CRITERIA in current use for the electrocardiographic diagnosis of left ventricular hypertrophy are lacking in both reliability and specificity. Many observers now use abnormally high QRS voltage as an index of hypertrophy. For example, Sokolow and Lyon concluded that hypertrophy of the left ventricle was present when the sum of RV5 or RV6 and SV1 exceeded 35 mv. However, the fact that many patients with left ventricular hypertrophy fail to show abnormal QRS voltage greatly diminishes the usefulness of such measurements. Other electrocardiographic findings suggestive of left ventricular hypertrophy are unquestionably helpful. These include the sloping S-T segments and the minus-plus T waves in left ventricular leads and, in some instances, a delayed onset of the intrinsicoid deflection in the same positions. The material which follows is an attempt further to evaluate the reliability of these criteria.

When fulfilled, the criteria of Sokolow and others constitute, apparently, an extremely reliable diagnostic sign of left ventricular hypertrophy. This has further been confirmed by Scott and other investigators. However, the data to be presented show that the voltage criteria of left ventricular hypertrophy are more often absent than present even when hypertrophy is severe. Since it is the belief of many that left ventricular hypertrophy is unlikely or impossible unless the criteria of abnormal QRS voltage are met, it seems timely to reassess the problem of the electrocardiographic diagnosis in left ventricular hypertrophy.

This evaluation was made by a study of antemortem electrocardiograms in a large number of patients who exhibited unmistakable left ventricular hypertrophy at autopsy. Correlation in these patients was attempted for all electrocardiographic criteria including voltage requirements. Additionally, factors were considered which modify voltage on the body surface.

MATERIAL AND METHODS

The material for this report was derived from an analysis of 200 consecutive patients in whom the Department of Pathology of the Massachusetts General Hospital found unequivocal left ventricular hypertrophy at autopsy, and in whom 1 or more conventional 12-lead electrocardiograms had been taken within 3 weeks prior to death. Patients under the age of 25 years were excluded to eliminate electrocardiograms in which high QRS voltage might be considered normal. All patients (by chance) were Caucasians and showed the expected spread as regards age, sex, and so forth. In nearly the entire group of patients cardiovascular disease was the underlying cause of death. Significant anatomic left ventricular hypertrophy was considered to exist when the postmortem heart weight exceeded 0.5 per cent of the patient's total body weight. As an added check left ventricular hypertrophy was confirmed by correlating the heart weight with the body length according to the tables of Zeck. All cases were discarded from the series in which the postmortem finding
of left ventricular hypertrophy was in any way equivocal, or in which there was evidence or reason for significant combined ventricular hypertrophy.

After 200 consecutive autopsied patients were collected who stringently met all of the above criteria, the antemortem electrocardiograms of each patient was analyzed in detail. This study included careful measurements of QRS voltage and use of the criteria of Sokolow. Other electrocardiographic abnormalities of left ventricular hypertrophy were tabulated, and finally each electrocardiographic deviation other than left ventricular hypertrophy was recorded. In an effort to make this study as "blind" and unbiased as possible, all electrocardiograms were read without knowledge of the pathologic diagnoses.

RESULTS AND COMMENTS

The various electrocardiographic findings in the entire series of 200 patients with autopsy-proved left ventricular hypertrophy are listed in Table 1.

Normal Electrocardiogram. Twenty-three patients exhibited electrocardiograms that were normal in all respects.

Abnormally High QRS Voltage. Forty-four patients (22 per cent) satisfied the Sokolow criteria. They were present as the sole manifestation of left ventricular hypertrophy in only 3 cases (1.5 per cent). If those patients are excluded in whom there were electrocardiographic findings of frank myocardial infarction or bundle-branch block, these values increase to 32 per cent and 2 per cent respectively.

ST-T Changes of the Left Ventricular Hypertrophy Type. These changes consisted of the classical sloping of the S-T segments with minus-plus T waves in the left ventricular leads. There were 96 patients in this group of which 41 had abnormal QRS voltage. Fifty-five cases had unremarkable voltage and showed no other electrocardiographic abnormalities except for isolated instances of small anteroseptal or posteroinferior myocardial infarctions which did not alter the ST-T changes.

