Determination of Right Atrial and Right Ventricular Size by Two-Dimensional Echocardiography

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SUMMARY No data are available on determining right atrial and right ventricular size by two-dimensional echocardiography. We performed two-dimensional echocardiograms on eight human right-heart casts obtained at autopsy and on 50 patients who underwent complete left- and right-heart catheterization. Measurement of individual dimensions of the long and short axes of the right atrium and ventricle from right heart casts closely correlated with the volume of these structures as determined by water displacement. Further, individual dimensions by cross-sectional echo correlated well with actual casts dimensions. Subsequently, echocardiographic measurements of right atrial and ventricular long and short axes were obtained in the apical four-chambered view in a group of normals and compared with a group of patients with right ventricular volume overload states. Mean values for right atrial short-axis and long-axis measurements were greater in right ventricular volume overload patients than in normals: 6.5 ± 0.3 vs 3.6 ± 0.1 cm, and 6.0 ± 0.3 vs 4.2 ± 0.1 cm, respectively (both p < 0.001). In addition, measurements of both individual dimensions as well as planed area of the right ventricle were greater in right ventricular volume overload patients than in normals: maximal short axis 6.1 ± 0.3 vs 3.5 ± 0.2 cm, mid-short axis 6.1 ± 0.4 vs 2.8 ± 0.2 cm, and area 40 ± 2.6 vs 18 ± 1.2 cm² (all p < 0.001). There were no differences in right ventricular long-axis measurement. Two-dimensional echocardiography provided better separation of normals from right ventricular volume overload patients than did M-mode techniques. Thus, two-dimensional echocardiography, with the apical four-chambered view, enables accurate visualization of the right atrium and ventricle in almost all patients. Further, measurements of right atrial and right ventricular size by two-dimensional echocardiography readily distinguish normal patients from those with right ventricular volume overload.

M-MODE ECHOCARDIOGRAPHY has dramatically altered cardiac diagnostics by providing a noninvasive method of documenting the presence of a variety of cardiac disorders, including valvular heart disease,1,2 cardiac myxomas,3 and pericardial effusion.4 This technique also permits accurate atraumatic determination of left atrial and left ventricular dimensions.5,6 One area in which M-mode echocardiography has not been important, however, is in evaluating the right-sided cardiac chambers. Because of an inaccessible intrathoracic position and an irregular geometrical shape, the right atrium and right ventricle are difficult structures from which to obtain reproducible echographic signals by M-mode examination.

Recently, two-dimensional echocardiographic methods have been developed which can provide a 30–80° sector arc image of cardiovascular structures.7–9 The spatial orientation afforded by such techniques has enabled cardiac imaging from new thoracic windows. Thus, with the ultrasound transducer positioned at the cardiac apex and directed toward the right shoulder, a simultaneous view of all four cardiac chambers has been obtained,10 overcoming the anatomical difficulties previously encountered in imaging the right atrium and ventricle. No data are available, however, regarding the reliability and usefulness of such ultrasonic recordings in assessing right-heart chamber dimensions. The present study was undertaken to evaluate the ability of two-dimensional echocardiography to determine accurately right atrial and right ventricular size.

Methods

Studies Performed on Heart Casts

Initially, we studied rubber casts fashioned from the cardiac chambers of human necropsy hearts to validate that the echographic dimensions obtainable from these chambers by two-dimensional echocardiography correlated with actual volume, and that accurate measurements of these dimensions could be determined by ultrasound. Casts were obtained from the hearts of eight persons without clinical or anatomical evidence of heart disease at the time of autopsy. Before fixation, the aorta, pulmonary artery and veins, and inferior and superior venae cavae were ligated, and silicone rubber (Dow Corning 3110 RTV) was injected into both atria at 10 cm of pressure. During the injection and curing process, the hearts were suspended in a solution of normal saline. After the casts had vulcanized, they were removed from the solution, cleaned, and dried to a constant weight. The casts were then immersed in water, freed of any surface bubbles and their volume was determined by the amount of displaced liquid.
We obtained two-dimensional echograms of the right-heart casts by immersing them in saline and lowering an insulated ultrasonic transducer to the liquid surface. Although the intense reflections from the casts made imaging difficult, careful adjustment of the ultrasonic gain and transducer position, yielded images of the casts. (fig. 1). Two-dimensional echographic images were obtained in the projection that would be achieved with the transducer positioned at the cardiac apex to visualize the mitral and tricuspid valves simultaneously during an in vivo examination.

