Cardiac Dimensions Determined by Cross-Sectional Echocardiography in the Normal Human Fetus from 18 Weeks to Term

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Assessment of cardiac dimensions of the chambers, great arteries and veins in the human fetus is important to distinguish abnormal dimensions from normal. This study establishes normal values based on cross-sectional echocardiographic measurements over the gestational period where these measurements may be clinically useful. Ventricular and atrial dimensions were measured from the 4-chamber view, the short-axis dimension immediately below the mitral and tricuspid valve leaflets in diastole, and the long axis from the closed apposed atrioventricular valves to their respective apices. The ventricular walls and septum were measured at the level at which cavity dimensions in diastole were measured, defining both the left and right ventricular wall thickness, as well as that of the ventricular septum. Furthermore, the long axis of the right and left atria was measured from the center of the apposed atrioventricular valve leaflets to the posterior atrial wall, and the sizes of the atrial chambers were defined using their widths at the prospective broadest points through the area of foramen ovale. From a variety of views, diameters were measured at maximal expansion of the main, left and right pulmonary arteries, the ductus arteriosus, and the superior and inferior venae cavae. The data were evaluated longitudinally from 18 weeks to term, and regression analysis was performed using the best fit of a linear or polynomial equation. The data provide a means for evaluating the normal sizes and dimensions of the fetal heart chambers, as well as the thickness of the ventricular walls and septum.
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Echocardiographic determination of fetal cardiac dimensions provides an important quantitative reference point for fetal cardiac assessment. Because of the growth of the fetal heart, one must obtain assessments based on gestationally matched normal values. Such data generally have been gathered from M-mode echocardiography[1] using cross-sectional echocardiographic systems, with the cursor placed through the frozen 2-dimensional image.[2–5] Cross-sectional ultrasound scanning does not need the precise perpendicular alignment of the M-mode cursor through the cross-sectional M-mode image and enables imaging to be performed under all circumstances. This technique provides a greater opportunity to obtain measurements directly from cross-sectional echocardiograms.[1,6,7] Furthermore, extracardiac structures such as the ductus arteriosus, the aorta, the pulmonary artery and its branches, and the great veins can also be more readily defined by means of 2-dimensional echocardiography. Therefore, we determined these measurements from cross-sectional echocardiography in a cohort of 100 fetuses both to determine the range of measurements one may expect at gestational ages of 18 to 40 weeks and to establish values for comparison with measurements in all normal fetuses. Furthermore, because cross-sectional ultrasound provides an opportunity to measure structures outside the range of conventional M-mode echocardiography, we also measured the pulmonary artery branches, the superior and inferior venae cavae, and the ductus arteriosus.

METHODS

This study was performed in a cohort of volunteer health care professionals at our institution, whose menstrual history, gestational age estimation and delivery at term confirmed that the measurements had been obtained at the stated time in the gestational period. Many of these subjects submitted themselves for serial examinations later in pregnancy; thus, the measurements reflect a combination of longitudinal and cross-sectional data.

The studies were performed with either an Advanced Technologies Laboratory Ultra Mark-8 (Bothell, Washington) or Acuson 128 XP (Mountain View, California) ultrasound system. The systems were interfaced with either 5 or 7.5 MHz transducers. The studies were recorded on VHS or Super-VHS for later playback and analysis.

Of 106 sequential studies from this cohort, 6 were rejected because image quality was not considered satisfactory for accurate measurements. The cohort of 100 examinations was then selected for evaluation. Because this was a volunteer population, the studies were usually brief, lasting <15 minutes. During the examination, the mother reclined supinely, with some rotation either to the right or left side to facilitate the evaluation. The study was performed in the usual manner,[8,9] with careful attention given to gain settings adjusted to produce the best possible image; magnification of the image was always attempted to minimize the error obtained from the caliper system. Complete studies of the heart were attempted, including the frequently used cross-sectional views equivalent to those obtained after birth, corresponding to long- and short-axis, 4-chamber and long-axis apical views, and the subcostal and arch equivalent views. No particular attention was given to producing every view from which the particular measurements could be obtained. Measurements were judged adequate based on the quality of the images and if they excluded congenital heart disease.

