Great Vessel, Cardiac Chamber, and Wall Growth Patterns In Normal Children

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SUMMARY
The purpose of this study was to establish normal echocardiographic measurements of valvular motion, cavity dimensions, great vessel diameters, and right, left, and septal wall thicknesses of children ranging in size from infants to full growth. The study group was composed of 205 normal, healthy children for whom echocardiograms and subsequent measurements were performed in a standardized manner. The following measurements were performed: left ventricular end-diastolic and end-systolic dimension, right ventricular end-diastolic cavity dimension, right ventricular end-diastolic anterior wall thickness, left ventricular end-diastolic posterior wall thickness, ventricular septal end-diastolic thickness, maximal left atrial dimension, end-diastolic aortic and pulmonary artery diameter, end-diastolic cardiac and septal depth, maximal aortic leaflet separation, and maximal anterior mitral and anterior tricuspid amplitude. Data are grouped into the fifth, fiftieth, and ninety-fifth percentiles according to body surface area. These graphs allow measurements of a single patient to be compared to normal measurements of individuals with similar body surface area.

Additional Indexing Words:
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CARDIAC CHAMBER, wall, and great vessel growth have not been accurately charted because of lack of a suitable in vivo measurement technique. Some of these measurements can be made by angiography, and others at the time of surgery. Nondynamic measurements can be made at autopsy. Electrocardiography, vectorcardiography, and other similar techniques provide only an indirect assessment and measurements based on them usually fail to confirm precise anatomic measurements.

Edler introduced sonar techniques for study of the heart in 1954.1 However, almost 15 years elapsed before echocardiography emerged as an asset for diagnosis of congenital cardiac defects. It is now used extensively.

Knowledge of the range of normal is essential in order to recognize the abnormal. For this reason, four groups of investigators developed normal data for neonates.2-5 However, only one investigator has established normal data for older children. These data exist only in four weight categories and are presented as mean and range values.6 Our study provides normal cardiac growth curves of the various cardiac walls, cavities, great vessels, and valve amplitudes with respect to the size of the subject as referenced by body surface area.

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Material and Method
Data were assembled from echocardiographic examinations of 205 normal, healthy children, ages six months to 18 years, examined at the University of Arizona or the University of Indiana. All children were randomly selected. Racial background was not available for children examined in Indiana. Ninety-one percent of those examined in Arizona were white, 7% were black, and the remainder were Oriental or East Indian.

Data collected in Indiana were previously published in a form that did not permit close comparison of a single patient to others of similar size.8 The raw data from that study were combined with data collected in Arizona.

After obtaining parental consent, unsedated subjects were examined in the supine position. Prandial state was not taken into account. Instrumentation in both institutions consisted of a commercially available Smith-Kline echograph and a Honeywell 1856 ultraviolet recorder.

Transducers used in this study included a 6 mm diameter, 5mHz or 3.5 mHz nonfocused transducer for smaller children and a 2.25 mHz, nonfocused 12 mm diameter transducer for larger children.

After the transducer was coupled to the chest with an air-free gel, it was directed posteriorly at the 4th left intercostal space to locate the mitral valve as the index structure. In small children it was at times necessary to place the transducer in the third interspace. The transducer position was then varied to identify all other structures according to standard methods as described by Feigenbaum.8 The pulmonary valve was sighted by directing the transducer posteriorly in the second interspace, as described by Solinger and coworkers.9

Measurement Techniques
Figure 1 shows a normal echocardiogram with the distances measured to determine the following structures.

Pulmonary artery root (PA root) was measured from the anterior to posterior outer wall at the beginning of the QRS
CARDIAC GROWTH IN CHILDREN

complex. This was measured only when both walls were clearly visible.

Pulmonic valve (PV) was measured from the inner aspect of anterior cusp to the inner aspect of posterior cusp at maximal excursion at the beginning of the QRS inscription if both cusps were visible.

Aortic dimension (AoD) was measured from the outside anterior aortic wall to the outside posterior aortic wall at the beginning of inscription of the QRS complex.

Aortic valve intercusp distance (ICD) was measured from the inner aspect of anterior valve to the inner aspect of posterior valve at the point of maximal excursion in early systole.

