Determination of left ventricular mass in systemic hypertension: comparison of standard and signal averaged electrocardiography

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Abstract

Objective—To investigate the quantitative relationship, if any, between signal averaged electrocardiographic variables and echocardiographically determined left ventricular mass in hypertensive subjects.

Design—Cohort analytic prospective study.

Setting—University hospital.

Subjects—50 hypertensive subjects selected consecutively from inpatients. Patients older than 75 years, with underlying cardiac disease, with inconclusive echocardiograms with bundle branch block, or in atrial fibrillation were excluded.

Interventions—Antihypertensive therapy involving 41 patients was continued.

Main outcome measures—Left ventricular mass calculated in accordance with the standards of the Penn convention. Thirteen criteria derived from combinations of signal averaged electrocardiographic X, Y, and Z Frank orthogonal leads, including voltage criteria, duration, and time-voltage integrals of the QRS complex. Four widely used standard electrocardiographic criteria for detection of left ventricular hypertrophy.

Results—There was no difference in the values for any of the electrocardiographic variables between patients with ($n = 29$) and without left ventricular hypertrophy ($n = 21$). The time-voltage integral of QRS in the horizontal plane was the best signal averaged variable related to left ventricular mass ($r = 0.33$, $P = 0.019$); however, the correlation with Rodstein voltage was stronger ($r = 0.46$, $P = 0.0009$). A positive correlation was also found between left ventricular indexed mass and Rodstein voltage ($r = 0.43$, $P = 0.0019$). Stepwise regression analysis revealed Rodstein voltage as the only predictor of indexed mass ($P = 0.0019$), and Rodstein voltage ($P = 0.0022$) and body weight ($P = 0.011$) as the only independent correlates of left ventricular mass.

Conclusions—The relation between electrocardiographic variables and left ventricular mass or indexed mass is of limited value; signal averaged orthogonal leads do not improve this assessment compared with standard electrocardiographic leads.

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Keywords: left ventricular mass; hypertension; standard electrocardiography; signal averaged electrocardiography

Increased left ventricular mass is a powerful predictor of cardiovascular morbidity and mortality in hypertensive patients¹ and in the general population.² Although standard 12-lead electrocardiography remains the most widely used technique for the identification of left ventricular hypertrophy, standard voltage criteria are known to be relatively insensitive at high levels of specificity. Recently, it has been suggested that the use of signal averaged computerised electrocardiography can improve the accuracy for the identification of left ventricular hypertrophy.^{3,4} However, the quantitative relationship between signal averaged electrocardiographic variables and echocardiographically determined left ventricular mass has not been verified in a prospective fashion in hypertensive subjects. Such was the purpose of this study.

Methods

M mode and two dimensional echocardiograms, 12-lead electrocardiograms, and signal averaged electrocardiograms were obtained in 50 consecutive hypertensive patients between October 1992 and August 1993. Patients with valvar heart disease, coronary artery disease, cardiomyopathy, or inconclusive echocardiograms were excluded, as were subjects with bundle branch block or who were in atrial fibrillation. Subjects older than 75 years were also excluded. Antihypertensive therapy (41/50 patients treated) was not interrupted at the time of evaluation. Left ventricular mass was calculated in accordance with the strict standards of the Penn convention (Vingmed 750 system with 3.5 MHz transducer, Diasonics Inc). Two dimensional guided M mode measurements were carefully performed by three independent observers; patients in whom the intraobserver variability for left ventricular mass evaluation was $> 10\%$ were excluded. Left ventricular mass (g) was defined as:

$$1.04 [(LVID + PWT + VST)^3 - LVID^3] - 13.6$$

where LVID = end diastolic left ventricular internal dimension, PWT = end diastolic posterior wall thickness, and VST = end diastolic ventricular septal thickness. No patient had

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Table 1 Clinical, morphological and echocardiographic data in men and women with and without left ventricular (LV) hypertrophy. Values are means (SD)

