Accuracy and Reproducibility of New M-mode Echocardiographic Recommendations for Measuring Left Ventricular Dimensions

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SUMMARY In order to assess the accuracy and reproducibility of the proposed American Society of Echocardiography (ASE) method for measuring left ventricular dimensions on M-mode echocardiograms, we measured the end-diastolic (Dd) and end-systolic (Ds) dimensions by the ASE method and our current technique in 50 normal subjects and 24 patients without coronary artery disease who had symmetrically contracting ventricles on cineangiography. Dd and Ds were significantly greater by the proposed ASE method than by our current technique (p < 0.001), but the correlation between the two was good (r = 0.93 and 0.83, respectively). In 10 of the normal subjects, the interobserver variability of both methods was excellent. In the 24 patients, the proposed method consistently overestimated the angiographic left ventricular volumes compared with our current technique and occasionally the discrepancies were quite large. Therefore, the proposed ASE method for measuring left ventricular dimensions is not clearly superior to other currently available techniques.

SEVERAL TECHNIQUES have been described for measuring left ventricular dimensions on M-mode echocardiograms. Most of the methods use the peak of the R wave on a simultaneously recorded ECG to designate end-diastole, but some studies have used the onset of the QRS complex and others have measured the largest dimension regardless of timing. There has been more diversity of opinion concerning the measurement of the end-systolic dimension. Some of the methods used for measuring end-systole are as follows: the end of the electrocardiographic T wave; the smallest dimension; at the timing of the aortic second heart sound; the maximum posterior wall anterior excursion; and our current technique, which is a variation of the method that uses the smallest dimension. Almost all of these methods have used the opposing edges of the septum and posterior wall endocardial echoes as the limits of the distance measured. Measurements by some of these techniques have been compared with angiographic measurements of left ventricular dimensions and volumes, and the correlations usually have been good.

Recently, in an effort to standardize the method for measuring these and other echocardiographic measurements, the American Society of Echocardiography (ASE) undertook a study to determine interobserver variability in measuring various dimensions from selected echocardiograms. A series of echocardiograms was handed out to nonselected participants who used their own measurement techniques and the results were then compared. Based on these data, the ASE proposed a new measurement method, which theoretically was the most reproducible way to measure left ventricular dimensions. The proposed method is different from all others that have been described and no normal values for it have been reported. Further, the accuracy of the proposed technique has not been assessed by comparing the results with similar measurements obtained by left ventricular cineangiography. Accordingly, we sought to compare the results of measurements made by our current technique with those made by the proposed technique and to compare both with the results of cineangiography.

Methods

Two groups of subjects were studied. First, 50 normal volunteers, ages 19-35 years, had echocardiograms recorded at rest in the left lateral decubitus position. Second, 24 patients without significant coronary artery disease or valvular regurgitation, and with symmetric left ventricular contraction on cineangiography had echocardiograms performed in the same manner within 48 hours of the angiographic study. Seventeen of the patients were studied because of atypical chest pain, four had idiopathic cardiomyopathy, one had mitral stenosis, one had a ventricular septal defect and one had constrictive pericarditis.

Echocardiograms were performed with either a Picker Echoview II coupled to a Honeywell Visicorder Model 1856, a Picker 80-C coupled to an Irex Continutrace 101, or an Electronics for Medicine Echo IV System. All recordings were made at 100 mm/sec paper speed, with a simultaneous ECG and indirect carotid pulse tracing. The transducers used were 2.25, 1.9 or 1.6 MHz. The standard interspace technique was used for recording the appropriate segment of the left ventricle for measuring minor-axis dimensions.
and the echocardiographic controls were set to optimize the endocardial echoes. Left ventricular volumes were estimated by cubing the appropriate echo dimension measurements.\textsuperscript{1, 2}

The cineventriculograms were performed with the patient in the right anterior oblique position and left ventricular volumes were determined, using the Kasser-Kennedy method,\textsuperscript{17} by an investigator who was not familiar with the echo results.

