The Effect of Left Ventricular Pressure or Volume Overload on Ventricular Dimension in Children

Left Ventricular Volume Determination from One or Two Ventricular Dimensions

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SUMMARY  The effect of pressure or volume overload on the geometry of the left ventricle (LV) was determined in order to examine the feasibility and accuracy of LV volume determinations from one minor axis or two dimensions (one minor axis and the longest length). The longest length (LL) and minor axis (MA) in both the anteroposterior (AP) view and lateral (LAT) view were determined from the LV cine silhouette in patients with normal LV volume and pressure (group 1), LV pressure (LVP) overload group (LVP > 140 mm Hg, group 2), and LV volume overload group (LV end-diastolic volume > 124% of normal, group 3). The ratio of the MA to the LL, which represents the spherical configuration of the LV, was less than "normal" in group 2, and higher than "normal" in group 3. In all groups the LV was less spherical at end-systole than at end-diastole. Additionally, the (MA)³ had a different relationship to true LV volume (biplane LV volume) in the three groups and from diastole to systole in each group. Left ventricular volume calculation from one minor axis was associated with a large error. In contrast, left ventricular volume can be accurately determined from two ventricular dimensions using either the anteroposterior or lateral ventricular image (r ≥ 0.97).

LEFT VENTRICULAR (LV) VOLUME DETERMINATION in children with congenital heart disease (CHD) is useful in evaluating LV function,¹ intracardiac and extracardiac shunts², ³ and is the most reliable method for quantitating pulmonary blood flow in patients with transposition of the great vessels (TGV).⁴ ⁵ In adults, LV volume can be determined from either biplane cineangiogram (cine)⁶ ⁷ or single plane cine.⁸ ⁹ In children, however, LV volumes have been quantitated only from biplane cine but not single plane cine. More recently, the anterior-posterior LV dimension obtained from single crystal echocardiography has been utilized to determine LV volume and function. Left ventricular cross-sectional area can be obtained using more recent echocardiographic equipment.¹⁰ For these reasons it is important to delineate the effect of LV pressure or volume overload on the geometry of the left ventricle, and evaluate the accuracy of determining LV volume and function from one or two ventricular dimensions.

Method

Patient Population

Seventy-seven patients who underwent diagnostic cardiac catheterization were divided according to LV pressure and end-diastolic volume into three groups:

Group 1 was composed of 25 patients with normal left ventricular end-diastolic volume (LVEDV). Normal LVEDV was defined as being in the range of the normal volume ± 2 SD (LVEDV = 74% to 124% of the predicted normal) as described by Graham et al.¹ The diagnoses included valvular pulmonic stenosis (10), small ventricular septal defect (3), coarctation of the aorta (3), mild aortic regurgitation (1), atrial septal defect (1), transposition of the great vessels (1), mitral stenosis (1), tricuspid regurgitation (1), double outlet right ventricle and pulmonic stenosis (1), arrhythmia and normal hemodynamic data (1), and one normal patient. The mean LVEDV was 111% ± 1% (SEM) of normal. The age ranged from nine days to 15.1 years (mean, 6.12 ± 0.92 years). All patients had normal LV pressure, and were cyanotic except for the two patients with transposition of the great vessels and double outlet right ventricle.

Group 2 was composed of 25 patients in whom the left ventricular pressure (LVP) was greater than 140 mm Hg or the peak systolic gradient across the aortic valve was more than 30 mm Hg. Sixteen patients had valvular aortic stenosis and nine patients had coarctation of the aorta. LVEDV in this group averaged 87% ± 3% of normal and was significantly (P < 0.001) less than group 1 ("normal"). The age ranged from three days to 14 years (mean, 5.48 ± 0.75 years). Peak LVP ranged from 110 to 220 mm Hg (mean, 159 ± 6 mm Hg), and LVP was less than 140 mm Hg in only three infants.