Left atrial internal dimension (LAID) was measured in the plane of the aortic valve leaflets from outer posterior aortic wall to inner left atrial posterior wall at the widest dimension, at end systole after aortic valve closure. At Indiana University, the anterior extent was measured from the inside of the aorta to the same posterior structure.

Right ventricular anterior wall (RVAW) was measured from the inner chest or pericardium (if visible) to the endocardial surface of the right ventricular anterior wall at beginning of the QRS inscription.

Right ventricular cavity (RVC) was measured from the right ventricular endocardial surface to the right septal surface at the beginning of the QRS inscription.

Septal thickness was measured from the right septal surface to the left septal surface (in the plane of posterior mitral valve leaflet) at the beginning of the QRS.

Left ventricular posterior wall (LVPW) was measured in the plane of the posterior mitral valve leaflet (PMVL) from the endocardial surface to the epicardial surface (or to anterior extent of the pericardial echo if epicardium were not clearly delineated) at the beginning of the QRS.

Cardiac depth was measured in the plane of the posterior mitral leaflet from the posterior limit of anterior chest wall to the anterior surface of posterior pericardium at the beginning of the QRS.

Septal depth was measured in the plane of posterior mitral leaflet from the posterior limit of anterior chest wall to right ventricular surface of the septum at the beginning of the QRS (= sum RVAW + RVC).

Left ventricular cavity diastolic dimension (LVIDd) was measured in the plane of the PMVL from the left septal surface to the endocardium of LVPW at the beginning of the QRS.

**Figure 1**

Example of a normal echocardiogram: The upper left-hand panel (a) demonstrates the usual echocardiographic configuration of the pulmonary valve and pulmonary artery. The crista supraventricularis lies directly posteriorly. We would not have measured pulmonary leaflet excursion or pulmonary artery size on this example. On the other hand, if the pulmonary artery had distinct walls and both valves were visible, each measurement could have been made. Panel b demonstrates the aorta and the left atrium. The right ventricular outflow tract and a portion of the right ventricular anterior wall are anterior to the aorta. The lower panel demonstrates the echocardiogram obtained in the plane of the posterior mitral valve leaflet. The mitral valve probably is not at maximal excursion in this example, but the measurement technique for maximal excursion is demonstrated. Abbreviations: CW = chest wall; PPV = posterior pulmonary leaflet; RVAW = right ventricular anterior wall; RVOT = right ventricular outflow tract; AAC = anterior aortic wall; PAW = posterior aortic wall; PAC = posterior aortic cusp; AoD = aortic dimension; LAID = left atrial internal dimension; LAPW = left atrial posterior wall; RVC = right ventricular cavity; SD = septal depth; RVD = right ventricular dimension; AMVL = anterior mitral valve leaflet; PMVL = posterior mitral valve leaflet; LVPW = left ventricular posterior wall; LVIDs = left ventricular internal dimension, systolic; MVA = mitral valve amplitude; en = endocardium; myo = myocardium; p = pericardium; “e” and “d” refer to points of the mitral valve excursion.
Left ventricular cavity systolic dimension (LVIDd) was measured from the left septal surface to the endocardium of LVPW in the plane of the PMVL at the ventricle's narrowest point at end systole.

Mitra1 valve amplitude (MVA) was measured from the D point vertically to the level of the E point at maximal excursion.

Tricuspid valve amplitude (TCVA) was measured from the D point vertically to the level of the E point at maximal excursion.

If a structure was not clearly defined, no measurement was made. A variable scale ruler was utilized in combination with calipers to permit measurements to be made to the nearest 0.5 mm.

Results

Figures 2 through 4 present the data as growth curves, similar in format to the Boston grid growth curves. All graphs are plotted so that body surface area is on the X axis, and the variable (measured in centimeters) is on the Y axis. Table 1 contains the highest and lowest value recorded for any patient.

Groups were established for each body surface area of 0.1 square meters and were age independent. Mean group size was 14.6 children and the range was from 9 to 20.

The objective of the study was to provide a useful

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**Figure 2**

Percentiles of various cardiac structures are plotted against body surface area.
display with respect to body surface area. The fifth, 50th, and 95th percentiles are indicated on the individual graphs.

