Left Ventricular Hypertrophy
A Study of the Accuracy of Current Electrocardiographic Criteria When Compared with Autopsy Findings in One Hundred Cases

By Ralph C. Scott, M.D., Vincent J. Seiwert, M.D., David L. Simon, M.D., and Johnson McGuire, M.D.

The current electrocardiographic criteria for the diagnosis of left ventricular hypertrophy have been analyzed in 100 cases of pure left ventricular hypertrophy proved at autopsy. Only those cases were used in which the greatest thickness of the left ventricle was 13 mm. or more, the right ventricle did not exceed 4 mm. in thickness, and the heart weight exceeded the upper limit of the expected normal. Also, only those cases were studied on whom multiple lead electrocardiograms were available. Conclusions are presented as to which sets of electrocardiographic criteria give the greatest accuracy in the diagnosis of left ventricular hypertrophy.

Left ventricular hypertrophy has long been known to give rise to certain characteristic changes in the electrocardiogram. The findings in the standard leads upon which this diagnosis is made have been well described.® These patterns consist essentially of the presence of left axis deviation with an increase in the amplitude of the QRS complex, the size of $R_1$ and $S_3$ exceeding 2.5 millivolts, or with depression of the S-T segment in lead I, or with a T wave in lead I of 1 mm. or less.® Barnes® has described what he calls the typical pattern of left ventricular strain. This consists of left axis deviation with S-T segment depression in lead I and a negative T wave with a convex contour to the anterior limb; reciprocal changes are seen in lead III. Distinction between the terms hypertrophy and strain has been suggested,® using the term hypertrophy when left axis deviation and high voltage are present, and strain when the characteristic changes occur in the S-T segment and T wave in the absence of high voltage or left axis deviation. Others®•° however, use the terms left ventricular strain and hypertrophy synonymously.

It has frequently been pointed out that left ventricular hypertrophy may occur with either normal axis or even right axis deviation in the standard leads, depending upon the heart position.®®®®®®®®®® It was desirable, therefore, to have additional electrocardiographic means of determining left ventricular hypertrophy.

Wilson and his associates®°° by using the precordial leads, set down additional criteria obtained from these leads; namely, the peak of the R waves in leads $V_5$ and $V_6$ is abnormally late and the deflection is abnormally tall. The QRS interval in these leads is often 0.10 or 0.11 second in duration and occasionally even 0.12 second. The R waves in leads $V_1$ and $V_2$ are small and the S waves are large. In more than one-half the cases Q waves occur in $V_5$ and $V_6$ and the T waves are frequently inverted. More recently Sokolow and his co-workers,® in a study of 147 patients with the clinical diagnosis of left ventricular hypertrophy, have suggested additional criteria for the electrocardiographic diagnosis of left ventricular hypertrophy. Others®•° have offered even different criteria for the diagnosis of left ventricular hypertrophy based on findings in the unipolar extremity leads.

Noth, Myers, and Klein® analyzed the findings in the precordial leads in 84 cases of...
pathologically proved left ventricular hypertrophy. They found that differentiation between the pattern of left ventricular hypertrophy and of normal subjects could not be made from the amplitude of the R waves in V4 and V6. Thirty-four of the 84 cases studied showed an abnormal Q-R and/or R duration.

Lewis7 in 1914 and Herrmann and Wilson8 in 1922 correlated the weight of the left ventricle with the electrocardiographic changes in the standard leads in cases of ventricular hypertrophy.

To our knowledge there has been no recent attempt to correlate the autopsy findings in cases of pure left ventricular hypertrophy with the 12-lead electrocardiogram. The present study was undertaken in order to determine which of the present sets of diagnostic criteria give the greatest accuracy when compared with the autopsy findings.

METHODS AND MATERIALS

The autopsy protocols of the Pathology Department of the Cincinnati General Hospital* from 1949-1951 were examined and all cases with a left ventricular thickness of 13 mm. or more and a heart weight of more than the expected normal for the length of the body13 were collected. Any case which had, in addition, a right ventricular thickness of more than 4 mm. was not included because in the present study we were concerned only with the diagnosis of left ventricular hypertrophy. The left ventricle was opened in the Pathology Department by a longitudinal incision along the anteroseptal portion (at right angles to the epicardial surface) carried around the apex and along the posteroseptal portion. The greatest thickness of the cut surface was measured from the epicardium to endocardium but care was taken not to include the thickness of the papillary muscles. The measurements were made by different prosectors but the technic was uniform; however, an allowable error of ±2 mm. was accepted as a definite possibility. Therefore, although most pathologic criteria16, 17 take 10 or 12 mm. as the upper limits of normal we chose 13 mm. in order to be reasonably certain that through inaccuracy in measurement we were not including any normal hearts.

