Distance Correction for Precordial Electrocardiographic Voltage in Estimating Left Ventricular Mass

An Echocardiographic Study

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SUMMARY This study was undertaken to assess both the relation between echocardiographic measurement of left ventricular (LV) mass and commonly used electrocardiographic criteria for LV hypertrophy and the effect of the distance from the center of LV mass to the anterior chest wall on precordial voltage. Echocardiograms and standard 12-lead electrocardiograms were obtained on 100 persons, ages 3 to 79. The correlation coefficients of echocardiographically determined LV mass with ECG precordial voltage (Sv, + Rv, or vL, the Estes point score system, and aVL, R wave voltage were .686, .721, and .581, respectively. Extrapolating from the dipole nature of the heart, the precordial voltage was multiplied by the square of the chest wall to mid-LV distance to correct for the loss of energy across the distance from LV to recording electrode. Utilizing this correction, a much improved precordial voltage estimation of LV mass (r = .846) was obtained. We conclude that the distance of the center of LV mass from the chest wall influences the amplitude of recorded precordial voltage and that correction for this influence improves the correlation of precordial voltage with LV mass.

LEFT VENTRICULAR MASS is an important parameter in evaluating the functional state of the heart. The most accessible method of estimating left ventricular size has been the 12-lead electrocardiogram (ECG). Many ECG criteria for left ventricular (LV) enlargement have been proposed and correlated with LV mass as determined at autopsy or by biplane angiography. Several studies have shown that the Sokolow voltage criteria (using Sv, + Rv, or vL, the Estes point score system, and R wave voltage in aVL, offer reasonable approximations of LV mass. Each set of ECG criteria has its limitations and, in particular, the effects of body habitus and age on these measurements have been repeatedly emphasized.

Echocardiography has become another accepted non-invasive means of estimating LV size. Methods for calculating LV volumes and mass from echo-derived parameters have been developed and good correlations have been demonstrated with angiographically-determined values.

The purpose of this study was to correlate the ECG criteria for LV size with the echo-determined LV mass and to correct the ECG precordial voltages for body habitus and chest size.

Materials and Methods

The study group was composed of 100 persons (54 males and 46 females) aged 3 to 79 years old (mean 41 yr) who underwent echocardiography in our noninvasive laboratory. Seven of these patients were younger than 16 years. Following echocardiographic examination, the clinical diagnoses were mitral valve prolapse in 31 persons, aortic valve disease in 27, mitral stenosis in 12, hypertension in nine, cardiomyopathy in two, and no discernible cardiovascular disease in 25 (some patients had more than one condition). Patients with known coronary artery disease, asymmetric septal hypertrophy, intraventricular conduction defects or pericardial effusions were excluded because of possible effects on ECG voltages or left ventricular echo measurements. The echocardiograms and electrocardiograms were independently evaluated by two of the authors and their measurements were averaged.

The echocardiograms were obtained using a Smith Kline Instruments Ekoline 20A ultrasonoscope interfaced with an Electronics for Medicine VR6 strip chart recorder. The echocardiograms were obtained with the patients recumbent and in full expiration. A 1.25 cm diameter 2.25 MHz crystal transducer was used to obtain full M mode scans of the left ventricle and outflow tract. The transducer position was considered optimal for the measurement of LV volume and wall thickness when both leaflets of the mitral valve were recorded with the transducer perpendicular to the chest wall and with clear definition of both the septum and the left ventricular posterior wall endocardium immediately below the tips of the mitral valve leaflets. Septal thickness, left ventricular posterior wall (LVPW) thickness, and left ventricular internal diameter (LVID) were measured at end diastole, as determined by the peak of the R wave on the ECG. The most anterior linear echo recorded was considered to represent the chest wall-transducer interface. The end-diastolic distances from the chest wall to the mid-septum (Dcw-Mid IVS) and mid-LV posterior wall (Dcw-Mid LVPW) were measured at the same level of the echo sweep. The chest wall to mid-LV distance (Dcw-Mid LV) was calculated by adding the mid-septal distance to the mid-LV posterior wall distance and dividing by two (Dcw-Mid LV = [Dcw-Mid IVS + Dcw-Mid LVPW] / 2) (fig. 1).

Using the echocardiographically-determined dimensions, LV volumes were calculated for each patient assuming that the LVID was equal to the minor axis (D) of a prolate ellipse. The LV cavity volume was then calculated as the cube of this dimension times π/3 (LV = π/3 × D³). The ex-
Figure 1. Echocardiogram of the left ventricle with measurements delineated. CW = chest wall, IVS = interventricular septum, LVID = left ventricular internal diameter, LVPW = left ventricular posterior wall.

ternal LV volume was calculated similarly using the sum of the LVID, septal thickness, and LVPW thickness as the diameter of the minor axis. The echo-determined LV mass was calculated assuming that the muscle mass of the left ventricle equalled the external LV volume minus the volume of the LV internal cavity times the weight of cardiac muscle per unit volume (fig. 2): LV mass = $(\pi/3 \times \text{LVID} + \text{IVS thickness} + \text{LVPW thickness})^3 - \pi/3 \times \text{LVID}^2 \times 1.05^{18,20}$