	Men			Women		
	LVH absent	LVH present	P	LVH absent	LVH present	P
n	13	12		8	17	
Age	49.2 (13.8)	49.1 (9.4)	NS	43.5 (15.9)	55.9 (12.2)	NS
Height (cm)	177 (6.7)	171 (8.1)	NS	161 (6.8)	160 (5.6)	NS
Weight (kg)	82.6 (11.4)	83.2 (12.4)	NS	66.1 (19.3)	75.2 (15.6)	NS
BMI (kg/m ²)	26.3 (3.8)	28.2 (3.7)	NS	25.4 (7.4)	29.3 (6.0)	NS
BSA (m ²)	2.00 (0.14)	1.96 (0.17)	NS	1.69 (0.21)	1.77 (0.17)	NS
SBP (mm Hg)	147 (9.7)	152 (22.6)	NS	146 (15.1)	150 (29.1)	NS
DBP (mm Hg)	91 (9.5)	96 (11.9)	NS	94.6 (13.4)	92.5 (20.8)	NS
LV mass (g)	208 (29.0)	323 (46.8)	0.001	155 (19.6)	273 (58.9)	0.001
LVMI (g/m ²)	104 (12.5)	164 (25.2)	0.001	93 (12.8)	154 (30.6)	0.001

BMI, body mass index; BSA, body surface area; DBP and SBP, diastolic and systolic blood pressure under treatment; LVH, left ventricular hypertrophy; LVMI, left ventricular mass indexed to body surface area.

asymmetrical left ventricular hypertrophy (VST/PWT < 1.5 in all cases). Left ventricular hypertrophy was considered present if the left ventricular mass indexed to body surface area was > 134 g/m² in men and > 110 g/m² in women.⁵ According to these criteria, hypertrophy was present in 29 patients (58%). In 17 of them left ventricular hypertrophy was concentric (2PWT/LVID > 0.45), and it was eccentric in the remaining 12 (2PWT/LVID < 0.45). Signal averaged electrocardiograms were recorded at rest in a fasting state from orthogonal bipolar X, Y and Z leads using an Arrhythmia Research Technology 1200EPX high resolution system. After amplification, sampling, and averaging of 150 to 210 cycles (noise level = 0.38 µV, SD 0.11), the data were stored for further processing. Thirteen criteria derived from signal averaged electrocardiography were taken into consideration, nine of which were calculated after combination of the leads into a maximal spatial vector ($X^2 + Y^2 + Z^2$)¹. These criteria were: root mean square voltage amplitude; peak voltage amplitude; time-voltage integral and mean voltage amplitude of the unfiltered QRS complex and of the QRS complex determined at 5 Hz high pass filtering with a Butterworth

bidirectional filter³; and QRS duration. Three additional criteria were obtained from the 5 Hz high pass filtered Z lead, including the root mean square voltage amplitude, time-voltage integral, and mean voltage amplitude of the QRS complex.³ The last variable, recently proposed by Okin *et al*,⁴ was the horizontal plane time-voltage integral of the vector magnitude ($X^2 + Z^2$)¹. For purpose of comparison, four widely used electrocardiographic criteria for the detection of left ventricular hypertrophy were examined. These included the Sokolow-Lyon voltage (SV₁ plus RV₅ or RV₆), the Cornell voltage (RaVL plus SV₃), the sum of QRS voltage in all 12 leads, and the Rodstein voltage (R in lead I plus S in lead III).

Means and standard deviations were calculated for the clinical, electrocardiographic, and echocardiographic results. Comparisons of means were made using Student's *t* test for independent samples. The Kolmogorov-Smirnov test was used to fit the normal distribution to the echocardiographic variables. The relationship between electrocardiographic criteria and left ventricular mass or indexed mass was determined by correlation analysis. Since regression calculations are based on the assumption that the relationship (if any) between the variables is linear, the assumption of linearity was tested before calculating the correlation coefficients through runs tests. Stepwise regression analysis was used to determine which of the univariate variables were significant independent predictors of left ventricular mass or indexed mass and the strength of these associations.

