Recommendations Regarding Quantitation in M-Mode Echocardiography: Results of a Survey of Echocardiographic Measurements

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with the technical assistance of Melissa Lebedeck

SUMMARY Four hundred M-mode echocardiographic surveys were distributed to determine interobserver variability in M-mode echocardiographic measurements. This was done with a view toward examining the need and determining the criteria for standardization of measurement.

Each survey consisted of five M-mode echocardiograms with a calibration marker, measured by the survey participants anonymously. The echocardiograms judged of adequate quality for measurement of structures. Seventy-six of the 400 (19%) were returned, allowing comparison of interobserver variability as well as examination of the measurement criteria which were used.

Mean measurements and percent uncertainty were derived for each structure for each criterion of measurement. For example, for the aorta, 33% of examiners measured the aorta as an outer/inner or leading edge dimension, and 20% measured it as an outer/outer dimension. The percent uncertainty for the measurement (1.97 SD divided by the mean) showed a mean of 13.8% for the 25 packets of five echoes measured using the former criteria and 24.2% using the latter criteria.

For ventricular chamber and cavity measurements, almost one-half of the examiners used the peak of the QRS and one-half of the examiners used the onset of the QRS for determining end-diastole. Estimates of the percent of measurement uncertainty for the septum, posterior wall and left ventricular cavity dimension in this study were 10–25%. They were much higher (40–70%) for the right ventricular cavity and right ventricular anterior wall.

The survey shows significant interobserver and interlaboratory variation in measurement when examining the same echocardiograms and indicates a need for ongoing education, quality control and standardization of measurement criteria. Recommendations for new criteria for measurement of M-mode echocardiograms are offered.

M-MODE ECHOCARDIOGRAPHY has rapidly achieved popularity as a noninvasive technique for obtaining quantitative dimensional measurements of cardiac chamber size, wall thicknesses, wall motion velocities, great vessel dimensions and valve motion. More recently, the complexity of the echocardiographic measurements themselves, and the data derived from them, have increased enormously with the application of computer processing to the echocardiogram. Limitations in the accuracy of angiographic measurements, as well as the effects of interobserver variability on angiographic interpretation, have been examined. Studies on the repeatability of the primary echocardiographic measurements, their potential for absolute accuracy and the effects of interobserver variability have not been undertaken. For both the raw and derived echocardiographic data to be clinically useful, the potential for individual error in measurements must be understood and the manner in which they are obtained standardized.

Three factors affect the accuracy of the primary echocardiographic measurements: 1) the theoretical resolution of the echocardiographic systems; 2) the overall technical quality of the derived echocardiographic trace; and 3) variability in interpretation and measurement of the clinical echocardiogram. Accordingly, the present study was undertaken to evaluate potential sources of observer error inherent in the interpretation of clinical M-mode echocardiograms. We hoped that by examining the reproducibility of echocardiographic measurements performed by a large population of interested echocardiographers examining the same preselected echocardiograms, we could 1) define the echocardiographic measurement criteria which were used by individual examiners; 2) identify which criteria led to the most consistently reproducible measurements, so that 3) recommendations could be made which might lead to future standardization of the manner in which echocardiograms are measured.

Methods

Four hundred echocardiographic measurement questionnaires were distributed to the membership of the American Society of Echocardiography at two successive semiannual meetings of the Society, the
first meeting held in November, 1976 in Miami Beach, Florida, and the second in March, 1977 in Las Vegas, Nevada. Each questionnaire had clear photocopies of five "adequate" echocardiograms for measurement, and they were distributed to people who expressed interest in M-mode echocardiography and were actively involved in performing and interpreting the M-mode echocardiogram. No specific assessment of their expertise in this field was available, other than their interest in participating in the survey and their membership in the organization. The echocardiograms used are shown in figure 1, panels 1 through 5, and represented tracings which were felt by the committee to be adequate for most echocardiographic measurements involving the left ventricle, mitral valve, right ventricular and aortic root and left atrial dimensions. The echocardiograms supplied were quite short and did not allow the examiner a large selection of areas for measurement, and, as a result, there are aspects of observer bias which were not examined and can therefore not be reported. The examiners were instructed to measure the parameters indicated on the figures if they were suitably recorded, using the indicated calibration marks, and to put the exact measurements in the appropriate box. They were also asked to indicate directly on the echocardiogram the points between which the individual structure was measured. A written description of the measurement criteria used was also requested. The echoes were to be mailed back anonymously to the chairman of the committee for analysis.

