Echocardiographically Determined Left Ventricular Mass Index in Normal Children, Adolescents and Young Adults

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Left ventricular hypertrophy is an important diagnostic and prognostic finding in children with cardiovascular disease, but there are currently no well established criteria for its determination by M-mode echocardiography. Three hundred thirty-four subjects, aged 6 to 23 years, who were free of cardiovascular disease were studied. Left ventricular mass was calculated using echocardiographic measurements in a regression equation for left ventricular mass. Intraobserver (r = 0.96, p < 0.01) and interobserver (r = 0.89, p < 0.01) variability were low. To anatomically validate the echographic formula for left ventricular mass, left ventricular measurements made at autopsy were inserted into the formula. Mass was then calculated and compared with the actual mass. There was a strong correlation between the calculated and the measured left ventricular mass (r = 0.89, p < 0.01).

Left ventricular mass was not statistically related to race, but it was strongly associated with gender (p < 0.001). It was strongly correlated with height (r = 0.82 for males, r = 0.71 for females) and body surface area (r = 0.83 for males, r = 0.74 for females). Echocardiographic criteria for left ventricular hypertrophy in children and adolescents, based on the 95th percentile, for left ventricular mass, left ventricular mass corrected for body surface area and left ventricular mass corrected for height are, respectively: 184.9 g, 103.0 g/m² and 99.8 g/m for males and 130.2 g, 84.2 g/m² and 81.0 g/m for females.

Until outcome-based standards for left ventricular hypertrophy are developed, application of gender-specific criteria derived from the distribution of left ventricular mass in a healthy population of children, adolescents and young adults is the best approach to the M-mode echocardiographic diagnosis of left ventricular hypertrophy. These standards should prove useful both in the clinical evaluation of children with cardiovascular disease and in future research.

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from the formula (3) $0.0001 \times 71.84 \times (\text{weight})^{0.425} \times (\text{height})^{0.725}$. Body mass index, a measure of ponderosity, was calculated by $\text{weight(kg)}/(\text{height(m)})^2$ (4).

Echocardiographic methods. Subjects were studied using standard M-mode echocardiography. The echocardiograms were obtained as has been previously described (5). Measurement techniques were consistent with the American Society of Echocardiography convention (6) using leading edge to leading edge methodology. The left ventricular end-diasstolic internal dimension was measured from the leading edge of the left septal surface to the leading interface of the left ventricular endocardium along a perpendicular line at the time of onset of ventricular depolarization as denoted by the beginning of the Q or R wave recorded on the simultaneous electrocardiogram (ECG) at the position where both anterior and posterior mitral leaflets were visible. Left ventricular posterior wall thickness was measured as the distance between the anterior surface of the endocardium and the surface of the epicardium of the left ventricular posterior wall. Interventricular septal thickness was measured as the distance between the right ventricular septal surface and the leading edge of the left ventricular surface of the septum. Left ventricular wall and interventricular septal thickness were measured during end-diastole at the same position that left ventricular end-diastolic internal dimension was measured. The subjects’ respiratory patterns were recorded on the strip chart. All echocardiographic measurements were made during the expiratory phase of respiration.

Each measurement was made three times and the average of those measurements was used to calculate left ventricular mass. Each of the structures had to be measurable for the echocardiographic study to be considered adequate.

Because the methods for measuring the echocardiograms were consistent with the recommendations of the American Society of Echocardiography, the formula, left ventricular mass (g) $= 0.80(1.04 \times (\text{interventricular septum + left ventricular internal dimension + posterior wall thickness})^{3} - (\text{left ventricular internal dimension})^{3} + 0.6$, described by Devereux et al. (7), was used to calculate left ventricular mass. This formula has been found to correlate closely with left ventricular mass calculated by the Penn convention methodology and to estimate left ventricular mass accurately in hearts ranging in size from those of small normal rabbits to those of large human adults with severe left ventricular hypertrophy (8).