After collecting all cases satisfying these criteria the electrocardiographic files were reviewed and only those cases on whom multiple lead electrocardiograms were available were studied. Cases of left bundle-branch block, right bundle-branch block, or those with pathologic evidence of myocardial infarction were not included. The measurements from the electrocardiograms were carefully made, utilizing a hand lens when necessary. Upward deflections were measured from the top of the base line to the peak of the upstroke; downward deflections were measured from the bottom of the base line to the nadir of the downstroke. If there were variations in the height of a deflection due to respiratory variations, an average of several deflections was used. The RS-T segment deflections were measured from the isoelectric level except in those cases where, because of tachycardia (rate over 100) or first degree A-V heart block, the P wave was superimposed on the preceding T wave and no true T-P level was obtained; in these cases RS-T segment shifts were measured in relation to the P-Q segment. The height of upright T waves in cases with depressed RS-T segments was measured from the level of the RS-T segment (rather than from the isoelectric line).

The electrocardiographic position of the heart was noted, using Wilson’s criteria.14 The last electrocardiogram taken before death was used in cases in which many tracings were available except in occasional cases where the last record was technically unsatisfactory.

RESULTS

Criteria of Gubner and Ungerleider

Gubner and Ungerleider1 have set down the following criteria for the diagnosis of left ventricular hypertrophy from the standard leads, namely, the occurrence of left axis deviation with: (1) R1 plus S2 exceeding 25 mm., or (2) depression of the S-T segment of 0.5 mm. or greater in lead I, or (3) a T wave in lead I of less than 1 mm.

Thirty-six of the 100 cases satisfied their criteria of left axis deviation with high voltage and S-T segment or T-wave abnormalities (table 1).

Criteria of Katz

Katz5 uses the term left heart strain synonymously with left ventricular hypertrophy. He classifies left heart strain into four groups: first type, second type, mixed type, and concordant type.

In the first type, there is left axis deviation, and the S-T segments and T waves are normal;

* In the study of Goldberger's criteria for ventricular hypertrophy, his criteria for rotation around the anteroposterior axis were used.
lead II consists of a small, equiphasic QRS complex, or a complex with a deep S wave.

The second type consists of left axis deviation with S-T segment depression in lead I with upward convexity of the segment and T-wave inversion.

In the mixed type, there is left axis deviation with a small equiphasic QRS complex in lead II or a complex with a deep S wave, and S-T-T changes in lead I such as those observed in type II.

In the concordant type, the QRS complexes are upright in the standard leads, and there is S-T segment depression and T-wave inversion in lead I (and II, III).

Katz also describes characteristic changes in the chest leads, namely, a QS in CF_{2} or an R wave of less than 1.5 mm., S-T segment elevation in CF_{2} of more than 2.5 mm., and an upright T wave; in CF_{4} the S-T segment is depressed and the T wave inverted.

Using Katz's criteria for the standard leads we found 40 per cent accuracy. If we add his criteria for the chest leads this increases the accuracy to 59 per cent (table 2).

Criteria of Schach, Rosenman, and Katz

Schach, Rosenman, and Katz found that criteria indicative of left ventricular strain included a negative deflection in aV_{R} greater than 14 mm., an R wave in aV_{L} exceeding 12

<table>
<thead>
<tr>
<th>Heart Position</th>
<th>No. Cases</th>
<th>aV_{R} Neg.</th>
<th>aV_{L} R &gt; 12</th>
<th>aV_{L} R &gt; 19</th>
<th>Neg. aV_{A} pos. aV_{L} (aV_{R})</th>
<th>Total Positives</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>13</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>(29)</td>
<td>3</td>
</tr>
<tr>
<td>SV</td>
<td>91</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>(23)</td>
<td>0</td>
</tr>
<tr>
<td>I</td>
<td>29</td>
<td>7</td>
<td>3</td>
<td>8</td>
<td>(26)</td>
<td>8</td>
</tr>
<tr>
<td>SH</td>
<td>91</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>(12)</td>
<td>0</td>
</tr>
<tr>
<td>H</td>
<td>36</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>(21)</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>96</td>
<td>9</td>
<td>9</td>
<td>17</td>
<td></td>
<td>21</td>
</tr>
</tbody>
</table>

If we combine these criteria with those of Katz for standard and chest leads, we get 59 + 8 = 67 per cent.

mm., an R wave in aV_{R} exceeding 19 mm., and a value for the sum of the negative deflection in aV_{R} and the positive deflection in aV_{L} or aV_{R} exceeding their maximum normal.