Group 3 was composed of 27 patients who had LVEDV greater than 124% of normal. The diagnoses in this group included: ventricular septal defect (9), total anomalous pulmonary venous return (2), surgically palliated tetralogy of Fallot (8), isolated valvular pulmonic stenosis (1), patent ductus arteriosus (2), coarctation of the aorta with mitral regurgitation (3), mitral regurgitation with atrial septal defect (1), and isolated mitral regurgitation (1). The mean LVEDV in this group was 179% ± 11% of normal and peak LV pressure was normal.

The age ranged from six days to 15.3 years (mean age, 6.01 ± 0.89 years). The mean age was not different in the three groups.
Data Acquisition and Analysis

All patients were studied in the supine position during diagnostic cardiac catheterization. Patients more than six months of age were studied under sedation with meperidine (1 mg/kg), promethazine (0.5 mg/kg), and chlorpromazine (0.5 mg/kg). All volume data were obtained from biplane cineangiograms filmed at 60 frames/sec after injecting 1.0 to 1.5 ml/kg of 76% renograin into the main pulmonary artery, or the right ventricle, or the left ventricle. Left ventricular volumes were calculated only from normal beats according to the area-length method, and were expressed as a percent of normal.

The following measurements were made in the anterior-posterior (AP) and lateral (LAT) views at end-diastole and end-systole. Left ventricular longest length (LL) was measured directly from the cineangiogram as the longest distance from the aortic valve to the apex. Left ventricular minor axis in the anterior-posterior projection (AP MA) and the lateral projections (LAT MA) were computed from the area and longest length of each view according to the equation:

$$\text{MA} = \frac{4 \text{ area}}{\pi \text{ LL}}$$

assuming that the ventricular chamber represents a prolate ellipsoid in which area represents the planimetered area of the ventricular image. In addition the minor axis in the lateral projection was measured directly from the cineangiogram in 50 patients with normal LV pressure. There was good agreement and excellent linear correlation between directly measured LV minor axis (X) and the computer LV minor axis (Y) in both systole and diastole ($Y = 0.92 X$, $r = 0.98$). Therefore, the computed values were used in all calculations. The ratio of the minor axis (MA) to the longest length was calculated in both the AP and lateral view at end diastole and end systole. Percent of shortening in all three dimensions was calculated by the equation:

$$\text{percent shortening} = \frac{\text{length at end diastole} - \text{length at end systole}}{\text{length at end diastole}} \times 100$$
TABLE 1. Spherical Configuration and Theoretical Volume Data in Normal Patients (group 1) and Patients with Left Ventricular Pressure (group 2) or Volume (group 3) Overload

<table>
<thead>
<tr>
<th></th>
<th>Theoretical Volumes</th>
<th>Ratios</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AP MA/LL</td>
</tr>
<tr>
<td>Diastole</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gr 1</td>
<td>0.66</td>
<td>0.58</td>
</tr>
<tr>
<td>Gr 2</td>
<td>0.56</td>
<td>0.55</td>
</tr>
<tr>
<td>Gr 3</td>
<td>0.71</td>
<td>0.64</td>
</tr>
<tr>
<td>Systole</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gr 1</td>
<td>0.51</td>
<td>0.46</td>
</tr>
<tr>
<td>Gr 2</td>
<td>0.45</td>
<td>0.44</td>
</tr>
<tr>
<td>Gr 3</td>
<td>0.54</td>
<td>0.50</td>
</tr>
</tbody>
</table>

The theoretical volumes are calculated using the mean minor axis longest length ratios assuming that the longest length is equal to 2 cm. The values in parenthesis express the ratio of the calculated volume to the biplane volume in each group.

Abbreviation: AP = anterior-posterior; LAT = lateral; MA = minor axis; LL = longest length.

\[
\text{diastolic dimension} - \frac{\text{systolic dimension}}{\text{diastolic dimension}} \times 100
\]

In addition the LV minor axis in both the AP and LAT were cubed in each patient. Left ventricular volume was calculated from one plane (the AP or lateral view) according to the equation:

\[
V = \frac{4}{3} \pi \cdot \frac{LL}{2} \left( \frac{MA}{2} \right)^2
\]

Volumes derived from uniplane cine or cubed minor axis were compared with LV volumes derived from biplane cines, and the data in groups 2 and 3 were compared with values in group 1 using the two-sample t-test.

