Accuracy of Echocardiography Versus Electrocardiography in Detecting Left Ventricular Hypertrophy: Comparison With Postmortem Mass Measurements

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The accuracy of electrocardiography, M-mode echocardiography and two-dimensional echocardiography in predicting left ventricular hypertrophy was compared in 50 patients who came to autopsy within 6 months after the studies were performed. Several methods for determining left ventricular hypertrophy were examined for each of the three techniques. M-mode echocardiography was technically adequate to evaluate the presence or absence of left ventricular hypertrophy more often than either electrocardiography or two-dimensional echocardiography. Measurements from M-mode echocardiography also correlated best with autopsy measurements. Both echocardiographic techniques had a higher sensitivity than electrocardiographic criteria in diagnosing left ventricular hypertrophy. Two-dimensional echocardiography was not shown to improve the M-mode assessment of left ventricular hypertrophy. In an attempt to simplify both M-mode left ventricular mass calculations and the diagnosis of left ventricular hypertrophy for the clinician, a left ventricular mass nomogram was constructed, enabling quick insertion of standard M-mode echocardiographic measurements.

Left ventricular hypertrophy is the response of the left ventricle to the stresses of pressure or volume overload (1). Although the 12 lead electrocardiogram is the standard method used in detecting left ventricular hypertrophy in patients, it has significant limitations in sensitivity and specificity, and little value in predicting the quantitative extent of hypertrophy. In practice, echocardiography, which can accurately quantitate left ventricular mass (2), is often used qualitatively in support of the electrocardiographic diagnosis of left ventricular hypertrophy. There are, however, few data regarding the relative accuracy of electrocardiography and echocardiography in identifying left ventricular hypertrophy (3). Therefore, this study was undertaken to compare electrocardiography, M-mode echocardiography and two-dimensional echocardiography in detecting left ventricular hypertrophy which was established by measurements of left ventricular mass at postmortem examination.

Methods

Study patients. The study group consisted of 50 patients aged 19 to 91 years (mean 65), who underwent autopsy at the University of California, Davis Medical Center over a 15 month period. It included all patients who had both electrocardiographic and M-mode echocardiographic examinations within 6 months of death (range 1 to 150 days), with the exception of 5 to 10 patients whose hearts were saved for instructional use and were hence unavailable. The mean interval from electrocardiogram to death was 30 days, and from M-mode echocardiogram to death 29 days. Of these patients, 23 had two-dimensional echocardiographic examinations at a mean of 21 days (range 1 to 98) before death.

Autopsy diagnoses. A formalin-fixed heart specimen was obtained from every patient for dissecting and weighing of the left ventricle. Final pathologic diagnoses in the 50 autopsy patients are shown in Table 1.
Table 1. Pathologic Diagnoses in 50 Autopsy Patients

<table>
<thead>
<tr>
<th>Cardiac Diagnoses (no. of patients)</th>
<th>Noncardiac Diagnoses (no. of patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary artery disease (27)</td>
<td>Sepsis (8)</td>
</tr>
<tr>
<td>Myocardial infarction (23)</td>
<td>Carcinoma (6)</td>
</tr>
<tr>
<td>Arteriosclerotic peripheral vascular disease (25)</td>
<td>Obstructive or restrictive lung disease (6)</td>
</tr>
<tr>
<td>Valvular heart disease (11)</td>
<td>Renal failure, chronic or subacute (5)</td>
</tr>
<tr>
<td>Stenotic or calcific valvular disease (7)</td>
<td>Cirrhosis (4)</td>
</tr>
<tr>
<td>Regurgitant valvular disease (3)</td>
<td>Cerebrovascular accident (4)</td>
</tr>
<tr>
<td>Subacute bacterial endocarditis (2)</td>
<td>Pulmonary embolus (3)</td>
</tr>
<tr>
<td>Idiopathic hypertrophic subaortic stenosis (3)</td>
<td>Hyperthyroidism (1)</td>
</tr>
<tr>
<td>Status post heart surgery (12)</td>
<td></td>
</tr>
<tr>
<td>Coronary artery bypass graft (6)</td>
<td></td>
</tr>
<tr>
<td>Valve replacement (5)</td>
<td></td>
</tr>
<tr>
<td>Valvotomy (1)</td>
<td></td>
</tr>
<tr>
<td>Ventricular septal defect repair (1)</td>
<td></td>
</tr>
<tr>
<td>Pericardial window (1)</td>
<td></td>
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</tbody>
</table>

or $V_0$. A total of 3.5 mV (35 mm deflection at normal standardization) or greater was diagnostic of left ventricular hypertrophy (5).