Data Analysis

Nineteen percent of the total distributed sample was returned, for a total of 76 packets of five echoes each. On approximately 15% of echoes, the written description of measurement criteria differed from the position on the echocardiograms where the measurements were drawn so all echo surveys were examined by one of the investigators and were subcategorized for measurement criteria by the way the measurements were actually drawn on the tracing. The data were then analyzed separately for each structure and separately on each echocardiogram (1 through 5) as follows: The mean and SD for each measurement on each recording were determined, first combining all measurement criteria. The 95th percentile confidence ranges were considered to be 1.97 standard deviations. The percent uncertainty was the 95th percentile confidence limit divided by the mean for the measurement times 100. Percent uncertainty is normalized by the

Figure 1, panels 1 through 5. Photographic reproductions of the actual photocopies used in this survey are provided. The actual size of the traces provided was 15 cm high and from 27-36 cm long. Each echo represents a rapidly performed sweep from the chordal level to the aortic root. In attempting to provide short sections of echoes, it was recognized that each echo was an adequate recording for most, but not all, of the structures. Abbreviations: Ao = aortic root dimension; RVC = right ventricular cavity dimension (diastole); LVPW = left ventricular posterior wall thickness; LA = left atrial dimension; SEPT = septal thickness; LVD = left ventricular dimension (diastole); RVAW = right ventricular anterior wall thickness; LVS = left ventricular cavity dimension (systole); MV = mitral valve excursion.
mean for the measurement, allowing comparison of the ranges of errors between the echocardiograms which differed in the absolute measurements. Each of the structure measurements were then separated by the measurement criteria used and the mean, SD, the 95th percentile confidence limits and the percent uncertainty were then determined. No attempt was made to separate the echoes by measurer experience or expertise. No measurements were made or checked compared to where they were drawn; only the numbers entered by the measurer in the spaces provided were used to constitute the raw data for this study.

Board Survey

A multiple choice questionnaire was also distributed to the executive board of the American
Society of Echocardiography. The Board consists of 15 expert echocardiographers who were asked to select which measurement criteria they preferred in their laboratories. The answers to this questionnaire were considered additional data to be used for comparison with the results of the measurement survey. The results of this brief questionnaire on preferences for measurement criteria are also reported.

Results

Seventy-six (19%) of the 400 echoes distributed were returned. Forty-five of the echoes were identified by the respondent. Of these, 34 were returned by physicians and 11 by technicians. Individual means of the measurements and percent uncertainties for each of the measurements on each of the five echoes, either combined or separated by criteria, are available in table form. Nonetheless, the amount of data presented as described above is beyond the scope of this report. As such, only the mean percent uncertainty for each of the structures for all five echoes together will be presented.

The mean percent uncertainty for each of the structure measurements on all five echoes unseparated by criteria is shown in figure 2. These results, unselected for criteria, will not be discussed in detail. However, they provide an estimate of the confidence limits that can be placed on echo measurements from different laboratories where individuals active in echo interpretation are reading traces without standardized criteria. The percentage of measurement uncertainty ranges, in general, from a low of 10% for left ventricular dimensional measurements, especially in diastole, to 14-20% uncertainty for aortic root dimensional measurements, and up toward 60-80% uncertainty for right ventricular wall and right ventricular cavity measurements.

Data Subanalyzed for Measurement Criteria

Aorta

Figure 3 (bottom) shows the mean percent uncertainty for the aortic root measurement separated by criteria.

Thirty-three percent of those measuring the aorta measured it as an outer/inner or leading edge dimension in diastole after the aorta had moved posteriorly and on a beat where the aortic cusps were visualized.