Figure 1 illustrates the two echo measurement techniques used. The proposed method illustrated in panel A uses the onset of the QRS complex for the timing of end-diastole and the maximum posterior septal movement for end-systole. Measurements are then made from the anterior or leading edge of each endocardial surface.\textsuperscript{18} Our current method, shown in panel B, uses the peak of the QRS complex to designate end-diastole and the minimum distance between the septum and posterior wall, whether or not the two walls are exactly apposed, as the end-systolic dimension. Measurements are then made from the apposing or inner edges of each endocardial echo.\textsuperscript{18}

In the 50 normal subjects, two observers measured the echocardiograms. One used our current technique and the second used the proposed ASE method. All measurements made using the ASE method were reviewed by a third observer to insure technical accuracy with this new method. The echoes of the 24 patients were measured in a similar manner, with one observer using the proposed technique and a second using our current method. All measurements made using the ASE method were reviewed by a third observer. Each observer team reported the average of measurements on five beats believed to be best suited for the technique being used. Thus, the beats measured by one observer team may or may not have been the same as those measured by the other observer team.

In 10 of the normal subjects, two observers independently measured the same five beats using the proposed ASE criteria and two other observers independently measured five beats (not necessarily the same ones the other pair measured) using our current method in order to evaluate the interobserver variability of the two techniques.

All measurements and calculations by the two echo methods and cineangiography were compared by means of the paired $t$ test, and correlation coefficients between measures were determined by linear regression analysis. These statistical comparisons were made on a NOVA computer (Data General Corp.) using the CLINFO program.

**Results**

Table 1 gives the results in the 50 normal subjects. The end-diastolic dimension by the proposed ASE method averaged 50.0 ± 4.2 mm (SD), which is significantly greater than 48.3 ± 4.0 mm by our current technique ($p < 0.001$), but the correlation coefficient between the measures by the two methods is good ($r = 0.93$). The end-systolic dimension averaged 33.9 ± 3.9 mm by the proposed method, which is significantly larger than 30.1 ± 3.6 mm by our current technique ($p < 0.001$), and the correlation between the two is good ($r = 0.83$). The calculated percent dimensional shortening averaged 33 ± 5% by the proposed method, which is significantly smaller than 38 ± 5% obtained by our current technique ($p < 0.001$), and the correlation between the two methods is fair ($r = 0.77$).

| Table 1. Dimension Measurements in 50 Normal Subjects by the Two Techniques |
|-----------------------------------------------|---------------|---------------|
|                                 | Dd (mm) | Ds (mm) | %ΔD |
| Proposed                        |            |            |      |
| Mean                            | 50.0 ± 4.2 | 33.9 ± 3.9 | 33 ± 5 |
| Range                           | 39.0–75.5 | 22.0–44.0  | 21–44 |
| Current                        |            |            |      |
| Mean                            | 48.3 ± 4.0 | 30.1 ± 3.6 | 38 ± 5 |
| Range                           | 39.5–55.5  | 21.0–36.5  | 26–49 |
| $p$                             | <0.001    | <0.001    | <0.001 |
| $r$                             | 0.93      | 0.83      | 0.77  |

Abbreviations: Dd = left ventricular end-diastolic dimension; Ds = left ventricular end-systolic dimension; %ΔD = percent change in dimension.
difference was calculated. Also, the two observers' measurements were compared to determine if there was a statistically significant difference, and the correlation coefficient was derived. The results of these computations are shown in Table 2. The mean differences between the two observers' measurements are similar by both techniques. The range of differences is somewhat larger with the proposed method, but the correlations are excellent. All the measurements by the two observers are significantly different with the exception of the end-diastolic dimension using the proposed technique. The most significant difference occurs with the measurement of end-systole using the proposed method, because one observer consistently measured a smaller dimension than the other.

