Epidemiological Study of the Electrocardiographic Diagnosis of Left Ventricular Hypertrophy

By Leon D. Ostrander, Jr., M.D.

The clinical diagnosis of left ventricular hypertrophy frequently depends in part on the electrocardiogram. The electrocardiographic criteria for such an important diagnosis should be uniform, specific, easily applied, and sensitive enough to detect the milder cases. The number of criteria proposed in the past and the continued search for additional items of diagnostic value are evidence enough that none is ideal.

In theory, increasing thickness of the left ventricular myocardium should result in activation waves of greater amplitude and duration. If this were true, a scale of values for amplitudes, activation time, and total duration of the QRS interval should be attainable which would permit the physician to diagnose left ventricular hypertrophy with a predictable degree of certainty. Unfortunately, many factors prevent such a precise diagnostic scheme.

Most of the current criteria depend on the amplitude of R or S waves in the various leads of the scalar electrocardiogram. Activation time and total QRS interval are included as ancillary items but are unreliable signs because of difficulty in measurement, unavoidable distortion in the leading systems, and minor degrees of intraventricular block.

T-wave changes, left axis deviation, and shift of the transitional zone to the left have been proposed as additional features of diagnostic value, but they are not specific for left ventricular hypertrophy.

The sensitivity of numerous electrocardiographic items proposed for the detection of left ventricular hypertrophy has been tested at autopsy on patients in the studies of Scott, Seiwert, Simon, and McGuire; Griep; Allenstein and Mori; and Soloff and Lawrence. Several features have correlated well with anatomic evidence of left ventricular enlargement, but they appeared to lack specificity. Because autopsy material is not representative of the general population in age, nutrition, or general health, conclusions based on the study of such individuals may not be applicable to the population as a whole.

Only a few investigators have reported the effect of constitutional factors such as age, sex, and body build on the amplitudes of the complexes used in the detection of ventricular enlargement. Simonson reported the effect of age and sex on the range of amplitudes recorded from apparently normal persons. Kilty and Lepeschkin recently reported the effect of the ponderal index on the sensitivity and specificity of a number of indices of left ventricular hypertrophy. Grubschmidt and Sokolow and Manning and Smiley reported that the usual QRS voltage criteria for left ventricular hypertrophy could not be applied to young males because of the frequency of false positive diagnoses. Although other authors have commented on the prevalence of false positive diagnoses among emaciated persons most have not mentioned age, sex, or body build as factors in diagnosis.

In this report a number of criteria of left ventricular hypertrophy are applied to electrocardiograms from the adult members of a total natural community.

Methods

The community of Tecumseh, Michigan, has...
been studied extensively since 1957 in an effort to identify and evaluate a large variety of possible factors which influence the health of the population.\textsuperscript{11, 12} As part of this investigation, complete medical histories were taken and physical examinations, electrocardiograms, and selected laboratory tests were performed on 8,641 persons from the total population of 9,822 in 1959 and 1960.\textsuperscript{13}

Electrocardiograms were recorded from 5,129 examined persons 16 years of age or older, 2,449 men and 2,680 women, approximately 85\% of the adult population.

Mercury sphygmomanometers were used to record blood pressures. The disappearance of sounds was accepted as the diastolic pressure for the current analysis.

Hypertension was defined as a systolic blood pressure of 160 mm Hg or more or a diastolic blood pressure of 95 mm Hg or more regardless of age or sex.\textsuperscript{14} Although median systolic and diastolic blood pressures varied greatly between the sexes and at different ages (table 1), absolute rather than relative levels were considered more pertinent to the development of left ventricular hypertrophy. Although diastolic hypertension is usually considered more important clinically, reports from several studies suggest that elevation of either phase of the blood pressure is associated with an increased prevalence of vascular disease.\textsuperscript{15, 16}

Histories were initially recorded on standardized forms by carefully trained lay interviewers. All positive answers were checked by the examining physicians who were experienced members of the clinical teaching staff of the University of Michigan Medical School. Data obtained on physical examinations were recorded on forms which were designed to emphasize precise reporting of physical findings, particularly those related to the cardiovascular system. Histories of angina pectoris and myocardial infarction were accepted only if they fulfilled strict criteria as described elsewhere.\textsuperscript{17} Valvular heart disease was considered a possible cause of left ventricular hypertrophy when there was a definite murmur of aortic stenosis or regurgitation or mitral regurgitation.

