Reference values for normal left atrial dimensions have been based primarily on blind M-mode measurements, with no reports based on two-dimensional echocardiography to provide a comprehensive analysis of the two-dimensional measurements from infancy to old age. This report analyzes the left atrial dimensions from two-dimensional echocardiographic studies in 268 normal healthy subjects to determine normal limits and relations among linear, area, and volume measurements of the left atrium.

The mean values change with body size, fitting well to the exponential growth model ($r = 0.78$ to 0.92). The variance about the mean (which determines normal limits) is represented effectively by a quadratic function of body surface area ($r = 0.84$ to 0.99). The variables determined by this modeling simplify evaluation of normal limits for any body size at any desired level of confidence, and the data are useful reference standards for interpretation of two-dimensional echocardiograms.

(J Am Coll Cardiol 1990;16:1168–74)

Two-dimensional echocardiography is performed routinely to define anatomic relations and to measure intracardiac dimensions for identification and quantitation of known or suspected cardiac abnormalities. This use demands accurate establishment of the normal limits of the dimensions, which should take into account their dependence on body size. Studies that generate normal limits for cardiac dimensions have been based primarily on blind M-mode measurements (1-7) or autopsy specimens (8,9). However, the M-mode measurements are restricted to a single dimension with limited ability to define the measurement axis, and autopsy specimens are fixed and not physiologic. Left atrial dimensions are used clinically to identify volume overload due to a shunt (10) and to predict atrial fibrillation and the likelihood of benefit from cardioversion (11). Two-dimensional echocardiography allows interactive alignment of the proper planes for measurement in relation to anatomic landmarks, permitting direct area measurements as well as more precise definition of the measurement axes that are not constrained to align with the beam of insonation. Our group has previously reported (12) the results of comprehensive analysis of left ventricular dimensions from infancy to full maturity as determined by two-dimensional echocardiography. This report extends that analysis to provide a detailed assessment of the normal left atrial dimensions and their relation to body size.

These data are based on two-dimensional echocardiographic studies acquired prospectively in 268 normal healthy subjects who were not hospitalized for any reason and who ranged in age from 6 days to 76 years. The group mean measurements and the variance about the mean values are modeled as functions of body surface area to provide an accurate and clinically useful determination of normal limits.

**Methods**

Study patients. A total of 268 normal subjects were recruited prospectively from children presenting for well child care at outlying pediatric clinics and from adult hospital employees. The group included 196 children (99 male, 97 female) with no cardiac or systemic disease suspected by their pediatrician and no hypertension, arrhythmia or evidence of structural heart disease by echocardiography. The 72 normal healthy adults (38 male, 34 female) were hospital employees with no evidence of cardiac or systemic disease by history, physical examination, electrocardiogram or chest
A summary of ages, weights and heights for this group was previously reported (12).

Echocardiography. Real-time two-dimensional echocardiographic images obtained with an ATL 300 series mechanical sector scanner with a 3.5 or 5 MHz transducer were recorded with a Panasonic video recorder on 0.5 in. (1.27 cm) videotapes and the desired views were transferred to videodisc. The echocardiographic views included 1) parasternal long-axis, 2) parasternal short-axis at the level of the mitral valve, 3) parasternal short-axis showing maximal left atrial cross-sectional area parallel to the mitral valve plane, and 4) apical four chamber. These views were standardized as previously described (13,14).

Echocardiographic measurements. The initial step was a review of all image frames to select segments in which structural definition was optimal at the appropriate point in the cardiac cycle. In views showing the aortic valve, the end-diastolic frame was selected as the frame immediately preceding aortic valve opening. For views not showing the aortic valve (for example, parasternal short-axis view at the level of maximal left atrial cross-sectional area), standardization was achieved by selecting the frame at the selected level that exhibited the largest atrial cross-sectional area, this occurred approximately at the end of the T wave of the electrocardiogram. Frame selection and measurements were performed after transfer to a digital videodisc by using calibrated electronic calipers (Microsonics Easy View II image analysis system).

Linear dimensions were measured along each of the three major axes: anteroposterior, mediolateral and superoinferior (Fig. 1). The anteroposterior diameter was obtained from the parasternal long-axis and parasternal short-axis views as the largest distance perpendicular to the left ventricular long axis, extending from the posterior wall of the aorta to the posterior wall of the atrium. The mediolateral diameter was similarly measured as the longest distance parallel to the left ventricular long axis, extending from the interatrial septum to the left atrial free wall in the apical four chamber and parasternal short-axis views. The superoinferior diameter of the left atrium was taken as the distance from the roof of the atrium to the plane through the mitral valve hinge points as seen in the parasternal long-axis and apical four chamber views. Distance and area measurements were based on the inner edge convention, which defines the chamber border by identifying the innermost bright edge of the echocardiographic reflections.