Results

Since the criteria for left ventricular hypertrophy were different in the two sexes, the means and standard deviations of the clinical, 12-lead and signal averaged electrocardiographic characteristics as well as echocardiographically estimated left ventricular masses

Table 2 Electrocardiographic data in men and women with and without left ventricular hypertrophy. Values are means (SD)

	Men			Women		
	LVMI < 134 (g/m ²)	LVMI > 134 (g/m ²)	P	LVMI < 110 (g/m ²)	LVMI > 110 (g/m ²)	P
Rodstein (mV)	1.15 (0.32)	1.38 (0.51)	NS	1.19 (0.33)	1.57 (0.78)	NS
Cornell (mV)	1.58 (0.65)	1.86 (0.54)	NS	1.31 (0.31)	1.79 (0.82)	NS
ΣV (mV)	1.43 (0.44)	1.57 (0.30)	NS	1.33 (0.48)	1.39 (0.48)	NS
Sokolow (mV)	2.53 (1.03)	2.62 (0.84)	NS	2.37 (1.16)	2.27 (0.86)	NS
QRS duration (ms)	104 (8.6)	99 (1.7)	NS	92 (6.1)	97 (8.8)	NS
0-250 Hz PVA (mV)	2.87 (1.12)	2.87 (0.88)	NS	2.85 (1.48)	2.39 (0.92)	NS
0-250 Hz RMSA (mV)	1.27 (0.51)	1.34 (0.34)	NS	1.24 (0.59)	1.14 (0.49)	NS
0-250 Hz TVI (µV.s)	88.8 (33.5)	92.2 (21.2)	NS	73.6 (33.8)	77.6 (31.5)	NS
0-250 Hz MVA (mV)	0.85 (0.33)	0.92 (0.19)	NS	0.79 (0.32)	0.79 (0.30)	NS
5-250 Hz PVA (mV)	1.59 (0.54)	1.67 (0.50)	NS	1.59 (0.78)	1.27 (0.38)	NS
5-250 Hz RMSA (mV)	0.66 (0.21)	0.72 (0.22)	NS	0.72 (0.36)	0.57 (0.19)	NS
5-250 Hz TVI (µV.s)	44.5 (12.7)	45.5 (10.2)	NS	40.7 (18.9)	37.9 (13.2)	NS
5-250 Hz MVA (mV)	0.43 (0.12)	0.45 (0.10)	NS	0.44 (0.18)	0.39 (0.13)	NS
5-250 Hz RMSA _Z (mV)	0.43 (0.19)	0.40 (0.22)	NS	0.43 (0.25)	0.34 (0.16)	NS
5-250 Hz TVI _Z (µV.s)	28.7 (12.5)	24.4 (13.8)	NS	23.7 (11.9)	22.1 (11.7)	NS
5-250 Hz MVA _Z (mV)	0.28 (0.12)	0.24 (0.13)	NS	0.25 (0.16)	0.25 (0.11)	NS
0-250 Hz TVI _{HP} (µV.s)	73.2 (29.0)	76.8 (21.4)	NS	61.0 (22.5)	68.6 (28.6)	NS

LVMI, left ventricular mass indexed to body surface area; MVA, mean voltage amplitude of the maximal spatial vector; MVA_Z, mean voltage amplitude on Z lead; PVA, peak voltage amplitude of the maximal spatial vector; RMSA, root mean square voltage amplitude of the maximal spatial vector; RMSA_Z, root mean square voltage amplitude on Z lead; TVI, time-voltage integral of the maximal spatial vector; TVI_{HP}, time-voltage integral in the horizontal plane; TVI_Z, time-voltage integral on Z lead; ΣV, sum of QRS voltage in all 12 leads.

were listed separately in men and women in tables 1 and 2. The distributions of left ventricular masses and indexed masses are shown in fig 1; neither cumulative distribution function differed significantly from normal distributions. The means of signal averaged and standard electrocardiographic variables were not significantly different among men and

women between patients with and without hypertrophy.