A single chest teleroentgenogram was recorded from each respondent, and the cardiothoracic ratio was calculated. The means of these values varied with age and sex but, for the purposes of this analysis, measurements of one standard deviation or more above the mean were considered suggestive of cardiomegaly.

Relative weight is the ratio of actual weight to a weight predicted from the regressions of weight on height, biacromial diameter, and bicristal diameter. The regressions were obtained separately for men and women, 20 through 29 years of age, in the Tecumseh population.\textsuperscript{18} Light and heavy persons were defined as those in the lower and upper quintiles of the relative weight distribution.

Twelve lead electrocardiograms were recorded on direct writing single channel instruments at a paper speed of 50 mm per second. All tracings from persons 16 years of age or older were classified according to the system of Blackburn and

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|c|c|}
\hline
Age, yr & \multicolumn{4}{|c|}{Men} & \multicolumn{4}{|c|}{Women} \\
\hline
 & Systolic & Diastolic & 80th centile & Median & Systolic & Diastolic & 80th centile & Median \\
\hline
15-16 & 150 & 126 & 140 & 74 & 80 & 155 & 122 & 134 & 74 & 82 \\
17-19 & 137 & 128 & 142 & 76 & 84 & 161 & 120 & 132 & 72 & 82 \\
20-24 & 181 & 130 & 142 & 76 & 88 & 257 & 120 & 132 & 72 & 82 \\
25-29 & 223 & 130 & 150 & 78 & 88 & 328 & 120 & 134 & 75 & 84 \\
30-34 & 332 & 132 & 146 & 80 & 92 & 364 & 124 & 138 & 76 & 88 \\
35-39 & 342 & 132 & 146 & 82 & 92 & 339 & 125 & 142 & 78 & 90 \\
40-44 & 242 & 132 & 148 & 84 & 94 & 262 & 130 & 150 & 80 & 92 \\
45-49 & 224 & 136 & 160 & 86 & 100 & 212 & 138 & 160 & 85 & 98 \\
50-54 & 170 & 140 & 160 & 86 & 100 & 168 & 146 & 172 & 88 & 102 \\
55-59 & 162 & 138 & 158 & 86 & 96 & 157 & 148 & 178 & 89 & 100 \\
60-64 & 97 & 142 & 170 & 86 & 98 & 94 & 156 & 188 & 88 & 102 \\
65-69 & 80 & 142 & 165 & 84 & 96 & 102 & 154 & 180 & 88 & 100 \\
70-74 & 65 & 142 & 162 & 82 & 94 & 75 & 160 & 190 & 86 & 100 \\
75-79 & 35 & 142 & 178 & 80 & 94 & 44 & 156 & 202 & 85 & 100 \\
80+ & 26 & 145 & 198 & 80 & 96 & 43 & 160 & 182 & 82 & 96 \\
\hline
N = number. \\
\end{tabular}
\caption{Blood Pressure Variations with Age and Sex in Tecumseh, Michigan}
\end{table}
Table 2