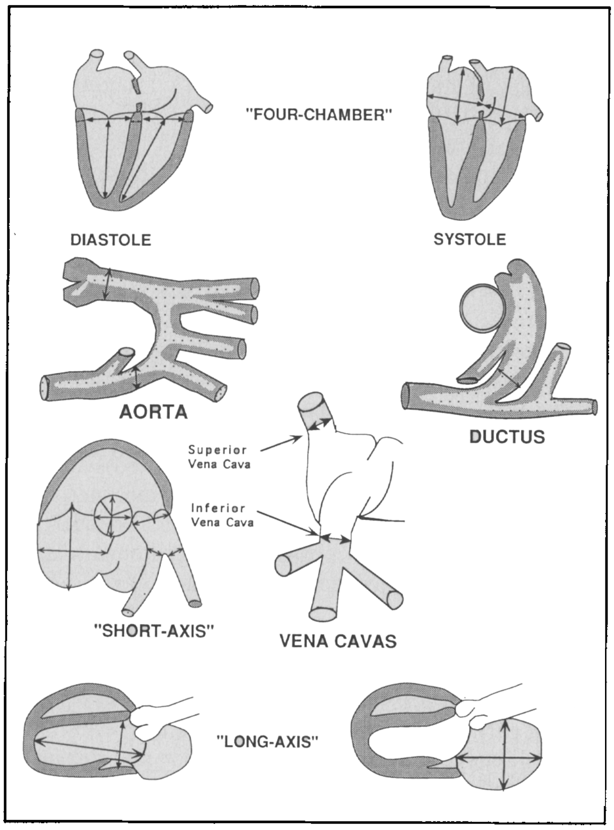

FIGURE 1. Graphic representation of views obtained and dimensions *(arrows)* measured. *Top row:* in 4-chamber view during diastole *(left)*, ventricular dimensions were measured immediately below opposed tips of atrioventricular valve leaflets; ventricular lengths were also measured, as well as wall and septal thickness. *Second row: left*, measurements obtained in ascending and aortic isthmic region, and *right*, measurement of ductus dimension. *Third row:* from short-axis view *(left)*, measurements of right atrial, aortic root, pulmonary arterial, and branch left and right pulmonary arterial dimensions. Superior and inferior caval veins were measured *(right)* at entrance of each cava into right atrium. In systole *(right)*, atrial dimensions were measured. *Bottom row: left*, measurements of left heart in diastole obtained from long-axis equivalent and left ventricular minor and major axis, and *right*, left atrial dimensions from this view measured in systole. Arch of aorta *(top left)* was often seen from this plane.

Analysis of the studies was performed using the GTI Prism Imaging System, model 16 (Freeland, Louisville, Colorado). This system can digitally acquire sequential frames of video information in high resolution, enabling acquisition of 32 consecutive frames of information. Stop-action and cycling from this digital memory enabled maximal and minimal size to be selected during the cardiac cycle, and the cycle could be stopped at any point for detailed analysis.

The sites at which sizes of the ventricles, atria and vessels were measured are shown in Figure 1. All measurements were obtained using the standard 2-dimensional technique (i.e., endocardial-to-endocardial measurement for cavities, and endocardial-to-epicardial surface for ventricular wall thickness). The ventricular walls and cavity measurements were obtained at a time corresponding to end-diastole when the chamber size was at maximum or the wall dimensions were at minimum. For the vessels, atria or veins, measurements were obtained at the maximum sizes corresponding to the maximum dimensions at end-systole. The following dimensions were defined: (1) The aortic annulus was measured at the valve level, the ascending aorta was measured immediately above the sinuses of Valsalva, and the aortic isthmus was measured immediately above the entrance of the ductus arteriosus. With slight angulation, the ductus was imaged and measured at its middle. (2) The superior and inferior venae cavae were measured at their entry into the right atrium. (3) The aortic and pulmonary annuli were measured in the equivalent of the parasternal short-axis view at the valve annuli. (4) In addition, the left and right pulmonary arteries were measured at their origin from the main pulmonary trunk. (5) From the 4-chamber view, the short axes of the left and right ventricles were measured immediately below their respective coapted valve leaflets; the thickness of the ventricular walls and septum was also measured at this point. In addition, the long axes of the ventricles were measured from the apex of the chamber to the point of the coapted valve leaflets. Furthermore, at the end of ventricular systole, the atrial dimensions were measured from the coapted atrioventricular valve leaflets to the respective posterior atrial walls, and the orthogonal dimensions through the respective atrial lateral wall to the line between the 2 portions of the foramen ovale. (6) The long-axis view, orthogonal to the 4-chamber view, was also used to measure the left ventricular long-axis and minor-axis dimensions, and the orthogonal dimension of the atrium.

The regression statistic used to define the best fit was either linear or quadratic, the latter being accepted when the correlation coefficient was significantly higher, as shown by an analysis of variance test. Furthermore, we used 95% confidence limits to define the normal limits for the data. For these numbers of measurements, the differences between confidence and tolerance limits are negligible.

Ten sets of measurements were obtained again by 1 investigator (JT) and a second observer (NHS) to define inter- and intraobserver variability. Variability was calculated by the formula $(O_1 - O_2) \times 100/(O_1 + O_2) \times 0.5$.[6]

TABLE I Regression Analysis Summary (corresponding figure numbers are listed in first column)