The following measurements were made from the right atrial and right ventricular casts. The long-axis dimension of the right ventricle was measured from the apex of this chamber to the midpoint of the medial aspect of the atrioventricular groove; the short axis of the right ventricle was measured as the greatest distance between the septal and free wall surfaces of the right ventricle in a plane perpendicular to the septum; the right atrial long axis was measured from the midpoint of the medial aspect of the atrioventricular groove to the most superior point of the atrial wall in the plane of the atrial septum; the right atrial short axis was measured as the greatest distance from septal to free wall surfaces of the right atrium in a plane perpendicular to the long axis. These measurements were then correlated with right atrial and right ventricular volumes as determined by water displacement. Subsequently, actual measurements of right ventricular cast dimensions were compared with those from two-dimensional sonograms of the casts.

**Clinical Studies**

Two-dimensional echocardiograms were obtained in all 25 patients in whom the presence of right ventricular volume overload was documented by cardiac catheterization. This group comprised 18 males and seven females 18–70 years old, with a mean age of 40 years. Fifteen patients had tricuspid regurgitation documented by either right ventricular cineangiography or by the appearance of indocyanine green dye in a sample of blood withdrawn from the right atrium after injecting this substance into the right ventricle. The tricuspid regurgitation was not felt to be artificial, since supple catheters were used, premature ven- tricular depolarizations were not recorded during injections, and prominent CV waves were usually present in the right atrium before catheterization of the

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**Figure 1.** A) A silicone rubber cast of the right atrium (RA) and right ventricle (RV) as viewed from the right anterior oblique position. B) The same cast as viewed from the right posterior oblique position. The photograph has been inverted to correspond with the two-dimensional echocardiogram. Although cast measurements were made in a plane bisecting the right ventricle and tricuspid annulus, they are projected on this oblique image for illustration. RVL = right ventricular long axis; RVS = right ventricular maximal short axis; RV-mid = right ventricular mid-short axis; RAL = right atrial long axis; RAS = right atrial short axis.
right ventricle. In 10 other patients, left-to-right shunts secondary to a septal defect at the atrial level ranging in magnitude from 1.5–3.1 were documented by indicator dilution curves, oxygen saturation determinations and cineangiography. Eight of the 25 patients had congestive heart failure.

Twenty-seven patients with atypical chest pain in whom right- and left-heart hemodynamics, oxygen saturations, indicator dilution dye curves, and left ventricular and coronary angiography were all within normal limits underwent M-mode and two-dimensional echocardiography. Twenty-five of these patients had technically adequate echograms, and served as a control group. Fifteen of the 25 received injections of indocyanine green dye into the right ventricle during simultaneous sampling of blood in the right atrium, and in no case did we observe the appearance of green dye (indicative of tricuspid regurgitation). The group included 14 males and 11 females who ranged in age from 35–60 years, with a mean age of 45 years.

All patients in the study underwent M-mode and two-dimensional echocardiography within 24 hours of cardiac catheterization. The M-mode and two-dimensional echoes were performed with the head of the bed elevated to 30° and the patient in either a supine or 30° left lateral decubitus position. M-mode echograms were obtained by placing the ultrasound transducer in the third, fourth or fifth intercostal space as perpendicular as possible to the chest wall and angled so as to provide an image of right and left ventricles through a plane just inferior to the free edge of the mitral valve leaflets. M-mode echograms were obtained with a commercially available echograph (Smith-Kline Instruments, Sunnyvale, California) using a 2.25 MHz transducer with a repetition rate of 1000/sec and distant focusing. The echograph was interfaced to a fiberoptic chart recorder (Honeywell Instruments, Denver, Colorado).