**Commonly Employed Items from Criteria of Left Ventricular Hypertrophy**

<table>
<thead>
<tr>
<th>Limb leads</th>
<th>Amplitude criteria</th>
<th>Chest leads</th>
<th>Other items</th>
</tr>
</thead>
<tbody>
<tr>
<td>R, R', R''</td>
<td>&gt; 20 mm&lt;sup&gt;19&lt;/sup&gt;</td>
<td>R&lt;sub&gt;T&lt;/sub&gt; &lt; 1 mm + S&lt;sub&gt;T&lt;/sub&gt; &lt; 24 mm&lt;sup&gt;25&lt;/sup&gt;</td>
<td>ST depression</td>
</tr>
<tr>
<td>R + S&lt;sub&gt;H&lt;/sub&gt;</td>
<td>&gt; 25 mm&lt;sup&gt;20&lt;/sup&gt;</td>
<td>S&lt;sub&gt;T&lt;/sub&gt; &lt; 24 mm&lt;sup&gt;25&lt;/sup&gt;</td>
<td>T wave inversion</td>
</tr>
<tr>
<td>Q or S aV&lt;sub&gt;6&lt;/sub&gt;</td>
<td>&gt; 14 mm&lt;sup&gt;21&lt;/sup&gt;</td>
<td>R&lt;sub&gt;V&lt;/sub&gt; &lt; 26 mm&lt;sup&gt;19&lt;/sup&gt;, 24</td>
<td>Flat T waves</td>
</tr>
<tr>
<td>R aV&lt;sub&gt;5&lt;/sub&gt;</td>
<td>&gt; 11 mm&lt;sup&gt;22, 23&lt;/sup&gt;</td>
<td>R&lt;sub&gt;V&lt;/sub&gt; &lt; 33 mm&lt;sup&gt;25&lt;/sup&gt;</td>
<td>T&lt;sub&gt;V&lt;/sub&gt; &lt; T&lt;sub&gt;V&lt;/sub&gt;&lt;sup&gt;27&lt;/sup&gt;</td>
</tr>
<tr>
<td>R aV&lt;sub&gt;6&lt;/sub&gt;</td>
<td>&gt; 12 mm&lt;sup&gt;21&lt;/sup&gt;</td>
<td>R&lt;sub&gt;V&lt;/sub&gt; &lt; 26 mm&lt;sup&gt;19&lt;/sup&gt;, 25</td>
<td>Activation time&lt;sup&gt;23&lt;/sup&gt;, 24, 28</td>
</tr>
<tr>
<td>R aV&lt;sub&gt;1&lt;/sub&gt;</td>
<td>&gt; 13 mm&lt;sup&gt;24&lt;/sup&gt;</td>
<td>S&lt;sub&gt;V&lt;/sub&gt; + R&lt;sub&gt;V&lt;/sub&gt; or V&lt;sub&gt;6&lt;/sub&gt; &gt; 35 mm&lt;sup&gt;23&lt;/sup&gt;</td>
<td>V&lt;sub&gt;1&lt;/sub&gt; or V&lt;sub&gt;6&lt;/sub&gt; &lt; 0.05 sec</td>
</tr>
<tr>
<td>R aV&lt;sub&gt;4&lt;/sub&gt;</td>
<td>&gt; 19 mm&lt;sup&gt;21&lt;/sup&gt;</td>
<td>R&lt;sub&gt;V&lt;/sub&gt; &lt; R&lt;sub&gt;V&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
<td>QRS ≥ 0.10 sec&lt;sup&gt;25&lt;/sup&gt;</td>
</tr>
<tr>
<td>R aV&lt;sub&gt;F&lt;/sub&gt;</td>
<td>&gt; 20 mm&lt;sup&gt;19&lt;/sup&gt;, 23, 24</td>
<td>R + S &lt; 45 mm *&lt;sup&gt;26&lt;/sup&gt;</td>
<td>LAD† (≥ 30°)&lt;sup&gt;29&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

ST and T items are common to many different criteria.

*Greatest R + greatest S.
†Left axis deviation.
‡Transitional zone displaced to the left.

associates,<sup>19</sup> which is referred to as the “Minnesota” code.

From 193 electrocardiograms classified III-I by the Minnesota criteria (high amplitude R waves), the mean amplitude of the R waves in leads I, II, III, aV<sub>1</sub>, aV<sub>F</sub>, V<sub>1</sub> and V<sub>2</sub> to V<sub>6</sub>, and the S waves in leads III and V<sub>1</sub> to V<sub>4</sub> were recorded. The QRS duration in the limb leads and the activation time in leads V<sub>5</sub> and V<sub>6</sub> were measured. Any ST segment depression, flat or inverted T waves in leads I, II, aV<sub>1</sub>, aV<sub>F</sub>, or V<sub>2</sub> to V<sub>6</sub> was recorded. The relative height of the T waves in leads V<sub>1</sub> and V<sub>6</sub> was noted for each tracing. Left axis deviation (−30° or less) or a shift of the transitional zone to the left beyond lead V<sub>4</sub> was recorded. Fifteen other tracings classified III-I were not technically suitable for these measurements.

Randomly selected age and sex-matched subjects without electrocardiographic evidence of infarction, high amplitude R waves, or complete bundle-branch block according to the Minnesota criteria were used as controls, and their tracings were measured in the same manner.