Results

The results are shown in table 1 and figures 1–8. Significantly different in the following text indicates P value less than 0.05.

In diastole the AP ratio of MA/LL in group 2 averaged 0.56 ± 0.02 and was significantly less than values in group 1 (0.66 ± 0.01) and group 3. This ratio in group 3 averaged 0.71 ± 0.02 and was significantly higher than group 1 (fig. 1, table 1). In the lateral view, the ratio of the minor axis to the longest length in groups 1 and 3 was significantly less than comparable ratios in the AP view, and averaged 0.58 ± 0.02, and 0.64 ± 0.02, respectively. In group 2 this ratio in the lateral view (0.55 ± 0.02) was not different from the ratio in the AP view. In the lateral view the ratios in both groups 1 and 2 were significantly less than in group 3. End-systolic MA/LL ratios in both views were significantly less than diastolic ratios in each group (table 1, fig. 1).

The percent of shortening in each of the three dimensions was not different from one group to another (fig. 2). The values for the two minor axes were similar and were significantly higher than the percent of shortening in the longest length in all groups.

Figures 3 and 4 show the correlation between the (AP minor axis)² and the LVEDV derived from biplane cine. Similar relationships are shown in figures 5 and 6 for the lateral view. The slopes of these relationships in groups 2 and 3 were different from group 1.

There was good correlation between biplane volume and the LV volume calculated from two dimensions in either the AP view or the lateral view in all groups (figs. 7, 8). There was no significant difference in this relationship between the different groups.
Left ventricular ejection fraction in group 2 averaged 0.72 ± 0.02 and was significantly higher than LVEF in groups 1 (0.67 ± 0.01) and 3 (0.66 ± 0.01).

**Discussion**

The accuracy of determining LV volumes from biplane cineangiocardiograms in adults and children is well established. The uniplane cine is used to derive LV volume in adult patients, but the feasibility of using the uniplane method in children has not been proven. Single beam echocardiography is quite widely used and is currently used for determining ventricular function in children. However, the accuracy of this method is not well established. In this study we examined the feasibility of determining LV volume and function from the uniplane cine or one minor axis.

Since LV volume can be determined accurately from biplane cine assuming that the LV is an ellipsoid, we should be able to determine LV volume from either uniplane cine or one minor axis provided that the following conditions are satisfied:

1) The shape and dimensional relationship of the LV does not change with age.
2) Both pressure and volume overload have no significant effect on the geometry of the LV.

3) If condition 2 is not met, then the change in ventricular geometry must be consistent to permit using different equations for the different hemodynamic groups.

The ratio of the minor axis to the longest length in the AP and lateral view could be used as an index of the spherical configuration of the ventricle. In the normal volume group, there was no correlation between these ratios and age. This indicates that the shape of the left ventricle does not change with age.

Data presented in figure 1 showed that the LV is less spherical in patients with pressure overload and more spherical in patients with large LVEDV as compared with normal volume groups. This finding is consistent with that described in adult patients, and indicates that different equations should be used to calculate LV volume from the minor axis in different hemodynamic groups, and in each group different equations should be used for diastole and systole. This is further supported by the different relationship between (MA)^3 and LV volume in the three groups (figs. 3–6).

In examining the relationship between biplane LV volumes and volumes derived from (MA)^3 two observations may be made: 1) the correlation coefficient was best in group 1; 2) the standard error of the estimate was large in all groups (figs. 3–6). Thus hemodynamic changes that cause...
The absolute errors in determining the minor axis become much larger as a percent of the minor axis and are further magnified by cubing this variable. The single beam echo has these same inherent limitations, even if the echo LV dimension represents the true LV minor axis.