Table 3 gives the derived volume and ejection fraction data in the 50 normal subjects using the two measurement techniques. End-diastolic volume by the proposed method averaged 128 ± 30 ml, which is significantly larger than 115 ± 27 ml by our current technique, but the correlation between the two methods is excellent (r = 0.93). End-systolic volume was also significantly larger by the proposed method, averaging 40 ± 14 ml compared with 28 ± 10 ml (p < 0.001), and the correlation is fair (r = 0.80). Ejection fraction averaged 69 ± 7% by the proposed method, which is significantly different from 75 ± 6% by our current method (p < 0.001), and the correlation between measurements is poor (r = 0.57). The upper limit of normal for end-diastolic volume is larger with the proposed technique (190 ml vs 171 ml by our current technique) and the lower limit for ejection fraction is less using the proposed technique (51% vs 61%).

In Figure 2, the end-diastolic dimension measurements by the proposed ASE echocardiographic method and those obtained by our current technique are compared with those determined by cineangio- gram. In both cases, most of the points and the regression lines lie below the lines of identity. Thus,

**Table 2. Interobserver Variability of the Two Measurement Techniques in 10 Normal Subjects**

<table>
<thead>
<tr>
<th></th>
<th>Dd (mm)</th>
<th>Ds (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proposed</td>
<td>Current</td>
</tr>
<tr>
<td>Mean difference</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>Range of difference</td>
<td>0.5-5.5</td>
<td>0-3.5</td>
</tr>
<tr>
<td>p</td>
<td>NS</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>r</td>
<td>0.94</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Abbreviations: Dd = left ventricular end-diastolic dimension; Ds = left ventricular end-systolic dimension.

**Table 3. Derived Volumes and Ejection Fraction in the 50 Normal Subjects from the Two Techniques**

<table>
<thead>
<tr>
<th></th>
<th>EDV (ml)</th>
<th>ESV (ml)</th>
<th>EF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>128 ± 30 (sd)</td>
<td>40 ± 14</td>
<td>69 ± 7</td>
</tr>
<tr>
<td>Range</td>
<td>59-190</td>
<td>11-80</td>
<td>51-82</td>
</tr>
<tr>
<td>Current</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>115 ± 27</td>
<td>28 ± 10</td>
<td>75 ± 6</td>
</tr>
<tr>
<td>Range</td>
<td>61-171</td>
<td>9-49</td>
<td>61-88</td>
</tr>
<tr>
<td>p</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>r</td>
<td>0.93</td>
<td>0.80</td>
<td>0.57</td>
</tr>
</tbody>
</table>

Abbreviations: EDV = end-diastolic volume; ESV = end-systolic volume; EF = ejection fraction.
the correlation coefficients are excellent. Also, both techniques have a similar number of points outside the 95% confidence limits.

From the dimensional measures presented above, left ventricular volumes were calculated. The average echo end-diastolic volume of 149 ± 110 ml by the proposed method is significantly larger than the volume of 133 ± 91 ml by our current technique (p < 0.05), which is similar to the volume of 130 ± 77 ml derived from the angiographic data. The mean difference between the end-diastolic volumes estimated by the proposed technique compared with the angiographic values is +15 ml with a range of -121 ml to +146 ml. The mean difference by our current technique is only +3 ml and the range of -120 ml to +77 ml is somewhat narrower. One patient is incorrectly classified as having a large end-diastolic volume by both echo methods compared with angiography. All the other patients are correctly classified, but there were some notable differences in the values obtained by the two echo techniques. The most striking examples are gross overestimations by the proposed technique. For example, in one patient, left ventricular end-diastolic volume is almost identical by our current echo technique and angiography (66 and 65 ml), but the proposed technique overestimated it by 72 ml at 137 ml. In another patient, our current technique overestimated a large left ventricle by 18 ml (375 vs 357 by angiography), but the proposed technique overestimated it by 127 ml at 484 ml.

The calculated ejection fractions by all three methods are significantly different from one another and both echo methods result in larger values for ejection fraction compared with the angiographic data. The value by the proposed technique of 65 ± 14% is closer to the angiographic value of 59 ± 14% than is 70 ± 14% by our current method. In figure 4, individual ejection fractions obtained by the echocardiographic methods are compared with the corresponding angiographic measurements. Both regression lines are above the line of identity; therefore, echocardiography tends to overestimate ejection fraction, but the correlation coefficients of 0.80 are good. However, with the proposed method, nine points fall outside the 95% confidence limits compared with 14 points by our current technique. Also, the mean difference between the calculated ejection fraction by the proposed technique is +5% with a range of -15 to +31%. The mean difference by our current technique is larger at +10%, but the range of -7 to +35% is similar.

