A Study of the Human Heart as a Multiple Dipole Source

IV. Left Ventricular Hypertrophy in the Presence of Right Bundle Branch Block

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SUMMARY This report concerns the task of electrocardiographic (ECG) diagnosis and quantitation of left ventricular hypertrophy (LVH) in patients with right bundle branch block (RBBB). In 36 patients with RBBB the left ventricular mass (LVM) of each patient was independently known from quantitative biplane angiography. Two ECG techniques, standard 12-lead ECG and multiple dipole electrocardiography (MDECG), were evaluated. In diagnosing LVH, the best performance of the several standard ECG criteria was sensitivity = 29%, specificity = 100%, and that of the MDECG was sensitivity = 94%, specificity = 96%. In quantitating LVH, the standard ECG gave a correlation with LVM of \( r = 46\% \) and a standard error of estimate of 98 g. The corresponding figures for the MDECG were \( r = 81\% \) and the root mean square prediction error = 64 g.

These results confirm other studies showing that the conventional ECG is of only marginal value in the task of diagnosing LVH in the presence of RBBB. In contrast, the MDECG performs well both in this task and that of quantitating LVH. The results provide further support of the accuracy of the model of the cardiac electrical generator and volume conductor used in the MDECG method.

The present report deals with the continuing assessment of an advanced electrocardiographic (ECG) method referred to as multiple dipole ECG (MDECG).

In 1969 the present authors published a report \(^1\) on the MDECG and its ability to detect and quantitate LVH. The results were established using a series of 72 patients with normal conduction. A strong correlation (predicted theoretically) was demonstrated experimentally between the dipole activity in the left ventricle and septal segments, which is a quantity derived from MDECG, and the left ventricular mass (LVM) derived from quantitative biplane angiography.\(^2\) The regression equation obtained from the correlation can now be used to predict LVM on the basis of MDECG measurements. A prospective study using a new series of 113 patients with normal conduction has proved that the prediction has a root mean square error of 66 g in such patients.\(^3\)

The effectiveness of an ECG technique for determining the presence or absence of some particular cardiac condition, or combination of conditions, may be studied by trials on a series of patients. This series must be composed of patients for whom the presence or absence of the conditions is independently and reliably known. Only then can the accuracy of the ECG predictions be assessed.

The present paper reports results on a series of patients with right bundle branch block (RBBB) and compares the ability of the standard 12-lead ECG and the MDECG to detect and quantitate LVH in this situation. In addition, this study provides further validation of the modeling assumptions used in the MDECG method. The non-ECG method used to determine the presence and degree of LVH was quantitative biplane angiography.\(^2\)

**Materials and Methods**

To date, 126-lead ECG data have been recorded on 1,234 patients and normal subjects, as part of the MDECG
evaluation study. Informed consent was obtained from all patients and subjects prior to the recording. From this series a subseries was selected consisting of all cases meeting the following two requirements: 1) technically satisfactory biplane angiograms available; 2) standard 12-lead ECG showing complete RBBB or incomplete RBBB, according to Minnesota code categories 7.2 and 7.3 respectively. Patients with grossly enlarged right ventricles were excluded since this condition is known to invalidate the determination of LVM from angiograms. There were 23 patients with complete RBBB and 13 with incomplete RBBB.

For each individual, the “anatomic” LVM was determined from the biplane angiogram, using the method of Rackley et al. This was used as the authoritative non-ECG method of assigning cases to the LVH or no-LVH categories for the diagnostic performance study. For assignment to the LVH category, the criterion level was derived from the measurements on normal subjects made by Kennedy et al. by taking two standard deviations (2 × 33 g) above the mean (188 g). The value of the upper limit of normal based upon this study is therefore 254 g. The angiographic method used by Kennedy et al. is the same as that used in the present study.