Left ventricular mass being a continuous variable, the clustering of the values near the hypertrophy cutpoints suggested that a correlation analysis between electrocardiographic variables and left ventricular mass or indexed mass would be of interest. These results are summarised in table 3. Left ventricular mass was found to correlate positively and linearly with the time-voltage integral of the maximal spatial vector complex, the horizontal plane time-voltage integral, and the Cornell and Rodstein voltages (fig 2). Positive linear correlations were also found between left ventricular indexed mass and Rodstein voltage (fig 2) or Cornell voltage. The linearity of these relations was always confirmed and discouraged the use of non-linear or polynomial equations. The strongest association was characterised by the following linear regression equation: left ventricular mass (g) = $(56.3 \times \text{Rodstein voltage}) + 173$, with standard error (SE) = 66.3 g.

Correlations were also observed between left ventricular mass and body weight ($r = 0.39$, $P = 0.0046$), body surface area ($r = 0.32$, $P = 0.023$), or body mass index ($r = 0.41$, $P = 0.0033$).

Stepwise regression analysis including age and morphological and electrocardiographic variables identified only two significant independent predictors of left ventricular mass: Rodstein voltage ($P = 0.0022$) and body weight ($P = 0.011$) (in that order). The linear equation was: left ventricular mass (g) = $(1.5 \times \text{body weight}) + (49 \times \text{Rodstein voltage}) + 66$. This final regression model was characterised by an adjusted correlation coefficient $r = 0.53$, with residual SE = 62.5 g (fig 3). When compared to the simple regression equation obtained with ventricular mass and Rodstein voltage, adding body weight to the

Figure 1 Left ventricular mass and indexed mass in the population studied.

Figure 2 Upper panel: relation between left ventricular mass and Rodstein voltage ($r = 0.46$, $P = 0.0009$). Lower panel: relation between left ventricular indexed mass and Rodstein voltage ($r = 0.43$, $P = 0.0019$). Solid line: linear regression line, dotted lines: 95% confidence interval.

Table 3 Correlation analysis between electrocardiographic variables and left ventricular mass and indexed mass

	LV mass		LV indexed mass	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
Rodstein (mV)	0.46	0.0009	0.43	0.0019
Cornell (mV)	0.36	0.012	0.34	0.016
ΣV (mV)	0.25	NS	0.21	NS
Sokolow (mV)	0.15	NS	0.12	NS
QRS duration (ms)	0.21	NS	0.06	NS
0-250 Hz PVA (mV)	0.04	NS	0.02	NS
0-250 Hz RMSA (mV)	0.17	NS	0.13	NS
0-250 Hz TVI (μV.s)	0.31	0.027	0.18	NS
0-250 Hz MVA (mV)	0.24	NS	0.17	NS
5-250 Hz PVA (mV)	0.05	NS	0.007	NS
5-250 Hz RMSA (mV)	0.11	NS	0.12	NS
5-250 Hz TVI (μV.s)	0.21	NS	0.14	NS
5-250 Hz MVA (mV)	0.17	NS	0.13	NS
5-250 Hz RMSA _Z (mV)	0.10	NS	-0.002	NS
5-250 Hz TVI _Z (μV.s)	0.14	NS	0.02	NS
5-250 Hz MVA _Z (mV)	0.10	NS	0.01	NS
0-250 Hz TVI _{HP} (μV.s)	0.33	0.019	0.24	NS

LV, left ventricular; MVA, mean voltage amplitude of the maximal spatial vector; MVA_Z, mean voltage amplitude on Z lead; PVA, peak voltage amplitude of the maximal spatial vector; *l*, linear correlation coefficient; RMSA, root mean square voltage amplitude of the maximal spatial vector; RMSA_Z, root mean square voltage amplitude on Z lead; TVI, time-voltage integral of the maximal spatial vector; TVI_{HP}, time-voltage integral in the horizontal plane; TVI_Z, time-voltage integral on Z lead; ΣV, sum of QRS voltage in all 12 leads.

Figure 3 Multiple regression between left ventricular mass, Rodstein voltage, and body weight. The final regression model is: left ventricular mass = $(1.5 \text{ body weight}) + (49 \text{ Rodstein voltage}) + 66$. Adjusted correlation coefficient is $r = 0.53$ with $SE = 62.5 \text{ g}$.

model slightly improved this standard error from 66.3 to 62.5 g. Similarly, Rodstein voltage was found to be the only independent predictor of left ventricular indexed mass (adjusted $r = 0.41$, $P = 0.0019$, and $SE = 34.4 \text{ g/m}^2$). The linear regression equation was: indexed mass (g/m^2) = $(27 \times \text{Rodstein voltage}) + 97$.