Differential items (table 2) from the currently used criteria of left ventricular hypertrophy were applied separately to each tracing in the two groups.

The groups were divided according to sex and age, 16 through 49 or 50 years and older. They were further separated into four groups according to clinical findings: hypertensives, persons with other conditions singly or in combination which could produce left ventricular hypertrophy, low relative weight, and no disease. The other conditions considered were valvular heart disease, coronary heart disease, or an increased cardiothoracic ratio in a normotensive subject. Hypertensives with valvular or coronary heart disease were included in the “other conditions” category.

Although the precise anatomic diagnosis of left ventricular hypertrophy requires confirmation at autopsy, normal size can be reasonably inferred when the heart is not enlarged in the chest x-rays and the history and physical examination reveal no cause for enlargement.

On the other hand, the detection of physical abnormalities that may produce evidence of enlargement or of cardiomegaly in chest x-rays merely suggests the possibility of anatomic left ventricular hypertrophy. An increased cardiothoracic ratio is an inexact sign of cardiomegaly in the individual case but has differential value in a large group.<sup>30</sup> Because sustained hypertension cannot be distinguished from less important labile changes in blood pressure on a single examination,<sup>31</sup> high blood pressure is not always associated with anatomic enlargement of the left ventricle. In spite of these qualifications, for the purposes of this report such findings are considered evidence of possible anatomic enlargement. Because the diagnosis of no anatomic enlargement is more certain than the diagnosis of hypertrophy, the associations between the various electrocardiographic items and anatomic hypertrophy are even less impressive than they appear.

Although the evidence of anatomic ventricular size is indirect, these classifications permit an assessment of the relative sensitivity and specificity of the separate differential items used in various diagnostic criteria of left ventricular hypertrophy. Items of high sensitivity detect a large proportion of persons with left ventricular hypertrophy but also many without anatomic enlargement, but items of high specificity are usually detected only in the presence of hypertrophy. A sensitive item frequently suggests many false positive diagnoses; a specific item may exclude
many abnormals, the false negatives. The sensitivity and specificity of amplitude items tend to be inversely related.

**Results**

**Differences between the Group with High Amplitude R Waves in the Electrocardiogram and the Control Group (Tables 3 and 4)**

Forty-six persons in the high amplitude group and only 30 of the controls had a cardiothoracic ratio one standard deviation or more above the mean (table 3). The mean cardiothoracic ratio for each age range of persons with high R wave amplitudes was greater than for the control groups (table 4).

Sixteen persons, seven with electrocardiographic changes and nine controls fulfilled the criteria for congestive heart failure. Among men 50 years of age or older, 68% with electrocardiographic changes and 42% of controls had a cause for enlargement. Three of the nine women from 16 through 49 years of age with electrocardiographic changes and two of the nine controls had cause for enlargement. Seventy-five percent of women 50 years of age or older with high amplitude R waves and 53% of the controls had cause for enlargement.

**Table 3**

*Differences Between 193 Persons with High Amplitude R Waves on the Electrocardiogram and Their Matched Controls*

<table>
<thead>
<tr>
<th>Persons with high amplitude R waves</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probable cardiomegaly on x-rays</td>
<td>46</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>7</td>
</tr>
<tr>
<td>BP $\geq$ 110 mm diastolic</td>
<td>15</td>
</tr>
<tr>
<td>Low relative weight</td>
<td>41</td>
</tr>
<tr>
<td>High relative weight</td>
<td>35</td>
</tr>
</tbody>
</table>

**Table 4**

*Mean Relative Weights and Cardiothoracic Ratios of Persons with High Amplitude R Waves on the Electrocardiogram and Matched Controls Arranged According to Age and Sex*