The percent uncertainty varied between 6% on echo 3 to 24% on echo 4, and was independent of the absolute size of the structure. Echo 3, which obviously has the clearest and longest portion of the aorta, was most accurately measured, but still showed a 6% uncertainty between examiner measurements. The mean percent uncertainty for the aorta measured in this fashion on all five echoes was 13.5%. For the 20% of the aortic roots measured outer/inner in systole, there was a similar range of uncertainties, slightly lower, especially for echo 4 and approaching 5% for echo 3. The mean percent uncertainty (24.2%) for those measuring inner/inner aortic diameter measurements in systole and for the 20% who measured as an out-

**Figure 2.** The mean percent uncertainty on all five echoes, regardless of criteria for the measurement of the individual structures measured in the survey, are shown by the height of the bar graph. Abbreviations: same as figure 1.
er/outer dimension (includes all walls) in diastole (not shown) (mean percent uncertainty 29.3%) were higher.

Left Atrium

Figure 3 (center) shows that 64% of the examiners excluded the aortic wall from the left atrial measurement at end-systole, while 34% included it. The mean percent uncertainty for this measurement was slightly lower (11.2%) when the wall was included.

Right Ventricular Wall (fig. 4, top)

The right ventricular wall is clearly a difficult structure to measure and is often poorly resolved on echocardiograms. Thirty-three percent of those reading the echocardiograms did not attempt to measure right ventricular wall on any of them. An additional 22% used 5 mm as a standard measurement for right ventricular wall thickness. Of the remainder who actually measured right ventricular wall thickness (34 surveys), 45% measured it at the onset of the QRS and 44% at the peak of the QRS. While the right ven-
ventricular endocardium at the peak of the R wave and 33% measured it at the onset of the QRS. The mean percent uncertainties, 34.8% and 22.8%, respectively, were similar for the two types of measurement and were both more acceptable than the mean percent uncertainty at 41% for the 10% of the measurers who arbitrarily subtracted 0.5 cm from the cavity measurement as the right ventricular anterior wall. Percent uncertainties in these measurements were most acceptable for echo 4 (about 20%), which appeared to have the least respiratory variation.

**Left Ventricular Internal Dimension (Diastole) (fig. 5, center)**

Left ventricular end-diastolic dimension was measured by 45% of examiners at the onset of the QRS, and by 46% at the peak of the R wave. The confidence limits shown on figure 5 reflect fairly good reproducibility of the measurements of this structure on almost all echoes and were slightly better at the onset of the QRS (mean percent uncertainty 8.2%) than they were at the peak of the R wave (mean percent uncertainty 11.8%). Likewise, in looking at the actual position of the measurements, it appeared that the accuracy of determination of the onset of the QRS was slightly better than the determination of the peak of the R wave, particularly on echoes 1 and 5, where the QRS morphology does not show a clear, discrete R wave. Eighty-two percent of the participants measured the left ventricular dimension at the level of the chordae and 15% at the level of the mitral leaflets.

**Left Ventricular Internal Dimension at End-Systole (fig. 5, bottom)**

Forty-three percent of the examiners measured this structure at the peak of the posterior wall motion. Forty-three percent measured it at the nadir of septal motion and the last 10% measured it at the smallest left ventricular dimension. The percent uncertainty of this measurement was greater than it was for the diastolic dimension of the left ventricle, and was most acceptable for echoes 1 and 2, with little difference in the percent uncertainty (14-16%) or the coefficient of variation between the criteria.

**Septum**

Measurements of the septum are shown in figure 4, center. Forty-four percent of the examiners measured it at the onset of the QRS and 41% at the peak of the QRS. Percent uncertainty for this measurement was high, in view of the importance placed on septal thickness measurements. It appeared that the most common error was inclusion of right-sided chordal echoes and resultant overestimation of the septum. The measurements at the onset of the QRS (mean percent uncertainty 19.5%) again appeared to have slightly less interobserver variation than those at the peak of the R wave of the QRS complex (mean percent uncertainty 23.8%).

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**Figure 5. Mean percent uncertainty for structures separated by criteria. The format is the same as in figure 3.**

- **Right Ventricular Cavity**
  - Figure 5 (top) shows that 33% of the respondents measured the right ventricular cavity from the right ventricular wall was measured by approximately 22 respondents on echo 1, and by 19 on echo 4, less than 15 of the total readers attempted to measure the right ventricular wall on echoes 2 or 5. The uncertainty limits shown on figure 4 reflect this low measure of confidence in this measurement. Even having separated out the timing of the measurement, mean percent uncertainty was still greater than 50% on echoes 1 and 4, where the wall did appear measurable.