Figure	Data	No.	Equation	SEE	r Value
2	4-chamber view				
	Left ventricular width	100	$y = -0.9478 + 0.1090x - 0.001153x^2$	0.200	0.807
	Left ventricular length	100	$y = -2.318 + 0.2356x - 0.002674x^2$	0.308	0.866
	Left atrial width	100	$y = -1.246 + 0.1305x - 0.001563x^2$	0.181	0.830
	Left atrial length	100	$y = -0.6508 + 0.0873x - 0.000674x^2$	0.196	0.838
3	4-chamber view				
	Right ventricular width	100	$y = -0.9869 + 0.1075y - 0.001036x^2$	0.179	0.860
	Right ventricular length	100	$y = -1.5082 + 0.1634x - 0.001514x^2$	0.316	0.836
	Right atrial width	100	$y = -1.4025 + 0.1410x - 0.001671x^2$	0.203	0.826
	Right atrial length	100	$y = -0.4873 + 0.06797x - 0.000202x^2$	0.199	0.862
4	4-chamber view				
	Right ventricular wall	100	$y = -0.2315 + 0.02677x - 0.000316x^2$	0.034	0.857
	Ventricular septum	100	$y = -0.1415 + 0.0200x - 0.000185x^2$	0.040	0.829
	Left ventricular wall	100	$y = -0.2135 + 0.02552x - 0.000295x^2$	0.033	0.862
	Short-axis view				
	Ductus arteriosus	38	$y = 0.01539 + 0.01325x$	0.052	0.787
	Sagittal view				
	Inferior vena cava	22	$y = -0.09012 + 0.01883x$	0.065	0.869
	Superior vena cava	22	$y = 0.004078 + 0.01673x$	0.082	0.815
5	Sagittal view				
	Long-axis view				
	Aortic valve annulus	71	$y = -0.1278 + 0.02497x$	0.089	0.855
	Ascending aorta	45	$y = -0.0523 + 0.0201x$	0.081	0.837
	Descending aorta	69	$y = -0.0185 + 0.0173x$	0.080	0.801
	Short-axis view				
	Main pulmonary artery	84	$y = -0.1517 + 0.0279x$	0.110	0.825
	Left pulmonary artery	23	$y = -0.0554 + 0.0136x$	0.056	0.839
	Right pulmonary artery	17	$y = -0.0058 + 0.0117x$	0.050	0.817
6	Short-axis view				
	Aortic width	75	$y = -0.4149 + 0.05327x - 0.000495x^2$	0.117	0.812
	Aortic length	75	$y = -0.2770 + 0.03759x - 0.000174x^2$	0.115	0.838
	Right atrial width	43	$y = -2.145 + 0.1976x - 0.00273x^2$	0.181	0.853
	Right atrial length	41	$y = -1.2949 + 0.1406x - 0.001393x^2$	0.279	0.813
7	Long-axis view				
	Left ventricular width	31	$y = -0.1739 + 0.0465x$	0.180	0.855
	Left ventricular length	29	$y = -0.4990 + 0.0868x$	0.296	0.887
	Left atrial width	54	$y = -0.3422 + 0.0498x$	0.231	0.778
	Left atrial length	54	$y = -0.6408 + 0.0707x$	0.290	0.810

All coefficients significant at $p < 0.05$.

RESULTS

Table I presents the variables measured, the frequency with which measurements were successfully obtained, the regression equation of dimension versus gestational age, SEE, and correlation coefficient. Graphs of the data were divided into 6 figures for convenience (Figures 2 to 7). These graphs display the number of measurements, the lines of regression, and the unweighted 95% confidence limits. The regression equation correlation coefficients and SEE are listed in Table I. The left heart measurements (i.e., left ventricular and atrial length and width, as measured in the 4-chamber view) are shown in Figure 2, the right heart measurements (i.e., right atrial and ventricular width, right ventricular length, and right atrial width) are shown in Figure 3, and the measurements of the ventricular walls and septum are shown in the left panels of Figure 4. The dimensions of the ductus arteriosus and inferior and superior venae cavae are shown in the right panels of Figure 4. The dimension of the aortic root from the long axis, the ascending aorta and the aortic isthmus, and the main and branch pulmonary arteries are shown in Figure 5. The dimensions of aortic and right atrial width and length (i.e., vertical and horizontal measurements as shown in Figure 1 in the short-axis view) are shown in Figure 6. The dimensions of left ventricular and left atrial width and length are shown from long-axis views in Figure 7.

The best fit for a particular dimension measured in >1 plane was accepted as the most reliable measurement of that dimension. All data showed a significant correlation with age ($p < 0.05$).

Intraobserver variability was 3%, and interobserver variability was 7%, which are consistent with other sets of inter- and intraobserver variability from our laboratory.

DISCUSSION

The data for left and right ventricular wall thickness, cavity dimensions and ventricular septum in this study are similar to those described in previous publications.[1,6,7] We used gestational age as the standard, rather than biparietal diameter of the skull or femur length, for several reasons. First, most standard obstetric programs convert measurement of biparietal skull dimension or femur length to an estimated gestational age. Second, all patients who had these studies had accurate estimation of gestational age obtained by their obstetricians or referring radiologists. In our clinical practice of cardiology, patients are referred from a prenatal counseling service whose sonographic physicians have always obtained an estimate of gestational age. Differences between studies can be explained based on the differing methods used to collect data; e.g., based on gestational age or weight estimates. In addition to these measurements, this study provides important information concerning the size of other cardiac structures not previously defined in standard publications of cardiac growth.

The advantage of measurement from cross-sectional echocardiography is obvious, because the measurements can be obtained with most modern equipment by means of electronic calipers from images acquired in a digitized loop, enabling appropriate selection of the phase of the cardiac cycle in which measurements are to be obtained. The opportunity to obtain cardiac measurements from planes inaccessible to M-mode echocardiography augments the number of fetal positions in which such measurements can be obtained. Furthermore, measurements such as those of the long axis can be used to define further the cardiac chamber dimensions.