Data analysis. All measurements were entered into a VAX 11-780 computer in tabular form using the RSI data management system (15). Measurements were related to body surface area by using the additive errors power growth model:

\[ Y = aX^b + e, \]

where \( Y \) is the observed measurement, \( X \) is body surface area computed by the modified DuBois method (16,17), \( a \) and \( b \) are variables of the model to be determined by curve fitting and \( e \) has the Gaussian distribution with a mean of 0 and variance \( \sigma^2 \). The model variables were initially determined by a least-squares nonlinear regression using the Marquardt algorithm, with all observations carrying equal weight. Variance was computed over a sliding window of 50 data points, assigned successively to the mean value of \( X \) for each of the overlapping windowed ranges. The resultant series of variance measurements were modeled by a third order polynomial in \( X \) (body surface area). The model variables were then re-fit with the data weighted inversely to the observed variance interpolated from the third order polynomial fit. The variance about the new fit was modeled...
by a second order polynomial (quadratic) to determine confidence intervals for normal limits; the lower terms of the quadratic were limited to positive values to prevent projecting negative variance for small body size.

Figure 2. Parasternal short-axis dimensions of the left atrium. All graphs in this and subsequent figures show mean dimension (solid line) and 90% confidence limits (broken lines) as a function of body surface. Linear dimensions are in units of centimeters and area measurements are in square centimeters. Solid diamonds mark data in normal infants and children; open diamonds mark data from normal adults. Graph A shows the anteroposterior dimension of the left atrium in the parasternal short-axis view (PSAP) and graph B shows the mediolateral dimension (PSML).

Figure 3. Parasternal long-axis anteroposterior dimension (PLAP). This graph shows the anteroposterior span of the left atrium measured in the short-axis view just before mitral leaflet separation. Units and symbols as in Figure 2.

Results

The raw data and results of analysis are presented in Figures 2 to 8. In each graph, the solid line shows the estimated group mean value as a function of body surface area and the dotted lines above and below represent the 90% confidence limits based on the quadratic model of variance as a function of body size (other confidence limits may be calculated as desired on the basis of the data in Table I). The graphs report the observed left atrial dimensions versus body surface area as well as the results from curve fitting.

Dimensions. Figure 2 shows the anteroposterior and the mediolateral diameters of the left atrium in the parasternal short-axis view. Figure 3 shows the anteroposterior span of the left atrium in the parasternal long-axis view. The superoinferior extent was not measured in this view because of difficulties defining the superior border. However, the parasternal long-axis view does provide a measurement of the anteroposterior extent of the mitral valve orifice (Fig. 4A), and the apical four chamber view presents its mediolateral aspect (Fig. 4B). Figure 5 shows the linear dimensions of the left atrium from the apical four chamber view in the mediolateral and superoinferior directions, respectively.

Atrial area and volume. The left atrial area in the apical four chamber view can be measured by planimetry (Fig. 6A) or calculated from the mediolateral and superoinferior (AFSI) dimensions (Fig. 6B) by the equation area = πr₁r₂, where r₁ = AFML/2 and r₂ = AFSI/2. Similarly, the area
encompassed by the left atrium in the short-axis view parallel to the mitral valve plane is measured by planimetry (Fig. 7A) or calculated from the short-axis mediolateral and anteroposterior extents (Fig. 7B). Three orthogonal dimensions provide a volume estimate by: \((4/3) \pi r_1 r_2 r_3\), where \(r_1 = \text{AFML/2, } r_2 = \text{AFSI/2 and } r_3 = \text{PLAP/2, where PLAP =}\)

\begin{align*}
\text{AFML} & \text{mediolateral dimension of the left atrium in the parasternal long-axis view,} \\
\text{AFSI} & \text{anteroposterior dimension of the left atrium in the parasternal long-axis view.}
\end{align*}

**Figure 4.** Linear dimensions at the mitral orifice. Graph A shows the distance between the mitral valve hinge points in the anteroposterior direction from the parasternal long-axis view (PLMD). Graph B shows the corresponding distance in the mediolateral direction from the apical four chamber view (AFMD). Graph symbols and units as in Figure 2.

**Figure 5.** Apical four chamber linear dimensions of the left atrium. Graph A shows the mediolateral expanse of the left atrium (AFML) and graph B shows its superoinferior extent in the apical four chamber view (AFSI). Graph symbols and units as in Figure 2.

**Discussion**

Relation to prior studies. Studies based on earlier technology using blind M-mode measurements had demonstrated that cardiac dimensions increase as a function of body size (1-7) and the growth curve fit well with observations of left
ventricular linear dimensions (4,6,12). Previous M-mode studies (3,5) had also identified increasing variance with increasing body size but reported constant width limits to simplify the analysis. Our current observations by two-dimensional sector scanning extend those conclusions to detail the dependence of the left atrial dimensions on body surface area in growth and development from 6 days to 76 years. The quality of curve fits both for group mean values and for variance about the mean is as good as for the modeling of left ventricular dimensions (12).