Two-dimensional echograms were obtained with either a dynamically focused phased-array ultrasonic sector scanner (Grumann Health Systems, Woodbury, New York) or a wide-angle mechanical sector scanner (Smith-Kline Instruments, Sunnyvale, California). In all patients the ultrasound transducer was positioned at the point of maximal cardiac impulse and angled toward the right shoulder until an image was obtained of all four cardiac chambers with portions of both the mitral and tricuspid valves visualized. Thereafter, the transducer was angulated to obtain the maximal right atrial and right ventricular size while recording portions of both atrioventricular valves. Real-time, two-dimensional echocardiographic images were recorded on videotape for subsequent analysis. Although the initial examination was performed with knowledge of each patient's clinical status, confirmation of pathophysiological findings by cardiac catheterization were not available. Subsequent measurements from M-mode and two-dimensional images were also made without knowledge of specific catheterization findings.

The right ventricular dimension on M-mode echocardiogram was measured as the end-diastolic distance between the anterior right ventricular wall (identified as a band of moving echoes just below the chest wall signal recorded at low-gain settings) to the leading edge of the ultrasonic signal of the right side of the septum in the echo plane just below the tips of the mitral valve leaflets. In one-third of patients a distinct right ventricular anterior wall echo could not be identified, and in these cases the anterior wall was estimated to be 0.5 cm from the chest wall echo.

Two-dimensional echograms revealing the largest right ventricular dimensions at end-diastole were selected for measurement. The following right ventricular dimensions were obtained from these images either in the plane of the septum (long axis) or perpendicular to this plane (short axis): The right ventricular long axis was measured from the apex of the right ventricle to the junction of the tricuspid valve and interventricular septum; the right ventricular mid-short axis was measured from the right septal surface to the free wall of the ventricle perpendicular to the midpoint of the long axis of this chamber; the right ventricular maximal short axis was measured from the right septal surface to the ventricular free wall in a plane perpendicular to the long axis at the point of maximal right ventricular width. In addition, the end-diastolic image of the right ventricle was traced on a transparent screen, and the area of this figure obtained by planimetry.

Right atrial measurements were obtained from two-dimensional echograms with the largest right atrial size at the end of ventricular systole. The following dimensions of the right atrium were obtained from two-dimensional recordings either in the plane of the interatrial septum (long axis) or perpendicular to this plane (short axis): The right atrial long axis was measured from the junction of the tricuspid valve and the interventricular septum to the roof of the right atrium; the right atrial short axis was measured as the maximum distance between the inner borders of the interatrial septum and the free wall of the right atrium. The area of the right atrium was also planed in a fashion similar to that of the right ventricle.

Opacification of the right-sided cardiac chambers by contrast echocardiography was performed by the rapid venous injection of 10 ml of 5% dextrose in water during two-dimensional recordings in all patients to verify the right-heart anatomy as visualized on the echogram. Accordingly, we insured that the ultrasonic dimensions that we measured actually represented the boundaries of the right atrial and right ventricular chambers. Measurements of actual cast dimensions were compared to the measurements of the corresponding echo distances, as well as to the actual right atrial and right ventricular volumes by means of linear regression analysis. Echographic measurements of right cardiac chamber dimensions in patients with right-sided volume overload were statistically compared to those recorded in the control group using the t test for group data.

To assess the reproducibility of the two-dimensional technique, two subjects underwent 20 echo examinations by two different examiners. The recorded
two-dimensional images were then measured by both observers. Thus, 40 right atrial and 40 right ventricular images of maximal size were recorded and measured for dimensions and area by two observers, yielding 560 independent measurements. Since each measurement was obtained by means of a sound-pen (Digisonics, Houston, Texas) with a remote data printout, the observers were not aware of prior measurements by themselves or by the other observer. These measurements were then compared for variations between the subjects, different examiners, and different observers, with the t test and analysis of variance.