We believe that the use of M-mode echocardiography for obtaining such measurements can be supplanted by cross-sectional methods for several reasons. First, although the higher sampling rate of M-mode echocardiography provides a greater number of points of inspection of dimension change, the use of a cineloop of images over several cycles on modern ultrasound equipment and the use of videotape enables such measurements to be obtained. The disadvantages of such a technique are more than compensated for by the frequency and facility for obtaining direct measurement when the conventional view used for M-mode measurements cannot be obtained. Furthermore, many sonographers working with obstetrical fetal problems have scanning

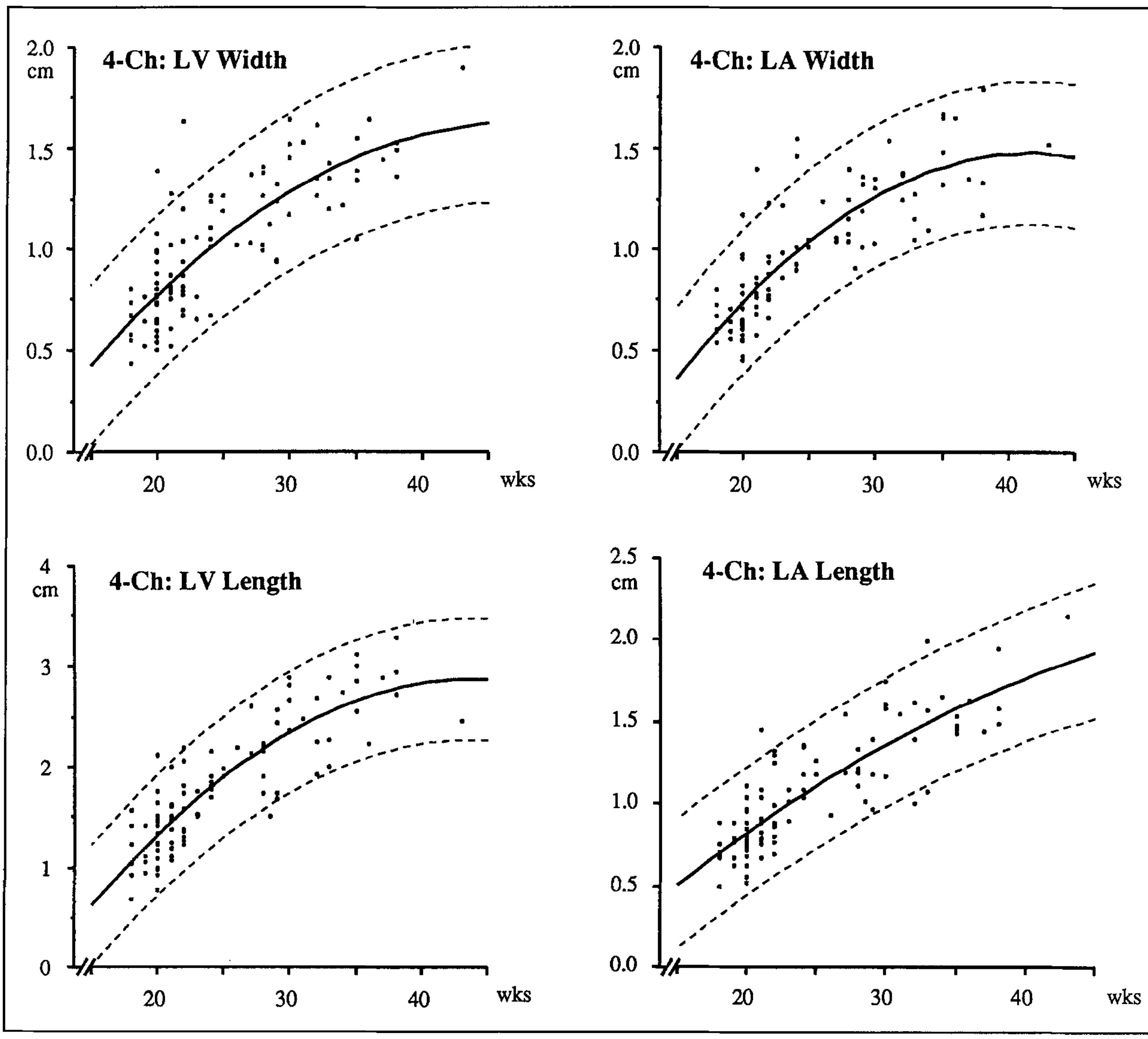

FIGURE 2. Left heart measurements from 4-chamber view (4-Ch). In each *graph* in this and the following figures, gestational age in weeks is displayed on *ordinate* measurement, and ultrasound dimension in centimeters on the *abscissa*. Likewise, all graphs show line of regression as *bold, continuous line*, 95% confidence intervals as *dotted lines*, and data points for each fetus. The equations in Table I are listed with corresponding figure numbers. LA = left atrial; LV = left ventricle.

equipment without M-mode capabilities. The only opportunity for measurement of cardiac and vascular dimensions from such equipment is from the 2-dimensional frozen image.