Twenty-one of our cases satisfied these criteria. If, in addition, an elevated S-T segment or an upright T wave in aV_{R} is included, the accuracy increases to 35 per cent (table 3).

If we combine these criteria for the unipolar extremity leads with those of Katz for the standard and chest leads, we get an accuracy of 67 per cent (table 3).

Criteria of Goldberger

Goldberger has pointed out that left ventricular hypertrophy may occur with a normal
LEFT VENTRICULAR HYPERTROPHY

Table 5.—Goulder and Kissane

<table>
<thead>
<tr>
<th>Heart Position</th>
<th>No. Cases</th>
<th>aV_L</th>
<th>R &gt; 11% T/R &lt; 10%</th>
<th>R &gt; 11% T/R &gt; 19%</th>
<th>R 10-11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi Hor .......</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hor ............</td>
<td>36</td>
<td>7</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Total ..........</td>
<td>45</td>
<td>7</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

12 of 45 Cases—27 Per Cent Accuracy

electrocardiogram, or with high voltage in the unipolar extremity leads (R in aV_L of 13 mm. or more in a horizontal heart, or R in aV_F of 20 mm. or more in a vertical heart). He uses the term left ventricular strain when there is RS-T segment depression and/or T wave inversion and/or prolongation of the Q-T in aV_L in a horizontal heart or in aV_F in a vertical heart. If both high voltage and ST-T changes coexist he speaks of left ventricular hypertrophy and strain.

Utilizing his criteria for the unipolar extremity leads we found an accuracy of 68 per cent* (table 4).

Criteria of Goulder and Kissane

Goulder and Kissane* have proposed criteria for the diagnosis of left ventricular hypertrophy in horizontal or semihorizontal hearts. Based upon the height of the R wave and the T to R ratio in aV_L, they found that 83 per cent of their 65 patients had an R wave in aV_L greater than 11 mm. with or without a T to R ratio less than 10 per cent or an R wave over 10 mm. always with a T to R ratio less than 10 per cent.

There were 12 of 45 cases (with horizontal or semihorizontal hearts) that could be diagnosed by utilizing their criteria, an accuracy of 27 per cent (table 5).

* Goldberger states that the changes characteristic of left ventricular hypertrophy (high voltage) or strain (ST-T changes) also occur in one or more precordial leads which face the epicardial surface of the left ventricle (V_4, V_5, and V_6). He states, in addition, that these precordial leads may show widening of the QRS, or delay in the onset of intrinsicoid deflection. Since these same criteria have been previously suggested by other authors*, they were not separately analyzed. Instead, analysis of Goldberger's proposed criteria has been limited to the unipolar extremity leads.

Table 6.—Noth, Myers, and Klein

<table>
<thead>
<tr>
<th>No. Cases</th>
<th>V_R, V_L</th>
<th>V_R, V_L</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>14</td>
<td>24</td>
<td>28</td>
</tr>
<tr>
<td>R 0.04 sec. or &gt;</td>
<td>Q-R 0.05 sec. or &gt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Criteria of Noth, Myers, and Klein

Noth, Myers, and Klein* have found an abnormal Q-R (0.05 second or more) duration and/or an abnormal R duration (0.04 second or more) in V_5, V_6 in 34 of their 84 cases of pathologically proven left ventricular hypertrophy.

We encountered these findings in 28 per cent of the present series (table 6).

Criteria of Wilson and Co-workers

Wilson and associates* have pointed out that the precordial leads in left ventricular hypertrophy differ from the normal in the following characteristics: (1) the R waves in V_1 are abnormally small (1 mm. or less) and may be absent*; the S waves are abnormally large (24 mm. or more)*; (2) the transition zone is often displaced to the left; (3) in V_5 and V_6 the peak of R is abnormally late (0.05 second or more)*; (4) the R waves in V_5, V_6 are abnormally tall (33 mm. or more in V_5, 26 mm. or more in V_6)*; (5) the T wave is often inverted in V_5 and V_6; (6) the QRS interval is frequently increased to 0.10 or 0.11 second.

One or more of these criteria were present in 81 per cent of our cases (table 7). If one requires a minimum of two of these criteria to be present, the positivity declines to 53 per cent; if three criteria are required the positivity diminishes to 18 per cent.

Criteria of Sokolow and Lyon

Sokolow and Lyon** have formulated the following criteria for the diagnosis of left ventricular hypertrophy.