These ST-T abnormalities are thought by many to be the most reliable indication of left ventricular hypertrophy. They probably are the manifestations of strain or dilatation of the left ventricle which serves also as a stim-

<table>
<thead>
<tr>
<th>Electrocardiographic findings</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Abnormal QRS voltage criteria fulfilled (44 patients, 22%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. As sole manifestation of left ventricular hypertrophy</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>2. Together with ST-T changes of left ventricular hypertrophy type</td>
<td>41</td>
<td>20.5</td>
</tr>
<tr>
<td>B. Abnormal QRS voltage absent (156 patients, 78%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Normal electrocardiogram</td>
<td>23</td>
<td>11.5</td>
</tr>
<tr>
<td>*2. ST-T changes of left ventricular hypertrophy type</td>
<td>55</td>
<td>27.5</td>
</tr>
<tr>
<td>3. Classical myocardial infarction</td>
<td>51</td>
<td>15.5</td>
</tr>
<tr>
<td>4. Myocardial infarction with peri-infarction block</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>5. Isolated left bundle-branch block</td>
<td>7</td>
<td>3.5</td>
</tr>
<tr>
<td>6. Isolated right bundle-branch block</td>
<td>9</td>
<td>4.5</td>
</tr>
<tr>
<td>†7. Patients in whom some tracings showed QRS voltage abnormalities and others did not</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>8. Nonspecific T-wave abnormalities</td>
<td>5</td>
<td>2.5</td>
</tr>
<tr>
<td>Total</td>
<td>200</td>
<td>100</td>
</tr>
</tbody>
</table>

*Some of these showed evidence of anteroseptal myocardial infarction or postero-inferior myocardial infarction.

†This group is included in the category of "abnormal QRS voltage absent" because the electrocardiograms did not satisfy the Sokolow criteria in every serial tracing.

It seems logical that these changes should precede and accompany abnormal QRS voltage, which is assumed to be a reflection of the increased muscle mass of the hypertrophied ventricle.

Classical Myocardial Infarction. This group included classical myocardial infarctions in differing degrees of chronicity and in various locations. Since it was clearly evident that most myocardial infarctions obviated abnormally high QRS voltage, no attempt was made to set forth a purposeless classification of the myocardial infarctions present. Localized anteroseptal or posteroinferior myocardial infarctions that did not influence the abnormal QRS voltage criteria or the classical ST-T
changes of left ventricular hypertrophy are not included in this group (vide supra).

Myocardial Infarction with Pre-infarction Block. In all of these instances except 1 the Sokolow criteria were not met. Presumably this finding can be attributed to the large mass of infarcted myocardium together with the associated vector shifts that characterize myocardial infarctions in this category.

Isolated Left Bundle-Branch Block. As Sokolow has pointed out, abnormal QRS voltage criteria are not applicable in the presence of left bundle-branch block. It does seem likely, however, that total QRS area rather than voltage may be abnormal in this situation.

Isolated Right Bundle-Branch Block. All electrocardiograms showing right bundle-branch block failed to meet abnormal QRS voltage criteria. The main reason was the lack of the usual deep S wave in V1. Similarly, the extra tall T waves in the outer precordial leads due to right bundle-branch block, interfere with the ST-T abnormalities which might otherwise result from left ventricular hypertrophy.

Serial Tracings in which Some Showed QRS Voltage Abnormalities and Others Did Not. In a few patients in whom several electrocardiograms were taken during the 3-week ante-mortem period, some records met the Sokolow criteria, and others did not. Except for the QRS voltage differences, these serial tracings were otherwise entirely similar. On the basis of voltage criteria alone, it would appear that a patient could have left ventricular hypertrophy one day and not the next. There was no evidence that these differences were technical.

Nonspecific T-wave Abnormalities. This small group of 6 patients did not satisfy the Sokolow criteria or show any electrocardiographic abnormality suggesting left ventricular hypertrophy, and yet some of the largest left ventricles were found in this group. Pathologic diagnoses included primary amyloid disease, hemochromatosis, para-amyloid disease, endocardial fibroelastosis, idiopathic interstitial myocarditis, and interstitial myocardiitits associated with acute glomerulotubular nephritis.