Estes point score. This was calculated by assigning points for key abnormalities on the electrocardiogram, such as QRS voltage and width, left axis deviation, delayed intrinsicoid deflection and strain (6). The maximal possible total score was 10; if 5 or greater, left ventricular hypertrophy was present; if 4, left ventricular hypertrophy was uncertain and if 3 or less, left ventricular hypertrophy was absent.

M-mode echocardiographic analysis. M-mode echocardiograms were obtained supine at the left sternal border through the fourth or fifth intercostal space using a Smith-Kline Instruments Ekoline 21 echocardiograph and a Honeywell strip chart recorder, or using the M-mode strip chart function of an Irex System 3, an ATL Mark III or an ATL Mark V sector scanner. Measurements were made at the tips of the mitral valve leaflets (Fig. 1). The onset of an R wave on the electrocardiographic tracing was used to time end-diastolic measurements (7). All measurements were the mean of at least three cardiac cycles.

Thicknesses of the interventricular septum (IVS) and the left ventricular posterior wall (LVPW), as well as the diameter of the left ventricular chamber (LVID), measured in centimeters, were inserted into the mathematical model for the prediction of left ventricular (LV) mass according to Devereux and Reichek (2):

$$LV mass (g) = 1.04 [(LVID + IVS + LVPW)^3 - LVID^3] - 13.6.$$  

Although these authors recommend the "Penn convention" (that is, exclude the most anterior septal echo and include the nearest posterior wall echo in left ventricular chamber diameter, generating thinner walls and larger left ventricular chamber diameter), after examining the first 25 patients using both the Penn convention and standard leading-edge to leading-edge measurements, we found the latter gave a better correlation with measured left ventricular weight. Thus, for this study we used the leading edge to leading edge convention in our mass calculations.

Two-dimensional echocardiographic analysis. Two-dimensional echocardiograms were made using videotaped recordings from an ATL Mark III or ATL Mark V mechanical sector scanner or an Irex System 3 or Toshiba SSH-10A phased array sector scanning device. They were performed with the patient supine, with the parasternal approach for a short axis view at the tips of the mitral valve leaflets and an apical four chamber view for a long-axis measurement of the left ventricle (Fig. 2). The observer traced the inner epicardial and inner endocardial echoes with a computerized light-pen system that calculated both an epicardial ($A_{ep}$) and endocardial ($A_{endo}$) area. Using the same light-pen system, left ventricular length was measured...
on the four chamber view from the most distal apical point visible to the juncture of the interventricular septum and the anterior mitral valve leaflet. These two-dimensional echocardiographic measurements were made at the onset of an R wave on the electrocardiographic tracing and visually verified by superimposing the light-pen tracings over at least three beats. Left ventricular mass was predicted by using a cylindrical approximation:

Left ventricular mass (g)

\[ \text{Left ventricular mass (g)} = (A_{ep} - A_{endo}) \times \text{length} \times \frac{5}{6} \] (8).

We also examined the left ventricular mass predicted by a second cylindrical model:

Left ventricular mass (gm)

\[ \text{Left ventricular mass (gm)} = (A_{ep} - A_{endo}) \times \text{length} \times 0.55 + 11 \text{ g} \] (9).