Table 7.—Wilson’s Criteria (100 Cases)

<table>
<thead>
<tr>
<th>V_1</th>
<th>V_1</th>
<th>V_5</th>
<th>V_5</th>
<th>QRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>R 1 mm. or &lt;</td>
<td>S 24 or &gt;</td>
<td>Trans. Zone Displaced to Left</td>
<td>Q Present</td>
<td>R 50 mm. or &gt;</td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>56</td>
<td>11</td>
<td>36</td>
<td>34</td>
<td>19</td>
</tr>
</tbody>
</table>

One or more of these criteria present in 81 cases
ventricular hypertrophy from the unipolar extremity leads: (1) RS-T segment depressed more than 0.5 mm. in aV_{L} or aV_{F}; (2) flat, diphasic, or inverted T waves, with an R wave of 6 mm. or more in aV_{L} or aV_{F} and item 1; (3) voltage of R wave in aV_{L} greater than 11 mm. or in aV_{F} greater than 20 mm.; (4) upright T wave in aV_{R}.

Employing these criteria we found 47 per cent accuracy in our series (table 8A). Seven cases were diagnosed by the unipolar extremity leads alone.

Sokolow and Lyon\textsuperscript{11} described the following changes in the precordial leads in left ventricular hypertrophy: (1) the RS-T segments are depressed and the T waves low or inverted in V_{5} or V_{6}; (2) R waves in V_{5} or V_{6} exceed 26 mm.; (3) the onset of the intrinsiceoid deflection in V_{5} or V_{6} exceeds 0.05 second*; (4) the R to T ratio in V_{5} (or V_{6}) is 10 or greater; (5) the R to S ratio in V_{4} divided by the R to S ratio in V_{1} is greater than 100; (6) the sum of the R wave in V_{5} (or V_{6}) and the S wave in V_{1} exceeds 35 mm.

Using these criteria for the precordial leads we found an accuracy of 75 per cent in our series (table 8B).

Combining Sokolow and Lyon's criteria for the unipolar extremity leads and the precordial leads we found 85 per cent accuracy. If we require two or more criteria to be present the accuracy declines from 85 per cent to 64 per cent.

Effect of Digitalis on the Accuracy of Diagnosis of Left Ventricular Hypertrophy

Digitalis is known to produce S-T-T changes which at times may be indistinguishable from those of left ventricular hypertrophy. In our series there were 33 patients who were receiving

| TABLE 8 | A. Sokolow and Lyon's Criteria for Unipolar Extremity Leads |
|---|---|---|---|---|
| No. Cases | R > 26 mm. | RS-T > 0.5 mm. | T low or ↓ | R > 20 mm. | RS-T > 0.5 mm. | T low or ↓ |
| 99 | 21 | 11 | 10 | 5 | 2 | 15 |

47 Per Cent Accuracy

B. Sokolow and Lyon's Criteria for Precordial Leads

<table>
<thead>
<tr>
<th>No. Cases</th>
<th>V_{1}</th>
<th>V_{4}</th>
<th>R/T in V_{5}, V_{6}</th>
<th>R/S in V_{4}, V_{5} &gt; 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>18</td>
<td>34</td>
<td>46</td>
<td>19</td>
</tr>
</tbody>
</table>

At least one of these criteria present in 75 cases. Unipolar + Precordial Leads: 85 per cent Accuracy

* Since Sokolow and Lyon found 88 per cent of their cases with left ventricular hypertrophy to have a ventricular activation time of 0.05 to 0.08 second, we have also analyzed our cases to include those with an onset of the intrinsocloid deflection of 0.05 second or greater.

| TABLE 9.—Effect of Digitalis Administration upon Accuracy of Criteria |
|---|---|---|
| Authors | Total No. of Positives Excluding Those Obscured by Digitalis |
| Gubner and Ungerleider... | 36 | 25 |
| Schach, Rosenman, and Katz | 34 | 29 |
| Goldberger... | 67 | 50 |
| Katz... | 59 | 45 |
| Sokolow and Lyon... | 85 | 73 |
| Wilson and colleagues... | 81 | 79 |
| Noth, Myers, and Klein... | 24 | 24 |
digitalis. We have compared the accuracy of the various authors' criteria after arbitrarily excluding those instances where the diagnosis rested on S-T-T alterations alone. As shown in table 9 almost all the authors' criteria suffered.