Using high-resolution ultrasound equipment, cross-sectional echocardiographic measurements of the fetal heart are accurate. In fetal lambs, such measurements of chamber dimensions or wall thickness have been shown to correlate well with direct measurements obtained at autopsy.[10] Two-dimensional measurement of the chamber volume is also possible[11] and may provide an even better estimate of chamber hypoplasia, enlargement and ventricular mass than that of single-diameter measurements. However, for screening of chamber size and cardiac dimension, the scattergrams established may provide an excellent comparison of chamber size.

Comparison with studies that include confidence limits, such as the data of Allan et al,[2] indicates close agreement with M-mode–derived measurements of chamber dimensions and wall thicknesses in which data were corrected for biparietal diameter for femur length[7] or without published confidence intervals.[4]

With regard to comparisons within this study, several dimensions such as aortic cross-sectional data, and atrial and ventricular dimensions were recorded from many sites. The data are similar from similar sites. It is reasonable to assume that if the measurement really reflects the dimension, where the measurement was recorded would make no difference. Variations may relate to the number of observations recorded, and the technique of measurement. Measurements using axial resolution are superior to those using lateral resolution.

Because the data were analyzed retrospectively, the frequency with which these measurements could be obtained is probably an underestimate of actual frequency. This is a problem with the design of this study; because the data were gathered from studies performed to exclude congenital heart disease, there was a greater fo-

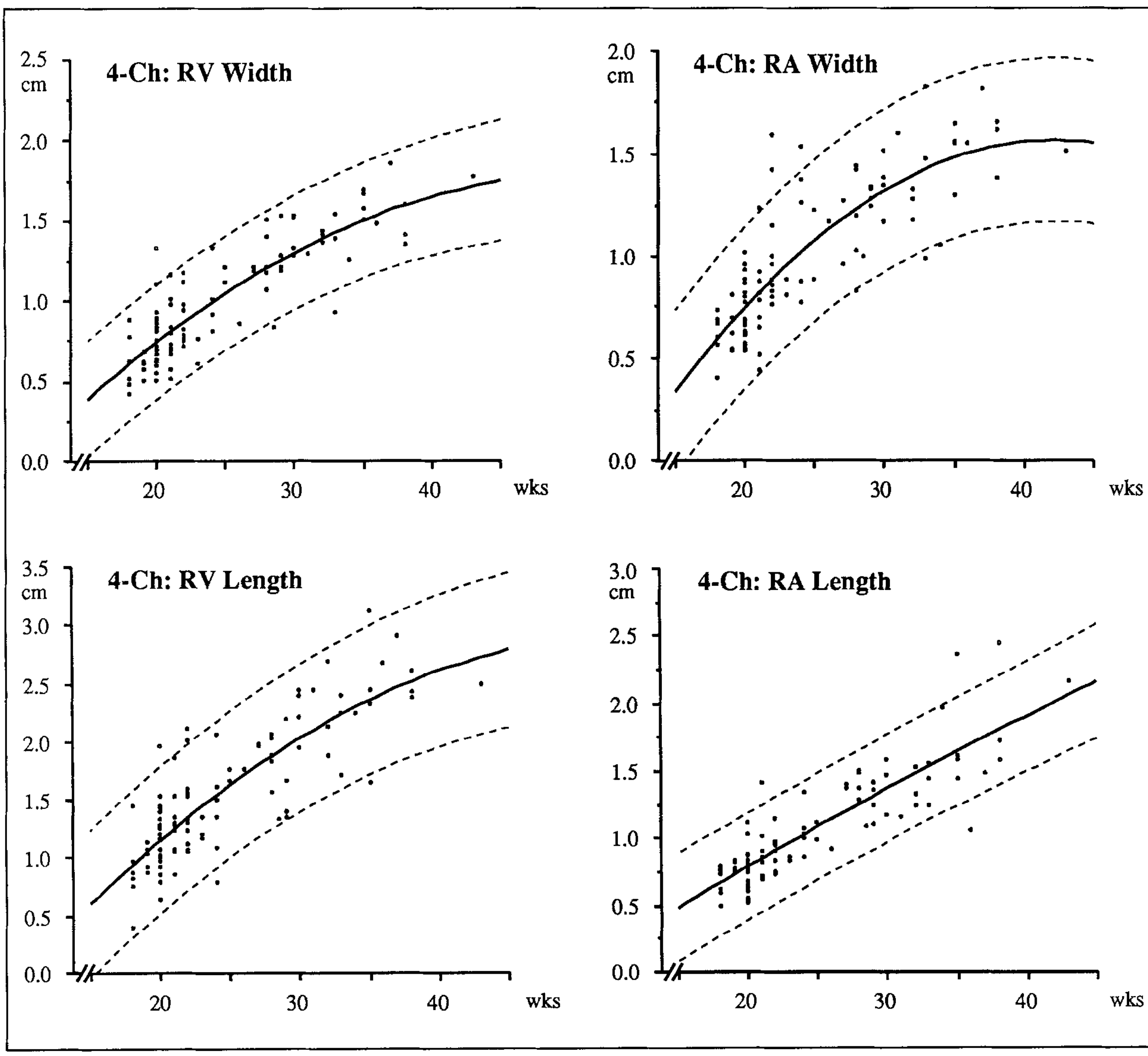

FIGURE 3. Right heart measurements from 4-chamber view (4-Ch). RA = right atrial dimensions; RV = right ventricular dimensions.

