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Relation of the Distance-Corrected Electrocardiographic and Vectorcardiographic Voltage with the Echocardiographically Determined Left Ventricular Muscle Volume

The Shimane Heart Study

(left ventricular muscle volume/ECG and VCG voltage/echocardiography)

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The left ventricular muscle volume (LVMV) and the distance from the surface of the anterior chest wall to the middle of the left ventricle (D) were determined echocardiographically in 476 children as a part of the Shimane Heart Study. Correlation of the summed ECG precordial voltage (SV_1+RV_5) and the summed VCG voltage (RX+SZ) with LVMV was poor (on ECG voltage $r=0.377$ in males and -0.095 in females; on VCG voltage $r=0.316$ in males and -0.069 in females). The ECG and VCG voltages, therefore, were corrected by the square of D to compensate for the diminution of electric potential by distance. Correlation of the corrected ECG voltage $D^2(SV_1+RV_5)$ and the corrected VCG voltage $D^2(RX+SZ)$ with LVMV were good in males ($r=0.712$ and 0.709, respectively) and relatively good in females ($r=0.467$ and 0.478, respectively). Moreover, the values of the corrected voltages were significantly different between both sexes at the age of 12–16 years ($P<0.002$).

The thickness of subcutaneous fat may be one of the most important factors for the difference in the values of the corrected voltages and correlation coefficients.

Electrocardiography (ECG) has been one of the most popular methods for the detection and assessment of left ventricular enlargement (1) (2). The summed voltage of the S wave in V_1 and the R wave in V_5 has been employed as a conventional index of left ventricular hypertrophy (3) (4). Spatial vectorcardiography (VCG) has not been so generally an available method as ECG, because such studies sometimes have required complex computations of data. Vectorcardiography, however, is claimed to be a superior method by some investigators (5). Various criteria have been proposed for estimation of left ventricular hypertrophy by VCG (6) (7). The summed voltage (RX+SZ) is one of the criteria for prediction of LV size.

Recently, it has become feasible to estimate left ventricular muscle volume (LVMV) non-invasively by echocardiography (8) (9) (10). Correlation of LVMV with the summed precordial voltage (SV_1+RV_5) and with the summed components of the maximum spatial left ventricular vector has been reported to be considerably good in the groups composed of both the normal subjects and the patients with left ventricular overload (11) (12) (13). However, there are few reports concerning the correlation in the groups exclusively composed of normal subjects of various ages and body sizes.

It was clarified previously that the corrected precordial ECG voltage $D^2(SV_1+RV_5)$ was correlated more closely with LVMV, where D was the distance from the middle of left ventricle to the surface of anterior chest wall (12) (14). In the present study, the VCG voltage (RX+SZ), that is, a sort of the summed components of maximal spatial left ventricular vector was compared with the echocardiographically determined LVMV, and was corrected by the square of D in the same manner as ECG voltage was done in order to establish a method of estimating the LVMV from the corrected one. The results of studies on corrected ECG and VCG voltage were then compared.

MATERIALS AND METHODS

Study Population

Healthy children from 6 to 16 years old were examined using electrocardiography, vectorcardiography, and echocardiography. The precise data for analyses were obtained from 478 among 652 subjects. Details of the study population are listed in Table I.

TABLE I. *Distance-Corrected ECG and VCG Voltage among Various Ages and Sexes*

Years	Sex	Number of subjects	Corrected ECG voltage*(cm²·mV) (mean±1 S.D.)	Test	Corrected VCG voltage**(cm²·mV) (mean±1 S.D.)	Test
6–7	m†	76	52.2±16.4	N.S.***	35.1±10.9	N.S.
	f††	42	50.7±18.0		33.2±8.6	
9–12	m	47	76.3±25.8	N.S.	44.0±12.1	$P<0.05$
	f	40	71.8±24.1		39.2±9.9	
12–15	m	75	120.1±38.2	$P<0.002$	75.3±21.4	$P<0.002$
	f	82	90.4±24.5		55.4±16.2	
15–16	m	67	149.0±46.3	$P<0.002$	88.0±28.8	$P<0.002$
	f	49	103.3±34.5		63.2±17.4	
Total	m	265				
	f	213				

* : $D^2(SV_1+RV_5)$, ** : $D^2(RX+SZ)$, *** : not significant,
† : male, †† : female