All the patients were classified similarly as having either normal or depressed ejection fractions by the two echo techniques. However, both techniques failed to detect slightly low ejection fractions of 48% by angiography in two patients. One patient's ejection fraction was calculated at 60% by the proposed method and at 62% by our current one. The other patient's ejection fraction was overestimated at 70% by the proposed technique and at 83% by our current method.
**Discussion**

An echocardiographic measurement method should conform to certain criteria. The most important criteria are that the technique be physiologically correct, that it be accurate in relation to any known standard, that it be reproducible between observers, and finally that it not be unnecessarily complex and difficult to perform. The degree to which various echo measurement techniques meet these criteria is discussed below.

End-diastole is the same as the onset of mechanical systole and occurs about 35 msec after the onset of the QRS complex. Our current echocardiographic measurement technique uses the peak of the electrocardiographic R wave as an approximation of this point because it is the simplest and most convenient reference point readily available on a standard echocardiogram. In a patient with a bundle branch block or other conduction abnormalities, we would choose a point 40 msec after the onset of the QRS. Also, if standard lead II did not show a dominant R wave, we would switch to a lead that did. The proposed ASE echocardiographic criteria suggest that the onset of the QRS complex be designated as end-diastole. Clearly, this point is before the end of diastole, since the ventricle is not activated until 25-50 msec later and thus further filling can occur after this point. The widest dimension has also been used, but this method is not accurate, because the ventricle may change shape during isovolumic contraction and increase the measured left ventricular dimension without any change in volume.

The end of systole or the onset of diastole is more difficult to define on the standard echocardiogram. The use of the electrocardiographic T wave as a reference point is inaccurate. Use of the second heart sound is cumbersome because it requires a simultaneous high-quality phonocardiogram, but usually occurs approximately 10 msec after the actual end of systole. A detailed echocardiographic study by McDonald et al., highlighted the problems of defining end-systole by analyzing the movement of the left ventricular walls. The septum is activated earlier than the posterior left ventricular wall and completes its posterior movement before the posterior wall completes its anterior movement. Also, at the end of these two excursions there is a variable period of time in which the two walls move with each other toward or away from the transducer. Presumably these periods of parallel motion of the two walls represent whole heart movement. Further shortening of the minor dimension near the end of systole is obscured by this motion of the whole heart.

One of the more popular techniques for measuring end-systole has been to estimate visually the smallest left ventricular dimension. For serial quantitative studies, a more precise determination would be desirable, which would require making several parallel measurements and selecting the smallest. Such a procedure would be tedious, which is a disadvantage of the smallest dimension technique. Our current...
method is a modification of this technique wherein the distance between the peak septal movement and peak posterior wall movement is measured whether or not the two inward motions are exactly apposed. This technique does not actually measure end-systole at any one point in time, but it has the advantage of being easy to perform.

Another popular method for measuring end-systole is to measure at the peak of posterior wall movement. However, in normal subjects this point is usually coincident with the dicrotic notch on a simultaneously recorded indirect carotid pulse tracing and with the opening motion of the anterior mitral valve leaflet echo. Because both these events occur after the end of systole, this point is incorrect in a strict physiologic sense. Why the ASE Committee on M-mode Standardization chose the peak septal motion for the end of systole is not clear from their interobserver variability data, because less than 4% of the respondents used this technique. Presumably, the decision was based on theoretical grounds.

Accuracy is perhaps one of the most important criteria for any measurement technique, especially when a recognized standard exists. In the case of the left ventricle, this standard would be cineangiography. The results of this study show that our current technique is more accurate than the proposed ASE technique for measuring both end-diastolic and end-systolic size. The proposed technique results in larger dimension measurements and hence overestimates ventricular volume compared with angiography. Interestingly, because the greater relative overestimation of volume occurs with end-diastole rather than end-systole, the ejection fraction is somewhat better estimated by the proposed ASE method.