The MDECQG method has been reported earlier and will be only briefly discussed here. ECG data are recorded from 126 electrodes situated over the entire chest. These data are reduced using a distributed source (12-dipole) model of the ventricles as a generator of electrical current, coupled to a realistically shaped inhomogeneous model of the chest as a current conductor. Activities for each of the 12 dipoles are computed from the body surface potential data. Simple modeling assumptions such as constancy of the propagation velocity of the depolarization wavefront through the ventricular myocardium are made. It then follows that the dipole activity for a particular anatomic segment is linearly related to the amount of electrically active myocardium in the same segment. The sum of the dipole activities from left ventricular and septal dipoles (LVSDA) should therefore be linearly related to the amount of electrically active myocardium in the entire left ventricle (electrical LVM).

Twelve lead ECGs were recorded using routine methods by experienced technicians. The records were then measured and classified by the Minnesota code. The following criteria were analyzed both for quantitative and diagnostic performance: 1) $SV_1 + RV_{aV_4}$ exceeding 35 mm; 2) $RV_{aV_6}$ exceeding 26 mm; 3) $SV_{1,2} + RV_6$ exceeding 40 mm; 4) $R + SV_{1,4}$ exceeding 35 mm.

In addition, the diagnostic performance of the criteria proposed by Scott et al. was analyzed. This method uses a combination of criteria consisting of 1) left axis deviation with $R_1 + SV_6$ exceeding 25 mm; 2) T of lead I greater than 0.5 mm in lead I or a T wave less than 1 mm in lead I (in the absence of digitalis); 2) a negative deflection in $aV_6$ greater than 14 mm; 3) an R wave in lead $aV_6$ greater than 11 mm in a horizontal heart; 4) an R wave in $aV_6$ greater than 20 mm in a vertical heart; 5) an R wave in $V_6$ or $V_6$ greater than 26 mm; 6) $R$ in $V_6$ or $V_6$ plus the $S$ in $V_6$ exceeding 35 mm; 7) QRS duration increased to 0.10 or 0.11 second; 8) a T wave inversion in $V_6$ or $V_6$ with ST depression (in the absence of digitalis); 9) delay in the onset of the intrinsicoid deflection between 0.05 and 0.07 in $V_6$ or $V_6$. If one or more of the criteria were met, LVH was considered to be present.

The diagnostic performances of the ECG methods were evaluated in the following way. The performance of a criterion was judged in terms of two quantities:

$$\text{sensitivity} = \frac{N_1 + N_2}{N_1 + N_3} \times 100\%$$

$$\text{specificity} = \frac{N_1 + N_4}{N_2 + N_4} \times 100\%$$

where $N_1$ is the number of cases in which the criterion is exceeded and the presence of LVH is confirmed by LV angiography.

$N_2$ is the total number of cases in which LVH is confirmed by LV angiography.

$N_3$ is the number of cases in which the criterion is not exceeded and LVH is confirmed by LV angiography.

$N_4$ is the total number of cases in which the LVH is confirmed by LV angiography.

Although the two quantities defined give important information, it is desirable to have a single number to summarize the performance of a criterion. Performance score (PS) is one possibility. Performance score was used in the current report where

$$\text{PS} = \frac{\text{sensitivity} + \text{specificity}}{2}$$

In the assessment of the quantitative performance the electrical LVM was computed from the MDECQG results using the regression equation obtained from the study previously reported. The electrical LVM was then correlated with the anatomic LVM and the root mean square prediction error calculated. Evaluation of the quantitating ability of the conventional ECG was done by correlating the various QRS criteria with the anatomic LVM. Since no predictive equation was available, the standard error of the estimate (SEE) was calculated.

**Results**

Table 1 shows the age, diagnosis, anatomic LVM, LVSDA, and electrical LVM for each of the 36 patients. The ages ranged from 17-67 years. All patients were male except case 638. This male sex preponderance is due to the chest model being patterned after an average-size male, and thus, data recorded from mostly male subjects. Three patients had no cardiac disease. The other 33 patients had no cardiac disease. The other 33 patients represent a broad spectrum of cardiac problems, with ten having coronary heart disease.