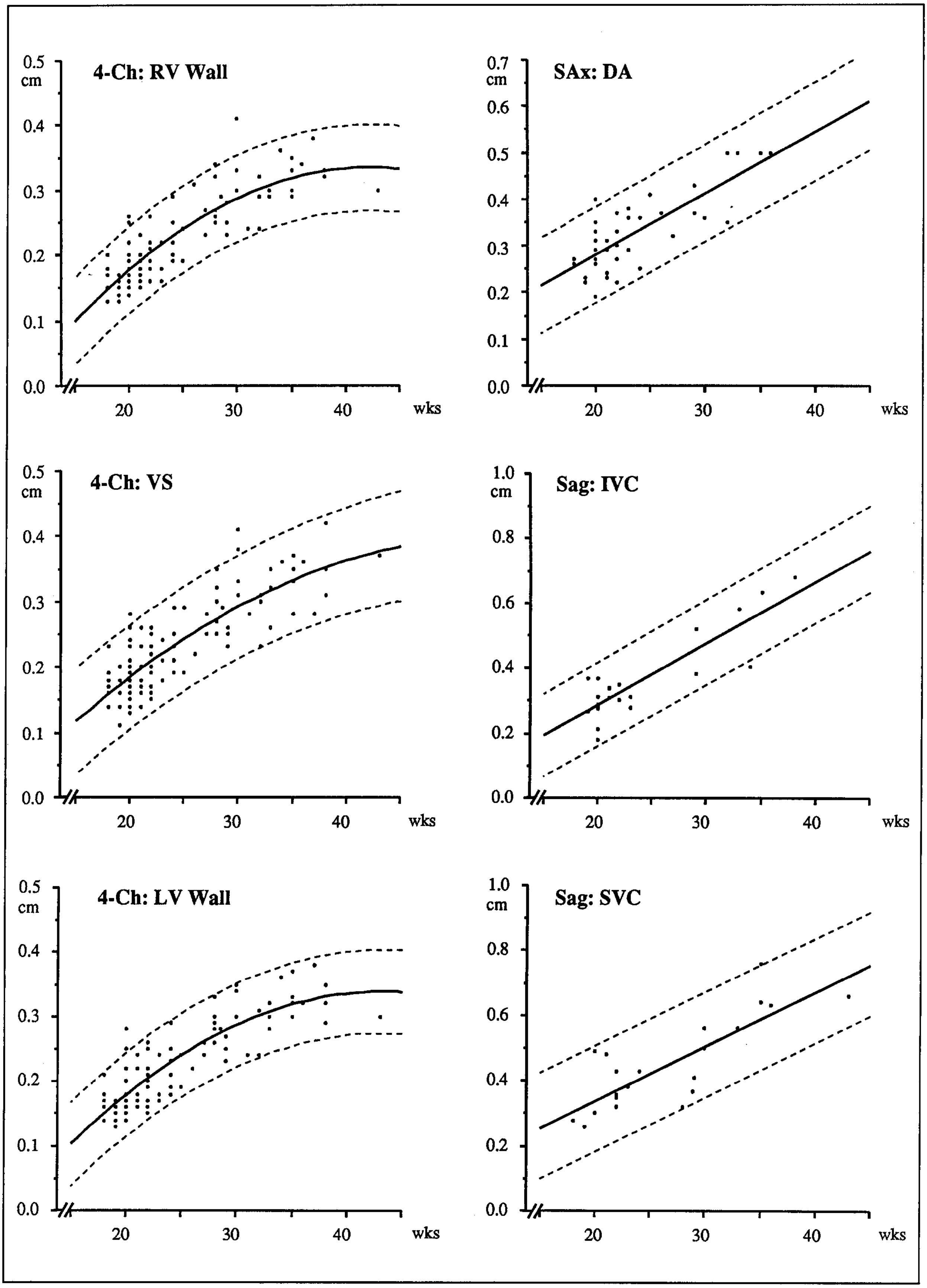

FIGURE 4. ***Left,*** **from 4-chamber view (4-Ch), dimensions of right ventricular (RV) wall, ventricular septum (VS) and left ventricular (LV) wall.** ***Right,*** **from short-axis view (SAx), dimensions of ductus arteriosus (DA), and from sagittal view** ***(Sag),*** **inferior vena cava (IVC) and superior vena cava (SVC).**