Intra- and interobserver variability. Reproducibility in left ventricular mass determination was assessed using methodology similar to that of Schieken et al. (9). Fifteen echocardiograms were assigned numbers and read in a group by each of two observers. Each observer read each echocardiogram twice, at separate sittings 1 week apart. A clear plastic sheet was placed over the strip chart, and the interfaces were measured from the plastic sheets so that observers were unaware of the points of previous measurement. Five car-
Table 1. Patient Characteristics

<table>
<thead>
<tr>
<th>No.</th>
<th>Race (black/white)</th>
<th>Age (yr)</th>
<th>Weight (kg)</th>
<th>Height (m)</th>
<th>Body surface area (m²)</th>
<th>Body mass index (kg/m²)</th>
<th>LV mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>167</td>
<td>45/122</td>
<td>12.6 ± 4.0</td>
<td>47.3 ± 18.8</td>
<td>1.54 ± 0.22</td>
<td>1.38 ± 0.35</td>
<td>18.9 ± 3.3</td>
</tr>
<tr>
<td>Females</td>
<td>167</td>
<td>46/121</td>
<td>12.7 ± 4.4</td>
<td>43.5 ± 15.3</td>
<td>1.49 ± 0.18</td>
<td>1.32 ± 0.31</td>
<td>18.7 ± 3.7</td>
</tr>
</tbody>
</table>

Values presented as mean ± SD. LV = left ventricular.

Anatomic validation. Linear regression demonstrated a strong correlation ($r = 0.89$, $p < 0.001$, slope = 1.12) between the calculated left ventricular mass and the anatomic (true) left ventricular mass (Fig. 1).

Reference values. Analysis of variance showed no relation of left ventricular mass to race ($p > 0.05$), but a strong relation to gender ($p < 0.001$) that persisted even after correction for body size. This suggests that separate standards are needed for males and females.

The correlation between left ventricular mass and independent variables, including age, weight, height, body surface area and body mass index, for males and females is presented in Table 2. The data demonstrate that body surface area, weight and height are consistently highly correlated with left ventricular mass. Reference values and criteria for left ventricular hypertrophy based on unadjusted mass would apply the same cutoff point to subjects with large differences in age, height and weight. This result would be inappropriate given the powerful influence of age and body size on left ventricular mass.

A widely used approach to this problem is to index left ventricular mass by body size. Body surface area has been commonly used for such indexing (13). However, Levy et al. (14) argued that using this approach in adults is too "forgiving" of obesity by virtue of the incorporation of weight into the calculation of body surface area. They suggested indexing left ventricular mass by height to account for differences in body size without making allowances for obesity. The data presented in Table 2 indicate that the correlation of left ventricular mass to height is close to that of body surface area for both males and females. This suggests that using height to index left ventricular mass (left ventricular mass [g]/height [m]) is also a reasonable approach for children, adolescents and young adults. In multiple regression analysis, the addition of age to the regression model containing height as the independent variable did not add significantly to the ability of height to explain the variance of left ventricular mass. Thus, it appears that it would be appropriate to apply a single set of normal limits for left ventricular mass indexed by height to children, adolescents and young adults.

Figure 2 presents the distribution of left ventricular mass indexed by height for males and females. The 90th and 95th percentiles are shown to assist in determining left ventricular hypertrophy. The mean values and upper limits of normal (95th percentile) for left ventricular mass indexed by height and by body surface area for males and females are presented in Table 3.

Discussion

Echocardiographic standards for determining left ventricular hypertrophy. The assessment of left ventricular hypertrophy by the echocardiographic determination of left ventricular mass may be useful in a number of disease states, including left-sided obstructive cardiac lesions and systemic hypertension. It is clear that echocardiography is the most sensitive and specific noninvasive method for detecting hypertrophic changes in both adults and children (1,2). However, there has been a lack of agreement on one accurate method for estimating left ventricular mass in children. This is in part due to the lack of anatomic validation of the various measurement methods and formulas for calculating left ventricular mass in pediatric patients. There are also currently no accepted standards for determining left
ventricular hypertrophy using left ventricular mass calculated from M-mode echocardiographic measurements.