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**Left Ventricular Posterior Wall**

Measurements of the left ventricular posterior wall are shown on figure 4, bottom. Again, a split occurred between the 40% of the respondents who measured this structure at the peak of the QRS and the 44% who measured it at the onset of the QRS. The mean confidence limits (23% and 23.4%, respectively) were similar to those for the septum and again were also very similar between the two criteria of measurement. Variable portions of chordal echoes and epicardial lines were often included in the measurements.

**Mitral Valve Excursion (fig. 3, top)**

Seventy-three percent of examiners measured a D-E excursion with a mean percent uncertainty of 17.6%, while only 17% measured a C-E excursion with a mean percent uncertainty of 22.2%.

**Statistical Differences in Percent Uncertainty**

With the exception of left atrium measured in diastole (fig. 3) and the aorta measured as an inner/inner dimension, none of the differences in the mean percent uncertainty between criteria were statistically different from other criteria. The two measurements cited above showed a statistically higher mean percent uncertainty than the other criteria used for measurement of structures.

**Board Survey**

The above results were compared with the results of the Board of Directors survey. In the survey, 41% of the board preferred identifying end-diastole at the peak of the R wave and 39% used the onset of the QRS. Fifty-three percent approximated the smallest dimension of the left ventricle at end-systole by eye, and only 41% by the peak of the posterior wall motion. Fifty-three percent measured the aorta using the leading edge methodology and 24% used an outer/outer diameter method. Forty-seven percent measured the aorta at end-systole, when it was anterior, and only 29% measured it in diastole. Despite the increased reproducibility of including the aortic wall in left atrial measurement, 71% of the Board preferred to exclude it. All expressed concern about finding the real left atrial posterior wall; one-half used the hardest or brightest intracavitary echo, and one-half preferred to demonstrate continuity of the left atrial wall with the atrioventricular ring on a sweep. All measured the left atrium at end-systole. Thirty-one percent of the Board preferred not to measure the right ventricular wall at all and 50% said they did so in approximately one-third of their echocardiograms. Sixty-three percent measured the right ventricular cavity from endocardium to the septum in a plane passing through the left ventricle in the classical short axis at the level of the chordae. Thirty-one percent subtracted 5 mm for the right ventricular anterior wall and measured from the transducer artifact to the septum. Seventy-six percent measured the left ventricle at the level of the chordae and only 24% at the mitral valve. Forty percent of the Board measured D-E excursion and 40% measured C-E excursion.

Finally, 100% of the Board suggested that they would be willing to change their measurement criteria in an effort toward standardization.

**Discussion**

Several factors affect the accuracy of primary echocardiographic measurements. These include: 1) the theoretical resolution of the echocardiographic system, which is a function of transducer frequency and the axial and lateral resolution characteristics of the instrumentation at the depth of the structure being imaged; 2) the overall quality of the echocardiographic data, i.e., the clarity of interface delineation, the avoidance of angulation errors, beam width artifacts, and other problems of echocardiographic structure identification; and 3) factors relating to the clinical interpretation of the echocardiogram, i.e., the selection of the structure interfaces, the specific criteria used for echocardiographic measurements, the interobserver variability, and even the observer bias.

The results of this study suggest that major problems exist with interobserver variability, raising questions as to the meaning of echocardiographic data from one laboratory compared with results from another. The present study does not examine the theoretical accuracy of M-mode measurements and was designed to eliminate the variabilities inherent in echo recording by providing adequate records for interpretation. As such, the study did not examine differences in the methods of recording of the echocardiograms themselves and the biases existing within those differences for what is an acceptable echo of a structure, nor have we approached the even greater problem of quality control and consistency in echocardiography. In general, the authors of this paper and the members of the committee believe that when questions exist as to the identifiable boundaries of a structure because of echo quality, either secondary to instrumentation, technique or a difficult patient, quantitation of that structure should be avoided.