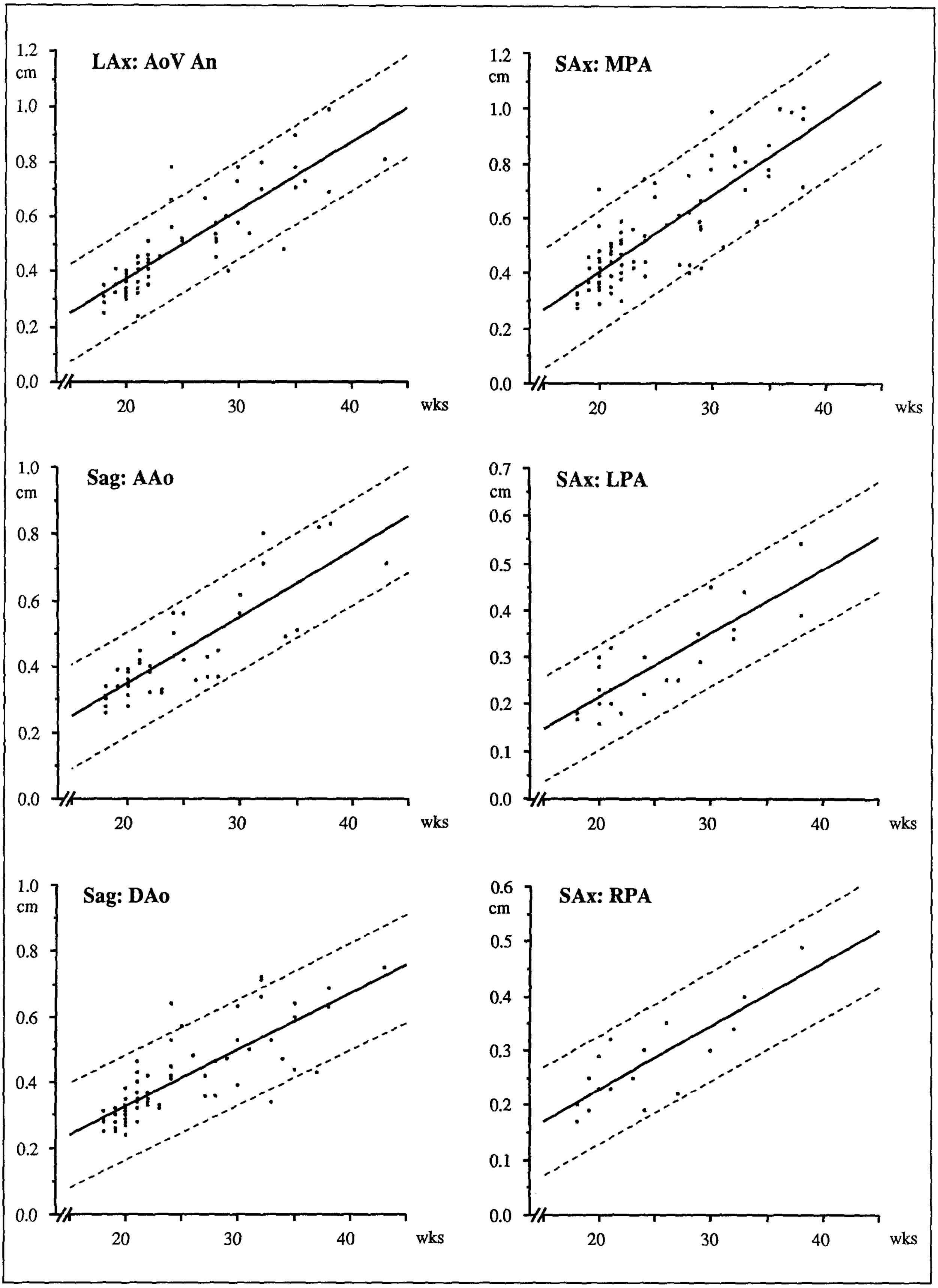

FIGURE 5. Measurements of aortic and pulmonary arteries. *Left,* from long-axis view (LAx), diameter of aortic valve annulus (AoV An), and from sagittal view (Sag), diameters of ascending aortic root (AAo) and descending aortic root (DAo). *Right,* from short-axis view (SAx), diameter of main pulmonary artery (MPA), left pulmonary artery (LPA) and right pulmonary artery (RPA).

