Basic Study for Computer Analysis of the Pediatric Electrocardiogram: Relation of the Distance-Corrected Precordial Electrocardiographic Voltage with the Echocardiographically Determined Left Ventricular Muscle Volume

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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^{1,2}. Recently, it has been able to estimate the left ventricular muscle volume (LVMV) non-invasively by echocardiography^{3,4}. Correlation between LV mass and $SV_1 + RV_5$ has been reported to be considerably good in the groups

composed of both the normal subjects and the patients with left ventricular overload^{5,6,7}. However, there are few reports concerning the correlation in the groups exclusively composed of normal subjects of various age and body size.

In this study, the precordial voltage ($SV_1 + RV_5$) was compared with the echocardiographically determined LVMV, and was corrected in

TABLE I DISTANCE-CORRECTED PRECORDIAL ECG VOLTAGE*
AMONG VARIOUS AGES AND SEXES

Years	Sex	Number of subjects	Corrected ECG Voltage* (mean $\pm$ 1 S.D.)	Test
6 - 7	m†	76	52.2 $\pm$ 16.4	N.S.**
	f††	42	50.7 $\pm$ 18.0	
9 - 10	m	47	76.3 $\pm$ 25.8	N.S.
	f	40	71.8 $\pm$ 24.1	
12 - 15	m	75	120.1 $\pm$ 38.2	P < 0.002
	f	82	90.4 $\pm$ 24.5	
15 - 16	m	67	149.0 $\pm$ 46.3	P < 0.002
	f	49	103.3 $\pm$ 34.5	
Total	m	265		
	f	213		

* $D^2 (SV_1 + RV_5)$ ** not significant † male †† female

Key Words:

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

order to establish a method of estimating the LVMV from the corrected ECG voltage.⁵

MATERIALS AND METHODS

1) Study Population

Healthy children from 6 to 16 years old were examined by electrocardiography and echocardiography. The precise data for analyses were obtained from 478 among 652 subjects. The details are listed in Table I.

2) Examination

Electrocardiograms were recorded by Fukuda Denshi SDC-30. The S wave in V_1 lead and the R wave in V_5 were measured and $SV_1 + RV_5$ were calculated. Ultrasonoscope and echocardiogram recorder were Fukuda Denshi SSD-110S type and ECO-125S type, respectively.

The echocardiograms were measured at the end-diastole, practically at the starting point of QRS complex in ECG. The LVMV was then estimated by the method of Troy et al.¹ with some modification. The formula used was given as following equation:

$$\begin{aligned} \text{LVMV} = & \frac{4}{3} \pi \left[\text{LVIDd} + \frac{\text{IVSTd} + \text{LVPWTd}}{2} \right] \\ & \left[\frac{\text{LVIDd}}{2} + \frac{\text{IVSTd} + \text{LVPWTd}}{2} \right]^2 \\ & - \frac{4}{3} \pi \left[\text{LVIDd} \right] \left[\frac{\text{LVIDd}}{2} \right]^2 \end{aligned}$$

In addition, D_1 (the end-diastolic distance from the midseptum to the anterior chest wall) and D_2 (the end-diastolic distance from the mid-LV posterior wall to 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) was calculated as follows:

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

RESULTS

The summed precordial voltage ($SV_1 + RV_5$) was plotted against LVMV in males and females, respectively (Fig. 2). There were no good correlations between $SV_1 + RV_5$ and LVMV ($r = 0.377$ in males and -0.095 in females). Therefore, the summed precordial voltage ($SV_1 + RV_5$) could

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

Fig. 3. Relation between the distance-corrected precordial ECG voltage $D^2(SV_1 + RV_5)$ and LVMV.

not be used as an index of the left ventricular size in healthy children.

We corrected the precordial voltage by multiplying this by D_2 , because electrical potential

diminished inversely with the square of the distance. The correlation between $D_2(SV_1 + RV_5)$ and LVMV was good in males, and relatively good in females, as plotted in Fig. 3 ($r = 0.712$ in males,

0.469 in females).

The values of D^2 ($SV_1 + RV_5$) scattered more widely in males than in females as shown in Fig. 3. As listed in Table I, the values of D^2 ($SV_1 + RV_5$) showed no significant difference between both sexes at the age of 6–7 years and 9–10 years. The values in males were significantly larger than in females between the ages 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^{1,2}. 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 containing both the normal subjects and the patients with LV overload ($r = 0.73$ by Bennett et al.; $r = 0.686$ by Horton et al.; $r = 0.71$ by McFarland et al.^{5,6,7}). But we found that correlation of $SV_1 + RV_5$ with LVMV was not good in normal children of school age.

As the heart is assumed to be a single dipole surrounded by an insulator, electrical potential diminishes inversely with the square of the distance. Then, the value of D^2 ($SV_2 + RV_5$), 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 the left ventricle (D) is considered to be proportional to the electrical potential of the heart. Therefore, it was assumed that the value of D^2 ($SV_1 + RV_5$) was correlated more closely with LVMV than $SV_1 + RV_5$, and we found the methods by which we could obtain close relation between the electrocardiographic measurements and the echocardiographic ones⁵.

Though we assumed a homogeneous insulator surrounding the heart, actually, insulator is not homogeneous. There exist various organs and tissues around the heart—lungs, muscles, ribs, subcutaneous fats, skin, and so on. Thicker subcutaneous fats in females causes lower electrical conductivity in vivo. Probably, because of both the fact mentioned above and weaker generating potential of heart, mean value of D^2 ($SV_1 + RV_5$) in females is lower than that in males. It is probable that weaker correlation of D^2 ($SV_1 + RV_5$) with LVMV in females results from wider variation in thickness of subcutaneous fats. Further investigations will clarify these facts.

SUMMARY

The left ventricular muscle volume (LVMV) and the distance from 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 precordial voltage ($SV_1 + RV_5$) with LVMV was not good ($r = 0.377$ in males and -0.095 in females). The precordial voltage ($SV_1 + RV_5$), therefore, was corrected by the square of D to compensate the diminution of electrical potential by distance. Correlation between D^2 ($SV_1 + RV_5$) and LVMV was good in males ($r = 0.712$) and relatively good in females ($r = 0.469$). Moreover, the values of D^2 ($SV_1 + RV_5$) were different between both sexes at the age of 12–16 years.

The thickness of subcutaneous fat may be one of the most important factors for these differences in D^2 ($SV_1 + RV_5$) and correlation coefficient.

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