It is important to note that this study reports normal dimensions measured by two-dimensional echocardiography (identifying perpendicular orientation for measurements) rather than by the older technologies. It uses a larger
sampling of nonhospitalized normal subjects (not referred to a cardiologist), and the normal limits are based on modeling of variance as well as the linear dimensions as functions of body size from infancy to full development.

Sources of variability. Quality of the echocardiogram was not a limitation in this study of normal subjects, but may be expected to interfere with plane selection and definition of measurements in a group that does not exclude patients with conditions such as pulmonary disease. Especially when the quality of images is a limiting factor, variance in results attributed to technician and observer performance becomes an important consideration. The measurements presented were not based on subcostal views, which are less reproducible than parasternal views in children (18) and are not routinely obtained in adults. The use of 90% confidence as the displayed limits of normality is based on the selection of appropriate levels for type I and type II errors (19). Wider bands representing higher levels of confidence may be computed from the data in Table I on the basis of the Z score (19) corresponding to the level of confidence desired.

For example, to calculate the 90% confidence normal limits of the parasternal short-axis anteroposterior dimension (PLAP) for a subject with a body size of 1.70 m², Table

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**Table 1. Summary of Echocardiographic Measurements**

<table>
<thead>
<tr>
<th>Y</th>
<th>First a</th>
<th>First b</th>
<th>a</th>
<th>b</th>
<th>r</th>
<th>P₁₀</th>
<th>P₀₁</th>
<th>P₀₂</th>
<th>cvar</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFML</td>
<td>3.119</td>
<td>0.342</td>
<td>3.119</td>
<td>0.356</td>
<td>0.85</td>
<td>0.023</td>
<td>0.200</td>
<td>0.128</td>
<td>0.180</td>
</tr>
<tr>
<td>AFSL</td>
<td>3.210</td>
<td>0.426</td>
<td>3.217</td>
<td>0.418</td>
<td>0.88</td>
<td>0.006</td>
<td>0.185</td>
<td>0.090</td>
<td>0.195</td>
</tr>
<tr>
<td>PSAP</td>
<td>2.378</td>
<td>0.384</td>
<td>2.386</td>
<td>0.386</td>
<td>0.89</td>
<td>0.035</td>
<td>0.000</td>
<td>0.034</td>
<td>0.076</td>
</tr>
<tr>
<td>PSML</td>
<td>5.412</td>
<td>0.376</td>
<td>5.466</td>
<td>0.377</td>
<td>0.84</td>
<td>-0.338</td>
<td>0.906</td>
<td>0.060</td>
<td>0.319</td>
</tr>
<tr>
<td>PLAP</td>
<td>5.400</td>
<td>0.402</td>
<td>5.402</td>
<td>0.403</td>
<td>0.92</td>
<td>0.022</td>
<td>0.000</td>
<td>0.048</td>
<td>0.089</td>
</tr>
<tr>
<td>PLMO</td>
<td>5.085</td>
<td>0.384</td>
<td>5.066</td>
<td>0.370</td>
<td>0.84</td>
<td>-0.063</td>
<td>0.180</td>
<td>0.093</td>
<td>0.102</td>
</tr>
<tr>
<td>AFMO</td>
<td>2.036</td>
<td>0.341</td>
<td>2.041</td>
<td>0.367</td>
<td>0.78</td>
<td>-0.105</td>
<td>0.270</td>
<td>0.090</td>
<td>0.134</td>
</tr>
<tr>
<td>MOCA</td>
<td>3.401</td>
<td>0.694</td>
<td>3.354</td>
<td>0.738</td>
<td>0.84</td>
<td>-0.151</td>
<td>1.185</td>
<td>0.000</td>
<td>0.964</td>
</tr>
<tr>
<td>AFFA</td>
<td>9.147</td>
<td>0.776</td>
<td>9.157</td>
<td>0.776</td>
<td>0.90</td>
<td>-0.498</td>
<td>4.919</td>
<td>0.000</td>
<td>4.378</td>
</tr>
<tr>
<td>APCA</td>
<td>7.926</td>
<td>0.743</td>
<td>7.968</td>
<td>0.750</td>
<td>0.89</td>
<td>1.769</td>
<td>0.002</td>
<td>0.033</td>
<td>3.377</td>
</tr>
<tr>
<td>PSAP</td>
<td>2.550</td>
<td>0.696</td>
<td>2.428</td>
<td>0.726</td>
<td>0.89</td>
<td>-0.904</td>
<td>3.631</td>
<td>0.000</td>
<td>3.162</td>
</tr>
<tr>
<td>PSCA</td>
<td>6.519</td>
<td>0.723</td>
<td>6.440</td>
<td>0.753</td>
<td>0.90</td>
<td>-0.323</td>
<td>3.116</td>
<td>0.000</td>
<td>3.339</td>
</tr>
<tr>
<td>CVOL</td>
<td>12.925</td>
<td>1.114</td>
<td>12.919</td>
<td>1.128</td>
<td>0.90</td>
<td>13.106</td>
<td>1.193</td>
<td>0.002</td>
<td>16.871</td>
</tr>
</tbody>
</table>