This tendency to overestimation by echo has been noted in other studies using different echo measuring methods and is especially prevalent at larger volumes. Some laboratories have developed regression equations based on their data to correct for this overestimation. However, we have not been able to demonstrate any advantage, as compared to the cube formula, using regression equations with measurements made by our current technique.

Whether these regression equations would improve the data derived by the proposed technique was not evaluated in the present study.

Although the proposed method is based on a study that examined interobserver reproducibility, the technique derived is entirely new and has never been tested for reproducibility. Therefore, we assessed the interobserver variability of the proposed method vs our current method in 10 of the normal subjects. In general, both techniques were highly reproducible with mean differences between observer’s measurements in diastole and systole being less than 2 mm and with all correlation coefficients being better than 0.91. However, there were some significant differences between the measurements made by the two observers. The most marked difference was in the end-systolic measurements using the proposed method — one observer’s measurements were consistently smaller than the others. A reason for this is that the septal endocardial echo often flattens in the latter half of systole, making the peak motion difficult to determine. Therefore, if the proposed method is used, we recommend selecting the latest point of maximum septal motion in systole to allow for more anterior movement of the posterior wall and hence a smaller end-systolic dimension.

The purpose of this report is to point out the problems we encountered in trying to implement the proposed ASE M-mode echocardiographic measurement method when we compared its results with those of cineangiography. Although the overall correlations between measurements by the proposed technique and cineangiography were very close to those using our current technique, individual gross discrepancies with the angiographic data occurred with the proposed technique. Also, it is not our purpose to champion our current technique as the best. For practical reasons it was the only other measurement method used. Other measurement techniques have also compared favorably to cineangiography in previous studies and these methods may be as good as or better than our current one. Perhaps computer processing of echo signals using complex criteria impractical for hand measurements may be the ultimate answer to the measurement method dilemma. Clearly, more information is needed about this important subject. However, the data do not support the ASE recommendations for measuring left ventricular dimensions as being a superior method compared with other currently available techniques.

References
Detection and Estimation of the Degree of Mitral Regurgitation by Range-gated Pulsed Doppler Echocardiography

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SUMMARY Sensitivity and specificity of detection of mitral regurgitation was assessed by range-gated Doppler echocardiography. The degree of mitral regurgitation was also estimated by the depth and width of the regurgitant jet detected with Doppler and compared with that assessed by left ventriculography. Of 47 patients with an adequate Doppler study, 24 had no mitral regurgitation by ventriculography. All but one were also negative for mitral regurgitation by Doppler, for a specificity of 96%. Of 23 cases with mitral regurgitation documented by ventriculography, Doppler detected mitral regurgitation in 21, for a sensitivity of 92%. Two cases with mitral regurgitation undiagnosed by Doppler had mild mitral regurgitation due to papillary muscle dysfunction. All cases with rheumatic mitral regurgitation were detected. The degree of mitral regurgitation estimated with Doppler had a high correlation with that determined by ventriculography (r = 0.88, p < 0.01).

CONVENTIONAL M-MODE echocardiography has limited value in the diagnosis of mitral regurgitation, because often no associated structural abnormality of the mitral valve can be detected. Also, when the mitral valve echo is abnormal, as in mitral valve prolapse or calcific mitral annulus, mitral insufficiency may or may not be present.

A range-gated pulsed Doppler has been recently developed that can identify normal or abnormal flow patterns within intracardiac locations and thus detect valvular regurgitation. In the present study, we analyzed the sensitivity and specificity of Doppler echocardiography in detecting mitral regurgitation. We also attempted to estimate the degree of mitral regurgitation using this technique.

Methods

The details of the principles and general application of Doppler echocardiography have been recently published. In summary, Doppler ultrasound instruments are based on Doppler shift or Doppler effect which indicates that sound frequency reflected from moving surfaces such as blood cells within the heart or blood vessels is altered in proportion to the velocity of their movement. Reflected sound waves from the blood cells are analyzed using a special Doppler shift-detector system. Range gating allows the signals to be accepted from a teardrop-shaped 2 × 4-mm sample.
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