulation of the transducer undoubtedly causes a further disparity between the direction and length of the echo dimension and

the LAmA as viewed from the horizontal plane.

Of significance was the necessity of having two regression equations in order to estimate LA volume from the LA echo dimension in patients with normal and enlarged LA. That this necessity was not due to a varying relationship between the LAmA and the LA volume in the two groups can be seen in figure 3. A change in LA configuration with volume overload, however, causing the echo beam to become less representative of the LAmA, may be the explanation (fig. 4).

As an example, enlargement of the left atrium with secondary indentation or "pancaking" could result in the LAmA, as the maximal lateral angio projection, becoming progressively larger than the LA echo, which passes through the left atrial indentation in the midline. To further investigate the increased disparity between the LA echo and the LAmA with volume overload, we reviewed the lateral angios and compared ratios of the LA dimensions in both groups of patients. No lateral angio disclosed overlapping of LA and aortic root, thereby minimizing the possibility of the atrium wrapping around central posterior mediastinal structures and having a central indentation. Posterior compression of enlarged left atria by posterior mediastinal structures could not, however, be completely excluded.

The ratio of the LA superior-inferior minor axis (mA') to the major axis (MA) did not change with volume overload, indicating no change in LA configuration when viewed from the frontal plane (table 2; fig. 2). In contrast, the LAmA increased an average of 16.5% more when compared to the increase of the other two LA dimensions. We showed, therefore, that in our patients with volume overload the LA

![Figure 4 Correlations of the LA echo dimension with the LAmA in patients with normal and increased LA volumes. All patients had echo dimensions less than or equal to the LAmA. In patients with volume overload (group II) the echo dimension was less representative of the actual LAmA. Thin line = line of identity.](http://circ.ahajournals.org/)

![Figure 5 Correlations of the cineangiographically determined maximum LA volume with the LA echo dimension.](http://circ.ahajournals.org/)

**TABLE 2. Dimensional Changes of the Left Atrium Caused by Volume Overload as Determined by Cineangiocardiography**

<table>
<thead>
<tr>
<th>Group</th>
<th>mA' (mean ± sd)</th>
<th>MA (mean ± sd)</th>
<th>MA' (mean ± sd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>.65 ± .08</td>
<td>.58 ± .07</td>
<td>.76 ± .10</td>
</tr>
<tr>
<td>Group II</td>
<td>.52 ± .08</td>
<td>.68 ± .08</td>
<td>.77 ± .06</td>
</tr>
<tr>
<td>% Change</td>
<td>↑ 16%</td>
<td>↑ 17%</td>
<td>↑ 1%</td>
</tr>
<tr>
<td>P Value‡</td>
<td>&lt;0.005</td>
<td>&lt;0.001</td>
<td>NS</td>
</tr>
</tbody>
</table>

*Dimensions as illustrated in figure 2.

‡P value as determined by the paired Student's t-test.

Abbreviations: mA = left atrial anterior-posterior minor axis; mA' = left atrial superior-inferior minor axis; MA = left atrial major axis; NS = not statistically significant.
assumed a more circular configuration when viewed from the lateral projection which in turn caused an increased obliquity of the echo beam and increased the LAmA in comparison to the echo dimension. We could not demonstrate flattening or “pancaking” of the left atrium in any of our patients with volume overload.

The finding of two formulae for the estimation of LA volume in children with normal and large left atria necessitated an accurate echocardiographic method for distinguishing between the two groups, so that the proper formula could be applied. The LA echo dimension normalized for body surface area showed a large degree of overlap in our two groups of patients, thus indicating that this dimension alone was not useful in identifying patients with large LA or in estimating the degree of left to right shunt. Absolute LA echo dimensions, as would be expected, proved to be even less useful.

Analysis of the LA/Ao ratio has been shown to be a very useful means of diagnosing LA enlargement by echocardiography. Recent reports have shown a mean ratio of 0.86 in normal premature infants and ratios of about 1.0 in normal full term infants. Similar studies in adults have reported mean ratios of 0.90 to 0.99. Patients with large left atria invariably have had ratios above 1.15 to 1.17. Our ratio in group I of 0.86 ± 0.11 clearly fits within the range of reported normal values for infants and adults, although values for normal children outside of infancy have not been previously reported. The LA/Ao ratios for the eight children with normal hemodynamics averaged 0.86 and did not differ from the values in the other children in group I (mean = 0.87) who had congenital heart disease but normal LA volumes angiographically. The values in 13 of the 16 patients in group II were larger than the maximum value in group I. The three values falling in the normal range were seen in patients with a large ascending aorta (tetralogy of Fallot or aortic stenosis). Although minor differences in methodology exist between the present paper and previously reported studies, the data fit well within previously reported ranges. In addition, the exclusion of the posterior aortic wall in the left atrial measurement produced little or no difference in our data compared to those in previous studies where this wall was included.

Thus we can conclude that in the absence of lesions predisposing to a large aorta, the LA/Ao ratio is a good method for separating children with large LA from those with normal left atrial size. It is suggested, therefore, that in patients having lesions predisposing to aortic root dilatation, the combined formula (LA volume = 8.16 LA echo\(^2\)) be used for estimating LA volume. For all other patients, one of the two more specific formulae, selected on the basis of the LA/Ao ratio, can be used to estimate the LA volume. Comparison with the normal predicted LA volume, based on age and body size according to the equations of Graham et al., will allow precise assessment of the degree of LA volume overload.

We have shown that LA/Ao ratios, already established for infants and adults, serve equally well for children of all ages. Although the technique of proportional echocardiographic comparison of LA dimension to the fibrous ring of the aortic root has proven useful, the echocardiographic quantitation of volume allows for a more precise determination of cardiac function. Our data in 52 children represent a preliminary attempt to apply echocardiography to the determination of LA volumes. We feel confident that the derived formulae may be used successfully in most children to quantitate the degree of mitral regurgitation and left-to-right ventricular and ductal shunts and to follow noninvasively patients with left atrial volume overload.

References
Echocardiographic determination of left atrial volumes in children with congenital heart disease.
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