Other aspects of reader bias were not examined in this study. These are obvious when a long record is presented to a large number of readers and each person finds the area of the septum or posterior wall which looks most like what he would expect it to, based on his own experience, and the clinical diagnosis of the patient, and then performs his measurement on that area. In this study, only a few beats of each structure were provided, and this cause of measurement scatter was not examined. Even after the elimination of the above factors, problems still exist with regard to quantitation in echocardiography which affect how one may interpret an echocardiographic report on a patient if it is performed in another laboratory. Quantitation in echocardiography appears to be most useful when serially applied to the same patients to detect
alterations in their conditions. Nevertheless, consistent reading within a single laboratory also requires strict use of quantitation based on clearly defined standards and criteria in echocardiography.

While the measurement uncertainties between the observers in this study, unselected as to reader expertise, were fairly large, our results in no way affect the validity of the many meticulously performed quantitative echo studies which have been published in recent years. Additionally, if the criteria for standardization recommended in this report are adopted for general use, continued vigilance will be required to carefully identify the methodology used in previously published studies when comparisons are made. However, this study indicates that some improvement in echocardiography can be achieved by standardization of echocardiographic criteria between laboratories.

There are multiple methods of actually measuring the echocardiogram. The classical method has always been to measure it directly with a millimeter ruler and calipers and then multiply or divide the raw measurements by a conversion factor which expressed how many real millimeters a 1 cm standard occupies on the echocardiogram. Another convenient method involves the use of a calipers and linear variable scale ruler. Most recently, ultrasonic spark gap digitizers or light pen X-Y digitizers have been used in echocardiography for measurement; these have very accurate measurement capability. Nonetheless, the greatest measurement problem is not in the actual determination of the distance between two points, but in the process of determining between which points the distance should be measured. The use of computer-derived continuous left ventricular minor axis dimensional plots or continuous wall thickness measurements during the cardiac cycle and first order derivatives (differentiated with respect to time) of these measurements may increase the accuracy of timing of enddiastole and systole, but these methods are not widely used.

Recommendations

The following recommendations (fig. 6) summarize the Committee's view of standardization as it can be best achieved with regard to criteria for structure measurement with M-mode echocardiography. For the most part, our criteria are selected to allow the greatest reproducibility between observers because there is little scientific evidence upholding the theoretical accuracy of one criterion over another for actually measuring cardiac structures by M-mode echocardiography. The criteria recommended appeared to be relatively reproducible on our survey, although the number of respondents was small and
there were few statistically significant differences between the mean percent uncertainties shown for the criteria. The criteria are also based on certain physical
and instrumentation constraints, such as the leading edge and thinnest possible continuous line constraints (see below) which appear to be more reproducible because they are less dependent on instrument gain or signal processing. The recommendations also take
into account the preferences of the Board of Directors of the American Society of Echocardiography, but are not based solely upon them. The recommendations are as follows:

Aortic Root

The Committee recommends that the aortic root be measured by the leading edge methodology — outer/inner; from the anterior portion of the anterior aortic wall to the inner or anterior-most boundary of the posterior aortic wall and only after a mitral/aortic sweep and in an area where at least two aortic cusps are visualized to reduce the potential for angulation error. The aortic tracing should be marked on the record by the technician when he or she has completed the sweep and finds his/her hand perpendicular to the chest wall when recording the aorta. Since aortic interfaces are often less clear in systole because of angulation, and in consideration of variable expansion of the aortic root in systole, the aortic root should be measured at end-diastole at the onset of the first rapid deflection of the QRS complex of the ECG.

Left Atrium

The left atrial dimension should be measured at end-ventricular systole, including the thickness of the posterior wall of the aorta, which was excluded from the aortic measurements. The measurement should be made after performing a sweep and demonstrating which of the lines in the left atrium is in continuity with the left ventricular posterior wall.

Timing of End-Diastole for Wall and Cavity Measurements

The Committee recommends that the onset of the QRS is the point at which end-diastolic measurement should be made. This recommendation is made since there is variability in identifying end-diastole and in the morphology of the QRS complex, and in the full knowledge that the onset of the QRS does not represent the real end of diastole. The peak of the R wave occupies a variable portion of the ECG, depending on the lead, and any arbitrary delay after the onset of the QRS must take into account the age of the patient and the heart rate. Therefore, it seems most reasonable to make all measurements at the onset of the first deflection of the QRS complex of the ECG.