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age, yr.</th>
<th>Person with high amplitude R waves</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean relative weight</td>
<td>Mean cardiothoracic ratio</td>
</tr>
<tr>
<td>Male</td>
<td>16-19</td>
<td>95.9</td>
<td>0.410</td>
</tr>
<tr>
<td></td>
<td>20-29</td>
<td>98.3</td>
<td>0.422</td>
</tr>
<tr>
<td></td>
<td>30-39</td>
<td>100.2</td>
<td>0.439</td>
</tr>
<tr>
<td></td>
<td>40-49</td>
<td>102.5</td>
<td>0.451</td>
</tr>
<tr>
<td></td>
<td>50-59</td>
<td>101.9</td>
<td>0.467</td>
</tr>
<tr>
<td></td>
<td>60+</td>
<td>93.4</td>
<td>0.490</td>
</tr>
<tr>
<td>Female</td>
<td>16-19</td>
<td>102.2</td>
<td>0.497</td>
</tr>
<tr>
<td></td>
<td>50-59</td>
<td>117.8</td>
<td>0.495</td>
</tr>
<tr>
<td></td>
<td>60+</td>
<td>106.4</td>
<td>0.541</td>
</tr>
</tbody>
</table>

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Table 5

Proportions of Persons with Possible Causes of Left Ventricular Enlargement Among Individuals with High Amplitude R Waves in the Electrocardiogram and Their Controls

<table>
<thead>
<tr>
<th>Age, yr. &amp; sex</th>
<th>Persons with high amplitude R waves according to the Minnesota criteria</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>HBP %</td>
</tr>
<tr>
<td>Men 16-49</td>
<td>104</td>
<td>9</td>
</tr>
<tr>
<td>Men 50+</td>
<td>31</td>
<td>12</td>
</tr>
<tr>
<td>Women 16-49</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Women 50+</td>
<td>49</td>
<td>26</td>
</tr>
</tbody>
</table>

HBP = high blood pressure; LRW = low relative weight not associated with other abnormalities; N = number.

The prevalence of any differential item in a given group is recorded in column 6, and the frequency with which an item was associated with acausal factor for anatomic enlargement is recorded in column 5.
### Table 6

**Prevalence of Electrocardiographic Diagnostic Items and Their Relationship to Possible Causes of Anatomic Left Ventricular Enlargement among Men, 16 through 49 Years of Age**

<table>
<thead>
<tr>
<th>Diagnostic items</th>
<th>104 men with high amplitude R waves</th>
<th>104 control men</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>( R_L + S_{III} \ &gt; \ 20 \ mm )</td>
<td>48</td>
<td>46</td>
</tr>
<tr>
<td>( R_1 \ + S_{III} \ &gt; \ 25 \ mm )</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>( Q \ or \ S\ aV_R \ &gt; \ 14 \ mm )</td>
<td>49</td>
<td>47</td>
</tr>
<tr>
<td>( R_{aV_L} \ &gt; \ 11 \ mm )</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>( R_{aV_L} \ &gt; \ 12 \ mm )</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>( R_{aV_L} \ &gt; \ 13 \ mm )</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>( R_{aV_F} \ &gt; \ 19 \ mm )</td>
<td>28</td>
<td>27</td>
</tr>
<tr>
<td>( R_{aV_F} \ &gt; \ 20 \ mm )</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>( R_{VI} \ &lt; \ 1 \ mm \ + S_{VI} \ &gt; \ 24 \ mm )</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( S_{VI} \ &gt; \ 24 \ mm )</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>( R_{V_{5}} \ &gt; \ 26 \ mm )</td>
<td>71</td>
<td>68</td>
</tr>
<tr>
<td>( R_{V_{5}} \ &gt; \ 33 \ mm )</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>( R_{V_{6}} \ &gt; \ 26 \ mm )</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>( S_{VI} \ + R_{V_{5}} \ or \ R_{V_{6}} \ &gt; \ 35 \ mm )</td>
<td>91</td>
<td>88</td>
</tr>
<tr>
<td>( R_{V_{6}} \ &gt; \ R_{V_{5}} )</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>( R \ + S \ &gt; \ 45 \ mm )</td>
<td>79</td>
<td>76</td>
</tr>
<tr>
<td>ST depression</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>T wave inversion</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Flat T wave</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( T_{VI} \ &gt; \ T_{V_{6}} )</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Activation time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_{5} \ or \ V_{6} \ \geqslant 0.05 \ sec )</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>( QRS \geqslant 0.10 \ sec )</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Left axis deviation</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Transitional zone to the left</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

See text for "Other"; HBP = hypertension; LRW = low relative weight; % abn. = per cent with abnormality.
Table 7