**Results**

**Right-Heart Casts**

Technically adequate right-heart casts were obtained from all hearts at autopsy. Figure 1A shows a representative silicone rubber cast of the right-sided cardiac chambers and is presented in the right anterior oblique projection. The right atrium, right ventricular inflow and outflow tracts, and pulmonary artery are outlined, and the trabecular pattern of the myocardium can be seen. Figure 1B is the same cast rotated 90° and shows the method of measuring long- and short-axis dimensions for each chamber.

A comparison of silicone cast dimensions and cast volumes revealed a good correlation between these variables. Thus, correlation coefficients of 0.70 and 0.71 were obtained for right atrial short and long axes, respectively, while values of 0.70, 0.93, 0.82 and 0.95 were observed for right ventricular mid-short, maximal short, long axes and area, respectively. Multiple linear regression analyses of right ventricular measurements yielded the equation: RV volume = −19.6 + 5.8 (RV maximal short) + 0.23 (RV area), (r = 0.98). Although an exact relationship between volume and dimensions cannot be inferred from the small number of casts, these data indicate that the sequence of increasing cast dimensions is strongly predictive of increasing cast volumes.

Figure 2 shows a right ventricular cast with the apex at the top of the picture and the two-dimensional echo obtained from this cast in the same projection. The similarity of size and shape between the two images is apparent. A comparison of dimensions obtained from actual casts and from two-dimensional echoes yielded correlation coefficients of 0.93 and 0.95 for right atrial short- and long-axis dimensions and 0.78 and 0.97 for right ventricular short and long axes, respectively (fig. 3).

**Clinical Studies**

Two-dimensional echograms in the four-chamber projection of suitable technical quality for analysis were obtained in all 50 patients included in this study. However, it was frequently difficult to obtain images of the entire long-axis expanse of the right ventricle in patients with right ventricular volume overload, and this chamber frequently appeared rounded, implying that the apex was omitted and the right ventricular image foreshortened.

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**Figure 2. A)** Another right ventricular (RV) cast as viewed from a right posterior oblique position, with the apex at the top of the photograph. **B)** The two-dimensional echocardiogram obtained from this cast is presented in an orientation identical to that of the cast. The similarity of size and shape of the cast and echogram are apparent. A scale factor of 1 cm is provided.
Figure 3. Comparison of measurements obtained by two-dimensional echocardiography vs the actual cast measurements, along with the regression analysis line and correlation coefficients for the right atrial short-axis measurements (upper left), right atrial long-axis measurements (upper right), right ventricular long-axis dimensions (lower right), and right ventricular short-axis measurements (lower left).

Figure 4 is an echogram in the four-chamber projection from a representative normal subject in this study recorded with the ultrasound beam centered over the right ventricle and atrium. The areas from which echographic measurements were obtained are illustrated. In contrast, figure 5 was obtained from a patient with tricuspid regurgitation who underwent a contrast echo study. Although the right ventricular long axis is markedly foreshortened, both right ventricular and right atrial short axes are greatly enlarged. The M-mode echogram from this patient is shown in figure 6, and reveals a right ventricular dimension that is well within normal limits.

M-mode echocardiography provided adequate right
ventricular measurements in all patients in this study. Although a difference existed between the mean value of right ventricular dimension in normals of 2.1 ± 0.1 cm (mean ± sem) and that in right ventricular volume overload patients of 2.8 ± 0.3 cm (p < 0.01), eight patients with right ventricular volume overload had M-mode dimensions which were within the normal range (fig. 6). Normalization of the M-mode dimension for body surface area improved the separation only slightly, since six overload patients continued to fall within the range of values recorded in normals.