A “corrected” LV mass was also derived from the echo measurements using LV internal and external volumes which had been multiplied by the Teichholz correction factor to compensate for changing minor to major axis ratios (Correction factor = $7/(2.4 + D)$, where D equals the length of the minor axis): “corrected” LV mass = external LV volume $\times 7/(2.4 + \text{LVID} + \text{IVS thickness} + \text{LVPW thickness}) - \text{internal LV volume} \times 7/(2.4 + \text{LVID}).^{18}$

A standard 12-lead electrocardiogram was taken on each patient at the same time as the echocardiogram. The R wave voltages in $V_n$, $V_a$, and $aV_a$ and the S wave voltage in $V_s$ were measured and recorded. The QRS duration, ST-segment deviation (if present), intrinscoid duration and mean electrical QRS axis were also measured and used to rank LV size using the Estes point score system.

Data Analysis and Results

The correlation coefficients for echocardiographically determined LV mass and the ECG estimates of LV size — precordial voltage ($S_{v_1} + R_{v_4}$ or $v_4$), the Estes point score system, and R wave voltage in $aV_L$ — were determined. None of these correlations were strong. There was no significant difference between the degree of correlation of LV mass with precordial voltage ($r = .686$) or the Estes system ($r = .721$). The correlation with R wave in $aV_L$ ($r = .531$) differed from the other ECG estimates ($P < 0.01$).

The summed precordial voltage ($S_{v_1} + R_{v_4}$ or $v_4$) was then correlated with each echo-measured LV parameter with the correlation coefficients given in table 1. All the correlations were weak with the strongest being between the precordial voltage and echo-determined LV mass ($r = .686$).

Figure 2. The left ventricle represented as a prolate ellipse of revolution about the major axis ($L$). The minor axis ($D$) is approximated echocardiographically by the LV internal cavity diameter (LVID). The muscle mass of the left ventricle equals the volume of the external LV ellipsoid minus the volume of the internal cavity ellipsoid times the specific gravity of heart muscle, i.e., LV mass = $(\pi/3 \times \text{LVID} + \text{IVS thickness} + \text{LVPW thickness})^3 - \pi/3 \times \text{LVID}^2 \times 1.05$.

The echocardiographically determined chest wall to mid-LV distance ranged from 3.8 cm to 10.4 cm for all patients (mean 7.3 ± 1.3 sd). These distances correlated poorly with body surface area ($r = .586$). The distances were smaller in the pediatric age group (mean 4.8 cm) but otherwise exhibited little relationship to age or sex.

A curve-fitting multiple regression analysis was undertaken to fit the echo-determined LV mass to the precordial voltage adjusted for chest wall size and body surface area. The pertinent correlations are listed in table 2. The best fit with echo-determined LV mass was found when the precordial voltage was corrected by multiplying the voltage by the square of the distance of the mid-LV from the anterior chest wall. The resulting correlation ($r = .846$) represented a significant ($P < 0.005$) improvement over the correlation of echo-determined LV mass with the uncorrected precordial voltage ($r = .686$). Echo-determined LV mass, as calculated without the Teichholz factor, is plotted against uncorrected and corrected ECG precordial voltage in figures 3 and 4.

Table 1. Correlation of Precordial Voltage and Echo-Determined LV Measurements

<table>
<thead>
<tr>
<th></th>
<th>LV mass</th>
<th>$T_{\text{TEPTAL}}$</th>
<th>$T_{\text{LVPW}}$</th>
<th>LVID</th>
<th>LVID + $T_{\text{TEPTAL}}$ + $T_{\text{LVPW}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precordial voltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r$</td>
<td>.686</td>
<td>.504</td>
<td>.517</td>
<td>.581</td>
<td>.630</td>
</tr>
</tbody>
</table>

Abbreviations: $T =$ thickness; LVPW = left ventricular posterior wall; LVID = left ventricular internal diameter.
No significant difference in precordial voltage – LV mass correlations was found when the echo-determined LV mass was recalculated using the Teichholz correction factor for varying LV geometry ($r = .661$). Again, a significant improvement ($P < 0.005$) in correlation with this corrected mass was found when the precordial voltage was multiplied by the square of the chest wall – mid LV distance ($r = .825$).

**Discussion**

Echocardiographic measurement of LV volume (volume = minor axis$^3 \times \pi/3$) has been correlated with angiographic measurement of LV volume in several studies. Correlation coefficients ranging from .81 to .94 have been found using biplane angiography$^{11-14}$ and .96–.97 using single plane RAO angiography.$^{14, 17}$ A correlation coefficient of .97 with an improved standard error of the estimate has been reported using the Teichholz correction factor in calculating the echo-determined LV volume.$^{13}$ Two studies correlating echocardiographically-determined LV mass (without the Teichholz factor) with angiographically determined LV mass have arrived at similarly strong correlations ($r = .81$ and .88).$^{13, 14}$ Because of the repeatedly confirmed good correlation between echocardiographic and angiocardiographic estimates of LV mass and the noninvasive nature of this technique, the echocardiographic measurements were used in this study as the standard by which ECG estimates of LV size were evaluated.