Examination

Electrocardiograms and vectorcardiograms were recorded by Fukuda Denshi SDC 30. On ECG recording paper, the S wave in V_1 lead and R wave in V_5 were measured, and SV_1+RV_5 were calculated. On Frank lead VCG recording paper, the R vector magnitude along X axis and S vector magnitude along Z axis were measured, and RX+SZ were calculated. Echocardiography was done utilizing transducers with a frequency of 3.5 MHz for younger children and 2.25 MHz for older children. Ultrasonoscope and echocardiogram recorder were Fukuda Denshi SSD-110S type and ECO-125S type, respectively. Paper speed for recording was 50 mm/sec and 100 mm/sec.

On standard left ventricular echocardiographic recordings, interventricular septal thickness (IVSTd), left ventricular posterior wall thickness (LVPWTd) and left ventricular internal dimension (LVIDd) were measured at the end-diastole, practically at the starting point of QRS complex on ECG. The LVMV was then estimated by the method of Troy *et al.* with some modification (8) (10). The formula used here was given as :

$$LVMV=\frac{4}{3}\pi\left(LVIDd+\frac{IVSTd+LVPWTd}{2}\right)\left(\frac{LVIDd}{2}+\frac{IVSTd+LVPWTd}{2}\right)^2 - \frac{4}{3}\pi(LVIDd)\left(\frac{LVIDd}{2}\right)^2$$

In addition, D_1 (the end-diastolic distance from the mid-septum to the surface of the anterior chest wall) and D_2 (the end-diastolic distance from the mid-LV posterior wall to the surface of the anterior chest wall) were measured at the same phase (Fig. 1). The distance from the middle of left ventricle to the surface of anterior chest wall (D) (12) was calculated as :

$$D=(D_1+D_2)/2$$

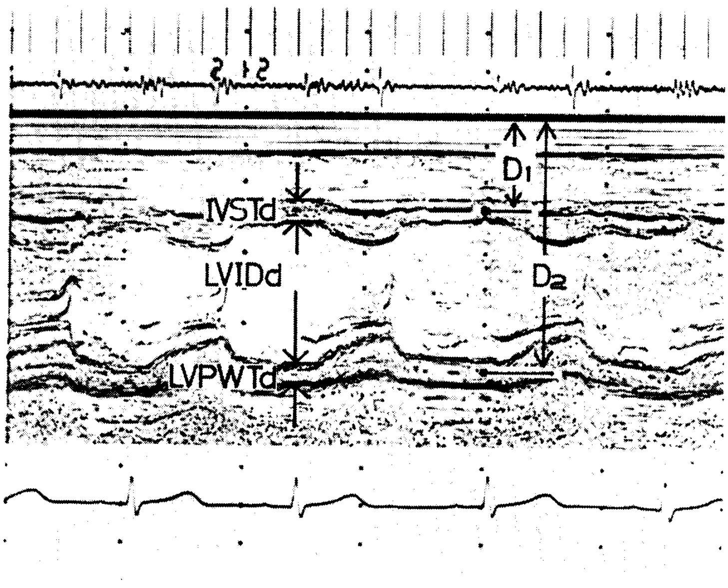

Fig. 1. Echocardiogram of the left ventricle with measurements delineated. IVSTd : interventricular septal thickness, LVIDd : left ventricular internal dimension, LVPWTd : left ventricular posterior wall thickness.

RESULTS

The summed precordial voltage (SV_1+RV_5) was plotted against LVMV in males and females, respectively (Fig. 2). There were poor correlations between SV_1+RV_5 and LVMV (r=0.377 in males and −0.095 in females). VCG voltage (RX+SZ) was plotted against LVMV in males and females, respectively (Fig. 3). There was a poor correlation between RX+SZ and LVMV (r=0.316 in males and −0.069 in females). Therefore, neither SV_1+RV_5 nor RX+SZ could be used as an index of left ventricular size in healthy children.