Cavities and Walls — Definition of the Standardized Plane

With regard to the level at which to measure cavities and walls, it has been shown that the mitral valve leaflets occupy a larger portion of the left ventricular cavity in the small heart than in the adult heart. In young children and infants, right and left ventricular cavity dimensions and wall thickness measurements should probably be measured at the level of the mitral leaflets. In older children and adolescents, the structures can be measured at the level of the chordae as in adults. Again, the transducer should be perpendicular to the chest wall or pointed slightly inferiorly and laterally at the end of a long axis and “T” scan sweep when these measurements are obtained.

Right Ventricular Anterior Wall

The right ventricular anterior wall can be measured, but only on echocardiograms in which the epicardial and endocardial surfaces have been brought out by damping and a high frequency transducer. It should be measured at the onset of the QRS in a plane passing through standard portions of the left ventricle.

Right Ventricular Cavity Dimension

The right ventricular cavity dimension should be measured only when the right side of the septum and the endocardium of the right ventricular anterior wall are clearly visualized and in the usual plane passing through the left ventricle, either at the chordal level or at the mitral valve level, depending on the age of the patient. Switch gain (see below) and/or damping may be used to avoid confusion of chordal echoes on the right septal surface. The right ventricle should be specifically measured in a part of the echo marked by the technician as end-expiration.

In some patients, even when the right ventricular wall is not imaged clearly, it may be useful to try to estimate the size of the right ventricular cavity. We recommend that such measurement be called a right ventricular dimensional estimate and that it be performed at end-expiration, at the onset of the QRS from the right septal surface to a point which most clearly approximates the right ventricular anterior wall echo. Left lateral decubitus positioning should be avoided during this portion of the echo, since this position alters the meaning of the right ventricular dimensional estimate, or the right ventricular dimension itself. As an alternative, a standard set of wedge pillows should be available to allow reproducible 30° and 45° left lateral decubitus positioning. Even with these precautions, right ventricular anterior wall and cavity measurements should be viewed with caution.

Left Ventricular Septum and Posterior Wall Thickness (End-Diastole) and Left Ventricular End-Diastolic Cavity Dimension

With good septal visualization of both the right and left septal surfaces and at the onset of the QRS, one may measure septal thickness, posterior wall thickness (if endocardial and epicardial surfaces are imaged clearly) and the end-diastolic dimension of the left ventricle. In all these measurements, switch gain or damping should be used to decrease the thickness of
the lines and separate chordal structures. Wall and cavity measurements should be made, in general, by relying on a leading edge methodology (from the anterior-most edge of endocardial lines) and by using the thinnest continuous echo lines. Although this methodology will require cavity measurements to be made slightly into the septum for the internal dimension of the left ventricle or into the right ventricular anterior wall for the internal dimension of the right ventricle, it avoids dependence upon the gain or the signal processing of the echo system inherent in the position of the trailing edge of echo lines.

**Left Ventricular Systolic Dimension**

There appears to be little difference in the reproducibility of measurements of the left ventricular dimension in systole between measurements at the peak of the posterior wall motion or the nadir of septal motion. Because of its closer timing relationship to end-systole, we recommend that the left ventricular systolic dimension be measured at the nadir of septal motion in patients whose septal motion is normal. In patients in whom septal motion is abnormal or paradoxical at the level of the chordae (standard plane), left ventricular systolic dimension, alternatively, should be measured at the peak of the posterior wall motion.

**Mitral Valve**

The mitral valve should be measured as a D-E excursion in an area derived from the standard sweep where both the anterior and posterior leaflets are imaged.

**Additional Observations**

1) A switch gain circuit initially described by Griffith and Henry18 or an automatic damping circuit is being provided in many echo systems. While no controlled study has been performed, switch gain appears to provide enhancement of the posterior epicardial interface, while clarifying that some weaker echoes arise from chordae. This type of system appears most useful in increasing the accuracy of cavity dimensional measurements, wall measurements and septal thickness measurements. The use of damping control in the near field in conjunction with higher frequency transducers appears to provide the greatest likelihood of adequately imaging the right ventricular anterior wall.