We have chosen the measurement method and formula used in the present study for several reasons. First, the measurement technique for left ventricular chamber size and wall and septal thickness has been angiographically validated for children (12) and anatomically validated for adults (11). Second, the mass formula employed to calculate mass has been validated in adult patients (11). Finally, we have been able to anatomically validate the formula used to compute left ventricular mass in children and adolescents.

Reproducibility. Schieken et al. (9) have shown good reproducibility of echocardiographic measurements. We have also shown that the inter- and intraserver variability are low for determining left ventricular mass using the techniques described. These results are similar to those reported by Wallerson and Devereux (15). Further studies that validate antemortem echocardiographic left ventricular mass determinations with measurements of mass made at autopsy will be needed to more closely define the accuracy and assess the limits of the echocardiographic method.

Reference values. In establishing reference values for left ventricular mass, it is important to determine whether race-specific or gender-specific standards, or both, are needed. We found no differences in left ventricular mass by race. This is consistent with the findings of Burke et al. (16) in the Bogalusa population; however, because our sample size for blacks (n = 91) was relatively small, we may not have detected small differences in mass by race. Rao et al. (17,18) investigated racial differences in electrocardiograms in children and adolescents and found that blacks have significantly higher voltage in the precordial leads than whites. They attributed this racial difference to increased thickness in the posterior wall of the left ventricle and decreased distance between the heart and the chest wall in blacks as measured with echocardiography. They did not find differ-

![Figure 2. Distribution and 90th and 95th percentile for left ventricular mass index in males (A) and females (B).](image-url)
ferences by race in the thickness of the interventricular septum or in the internal dimension of the left ventricle at end-diastole, and they did not investigate racial differences in left ventricular mass (17).

In our present study there were significant differences in left ventricular mass by gender, even after correction for body size by indexing by height or body surface area. It is clear that the adoption of gender-specific reference values for left ventricular mass indexed by body size is warranted. This observation was previously made in an echocardiographic study of the Bogalusa population (16) and in a series of normal hearts from infants, children and adolescents studied at autopsy (19). Similarly, Levy et al. (14), who investigated the distribution of left ventricular mass in healthy adults from the Framingham study, pointed out that applying nongender-specific criteria for left ventricular hypertrophy would result in an unacceptable compromise of sensitivity in females and specificity in males.

Past studies of left ventricular mass in children have used several different schemes for normalizing or indexing by body size. Several studies (20–22) have used body surface area. Culpepper et al. (23) used a bivariate exponential combination of body surface area and heart rate, whereas Schieken et al. (24) used a multivariable linear combination of age, gender, height, weight and skinfold thickness. The use of height alone as the indexing variable has a number of attractive aspects. First, the correlation of height with left ventricular mass is close to that of body surface area with left ventricular mass. The use of height is also less "forgiving" of obesity, which may be associated with the pathologic increase in left ventricular mass (25). Height is also relatively easy to use in the clinical setting because information on height is usually readily available, and the use of a single variable does not require the use of a multivariable equation for indexing. However, further studies will need to be performed to investigate the premise that the increased left ventricular mass associated with obesity carries with it the same adverse prognostic implication that has been found in adults for increased mass associated with hypertension (26).

Conclusions. The strategy for defining left ventricular hypertrophy outlined in this report depends on a statistical definition. Future standards for defining left ventricular hypertrophy should be linked to increased risk of cardiovascular morbidity and mortality. However, at present such an outcome-based definition is not available for our young population. With the establishment of a reproducible, anatomically validated echocardiographic method for determining left ventricular mass in children, adolescents and young adults, and with the elucidation of reference values for normal children, it will be possible to perform studies to achieve outcome-based criteria for left ventricular hypertrophy for this group in the future.

References