We corrected ECG and VCG voltage by multiplying these by D^2, because electric potential diminished inversely with the square of the distance. As plotted in Figs. 4 and 5, the correlation between the corrected voltage and LVMV was good in males and relatively good in females. Correlation coefficient on ECG voltage was 0.712 in males, and 0.469 in females ; on

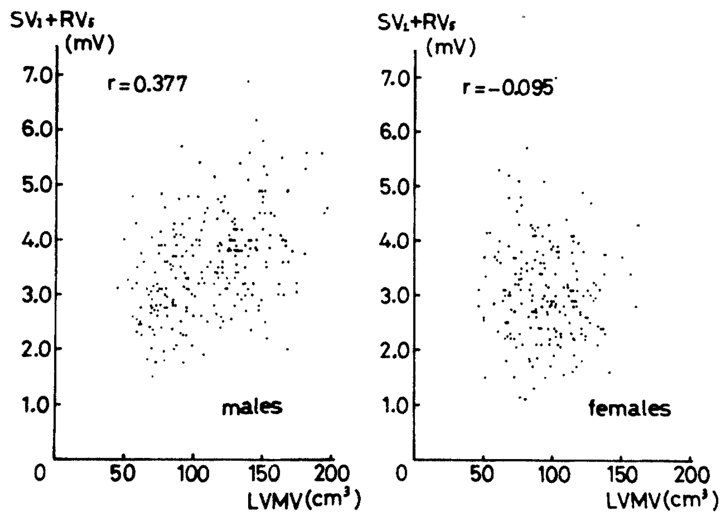

Fig. 2. Relation between the summed precordial ECG voltage (SV_1+RV_5) and LVMV.

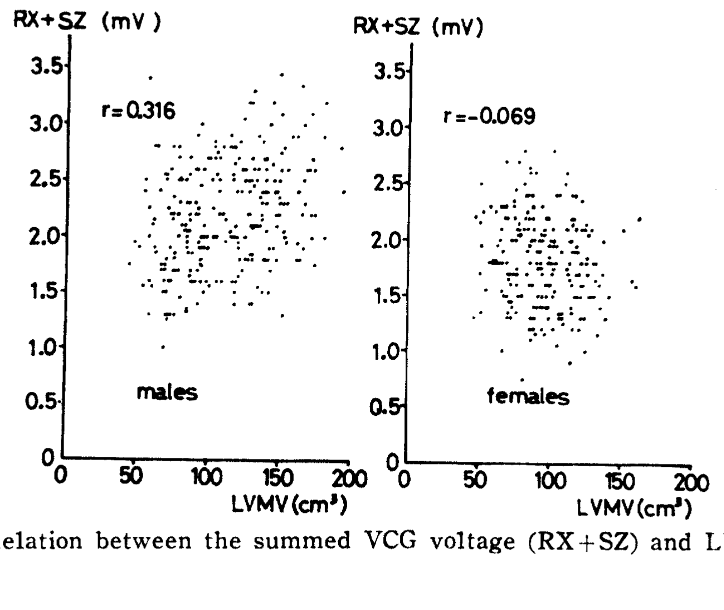

Fig. 3. Relation between the summed VCG voltage (RX+SZ) and LVMV.

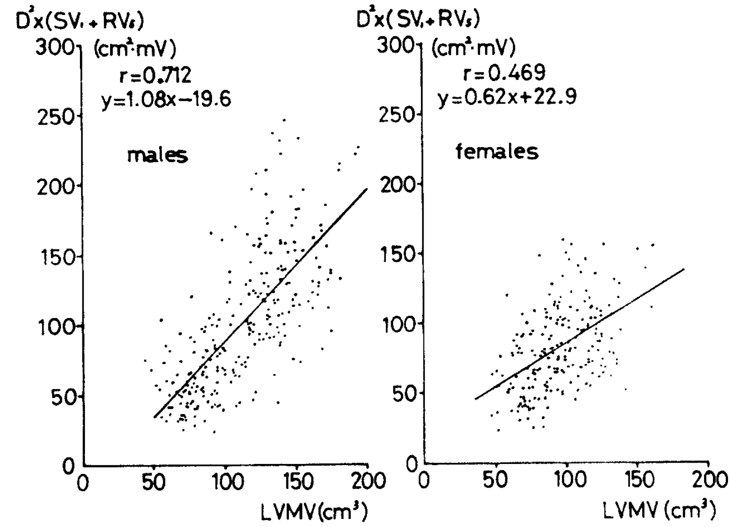

Fig. 4. Relation between the distance-corrected precordial ECG voltage $D^2(SV_1+RV_5)$ and LVMV.