Necropsy left ventricular mass. Dissection of each heart specimen was performed according to the method of Bove et al. (10,11). First the right ventricular free wall was removed along the curve of the interventricular septum so that the remaining left ventricle plus interventricular septum had a nearly smooth, circular cross section. Then the aorta was removed just below the three semilunar valve cusps and the left atrium excised at the level of the mitral valve anulus. What remained was a left ventricle, free of atria and great vessels. After excess epicardial fat greater than 1 mm thick was dissected away, the ventricle was weighed on a precision balance. Weights ranged from 109 to 437 g (mean 223). Left ventricular hypertrophy is definitely present when the mass of left ventricle plus septum is 225 g or greater (12,13). On the basis of this criterion, pathologic left ventricular hypertrophy was judged present in 18 specimens; the other 32 had a weight within normal limits.

Results

Sensitivity and specificity of the three methods. Of the 50 patients, 5 had left bundle branch block, 1 had complete heart block and 2 had active ventricular pacing wires, invalidating both voltage and Estes point score as electrocardiographic diagnostic methods in these 8 patients. For the remaining 42, the sensitivity and specificity of the electrocardiographic variables are shown in Table 2. M-mode echocardiograms in 2 of the 50 patients were of sufficiently poor quality that they could not be read for measurements. Two-dimensional echocardiographic measurements could be made in 19 of the 23 patients who had two-dimensional echocardiographic examinations. Sensitivities and specificities for the M-mode and two-dimensional echocardiographic mass predictions are also shown in Table 2. Two-dimensional echocardiographic estimates of left ventricular mass had the highest sensitivity when used in diagnosing left ventricular hypertrophy in the 19 patients.

Figure 2. Two-dimensional echocardiographic analysis. The parasternal short-axis view at the tips of the mitral valve leaflets (left) was imaged at the onset of an R wave on the electrocardiographic tracing and traced with a computerized light-pen system. Inner endocardial (ENDO) and inner epicardial (EPI) outlines of the left ventricle were traced, generating areas for each. The apical four chamber view (right) was used for measuring long-axis length with the same computerized light-pen system. Again, at the onset of an R wave, the observer marked the point where the interventricular septum and anterior mitral valve leaflet met, as well as the most distal apical point visualized.
Table 2. Sensitivity, Specificity and Predictive Value of Variables Examined in Diagnosing Left Ventricular Hypertrophy

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Predictive Value (%)</th>
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<tbody>
<tr>
<td>ECG voltage</td>
<td>54</td>
<td>77</td>
<td>54</td>
</tr>
<tr>
<td>(deflection ≥ 35 mm)</td>
<td>(n = 42, p &lt; 0.05)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sokolow voltage</td>
<td>54</td>
<td>86</td>
<td>64</td>
</tr>
<tr>
<td>(deflection ≥ 35 mm)</td>
<td>(n = 42, p &lt; 0.01)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estes score</td>
<td>54</td>
<td>86</td>
<td>64</td>
</tr>
<tr>
<td>(score ≥ 5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M-mode mass</td>
<td>88</td>
<td>84</td>
<td>75</td>
</tr>
<tr>
<td>(n = 48, p &lt; 0.0001)</td>
<td>(mass ≥ 265 g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-D echo mass</td>
<td>92</td>
<td>43</td>
<td>73</td>
</tr>
<tr>
<td>(n = 19, p = 0.108)</td>
<td>(mass ≥ 225 g)</td>
<td></td>
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Numbers (n) in parentheses are sizes of patient population tested and probability (p) of four-fold table distribution with pathologic left ventricular mass (Fisher exact test [25]). Thresholds beneath the variables denote the diagnostic criteria used as positive evidence for left ventricular hypertrophy. M-mode mass threshold of 265 g was derived from linear regression against actual mass of 225 g. Significant differences at the 5% level are M-mode mass, significantly higher sensitivity than electrocardiographic (ECG) voltage. Sokolow voltage and Estes score in diagnosing left ventricular hypertrophy (p < 0.05 by chi-square McNemar test [25]).

- ECG voltage = larger S wave in V1 or V2 + larger R wave in V6 or V4 on electrocardiogram; M-mode mass = M-mode echocardiographic prediction of left ventricular mass; Sokolow voltage = S wave in V1 + larger R wave in V6 or V4 on electrocardiogram; 2-D echo mass = two-dimensional echocardiographic prediction of left ventricular mass.