2) Manufacturers should be encouraged to provide an impedance respirometer trace which can be superimposed on the echocardiogram, or in its absence, the technician should mark the end of expiration for several respiratory cycles on adequate portions of the echocardiogram. We would suggest that right and left ventricular cavity measurements and left atrial measurements should be obtained at end-expiration.

3) We would encourage that ECG leads be placed and electrocardiographic amplification systems be provided to allow the recording of a standard lead II of the electrocardiogram. This should minimize variability of electrocardiographic QRS complex morphology, especially for serial studies on the same patient. It may also provide additional diagnostic information under some circumstances.

4) While we have no data to support improved accuracy, we would encourage that all measurements report an average of determinations of three to four beats, since averaging will make each measurement representative of a reproducible portion of the echocardiogram.

**Conclusion**

The potential for measurement of structures by two-dimensional echocardiography and the additional use of computers complicates the field and will require ongoing revision of these criteria. Nonetheless, substantial problems exist in interobserver measurement in M-mode echocardiography that can, to some extent, be improved by standardization. In order to maximize reproducibility and standardize measurement criteria and terminology in M-mode echocardiography, we recommend these criteria for measurement.

**Addendum**

The recommendations included in this report were approved by the Board of Directors of the American Society of Echocardiography by unanimous vote on March 8, 1978.

**References**

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The Echocardiographic Profile of Patients After Mustard's Operation

NORMAN H. SILVERMAN, M.D., MAURICE PAYOT, M.D., PAUL STANGER, M.D., AND ABRAHAM M. RUDOLPH, M.D.

SUMMARY In order to establish an echocardiographic profile of patients with simple transposition after Mustard’s operation, we examined the M-mode records of 10 patients who were found to be free of significant abnormalities at follow-up cardiac catheterization. When compared with established normals, right ventricular wall thicknesses and cavity dimensions were increased, while left ventricular wall thicknesses and cavity dimensions fell below the mean. The wall thicknesses, cavity dimensions and ratios of right ventricular prejection period/ejection time and left ventricular prejection period/ejection time were appropriate for the physiologic role of the ventricles rather than their morphologic identity.

In each patient, a portion of the intra-atrial baffle was identified behind the pulmonary root. There was variation in baffle position and baffle mobility within the group, as well as in individual echograms. A variety of valve motion abnormalities were noted; these included diastolic flutter of the atrioventricular valves in all 10 patients and systolic anterior motion of the mitral valve in six patients. Paradoxical septal motion was found in nine patients. Although only minimal or no left ventricular outflow gradients were found at catheterization, nine patients had narrowing of the left ventricular outflow tract, 10 had systolic flutter of the pulmonary valve and eight had early partial closure of the pulmonary valve.

The finding of a large number of echocardiographic abnormalities in a group of patients with good hemodynamic results suggests that these echocardiographic features are to be expected after Mustard’s operation. Furthermore, the reversal of the physiologic role of the ventricles must be considered when interpreting the echocardiographic dimensions and systolic time intervals.

PATIENTS WHO HAVE UNDERGONE Mustard’s operation have been found to have a wide variety of anatomic, hemodynamic and echocardiographic abnormalities, and each of these may change over time.1-11 Evaluation of such changes by serial cardiac catheterization is associated not only with risk but also with cumulative radiation dosage and technical problems related to peripheral vessel reentry. Although echocardiography provides more limited anatomic and physiologic information than cardiac catheterization, such noninvasive studies augment clinical evaluation in deciding an appropriate time for recatheterization. Because the cardiac anatomy and physiology of patients who have undergone Mustard's operation is quite different from that of normal individuals, conventional echocardiographic standards may not be applicable to these patients. Although several echocardiographic abnormalities have been reported in post-Mustard patients12-16 it is not clear which of these abnormalities are indicative of a significant hemodynamic disturbance. Therefore, we have attempted to establish a qualitative and quantitative echocardiographic profile of patients with simple transposition who underwent Mustard's operation and who, at postoperative cardiac catheterization, were found to have a good hemodynamic result.

Methods

Ten post-Mustard patients with good hemodynamic results shown by cardiac catheterization, who also had M-mode echocardiograms, were studied.
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