The columns headed "First a" and "First b" show the values of "a" and "b" for the growth model Y = aX⁰ (Y = observed atrial dimension, X = body surface area) obtained by first pass nonlinear regression. The values "a" and "b" show the results of refitting the curve when data are weighted inverse to the variance computed about the first fit. The next column shows the r value for the goodness of fit, where r = 1.0 indicates an exact match between observations and the model and r = 0.0 indicates no relation between them. The remaining columns show the results of the polynomial fit to the variance about the growth curve. The values under the columns headed P₁₀, P₀₁, and P₀₂ are the values fitted to a second order polynomial: P₁₀ is the coefficient of X², P₀₁ (nonnegative) is the coefficient of X¹ = X and P₀₂ (nonnegative) is the constant item that is, multiplier of X⁰ = 1. This second order fit was selected on the basis of balancing accuracy curves fitting to complexity of the model; it explains the variance well at minimal cost in complexity. The lower terms (P₁₀, P₀₂) were limited to positive values to prevent projection of negative variance at small body size. The final column (cvar) shows the variance in the observed atrial dimensions using only a constant item that is, for each measurement independent of body size. AFCA = apical four chamber view; calculated area; AFML = apical four chamber view; mediolateral dimension; AFMO = apical four chamber view; mitral orifice; AFFA = apical four chamber view; phonocardiograms and phonocardiograms; MOCA = mitral orifice calculated area; MOCA = mitral orifice calculated area; PLAP = parasternal long-axis view; APFA = apical four chamber view; parasternal long-axis view; PSCA = parasternal short-axis view; calculated area; CVOL = parasternal short-axis view; calculated area; PSAP = parasternal short-axis view; calculated area; PLAP = parasternal long-axis view; PSCA = parasternal short-axis view; calculated area; PSAP = parasternal short-axis view; phonocardiograms and phonocardiograms; PSCA = parasternal short-axis view; phonocardiograms and phonocardiograms; CVOL = parasternal short-axis view; phonocardiograms and phonocardiograms.
I gives the variable values $a = 2.3861$, $b = 0.3855$, $P_2 = 0.0352$, $P_1 = 0.0$, and $F_2 = 0.03342$. These values indicate that the mean for normal subjects with a body surface area of $1.70 \text{ m}^2$ is $aX^2 = 2.3861(1.70^{0.3855}) = 2.93 \text{ cm}$, and using the second order polynomial model for the variance:

$$V(X) = P_2X^2 + P_1X + P_0$$

$$= 0.035(1.70^2) + 0.0(1.70) + 0.034$$

$$= 0.44.$$

One standard deviation is the square root of the variance (that is, $0.44^{0.5} = 0.67 \text{ cm}$). Because $90\%$ limits correspond to a $Z$ score of 1.65, the normal limits for this measurement with a body surface area of $1.70 \text{ m}^2$, based on $90\%$ confidence, are $2.93 \pm 1.65(0.67)$ (that is, 1.8 to 4.0 cm). These ranges differ somewhat from $M$-mode--determined normal values. Clinically, we favor the measurements based on two-dimensional images because blind $M$-mode measurements provide fewer landmarks and may either underestimate or overestimate lengths if the single axis is tilted or misaligned. In particular, $M$-mode normal ranges may be erroneously small because of subjectivity in view selection, whereas views are defined more objectively when two-dimensional echocardiography is used to establish perpendicular axes of measurement.

Conclusions. This study reports the results of detailed analysis of left atrial dimensions observed in 268 normal subjects to establish the normal limits by cross-sectional echocardiography and to model changes in the cardiac dimensions and their variance representing normal growth and development. The group mean values fit well to the growth model $aX^2$ ($r = 0.78$ to 0.92) and the variance about the mean was modeled effectively by a quadratic function of body surface area ($r = 0.84$ to 0.57). In modeling variance in left atrial dimensions, the unconstrained quadratic model could project a $0$ at very small body surface area, interfering with projection of normal limits for small bodies. Because we know a priori that variance is nonnegative, the model was constrained at the linear and constant terms to nonnegative values so that a single quadratic expression can be used to compute normal limits regardless of body size. Consequently, the model variables allow calculation of normal limits at any desired level of confidence for any body size. The data presented should be useful as reference standards for interpretation of two-dimensional echocardiograms.

References