*Prevalence of Electrocardiographic Diagnostic Items and Their Relationship to Possible Causes of Anatomic Left Ventricular Enlargement among Men 50 or More Years of Age*

<table>
<thead>
<tr>
<th>Diagnostic items</th>
<th>31 men with high amplitude R waves</th>
<th>31 control men</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>R_L, II, III &gt; 20 mm</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>R_I + S_II &gt; 25 mm</td>
<td>12</td>
<td>39</td>
</tr>
<tr>
<td>Q or S aV_R &gt; 14 mm</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>R aV_L &gt; 11 mm</td>
<td>13</td>
<td>42</td>
</tr>
<tr>
<td>R aV_L &gt; 12 mm</td>
<td>12</td>
<td>39</td>
</tr>
<tr>
<td>R aV_L &gt; 13 mm</td>
<td>9</td>
<td>29</td>
</tr>
<tr>
<td>R aV_L &gt; 19 mm</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>R aV_L &gt; 20 mm</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>R_V1 &lt; 1 mm + S_V1 &gt; 24 mm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S_V1 &gt; 24 mm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>R_V6 &gt; 26 mm</td>
<td>23</td>
<td>74</td>
</tr>
<tr>
<td>R_V6 &gt; 33 mm</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>R_V6 &gt; 26 mm</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>S_V1 + R_V2 or R_V6 &gt; 35 mm</td>
<td>22</td>
<td>71</td>
</tr>
<tr>
<td>R_V6 &gt; R_V2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>R + S &gt; 45 mm</td>
<td>15</td>
<td>48</td>
</tr>
<tr>
<td>ST depression</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>T wave inversion</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Flat T waves</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>T_V1 &gt; T_V6</td>
<td>14</td>
<td>45</td>
</tr>
</tbody>
</table>

**Activation time**

| V_6 or V_6 | ≥ 0.05 sec | 2  | 6  | 0   | 1    | 50  | 1    | 0  | 2  | 6  | 0    | 0    | 0   | 2    |
| QRS ≥ 0.10 sec | 6  | 19 | 1   | 4    | 83  | 1    | 0  | 3  | 10 | 1    | 0    | 33  | 0    |
| Left axis deviation | 5  | 16 | 3   | 2    | 100 | 0    | 0  | 2  | 6  | 1    | 0    | 50  | 0    |
| Transitional zone to the left | 3  | 10 | 0   | 1    | 33  | 0    | 2  | 2  | 6  | 0    | 0    | 0   | 1    |

See table 6 for abbreviations

OSMENDER
with abnormalities. The \( T_{v1} > T_{v6} \) criterion was more frequently fulfilled than among younger men and was usually associated with causes of hypertrophy.

Prolongation of the QRS interval and left axis deviation were infrequent but usually were associated with a cause for enlargement.

Women from 16 through 49 Years of Age (Table 8)

Only nine women fulfilled any amplitude criteria for left ventricular hypertrophy. If many women in this age range have anatomic left ventricular hypertrophy, it is infrequently detected from the electrocardiogram.

Women 50 Years of Age and Older (Table 9)

The limb lead items, \( R_1 + S_{II} > 25 \) mm and \( R aV_L > 11, 12 \) or \( 13 \) mm, were encountered more frequently than other changes and were usually associated with causes for enlargement. They rarely appeared in the control group. Chest lead items were almost always associated with causes for enlargement, but even the most prevalent items, \( R_{v5} > 26 \) mm, \( S_{v1} + R_{v5} \) or \( R_{v6} > 35 \) mm, and greatest \( R + S > 45 \) mm, were only satisfied in about a third of the group with high amplitude R waves.

ST-segment depression or T-wave changes were usually associated with causes for enlargement in either group. The \( T_{v1} > T_{v6} \) criterion was fulfilled in 37% of the group with electrocardiographic changes and 12% of the controls and was usually associated with possible causes of enlargement.

Prolongation of the activation time or the QRS interval was infrequent but usually associated with causes for enlargement.