RV6 Greater Than RV5. When this study was undertaken it was suggested 5 that an RV6 of greater voltage than RV5 might indicate the presence of gross left ventricular hypertrophy. This was believed to be due to the leftward position of the enlarged heart with the apex in the mid-axillary line so that the electrode at V6 was closer to the heart than at V5. Patients with midanterior myocardial infarctions were excluded, since they normally are expected to have higher R waves in the lateral leads that are at the same time farther from the site of injury. Despite these exclusions, the finding of RV6 greater than RV5 was present in 51 patients (25.5 per cent of the whole series) with known left ventricular hypertrophy. This number is comparable to that in which abnormal voltage criteria are met and would appear, therefore, to have equal diagnostic importance.

Discussion

This study reemphasizes the shortcomings of the scalar electrocardiogram in determining the presence or absence of left ventricular hypertrophy by the use of any single criterion or, indeed, by the application of several criteria. The electrocardiogram can, in fact, be entirely normal in the presence of severe left ventricular hypertrophy, as was demonstrated in 15 per cent of patients in this series. The presence of Sokolow’s criteria of abnormal QRS voltage apparently correlates well with the demonstration of left ventricular hypertrophy at autopsy.1 However, the absence of abnormal QRS voltage criteria in no way assures that severe left ventricular hypertrophy will not be found at postmortem examination. If these criteria were adhered to, the diagnosis of left ventricular hypertrophy by electrocardiogram could have been made in only 22 per cent of the patients in this group. Or, if those cases are excluded who demonstrated myocardial infarction or bundle-branch block (63 cases), the diagnosis by abnormal voltage would have been appar-
ELECTROCARDIOGRAM IN LEFT VENTRICULAR HYPERTROPHY

ent in 32 per cent of the remainder. Some of the factors that obviated abnormal QRS voltages are readily explainable (e.g., myocardial infarction and bundle-branch block). Other situations in which severe left ventricular hypertrophy occurred without abnormal QRS voltages, are not so easily explained (e.g., normal electrocardiogram, serial tracings with and without abnormal QRS voltage, and diffuse myocardial disease with no specific electrocardiographic abnormalities).

The electrocardiographic finding of the classical ST-T change, which has been attributed to left ventricular hypertrophy, was the most reliable criterion for the diagnosis of left ventricular hypertrophy in this series (Table 1). It was present, however, in only 55 per cent of the group. Here again, both myocardial infarction and intraventricular block often altered the S-T segments and T waves in such a fashion that left ventricular hypertrophy could not be diagnosed. When those electrocardiograms showing frank myocardial infarction and bundle-branch block were rejected, the ST-T abnormalities of left ventricular hypertrophy were found in 80 per cent of the remaining 137 patients.

The fact that 51 patients out of 200 showed a taller R wave in V6 than in V5 may be of some diagnostic importance. This finding is, of course, significant of hypertrophy only in the absence of a mid-anterior myocardial infarction in which the lateral wall of the left ventricle has been spared.

The intrascioid deflection was measured in all electrocardiograms in this series and, although such measurements may at times be helpful in the diagnosis of left ventricular hypertrophy, consistent abnormalities were not found.

The criticism might be advanced that this series is loaded with too many abnormalities that interfere with abnormal QRS voltages and other criteria used in the electrocardiographic diagnosis of left ventricular hypertrophy. However, this group of 200 autopsied patients with proved left ventricular hypertrophy is consecutive and believed to be entirely representative of the variety and kind of abnormalities normally encountered in cardiologic practice.

The electrocardiogram is but one diagnostic means, albeit one of the best, for the determination of disorders of the heart. It often provides the first and occasionally the sole clue to the presence of ventricular enlargement. It would seem unwise, therefore, to limit its diagnostic worth by linking it to a special criterion with a low index of specificity. When abnormal voltage requirements are met, hypertrophy is almost certainly present. However, left ventricular hypertrophy must not be excluded when presently accepted electrocardiographic criteria are not fulfilled.