Digitalis shortens the Q-T interval, whereas left ventricular hypertrophy is reported to prolong the Q-T interval.4, 6, 19, 20, 21 We have measured the Q-T interval in our 100 cases. Sixty-seven cases did not receive digitalis; 29 (43.3 per cent) had a normal Q-T interval while 38 (56.7 per cent) showed a prolonged Q-T interval. Thirty-three cases received digitalis; 22 (66.7 per cent) had a normal Q-T while only 11 (33.3 per cent) showed a prolonged Q-T interval. Thus, although more than one-half of our cases with left ventricular hypertrophy who were not receiving digitalis had abnormally long Q-T intervals, only one-third of those who were receiving digitalis had prolonged Q-T intervals.

Analysis of Cases Missed by Current Electrocardiographic Criteria

There were two cases in which hypertrophy was missed by all authors' criteria. The salient features of these are shown in table 10.

There were four cases in which hypertrophy was missed by the criteria of Sokolow and/or Wilson, but three of these were diagnosed by

<table>
<thead>
<tr>
<th>Case No.</th>
<th>RV (mm.)</th>
<th>LV (mm.)</th>
<th>Heart Wt. (Gm.)</th>
<th>% Heart Wt. above Normal</th>
<th>ECG Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>15</td>
<td>435</td>
<td>15</td>
<td>Normal</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>16</td>
<td>400</td>
<td>5</td>
<td>Normal</td>
</tr>
</tbody>
</table>

Katz's criteria and one by Goldberger's criteria. These are shown in table 11.

Incidence of Positive Results Based on Percentage of Heart Weight above Expected Maximum Normal

We employed Zeek's criteria15 for normal heart weight which is based upon body length; only those cases which exceeded the standard deviation above the mean were used in this study.

We analyzed our cases from the standpoint of accuracy of the various authors' criteria when compared with the percentage of heart weight above the maximum expected normal. As seen in table 12, Sokolow's and Wilson's criteria gave the greatest accuracy for all heart weights.

Remarks

This study tested only the positivity of the various authors' criteria in cases of proved pure left ventricular hypertrophy. It did not test the specificity of these criteria, that is, the occurrence of false positives. In order to do that, these same criteria should be applied to the electrocardiograms in a series of cases with hearts of normal size proved at autopsy.

The various authors' criteria depend on one or more of the following features: (a) RS-T segment or T-wave abnormalities (67 per cent); (b) prolonged Q-T (48 per cent); (c) high voltage (29 per cent); (d) delayed onset of the intrinsicoid deflection or prolonged duration of the QRS (28 per cent); (e) ratios derived from these findings (57 per cent).
SUMMARY AND CONCLUSIONS

1. The current electrocardiographic criteria for the diagnosis of left ventricular hypertrophy have been subjected to analysis in 100 cases of pure left ventricular hypertrophy proved at autopsy.

2. The criteria of Sokolow, Wilson, Goldberger, and Katz are, in order, the most accurate in the electrocardiographic diagnosis of left ventricular hypertrophy.

3. Using the criteria of Sokolow and/or Wilson, we were able to diagnose correctly 92 of the 100 cases; three in addition were diagnosed by Katz's criteria, and one by Goldberger's criteria giving a total of 96 per cent accuracy in proved cases of left ventricular hypertrophy.

4. Digitalis obscures the diagnosis in many instances where criteria based only upon RS-T segment and T-wave changes are used.

5. A significant association was found between increasing heart weight and increasing accuracy of diagnosis, using Sokolow's criteria.

6. The cases missed by the application of the criteria of Sokolow and Wilson had only minimal left ventricular hypertrophy.

SUMMARIO E CONCLUSIONES IN INTERLINGUA

1. Le criterios electrocardiographic traditional pro le diagnose de hypertrophia sinistroventricular eseva analyse en 100 casos de pur hypertrophia sinistroventricular confirmate per medios autopic.

2. Le criterios de Sokolow, Wilson, Goldberger, e Katz es in iste ordine le plus exacte criterios in le diagnose electrocardiographic de hypertrophia sinistroventricular.

3. Per medio del criterios de Sokolow e/o Wilson nos succedeva a diagnosticar correctemente 92 del 100 casos. In plus tres casos eseva diagnosticate secundo le criterios de Katz; un altre secundo illos de Goldberger. Assi le total del exactitude diagnostic in demonstrate casos de hypertrophia sinistroventricular amontava a 96 pro cento.

4. Digitalis obsura le diagnose in multe casos si le criterios usate es limitate a illos basate super cambiamentos del segmento RS-T e del unda T.

5. Esseva constatare un significative correlazione inter augmentate pesos cardiac e augmentate exactitudes diagnostic secundo le criterios de Sokolow.

6. Le casos non identificate per le criterios de Sokolow e Wilson habeva hypertrophia sinistroventricular solmente in grados minimal.

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