Individual mean ± sem values for the right atrial measurements recorded by two-dimensional echo for all patients in this study are shown in figure 7. A difference was observed between the mean right atrial long-axis dimension of 4.2 ± 0.1 cm in normals, and that of 6.0 ± 0.3 cm in patients with right ventricular volume overload (p < 0.001). However, in 10 patients with right ventricular volume overload, the value for the long-axis dimension of the right atrium overlapped that of normals. The difference in right atrial short-axis dimension in normals of 3.6 ± 0.1 cm, and right ventricular volume overload patients, 6.5 ± 0.3 cm, was also significant (p < 0.001). For the right atrial short-axis dimension, only three overload patients had values that overlapped with the control group. The planed area of the right atrium was 13.9 ± 0.7 cm² for the normal group and 36.1 ± 3.2 cm² (p < 0.001) in the patients with right ventricular volume overload, with four abnormal patients overlapping the normal values. Since the right atrium appeared fairly constant in shape in the patients studied, an index of right atrial size was obtained as the product of the right atrial long axis and short axis, and revealed a smaller value in normals — mean index 15.0 ± 0.7 cm² (p < 0.001). This index yielded a similar statistical separation of the groups as well as the number of abnormal patients who overlapped the normal values, as did the planed right atrial area.

The two-dimensional measurements of the right ventricle are shown in figure 8. Although the mean right ventricular long-axis dimension was larger in patients with right ventricular volume overload than in normals, 7.8 ± 0.2 and 7.4 ± 0.3 cm, respectively, this difference was not statistically significant. A significant difference did exist between right ventricular maximum short-axis dimensions, with a mean of 3.5 ± 0.2 cm in normals and 6.1 ± 0.3 cm for the right ventricular volume overload group (p < 0.001). Measurements of right ventricular maximal short-axis dimension fell into the normal range in five volume overload patients. The mean value for the right ventricular short-axis measurement at a point midway between the tricuspid valve and apex of the right ventricle was smaller in normals, 2.8 ± 0.2 cm, than in right ventricular volume overload, 6.1 ± 0.4 cm (p < 0.001), with an overlap of four patients. The planed area of the right ventricle was also different in normals, 18 ± 1.2 cm², and right ventricular volume overload patients, 41 ± 2.6 cm² (p < 0.001). The right

![Figure 5](http://circ.ahajournals.org/)

**Figure 5.** A) The two-dimensional echocardiogram from a patient with right ventricular volume overload. The right atrial long- and short-axis dimensions and right ventricular maximal short-axis and mid-short-axis dimensions are increased over that of the control group. B) This stop-frame image from the same patient was obtained during a peripheral echo contrast injection. The contrast fills the right ventricular cavity out to the boundaries measured previously. RV = right ventricle; TV = tricuspid valve; RA = right atrium.
ventricular planed area separated the groups better than any single dimension, since only two right ventricular volume overload patients manifested values in the normal range. Both the short-axis dimensions and the right ventricular area were superior to the M-mode measurements in separating normals from overload patients.

In the patients evaluated for reproducibility, the mean, standard deviation, and t test probability value for the individual measurements of the smaller vs the larger subject were: right atrial long axis 4.43 ± 0.40 cm vs 4.65 ± 0.33 cm, p > 0.05; right atrial short axis 4.63 ± 0.31 cm vs 4.96 ± 0.29 cm, p < 0.005; right atrial area 18.72 ± 1.60 cm² vs 19.97 ± 1.97 cm², p < 0.05; right ventricular long axis 7.55 ± 0.46 cm vs 8.58 ± 0.40 cm, p < 0.001; right ventricular maximal short axis 4.53 ± 0.35 cm vs 4.73 ± 0.33 cm, p > 0.05; right ventricular short axis (midway) 3.56 ± 0.28 cm vs 3.77 ± 0.39 cm, p > 0.05; right ventricular area 25.81 ± 2.85 cm² vs 30.57 ± 3.53 cm², p < 0.001, showing a statistical difference in the right atrial short-axis and area measurements and the right ventricular long-axis and area measurements. In evaluations of the same subject, no significant difference existed between the different examiners or the different observers for any of the measurements (p > 0.05 by t test). When the different examiner and observer measurements for each subject were evaluated by analysis of variance, the calculated F ratio values were below F = 0.05. No significant difference existed between observers in the same patient.