Examine, although these results are not significant. Mass prediction by M-mode echocardiography was high in both sensitivity and specificity when used in detecting left ventricular hypertrophy in 48 patients, with a predictive value similar to that of two-dimensional echocardiography. The M-mode sensitivity is significantly higher than the sensitivity of any electrocardiographic variable in diagnosing left ventricular hypertrophy.

Electrocardiographic correlations. Linear regression analysis was performed comparing necropsy left ventricular mass with electrocardiographic voltage, M-mode predicted mass and two-dimensional echocardiographic predicted mass (Fig. 3). Despite a large degree of scatter, electrocardiographic voltages correlated significantly with necropsy left ventricular mass in 42 patients. Sokolow's electrocardiographic voltage measurements correlated similarly with necropsy left ventricular mass (correlation coefficient [r] = 0.36).

The Estes point score versus anatomic left ventricular mass linear regression (whose graph is not shown) had a poor correlation coefficient of r = 0.34 in 42 patients. Although the linear regression of Estes score versus necropsy left ventricular mass was quoted in another study (3), we believe that this value does not lend itself to linear regression analysis, because the Estes point score is a measure of the probability that left ventricular hypertrophy is present rather than a grading scale for its severity.

Echocardiographic correlations. M-mode mass prediction (Fig. 3B) correlated well with actual left ventricular mass in 48 patients (standard error of the estimate = 51 g) in spite of increased scattering of points at extremely large weights. It was noted that the M-mode mass linear regression analysis that a heart with left ventricular mass of 225 g would yield M-mode measurements predicting 265 g for left ventricular weight. For this reason, 265 g was used as the M-mode mass criterion for diagnosing left ventricular hypertrophy. Two separate groups of M-mode echocardiograms were also examined: those performed less than 1 month before death and those performed between 1 and 6 months before death. Correlations with necropsy left ventricular mass (r = 0.81 and r = 0.83, respectively) were similar.

Two-dimensional echocardiographic mass prediction (8) in 19 patients also correlated significantly with actual left ventricular mass, but there was marked scatter (Fig. 3C). This correlation persisted when linear regression was performed between necropsy left ventricular mass and the other two-dimensional echocardiographic mathematical model examined (9) (y = 0.65x + 57; r = 0.50).

Discussion

In this study, no single diagnostic technique for left ventricular hypertrophy could be examined in all 50 patients. Left bundle branch block, complete heart block and ventricular pacing wires eliminated electrocardiographic evaluation in a number of patients, and recordings of poor quality eliminated two-dimensional echocardiographic quantification in a sizable group. Though M-mode echocardiographic measurements were the least often hampered by an unmeasureable study, this finding can vary with patient population, examination technique and proficiency of M-mode echocardiographic interpretation.

Electrocardiography. Electrocardiographic variables are known to have little value in detecting mild to moderate left ventricular hypertrophy (5,14–15). This study also shows that electrocardiographic voltage correlates poorly with left ventricular weight and has limited diagnostic accuracy when assessing left ventricular hypertrophy. The Estes point scoring system (6), first devised from an analysis of the electrocardiographic changes noted in left ventricular hypertrophy (16), was originally reported to be 60% sensitive and 95% specific in diagnosing left ventricular hypertrophy. Our values of 54% and 86%, respectively, are similar. Although other point scoring systems have been proposed (17), they involve more complicated data acquisition and have not improved on the Estes score in diagnosing left ventricular hypertrophy.
M-mode echocardiography. By using left ventriculography, excellent left ventricular mass predictions were developed requiring similar wall thickness and diameter measurements to those from echocardiograms (9,18–20). M-mode echocardiographic prediction of left ventricular mass was first correlated with this angiographic mass determination (21), and then with anatomic left ventricular mass (2,22). Our linear regression showed a similar correlation to that found in these three studies. Within 6 months of death, we found no time-related change in patients’ left ventricular hypertrophy that affected our prediction of postmortem left ventricular mass by M-mode echocardiography. Myocardial infarction leading to thin scarred walls and isolated compensatory hypertrophy, as well as asymmetric septal hypertrophy, can all affect mass determinations by echocardiography, particularly M-mode mass predictions. This may well limit the linearity of correlation in a broad patient population such as the one studied.

