Comparison of Total 12-Lead QRS Voltage in a Variety of Cardiac Conditions and Its Usefulness in Predicting Increased Cardiac Mass

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Echocardiography provides a more accurate method to determine increased cardiac mass than does electrocardiography. Nevertheless, most offices of physicians do not possess echocardiographic machines, but many possess electrocardiographic machines. Many electrocardiographic criteria have been used to determine increased cardiac mass, but few of the criteria have been measured against cardiac weight determined at necropsy or after cardiac transplantation. Such was the purpose of the present study. Cardiac weight at necropsy or after transplantation was determined in 359 patients with 11 different cardiac conditions, and total 12-lead electrocardiographic QRS voltage (from the peak of the R wave to the nadir of either the Q or the S wave, whichever was deeper) was measured in each patient. Even in hearts with massively increased cardiac mass (>1,000 g), the total 12-lead QRS voltage was clearly increased (>175 mm) in only 94%, but this criterion was superior to that of previously described electrocardiographic criteria for "left ventricular hypertrophy." Hearts with excessive adipose tissue infrequently had increased total 12-lead QRS voltage despite increased cardiac weight. Likewise, patients with fatal cardiac amyloidosis had hearts of increased weight but quite low total 12-lead QRS voltage. In conclusion, 12-lead QRS voltage is useful in predicting increased cardiac mass, but that predictability is dependent in part on the cause of the increased cardiac mass. © 2013 Elsevier Inc. All rights reserved. **(Am J Cardiol 2013;112:904–909)**

Various electrocardiographic criteria have been used to predict left ventricular hypertrophy (LVH), but few have been compared with the actual weight of the heart at necropsy or after cardiac transplantation. Exceptions are the studies by Griep[1] in 1959, and by Allenstein and Hiroyoshi[2] in 1960. The most common criterion used in the past 60 years is that recommended in 1949 by Sokolow and Lyon,[3] who studied 12-lead electrocardiograms in patients who were believed to have LVH on the basis of "a cardiac disorder capable of producing increased strain on the left ventricle (such as hypertension, aortic valve lesions, coarctation of the aorta, patent ductus arteriosus)." These investigators produced a variety of electrocardiographic criteria for LVH, including among others R in lead $V_5 + S_1$ in lead $V_1 \geq 35$ mm. A number of other criteria have been suggested subsequently (Table 1).[4–11] Siegel and Roberts[12] in 1982 proposed that measuring the total amplitude (from the peak of the R wave to the nadir of either the Q or the S wave, whichever was deeper) of the QRS complex in all 12 electrocardiographic leads was a better determinant of cardiac mass than the previously reported criteria (Figure 1). Subsequently, several investigators from the same laboratory measured total 12-lead QRS voltage in a variety of cardiac conditions and in each compared it with the heart weight determined by the same investigators.[13–22] Here, we review their findings in 11 different cardiac conditions.

Methods

To be included in this study, a heart had to be studied in the Pathology Branch of the National Heart, Lung, and Blood Institute of the National Institutes of Health (Bethesda, Maryland). An accurate heart weight and a 12-lead electrocardiogram had to be available in all cases to be included in this study. The patients were divided into 11 groups (Table 2). The electrocardiographic QRS voltage was measured in each of the 12 leads, as demonstrated in Figure 1. In patients with >1 twelve-lead electrocardiogram available, the one measured was the one recorded closest to the patient's death or closest to cardiac transplantation. The medical records were reviewed in all cases to provide pertinent clinical information. All hearts were examined and classified morphologically by one investigator (WCR). The QRS measurements were

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See page 909 for disclosure information.