Discussion

An established method does not exist for estimating right atrial size by M-mode echocardiography. Gramiak and Shah initially assessed the right atrial chamber during echo-contrast studies with the transducer along the right sternal border. Subsequently, M-mode echocardiographic findings for interatrial septa, intra-atrial baffles, coronary sinus catheters, and right atrial echo-contrast injections, but not atrial size, were described. Although a preliminary report suggested that the distance between the tricuspid valve annulus and the right atrial posterior wall at end-systole as determined by M-mode echogram was increased in patients with

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**Figure 6.** The M-mode echocardiogram from the same patient as in figure 5. The right ventricular measurement was made from the anterior right ventricular wall to the leading edge of right side of the septum. Although this patient had clinically severe tricuspid regurgitation which was confirmed at catheterization and surgery, the M-mode right ventricular dimension does not appear enlarged. This patient had mitral regurgitation in addition to right ventricular volume overload resulting in normal septal motion. CW = chest wall echoes; RV = right ventricle; LV = left ventricle.
FIGURE 7. A) Individual, mean, and SEM values for right atrial (RA) long-axis dimension are shown for both the normal (NL) and right ventricular volume overload (RVVO) groups. B) Similar data are provided for maximal right atrial short axis dimension. C) Values for an index of right atrial size obtained as the product of right atrial long and short axes are shown for all subjects in the present study. D) Similar data are shown for the planed area of the right atrium.

FIGURE 8. A) Individual, mean, and SEM for right ventricular (RV) long-axis measurements are shown for patients with right ventricular volume overload (RVVO) and normals (NL). B) Similar values are delineated for RV maximal short axis, C) RV mid-short axis, and D) RV planed area.
right ventricular volume overload, this technique has never been documented to be reliable enough for clinical application.

Significant limitations also exist in the measurement of right ventricular size by M-mode echocardiography. In contrast to the left ventricle, which is nearly circular in cross section, the right ventricle has a half-moon configuration, and the echographic dimension of this chamber is markedly influenced by the area that is traversed by the ultrasound beam. Thus, right ventricular dimension can vary considerably, depending on the position and angulation of the ultrasonic transducer, as well as the position or rotation of the heart within the thoracic cavity. Accordingly, different normal values exist for right ventricular dimensions in the supine and left lateral decubitus examinations.\textsuperscript{16} Finally, identifying the anterior wall of the right ventricle is frequently a problem, and this structure is often obscured by echoes from the chest wall by M-mode techniques. Some authorities have suggested that the right ventricular dimension be measured with a technique which assumes that the right ventricular endocardium is 0.5 cm posterior to the chest wall echoes at low-gain settings.\textsuperscript{17, 18}

Many of the problems associated with examining the right atrium and right ventricle by M-mode echocardiography occur because these chambers lie behind the echo-dense sternum. Thus, the ultrasonic beam directed from the left sternal area must pass obliquely through the right atrium, and the relative angle and position of the transducer therefore play an important role in the measurements obtained by M-mode techniques. In addition, a substantial area of these chambers cannot be imaged at all by M-mode echo because the ultrasonic beam cannot be manipulated into these segments.

Cross-sectional ultrasonic techniques, by providing spatial orientation, allow the heart to be imaged from new thoracic windows, including the cardiac apex. The ultrasound beam may be manipulated so as to examine nearly the total expanse of the right atrium and ventricle. A two-dimensional sector passing through the point of maximal cardiac impulse allows visualization of the mitral and tricuspid valve leaflets, and therefore enables better standardization of beam position by which to measure right atrial and ventricular size. Two-dimensional imaging from the cardiac apex obviates the problem of chest wall echoes overshadowing those of the anterior right ventricular wall, and allows the ultrasound transducer to be rotated to record the maximal right ventricular size. It is not surprising, therefore, that two-dimensional echocardiography performed from the point of maximal cardiac impulse provides an excellent technique for assessing the size of the right-sided cardiac chambers.