Although the Penn convention of wall thickness measurement was devised to better estimate mean myocardial thickness because of apical thinning and absence of myocardium at the valve orifices (2), we found no improvement over calculations from standard leading edge to leading edge measurements and thus used the latter in our calculations. Our M-mode echocardiographic predicted value for left ventricular mass gave good sensitivity and specificity in diagnosing left ventricular hypertrophy. In agreement with another study (3), this was superior to all current electrocardiographic criteria.

Two-dimensional echocardiography. Numerous two-dimensional echocardiographic mathematical models were recently developed for quantifiable two-dimensional echocardiographic image tracings (8,9,22,23). Two of the best models for quantifying left ventricular mass were tried in the present study and found to be poorer in correlation with actual left ventricular mass in our patient group than originally reported (8,9,23). This may be due to technical difficulties encountered in obtaining quality images in patients in a premorbid condition and also to sampling error in the 19 patients studied. Many factors restrict two-dimensional echocardiographic image quality, and these, in turn, affect the predicted left ventricular mass and its accuracy in diagnosing left ventricular hypertrophy (24). In 19 patients it was surprising to observe a sensitivity of 92% for two-dimensional echocardiographic diagnosis of left ventricular hypertrophy, but this was coupled with a low specificity of 43% and a poor correlation when linear regression was performed with necropsy left ventricular mass. At present, we believe two-dimensional echocardiography cannot diagnose left ventricular hypertrophy better than M-mode echocardiography.

Nomogram for M-mode echocardiographic left ventricular mass. Because automated equipment for performing the calculation of Reichek and Devereux for M-mode echocardiographic left ventricular mass is not universally available at present, we devised a nomogram with left ventricular mass meridians (Fig. 4). It represents graphically the M-mode echocardiographic mass prediction formula of Reichek and Devereux, with meridians plotted for resultant masses of 100, 200, 300 and 400 g. This mathematical model has been verified both in their work (2,3) and in this study. After measuring interventricular septal and left ventricular posterior wall thicknesses with standard measurements, the observer locates their mean on the vertical axis and follows this to where it intersects measured left ventricular internal diameter on the horizontal axis. The predicted left ventricular mass may be estimated closely from
the four mass meridians plotted. A mass above 265 g (shaded region) reflects a hypertrophic left ventricle. The upper left of the shaded zone is consistent with concentric left ventricular hypertrophy, and the lower right is consistent with a dilated left ventricle with hypertrophy or eccentric left ventricular hypertrophy.

This graph, then, dispenses with upper limits for normal wall thickness and chamber diameter and allows visualization of the severity of left ventricular hypertrophy, which can be followed in a patient. Because left ventricular masses rarely reach 400 g, a predicted left ventricular mass slightly above the 265 g meridian is abnormal and should be considered hypertrophic until proved otherwise. In situations that affect wall and chamber measurements, such as asymmetric septal hypertrophy and isolated scarring with compensatory hypertrophy, this prediction of mass may be suspect and needs further verification.

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References
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Figure 4. Nomogram for the clinical determination of left ventricular (LV) mass from M-mode echocardiographic measurements. After end-diastolic M-mode measurements are made, the mean of interventricular septal (IVS) and left ventricular posterior wall (LVPW) thicknesses is found on the vertical axis and followed to where it intersects with the left ventricular internal chamber diameter (LVID) on the horizontal axis. Left ventricular mass can then be estimated from the relation of this point to the four left ventricular mass meridians plotted. All points above the 265 g mass meridian (grey zone) reflect an abnormally heavy left ventricle using criteria from the present study. Coordinates that lie in the upper left of the grey zone reflect concentric left ventricular hypertrophy with thickened left ventricular walls and no corresponding chamber dilatation. Toward the middle and lower right of the grey zone lie regions where the chamber dilatation is in proportion with the wall thickening in the situation of eccentric left ventricular hypertrophy.
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