One criterion for inclusion of an echocardiogram into the Arizona normal study was that all structures could be measured in each echocardiogram with the exception of pulmonary intercusp distance and pulmonary artery dimension. Right ventricular anterior wall, mitral and tricuspid maximal excision, and septal and cardiac depth were not evaluated in the Indiana study. Accordingly, the numbers of patients for those determinations were only half as large as for other measurements. The most difficult structure to clearly delineate was the right ventricular anterior wall, but this was achieved in each instance in Arizona patients with high frequency transducers and careful gain control.

**Left ventricular cavity.** Figure 2 demonstrates the growth curve for the left ventricular cavity measurements in systole and diastole. Both measurements approximately doubled as the body surface area increased from 0.3 to 1.7 m².

**Right ventricular cavity.** The growth rate of this cavity is very similar to that of the left ventricle, but the absolute values are only about 30% as large.

**Right ventricular anterior wall.** Figure 2 demonstrates that the right ventricular anterior wall increases in thickness by only about 0.5 mm from 6 months to 18 years.

**Interventricular septum.** The septum increases in thickness from a 95th percentile value of approximately 0.5 cm in the 6-month-old to 0.65 cm in the oldest children. The thickest normal septum was 0.8 cm.

**Left ventricular posterior wall.** The left ventricular posterior wall measurements were very similar to those of the septum. Thickness increases from approximately 0.5 cm to 0.8 cm at the 95th percentile. The thickest wall found in a normal was 0.85 cm.

**Left atrium.** The growth curve for the left atrium is shown in figure 3. The variation in size is very slight in the smaller body ranges, then increases with growth. Data from Arizona and Indiana were statistically different from 0.3 to 0.8 m² body surface area. Indiana values were significantly larger. Arizona means for each 0.1 m² of body surface area were about 0.2 cm less than the Indiana means. Above 0.8 m², means were statistically similar. Figure 3 shows combined data.

**Aortic root.** The growth curve for the aortic root is

![Figure 3](http://circ.ahajournals.org/)

**Figure 3**

Percentiles of various cardiac structures are plotted against body surface area.

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depicted in figure 3. The curve is very similar to that of the left atrium for each body size group.

Cardiac depth. Cardiac depth (fig. 3) shows relatively linear growth. This measurement is a reflection of cardiac size in the Z axis. Knowledge of this depth is useful for presetting the depth of the echoscope.

Septal depth. Figure 3 also shows the growth curve for septal depth. This measurement is essentially the sum of the RVAW and right ventricular cavity. This value is useful for initial setup of depth compensation on the echoscope.

Table 1

<table>
<thead>
<tr>
<th>Maximum and Minimum Values Recorded in Measurement of Cardiac Structures</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVAW</td>
<td>0.35</td>
<td>0.1</td>
</tr>
<tr>
<td>Septum</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>LV PW</td>
<td>0.85</td>
<td>0.3</td>
</tr>
<tr>
<td>LVId</td>
<td>4.0</td>
<td>1.5</td>
</tr>
<tr>
<td>LVIda</td>
<td>5.2</td>
<td>1.3</td>
</tr>
<tr>
<td>RV C</td>
<td>1.8</td>
<td>0.5</td>
</tr>
<tr>
<td>LA</td>
<td>3.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Ao root</td>
<td>3.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Aortic valve excursion</td>
<td>2.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Mitral valve excursion</td>
<td>3.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Tricuspid valve excursion</td>
<td>3.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Cardiac depth</td>
<td>8.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Septal depth</td>
<td>2.1</td>
<td>0.8</td>
</tr>
</tbody>
</table>

The largest and smallest values for a cardiac parameter (in centimeters) irrespective of age are indicated. Abbreviations are the same as for figure 1.

Aortic valve. The aortic valve excursion curve is seen in figure 4. The leaflet separation has extremely limited variability from patient to patient.

Mitral valve. The curve for the mitral valve excursion (fig. 4) correlated more weakly with body surface area than most measurements. The mean increased by only a factor of 1.4 when the smallest and largest patients were compared.

Tricuspid valve. In contrast to the mitral valve, the mean maximal tricuspid excursion approximately doubled with growth. The excursion, as measured, was greater than for the mitral; perhaps this is a function of the angle of examination (fig. 4).