Numerous criteria have been proposed for the estimation of LV size using the 12-lead ECG. In this study, echocardiographically-determined LV mass was correlated with commonly accepted ECG criteria in 100 patients. No significant difference was found between the degree of correlation of echo-determined LV mass with the precordial voltage ($SV_1 + RV_4$ or $a_V$) ($r = .686$) or with the Estes point system ($r = .713$). Correlating the R wave voltage in $a_V$ with LV mass yielded a significantly weaker correlation ($r = .531$). The best estimate of LV size using these ECG systems therefore appears to be afforded by the precordial voltages and little is gained by adding the criteria in the Estes system to the precordial voltage. This finding is not unexpected since precordial voltage is the major single criterion for evaluating LV enlargement in the Estes system. The degree of correlation of precordial voltage with echo-determined LV mass is similar to that found by Bennett and Evans in a smaller series of adults ($r = .71$).$^{19}$

ECG voltage was correlated with multiple echo-determined LV parameters to determine if the ECG precordial voltage is a measure of LV muscle mass or more closely related to other LV dimensions. The strongest correlation was found between the precordial voltage and LV mass.

It has long been recognized that the distance of the recording electrode from the voltage source greatly influences the voltage recorded. In 1930, Wilson noted that the potential differences produced by the heart are very large in its immediate vicinity but diminish quickly as the distance from the heart increases.$^{28}$ The dipole theory asserts that the electrical potential of the heart may at any moment of the cardiac cycle be depicted as a single dipole when the potentials are measured at distant points. This theory has been given substance mathematically and experimentally.$^{28}$ Considering the heart as a dipole surrounded by an insulator, the potential recorded at any distance from the dipole can be determined to vary inversely with the square of that distance.$^{28}$

In the clinical setting, several problems arise in evaluating voltages recorded on the chest wall. First, the medium across which the voltage must travel is inhomogeneous and

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**Table 2. Correlation Coefficients for Echo Determined LV Mass and Adjusted Precordial Voltage**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Precordial voltage</th>
<th>Precordial voltage</th>
<th>Precordial voltage</th>
<th>Precordial voltage</th>
<th>Precordial voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echo determined</td>
<td>$r$</td>
<td>.686</td>
<td>.694</td>
<td>.720</td>
<td>.635</td>
</tr>
</tbody>
</table>

**Abbreviations:** Dw-Mid LV = distance from the chest wall to mid-ventricular septum; Dw-Mid LV = distance from the chest wall to the mid-left ventricle; BSA = body surface area.

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**Figure 3.** Plot of the echo-determined left ventricular mass and ECG precordial voltage.

**Figure 4.** Plot of the echo-determined left ventricular mass and ECG precordial voltage corrected for chest size by multiplying the voltage by the square of the anterior chest wall to mid-LV distance.
composed of substances of varying conductance. Second, the electrical center of the heart is difficult to define and varies with time. Third, and most important, the distance of the dipole from the recording electrode cannot be determined in the individual patient by the scalar ECG; clinically this problem is reflected in the inability to find voltage criteria applicable to persons of all ages and body sizes.

In this study, it was found that the precordial ECG voltages tend to vary inversely with the square of the distance of the recording electrode from the approximate center of LV mass. The product of the precordial voltage and the square of the recording distance from the mid-LV affords a correlation with LV mass \( r = .846 \) that is significantly improved over the correlation of LV mass with unadjusted voltage measurements \( r = .686 \). Correcting the LV mass determination for changing LV geometry \( 4^4 \) does not change the improvement in the correlation of mass and precordial voltage noted when the latter is corrected by the square of the mid-LV to chest wall distance. This distance correction afforded the best correlation of voltage and mass using multiple parameters for voltage correction in a curve-fitting statistical approach.

Despite the marked improvement observed in the correlation between precordial ECG voltage and LV mass when the voltage is multiplied by the square of the mid-LV-chest wall distance, some scatter along the line of regression remains. Therefore, although this correction affords a much improved correlation between ECG voltage and LV mass, it does not afford a method whereby the exact LV mass may be determined in each individual case. The results do emphasize, however, the importance of considering thoracic size when evaluating ECG voltage.

The inability to arrive at an even better correlation is probably related to a number of factors: the chest being a relatively heterogeneous and impure insulator; the distances from each recording electrode to the LV center not being equal to each other and to the echo-determined distance; echo-determination of LV mass not being absolute; \( 4^4 \) the electrical center of the left ventricle varying with time and being inconsistently near the center of LV mass; and right ventricular (or opposing) electrical forces.

This study suggests that precordial ECG voltage is related to LV mass and that ECG criteria for LV size employing precordial voltage offer moderately accurate estimations of LV mass as determined by echo. However, the distance from the center of the LV to the precordial electrodes appreciably affects the magnitude of voltage recorded. Correcting for the influence of this distance by multiplying the precordial voltage by the square of the chest wall to mid-LV distance yields a significantly improved correlation with LV mass. This finding supports the suspicion that the amplitude of precordial ECG voltage is significantly influenced by the thoracic size in a manner predicted by the dipole theory of cardiac depolarization.

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