Summary

The antemortem electrocardiograms of 200 consecutive patients with autopsy-proved left ventricular hypertrophy were studied, and correlations were made with the anatomic findings. Special attention was given to the presence or absence of abnormal QRS voltage criteria to determine their validity and specificity in left ventricular hypertrophy.

The shortcomings of the scalar electrocardiogram in determining the presence or absence of left ventricular hypertrophy by the use of any single criterion or, indeed, by the application of several criteria, are emphasized.

The absence of abnormal QRS voltage criteria in the electrocardiogram is highly unreliable in dismissing left ventricular hypertrophy as a diagnostic possibility.

The reliability of the presently accepted electrocardiographic signs of left ventricular hypertrophy is discussed, and the factors that commonly alter their reliability are considered.

The characteristic ST-segment and T-wave changes associated with left ventricular hypertrophy probably remain the most reliable electrocardiographic sign available; however, ST-T changes of the left ventricular hypertrophy type were present in only 55 per cent of patients in this series. If patients with obvious myocardial infarction or bundle-branch block are excluded, ST-T changes were seen in 80 per cent of the remainder.
In the absence of midanterior myocardial infarction the finding of a taller R wave in V₆ than the R wave in V₅ may be a helpful hint as to the presence of left ventricular hypertrophy.

Abnormally high voltage of the QRS complexes was found in 22 per cent of the whole group or 32 per cent when frank myocardial infarction and bundle-branch block were excluded. Abnormally high voltage as the sole manifestation of left ventricular hypertrophy was exceedingly rare in this series.

Acknowledgment

The author expresses his gratitude to Dr. Conger Williams, Massachusetts General Hospital, Boston, Mass., and to Dr. David Littmann, U.S. Veterans Hospital, West Roxbury, Mass., for their kind advice and encouragement in the preparation of this work.

Summario in Interlingua

In 200 casos consecutiva de hypertrophia sinistro-ventricular con confirmation necrotic, le electrocardiogrammas de ante morte es essa studiate e correlationate con le constatazioni anatomic. Attention special essa prestate al presentia o absentia de criterios de anormalitate del voltage de QRS con le objectivo de determinar lor validitate e specificitate in hypertrophia sinistro-ventricular.

Le imperfecciones del electrocardiogramma scalar in determinar le presentia o absentia de hypertrophia sinistro-ventricular per le uso de un sol criterio o, de facto, de un combination de plure criterios es sublineate de novo.

Le absentia de criterios de anormalitate del voltage de QRS in le electrocardiogramma es un base multo incerte pro rejecer hypertrophia sinistro-ventricular como possibilitate diagnostic.

Es discutite le fidelitate del currentemente acceptate signos electrocardiographic de hypertrophia sinistro-ventricular. Le factores que comunmente affee ille fidelitate es considerate.

Le alterationes characteristic del segmento ST e del unda T que occurre in association con hypertrophia sinistro-ventricular remane probablemente le plus fidel signos electrocardiographic que existe. Tamen, alterationes de ST-T del typo characteristic de hypertrophia sinistro-ventricular esessa presente in solmente 55 pro cento del patientes in le presente serie. Quando le patientes con obvie infarcimento myocardial o bloco de branca es exclusite, le proportion del casos con alterationes de ST-T monta a 80 pro cento.

In le absentia de infarcimento myocardial centro-anterior, le constatation que le unda R in V₆ es plus alte que in V₅ es possiblemente un indicio de valor con respecto al presentia de hypertrophia sinistro-ventricular.

Anormalmente alte voltages del complexes QRS esessa trovate in 22 pro cento del gruppo total e in 32 pro cento post exclusion del casos de franc infarcimento myocardial e bloco de branca. Anormalmente alte voltages como sol manifestation de hypertrophia sinistro-ventricular esessa excessivamente rar in iste serie.

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Pitfalls in the Electrocardiographic Diagnosis of Left Ventricular Hypertrophy: A Correlative Study of 200 Autopsied Patients

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