**ECG Quantitation of Left Ventricular Mass (LVM)**

For the series of 36 patients (including both complete and incomplete RBBB) the correlation coefficient between the electrical LVM and the anatomic LVM was 81%, and the root mean square prediction error was 64 g. These results are shown in table 2. A major contribution to the prediction error is case 638, a 17-year-old girl with idiopathic hyper-}

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ECG Diagnosis of LVH

The diagnosis of LVH is conveniently viewed as a special case of quantitation of LVM. Assignment of patients to the LVH or to the no-LVH categories by either the ECG or the non-ECG method requires the choice of a dividing line or criterion level. The criteria levels for the conventional ECG are commonly used ones. In addition the criterion proposed by Scott et al.10 was evaluated. Since the MDECG is evaluated prospectively, the upper limit of normal for electrical LVM is the same as for anatomic LVM. As noted above, the upper limit of normal for anatomic LVM is 254 g.

These criteria levels and their performances are shown in table 3. For the entire group, the specificity of all ECG criteria and the MDECG was quite good. However, the sensitivities of the ECG criteria were uniformly low while the MDECG sensitivity was high. A similar pattern was found for the complete and incomplete RBBB groups separately.

Discussion

Part of this study concerns the use of the 12-lead ECG to diagnose LVH in the presence of RBBB. The performance score ranged from 58 to 64% for this patient series. In a study by Booth et al.13 using the conventional ECG, a performance score of 47% was obtained. In another study by Murata et al.12 using the Frank vectorcardiogram, the PS was 55%. This gives some confidence that our series of patients is similar to those of the earlier workers. Since a performance score of 50% corresponds to random assignment of patients to the diagnostic categories, our result is further evidence that the standard 12-lead ECG is only marginally useful for detecting LVH in the presence of RBBB.

In applying the MDECG method to patients with RBBB, the question arises whether the model used for normal LV conduction could be used in the presence of RBBB. Penetrating electrode studies in the dog with experimental RBBB18 have shown that the LV depolarized normally, and that septal activation proceeded entirely from left to right. Thus the presence of RBBB does not drastically alter the propagation directions of the depolarization wavefronts in the left ventricle and septum. It was therefore expected that diagnosis and quantitation of LVH by the MDECG would not be greatly affected by the presence of RBBB. The present results confirm this expectation.

In this paper it has been shown that, using the MDECG method, LVH can be diagnosed in the presence of RBBB with that of the standard 12-lead ECG, the various QRS quantities were correlated with the anatomic LVM. The results of this correlation are also shown in table 2. The r value ranged from 98–108 g and the r from 19 to 46%.

The quantitative results on the complete and incomplete RBBB series separately are also shown in table 2. In the complete RBBB group, the MDECG performance is improved and the ECG performance is about the same. For the incomplete RBBB group, the ECG performance is notably better and similar to the MDECG. This apparent improvement is largely due to the more narrow range of the anatomic LVM in the incomplete RBBB group.
with a sensitivity of 93% and a specificity of 96%. For comparison, it may be noted that Rombilt and Estes,14 when applying their "point score" method to diagnose LVH in a series of patients without RBBB, obtained a sensitivity of 62% and a specificity of 97%.

The ability to accurately quantitate the entire left ventricular mass in humans using a noninvasive technique has important clinical, therapeutic, and research implications. The work presented here provides further evidence that the MDECG method performs significantly better than the conventional ECG in this regard. Further development and testing of the method seems justified.

Acknowledgment

The results in this paper rest on the 126-lead electrocardiographic recordings made with skill and care by Mrs. Johanna E. Wellborn and angiographic work by many staff members of the University of Alabama in Birmingham.

References


8. Sokolow M, Lyon TP: Ventricular complex in left ventricular hypertrophy as obtained by unipolar precordial and limb leads. Am Heart J 37: 161, 1949


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**Table 3. Diagnosis of LVH in Presence of RBBB**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Ref</th>
<th>Combined</th>
<th>Complete</th>
<th>Incomplete</th>
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<td></td>
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<td>Sens.</td>
<td>Spec.</td>
<td>PS</td>
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</table>

*See text for criteria.

Abbreviations: Ref = reference; Sens. = sensitivity; Spec. = specificity; PS = performance score.
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