Assuming that the LV minor axis in both the AP and lateral view are both equal to one half the longest length, the LV volume equation

$$\text{Volume} = \frac{4}{3} \pi \left( \frac{\text{LL}}{2} \right)^2 \frac{(\text{MA})^3}{2} \frac{\text{LAT MA}}{2}$$

could be written as follows:

$$\text{Volume} = \frac{4}{3} \pi \left( \frac{2 \text{MA}}{2} \right)^2 \left( \frac{\text{MA}}{2} \right)^3 = 1.05 (\text{MA})^3$$
or approximately $(\text{MA})^3$.

Our results indicate that the actual ratios of MA to LL (MA/LL) varied in each group from AP view to lateral view and from diastole to systole and were different from one group to another in the same view. We therefore conclude that the $(\text{MA})^3$ cannot represent the true LV volume. Using the average MA/LL ratio obtained for each group and in each view at diastole or systole, we determined the theoretical volumes derived from one dimension [(MA)$^3$] or two dimensions

$$\left( \text{Volume} = \frac{4}{3} \pi \left( \frac{\text{LL}}{2} \right)^2 \left( \frac{\text{MA}}{2} \right)^3 \right)$$

assuming that the longest length was equal to 2 cm (table 1).

In comparing volumes derived from $(\text{MA})^3$ or uniplane volumes with LV volumes derived from biplane cine we found: 1) LV volume calculated from the (AP minor axis)$^3$ was 1.09 to 1.51 times the biplane volume during diastole, and only 0.87 to 1.12 times the biplane volume during systole. 2) In the lateral view, however, the $(\text{MA})^3$ ap-

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**Figure 6.** The end-systolic (lateral minor axis)$^3$ on the ordinate versus biplane left ventricular end-systolic volume on the abscissa in the three groups.

**Figure 7.** Left ventricular volume calculated from the AP view on the ordinate versus biplane left ventricular end-diastolic volume on the abscissa in the three groups.

**Figure 8.** Left ventricular volume calculated from the lateral view on the ordinate versus biplane left ventricular end-diastolic volume on the abscissa in the three groups.
The biplane volume was approximated during diastole and variation between groups was minimum. It is interesting that the relationships between the biplane LV volume and uniplane LV volume calculated from either the AP view or lateral view were similar in the three groups for each view (figs. 7, 8). The superiority of using uniplane over (MA)² might be due to the fact that the uniplane method used the two dimensions, thus taking into account some of the changes in LV geometry, and minimizing the errors committed by calculating LV volume from only one minor axis.

It is interesting to note that the lateral uniplane/biplane volume ratio ranged from 0.88 to 0.98 (table 1) and similar ratios for the AP view ranged from 1.02 to 1.14. Similar observation can be made from figures 7 and 8 which show that the AP uniplane volume overestimates biplane cine by 20%, but they are identical in the LAT view. The reason for this difference is that the AP minor axis is larger than the lateral minor axis.

The fact that the percent of shortening in the AP minor axis was not different from that of the lateral minor axis and both were higher than the percent of shortening in the longest axis indicates that the circumferential shortening at the mid-equator of the LV is the major determinant of ventricular ejection.

In this study LVEF in group 2 was significantly higher than normal while there was no significant difference in the percent of shortening in each axis between the three groups. This discrepancy might be explained by the fact that the percent of shortening in LL and LAT MA in group 2 was slightly higher than in groups 1 and 3. This finding suggests that percent of shortening of one ventricular dimension is not as sensitive as the ejection fraction in describing the pumping characteristics of the LV.

In conclusion, the data indicate the following observations in the pediatric patient with congenital heart disease.

1) The AP or lateral uniplane cine is quite useful for LV volume determinations in any patient irrespective of his or her hemodynamic status.

2) LV volume can be calculated with some loss of accuracy from one minor axis; however, knowledge of the patient's hemodynamics and the phase of the cardiac cycle (systole vs diastole) is important to ensure use of the proper equation to minimize loss of accuracy.

3) The percent of circumferential fiber shortening derived from one ventricular dimension is not as useful as LVEF in quantifying LV pumping characteristics.

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References

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