Discussion

The diagnosis of left ventricular hypertrophy is a simplified concept, implying the existence of a clearcut demarcation between normality and abnormality. Actually, left ventricular mass covers a continuous spectrum ranging from subnormal at one end to severely hypertrophied at the other. Thus quantitation is a more general aspect of the task of evaluating the left ventricular condition. The results of this study underscore the weakness of electrocardiographic voltage criteria in quantifying left ventricular hypertrophy; our conclusions, however, do not rule out the possible clinical value of these criteria in detecting hypertrophic states. Despite a wide range of left ventricular mass in our population, the relative proportion of patients with borderline echocardiographic hypertrophy was high. This explanation may account for the absence of significant differences in the values of voltage criteria when patients were separated according to the absence or presence of hypertrophy.

The results of our study concerning the usefulness of signal averaged electrocardiographic criteria to assess left ventricular mass conflict with those of Vacek *et al.*³ The criteria advocated by Vacek were the time-voltage integral of the 5-250 Hz high pass filtered QRS complex, computed either from the vector sum or from the Z lead alone. We found that these variables did not correlate with left ventricular mass and their mean values did not differ significantly between patients with and without hypertrophy. This disagreement

led us to examine whether our population had been chosen appropriately. The first observation was that only unselected and hypertensive subjects had been consecutively recruited in order to test our hypothesis in a clinical and realistic condition. The span of left ventricular masses in our population was also compared with other studies^{3,4} and did not differ significantly, as evidenced by variance comparison tests (F tests). In addition, severe left ventricular hypertrophy (indexed mass $> 208 \text{ g/m}^2$ in men or 162 g/m^2 in women)⁶ was identified in seven of our patients (14%).

The explanation for the discrepancy with Vacek's results could lie in the fact that the cohort prospectively studied by this author was restricted to 20 patients, 14 of whom had normal hearts. An alternative explanation could be related to identical blood pressure levels in our patients with and without hypertrophy (due to the continuation of anti-hypertensive treatment), whereas neither blood pressure levels nor haemodynamic data were mentioned by Vacek *et al.* Intraventricular and transmural pressures are in fact thought to participate in the mechanism of voltage increase during left ventricular hypertrophy.⁷

On the other hand, our results are in agreement with those of Okin *et al.*,⁴ obtained in men presenting with left ventricular hypertrophy and regurgitant valvar heart disease. These investigators reported that the horizontal plane time-voltage integral of the unfiltered QRS complex was a promising index for detecting left ventricular hypertrophy, but unfortunately no correlation was attempted between the values obtained and left ventricular mass. In our study conducted in hypertensive subjects, this variable was the best signal averaged electrocardiographic correlate of left ventricular mass; however, the correlation between left ventricular mass and Rodstein voltage was stronger, as revealed by multivariate analysis.

The superiority of 12-lead electrocardiograms over computerised high resolution signal averaged electrocardiograms strongly suggests that orthogonal X, Y, and Z leads (separate or combined) are inadequate to assess left ventricular mass in treated hypertensive subjects. This hypothesis is supported by previous studies examining the heart as a multiple dipole electrical source which have shown an improvement in left ventricular mass quantitation over conventional electrocardiographic or vectocardiographic techniques. In the series of 72 patients studied by Holt *et al*⁸ the standard vectocardiographic time-voltage integral was correlated with the angiographically determined left ventricular mass ($r = 0.77$, $SE = 80$ g) but the use of a realistic model with 12 dipoles dramatically increased the strength of the correlation ($r = 0.93$, $SE = 49$ g).⁶

In conclusion, the relation between electrocardiographic variables and left ventricular mass is of limited value for the purpose of quantitation. Signal averaged electrocardiography obtained from three orthogonal leads does not improve this assessment compared to standard electrocardiography.

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