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Table 1
Recommended or modified electrocardiographic criteria for determining left ventricular hypertrophy as to 17 patients with hearts at necropsy weighing >1,000 grams*

No.	QRS Complex Measured	Value Considered Upper Limit of Normal (mm)	No. (%) of 17 Patients Above Normal Limit
1a	$SV_1 + RV_5$ or V_6 (larger)	35	12 (71%)
1b	$SV_1 + RV_5$ or V_6 (larger)	40	11 (65%)
2a	SV_1 or V_2 (larger) + RV_5 or V_6 (larger)	35	15 (88%)
2b	SV_1 or V_2 (larger) + RV_5 or V_6 (larger)	40	14 (82%)
3a	SV_1 or V_2 (larger) + RV_6	35	15 (88%)
3b	SV_1 or V_2 (larger) + RV_6	40	13 (76%)
4a	$SV_2 + RV_5$	35	14 (82%)
4b	$SV_2 + RV_5$	40	14 (82%)
5a	Deepest $SV_1 - V_3$ + tallest $RV_4 - V_6$	35	14 (82%)
5b	Deepest $SV_1 - V_3$ + tallest $RV_4 - V_6$	40	13 (76%)
5c	Deepest $SV_1 - V_3$ + tallest $RV_4 - V_6$	45	13 (76%)
5d	Deepest $SV_1 - V_3$ + tallest $RV_4 - V_6$	50	13 (76%)
6a	Tallest R + deepest S in any V lead	35	14 (82%)
6b	Tallest R + deepest S in any V lead	40	14 (82%)
7a	Deepest $SV_1 - V_3$	25	14 (82%)
7b	Deepest $SV_1 - V_3$	30	12 (71%)
8a	Tallest $RV_4 - V_6$	25	9 (53%)
8b	Tallest $RV_4 - V_6$	30	8 (27%)
9a	Deepest $SV_1 - V_2$	25	14 (82%)
9b	Deepest $SV_1 - V_2$	30	12 (71%)
10a	Tallest RV_5 or V_6	25	9 (53%)
10b	Tallest RV_5 or V_6	30	8 (27%)
11	$RV_6 > RV_5$	≤1	13 (76%)
12a	Tallest limb-lead R + deepest limb-lead S	15	15 (88%)
12b	Tallest limb-lead R + deepest limb-lead S	20	12 (71%)
13a	$R_1 + S_3$	15	12 (71%)
13b	$R_1 + S_3$	20	10 (59%)
14a	Tallest limb-lead R	10	14 (82%)
14b	Tallest limb-lead R	15	6 (35%)
15a	Deepest limb-lead S	10	10 (59%)
15b	Deepest limb-lead S	15	6 (35%)
16	R_1	10	11 (65%)
17	S_3	10	7 (41%)
18a	Total 12-lead QRS voltage	175	16 (94%)
18b	Total 12-lead QRS voltage	200	15 (88%)
18c	Total 12-lead QRS voltage	225	13 (76%)
18d	Total 12-lead QRS voltage	250	13 (76%)

* From Roberts and Podolak.[13]

performed by the first author of each study and "spot checked" by WCR when not the first author.

Means, SDs, and percentages were calculated to describe the study cohort (n = 359). A multivariate linear regression model was used to assess the adjusted association between patients' heart weight (grams) and 12-lead QRS voltage (millimeters).[23] Covariates included gender, age, and cardiac condition. Restricted cubic splines were used for all continuous variables.[24] Adjusted p values and plots of the association between patient's heart weight and 12-lead QRS voltage were also estimated.

Results

A total of 359 patients, 208 men (58%) and 151 women (42%), were included and divided into 11 groups (Table 2). Their ages ranged from 14 to 85 years; of the 359 patients, 8 (2%) were aged ≤20 years, including 1 aged 20 years, 5 aged 19 years, 1 aged 16 years, and 1 aged 14 years. The heart weights in the 359 patients ranged from 150 to 1,360 g, and the mean heart weights were of increased mass (heart weight >350 g in women and >400 g in men) in 8 of the 11 groups in men and in 10 of the 11 groups in women. Total 12-lead QRS voltage (measured with normal [10 mm] standardization [10 mm = 1 mV]) ranged from 58 to 601 mm. In 8 of the 11 groups, the mean total 12-lead QRS voltage was lower in male than in female patients; in contrast, the mean heart weight was higher in male than in female patients in 9 of the 11 groups. Additionally, the ratio of total 12-lead QRS voltage (millimeters) to heart weight (grams) was lower in male than in female patients in all 11 groups. Figure 2 depicts the adjusted (by age and gender) association between heart weight and total 12-lead QRS voltage in the 10 patient groups and in the normal group. (Individual patient-level data in the aortic stenosis patient group were not available.) The electrocardiograms obtained in the patients who underwent