The nonuniform geometry of the right atrium and ventricle made it uncertain whether one, or even a combination, of individual dimensions existed which would correlate well with the volume of the chamber. However, data from a comparison of right atrial and ventricular dimensions and volumes from rubber casts indicated that specific chords existed for each chamber which accurately reflected volume. Subsequently, echograms of the casts themselves, performed in a waterbath, documented unequivocally that these respective dimensions could be accurately delineated by means of two-dimensional echocardiography. This provided the basis for the clinical studies evaluating the ability of echocardiography to discern differences in right atrial and ventricular size between normal subjects and patients in whom right-heart chamber dimensions would be anticipated to be enlarged due to right ventricular volume overload.

This investigation demonstrated that two-dimensional echocardiography provides a reasonably good method for identifying the boundaries and assessing the size of the right atrium. We found distinct and reproducible visualization of the right atrium in all patients. Although measurements of the right atrium by two-dimensional echo separated the normal group from patients with right ventricular volume overload, values for right atrial size overlapped those of normals in three to four patients. Two of these patients had minimal tricuspid regurgitation on cineangiography, however, and the regurgitant volume may have been insufficient to produce right atrial dilation.

Two-dimensional echocardiography also provided a technique to evaluate the size of the right ventricle. Values for right ventricular mid- and maximal short-axis and planimetric area distinguished normals from patients with right ventricular volume overload, with minimal overlap between the groups. There was no difference in the right ventricular long-axis measurement between normals and volume overload patients in this study. This limitation was primarily related to an inability to image the entire long-axis expanse of the enlarged right ventricle, which resulted in a foreshortening of this dimension (fig. 5). However, the planed right ventricular area readily discerned normals from overload patients and, although it was the most complicated and time-consuming method of measuring this chamber, it provided the optimal separation of the two groups.

The shape of the right ventricle is complex, and this complexity has led to a variety of different formulas and models for computing the size of the chamber from cineangiography. The angiographic models have included pyramids,\textsuperscript{19} stacks of cylinders,\textsuperscript{20} slices of ellipsoids,\textsuperscript{21} and divided chambers,\textsuperscript{22} with volume estimates using Simpson's rule,\textsuperscript{20, 21} area-length determinations,\textsuperscript{19, 21, 22} and area sum and product calculations.\textsuperscript{22} Despite the obvious dissimilarity of the shape of the models from that of the right ventricle, and from each other, good correlations with right ventricular volume have been made with each model.\textsuperscript{19-22} One reason for the rather good correlation of the various dissimilar models may be the constancy of shape of the right ventricle. Thus, the lateral height and the maximal length of the right ventricle correlate with a coefficient of 0.96 throughout the entire cardiac cycle.\textsuperscript{22} If the shape of the right ventricle remains somewhat constant through the cardiac cycle and
among normal ventricles, then a relationship should exist between any standard dimension and the corresponding right ventricular volume. The data from the present study are consistent with the concept that the accurate measurement of a single dimension of the right ventricle correlates well with the actual chamber size, and is of value in distinguishing normal from dilated ventricles.

An important question relates to a comparison of M-mode two-dimensional echocardiography in the evaluation of the size of the right-sided cardiac chambers. Two-dimensional echo readily enabled high-quality, standardized right atrial imaging by which to determine chamber size in all patients, a capability not previously demonstrated for M-mode techniques. As regards the right ventricle, in addition to enhanced images, two-dimensional echocardiography eliminated all but two volume overload patients from overlapping normal, compared with the overlap of six patients on M-mode recordings. Accordingly, these data indicate that cross-sectional echocardiography provides additional information to that obtainable by M-mode techniques.

The patients in this study had a fairly limited range of body surface area (1.85 ± 0.35 m²). Consequently, when both the M-mode and two-dimensional measurements were corrected for body surface area, no appreciable change in the results was noted. Although it was more convenient to measure only the absolute dimensions in these adult patients, the evaluation of patients outside of this body surface area range may require correction for surface area. Further evaluation of infants and children will be needed to determine the best relationship between the normal two-dimensional echo values and the body surface area.

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