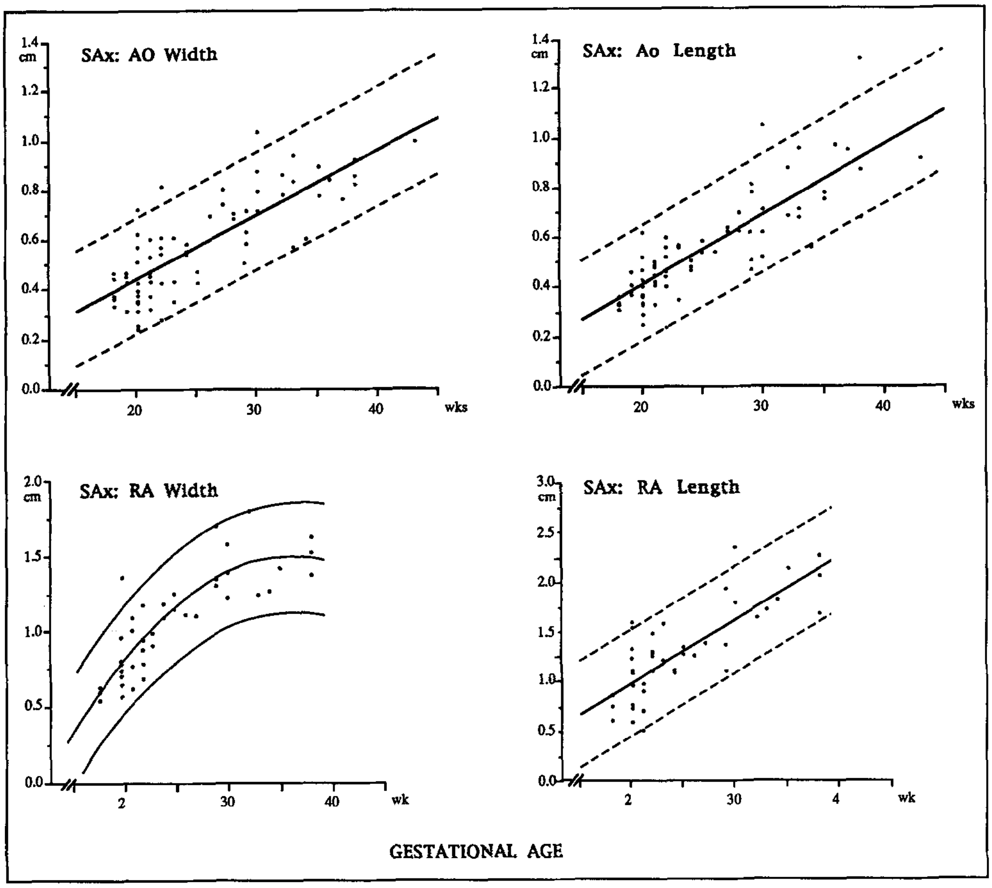

FIGURE 6. Measurements obtained from short axis (SAx). *Top,* dimension of aorta (AO) from horizontal plane (Width) on *left,* and from sagittal plane (Length) on *right. Bottom,* corresponding right atrial measurements (RA).

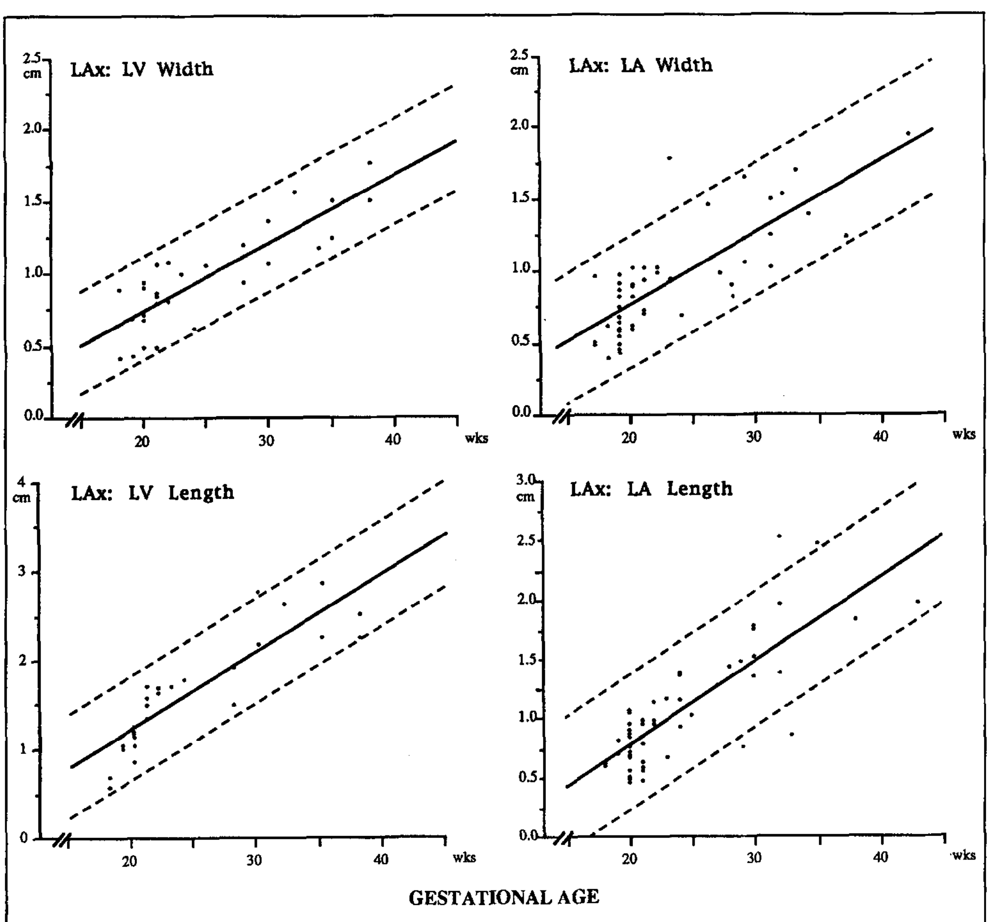

FIGURE 7. Left heart dimensions from long-axis view (LAx). *Left,* diastolic left ventricular (LV) minor axis (Width) and major axis (Length); *right,* left atrial (LA) anteroposterior (Width) and superoinferior (Length) dimensions.

cus on views of the heart. We believe that with a targeted study, more measurements of these structures could be obtained, and that this study does not reflect the actual frequency with which these observations may be obtained.

The chamber dimensions displayed in Table I frequently show both a curvilinear and linear function when obtained in a different view. This probably relates to the numbers of measurements, because the small degree of curvilinearity did not reach significance when the numbers were small.

This study provides a series of normal measurements of the change in fetal cardiac dimensions with regard to gestation. Because of the central role of cross-sectional imaging, the data appear to be achieved best using the 2-dimensional method.

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