Pulmonary artery root and valve. Pulmonary root and pulmonary artery leaflet opening measurements were difficult to obtain. It was possible to image both pulmonary leaflets simultaneously only a few times, and when they were imaged, the intercusp distance varied depending on angulation. The anterior wall of the pulmonary artery was visualized relatively often, but simultaneous visualization of both pulmonary arterial walls was very rare. When this was accomplished, the distance between them could be varied by transducer angulation. For these reasons, no usable data were collected for pulmonary artery root measurement or intercusp distance.

Ten percent of the echocardiograms recorded in Arizona showed small systolic and early diastolic epipericardial posterior separation. These may have occurred in echocardiograms recorded in Indiana but were not an object of search. Almost all patients had anterior epipericardial systolic separations.

The measurements for the interventricular septum
and left ventricular posterior wall closely parallel each other. Because of this similarity, we examined the septal/posterior wall ratio. The ratio is independent of age and body size and varies from 0.67 to 1.33 in individual patients. The mean ratio was 1.00.

For each body size group, the dimensions for the aortic root and left atrium were similar. Therefore, in the normal, the left atrial dimension provides a good reference for the expected aortic root size and vice versa. We examined this ratio in individual patients, and determined that the mean ratio at the fifth percentile was 0.84; the 50th percentile, 1.06; and the 95th percentile, 1.28.

Discussion

Echocardiography has become an important diagnostic technique for evaluation of patients with congenital and acquired cardiac disease. The safety factor is high and the measurement repeatability is great. However, the lack of normal growth related values has been a major problem. The three newborn studies have provided data for that group, but beyond that age only the data of Feigenbaum are available. These data, while accurate and properly collected, cannot be easily adapted to clinical use. We were permitted to use the raw data from that study to combine with our own to make a large series.

Numerous biological data are not expressed by statistically normal distribution. The data presented are no exception to this principle. For this reason data were represented as 5th, 50th, and 95th percentiles rather than in the form of standard deviations.

The data are plotted against body surface area rather than age or height. At each age distribution, there is a wide spectrum of body sizes, making age alone an illogical parameter. Likewise, height or weight alone have limitations in a given patient. Accordingly, a measurement that incorporated height and weight was selected.

Measurements of most of the structures were made at the beginning of the QRS complex. This was done in order to standardize measurements. Diastole does not end exactly with the inscription of the QRS, but rather a few milliseconds afterward. However, the precise end point is very difficult to determine. Accordingly, a standardized convention was adopted.

Data from Arizona and Indiana are not statistically different except for the left atrial dimension distributions between 0.3 and 0.8 m². The means of these distributions were significantly different at the 5% level of confidence. The Indiana left atrial dimensions were consistently larger than the Arizona measurements. Since a different technique was used for measurement, the reason for the difference of 0.2 cm was the aortic wall thickness. For children greater than 0.8 m², the variability and chamber size apparently precluded finding a statistical difference between the two institutional measurements.

Our studies show very little thickening of the right ventricular anterior wall with age. A thickness of 3.5 mm was the upper limit of normal in an individual patient (table 1). These normal data should be useful in judging the extent of right ventricular hypertrophy.

With the child in the supine position, the right ventricular anterior wall frequently separates from the chest wall. In these children, measurement from the chest wall to the right ventricular endocardial surface will produce a falsely large wall thickness. The anterior surface of the wall can usually be identified by decreasing the gain and using high frequency transducers.

The ratio of interventricular septal to posterior left ventricular wall thickness ranged from 0.67 to 1.33 in individual patients. This ratio is of considerable importance because it is used as the criterion for the diagnosis of asymmetric septal hypertrophy. Our upper ratio agreed with that found by Henry and coworkers.

The left atrial to aortic ratio had a 50th percentile value of 1.06. Although this ratio in individual patients varies over a wide range — 0.84 to 1.28 — the size of the two structures are generally related to one another in normal individuals. However, the assumption of a one-to-one ratio for an individual patient is unwarranted.

The pulmonary artery size is very difficult to standardize by single crystal techniques. Different values could be obtained from the same child by using different transducer angulation. We regard this measurement as unreliable.

This study provides growth related, quantitative measurements in normal children which will be useful in assessment of children with congenital cardiac disease.

References

6. Ibid, ch 3

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