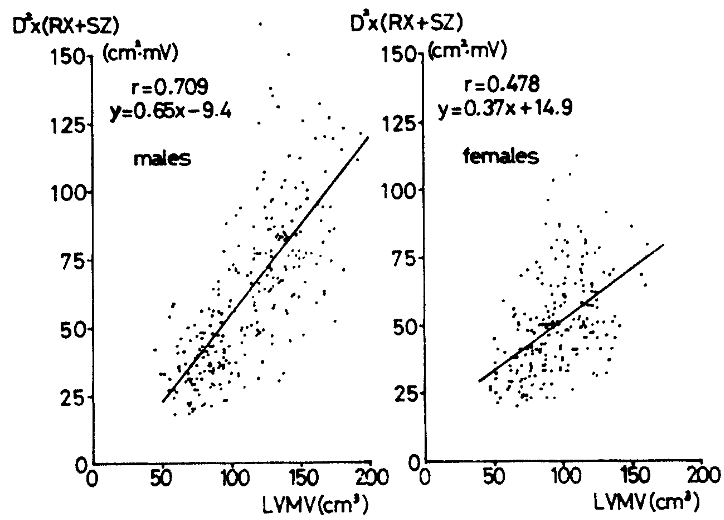

Fig. 5. Relation between the distance-corrected VCG voltage $D^2(RX+SZ)$ and LVMV.

VCG voltage 0.709 in males, and 0.478 in females.

The values of D^2 (SV_1+RV_5) and D^2 $(RX+SZ)$ scattered more widely in males than in females as shown in Figs. 4 and 5. These findings suggest that an appreciable difference exists between the sexes. We, therefore, calculated mean values and standard deviation (S. D.) of the D^2 (SV_1+RV_5) and of the D^2 $(RX+SZ)$ among different age and sex groups. As listed in Table I, the values of D^2 (SV_1+RV_5) and D^2 $(RX+SZ)$ showed no significant difference between both sexes at the age of 6−7 years. These values were clearly and significantly larger at the age of 12−16 years ($P<0.002$).

DISCUSSION

It is well known that the echocardiographically determined LVMV is well correlated with the angiographically determined one (8) (15) (16). The echocardiographically determined LVMV, therefore, was used in this study as the true LV size. Previous investigators have indicated that the summed precordial voltage (SV_1+RV_5) was closely correlated with LVMV in the groups composed of both the normal subjects and the patients with LV overload ($r=0.73$ by Bennett and Evans; $r=0.686$ by Horton *et al.*; $r=0.71$ by McFarland *et al.*) (11) (12) (13). Estimations of LV size by vectorcardiography are reportedly well correlated with LVMV in the groups mentioned above ($r=0.90$ by Bennett and Evans; $r=0.53$ to 0.63 by Vine *et al.*) (11) (17). We found that correlations of SV_1+RV_5 and RX+SZ with LVMV were poor in healthy school aged children.

As the heart is assumed to be a single dipole surrounded by an insulator, electric potential diminishes inversely with the square of the distance. Then, the value of D^2 (SV_1+RV_5), that is, the product of the potential difference SV_1+RV_5 and the square of the distance from the anterior chest wall to the middle of left ventricle (D) is considered to be proportional to the electric potential of the heart (11). Therefore, it was assumed that the value of D^2 (SV_1+RV_5) was correlated more closely with LVMV than that of SV_1+RV_5. The same concept can be applied to interpretation of the good correlation between D^2 (RX+SZ) and LVMV. We found that we could obtain a close relationship between the echocardiographic measurements and electrocardiographic or vectorcardiographic ones.

Some investigators stated that vectorcardiographic estimation of LV size was superior to electrocardiographic approaches (5). In our study, we could not conclude which was superior.

Though we assumed a homogeneous insulator surrounding the heart, actually, an insulator is not homogeneous. There exist various organs and tissues around the heart — lungs, muscles, ribs, subcutaneous fat, skin, and so on. The thicker subcutaneous fats in females produces a lower electric conductivity *in vivo*. Probably, because of this and a weaker generating potential of the heart, mean values of D^2 (SV_1+RV_5) and D^2 (RX+SZ) in females are lower than those in males. It is probable that weaker correlation of D^2 (SV_1+RV_5) and D^2 (RX+SZ) with LVMV in females results from a wider variation in thickness of subcutaneous fat.

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