Discussion

The amplitude criteria for left ventricular hypertrophy proposed by Blackburn and associates\(^\text{19}\) do not separate persons sharply in accord with other indications of possible enlargement such as radiographic cardiomegaly or reasonable physical cause for hypertrophy. Although more individuals with the electrocardiographic diagnosis had cardiomegaly on the chest x-rays or a reasonable cause for enlargement, the differences from the control group were not striking. Because this apparent lack of specificity was common to all the other sensitive items or groups of items, the Minnesota criteria are probably as useful as any for screening purposes.

The insulating effect of fat or fluid tends to decrease the amplitudes of the complexes and leanness may account for high voltages. Congestive heart failure or obesity should then be more frequent among control subjects and a low relative weight more common among those with electrocardiographic signs of hypertrophy but these differences were slight and inconsistent. More persons with electrocardiographic evidence of left ventricular hypertrophy had relative weights in the upper and lower quintiles of the distributions than did individuals in the control groups. The mean relative weights were lower among men of all ages in the hypertrophy group but the reverse was true for women.

The amplitude items appeared to be reasonably sensitive and specific for men 50 years of age or older. Among younger men they were overly sensitive and so nonspecific as to be of questionable value.

Among women the amplitude criteria appear to lack both sensitivity and specificity. Roentgenographic evidence of cardiomegaly or reasonable causal factors for left ventricular hypertrophy were found in more than half of the women in the control groups, but a quarter of those with electrocardiographic changes had no apparent reason for enlargement.

Deficiencies in diagnostic criteria result in part from a failure to appreciate the considerable differences in mean amplitudes which are found between the sexes and at different ages.\(^\text{5, 32}\) Young men have QRS complexes of higher amplitude, particularly in leads II, III, aVF, and V1 through V6 than older men or women. Older women have complexes of higher amplitude than younger women.

Among persons of each sex there is a marked tendency toward a more horizontal electrical axis and left axis deviation with age.

It is unrealistic to expect a single item or a group of items to discriminate equally well
Table 8

Prevalence of Electrocardiographic Diagnostic Items and Their Relationship to Possible Causes of Anatomic Left Ventricular Enlargement Among Women, 16 through 49 Years of Age

<table>
<thead>
<tr>
<th>Differential items</th>
<th>9 women with high amplitude R waves</th>
<th>9 control women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>R&lt;sub&gt;L&lt;/sub&gt; II, III &gt; 20 mm</td>
<td>4</td>
<td>44</td>
</tr>
<tr>
<td>R&lt;sub&gt;L&lt;/sub&gt; + S&lt;sub&gt;III&lt;/sub&gt; &gt; 25 mm</td>
<td>4</td>
<td>44</td>
</tr>
<tr>
<td>Q or S aV&lt;sub&gt;R&lt;/sub&gt; &gt; 14 mm</td>
<td>3</td>
<td>33</td>
</tr>
<tr>
<td>R aV&lt;sub&gt;L&lt;/sub&gt; &gt; 11 mm</td>
<td>4</td>
<td>44</td>
</tr>
<tr>
<td>R aV&lt;sub&gt;L&lt;/sub&gt; &gt; 12 mm</td>
<td>4</td>
<td>44</td>
</tr>
<tr>
<td>R aV&lt;sub&gt;L&lt;/sub&gt; &gt; 13 mm</td>
<td>4</td>
<td>44</td>
</tr>
<tr>
<td>R aV&lt;sub&gt;L&lt;/sub&gt; &gt; 19 mm</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>R aV&lt;sub&gt;L&lt;/sub&gt; &gt; 20 mm</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>R&lt;sub&gt;V&lt;/sub&gt; &lt; 1 mm + S&lt;sub&gt;V&lt;/sub&gt; &gt; 24 mm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S&lt;sub&gt;V&lt;/sub&gt; &gt; 24 mm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>R&lt;sub&gt;V&lt;/sub&gt; &gt; 26 mm</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>R&lt;sub&gt;V&lt;/sub&gt; &gt; 33 mm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>R&lt;sub&gt;V&lt;/sub&gt; &gt; 36 mm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>R&lt;sub&gt;V&lt;/sub&gt; &gt; 26 mm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S&lt;sub&gt;V&lt;/sub&gt; + R&lt;sub&gt;V&lt;/sub&gt; or V&lt;sub&gt;6&lt;/sub&gt; &gt; 35 mm</td>
<td>3</td>
<td>33</td>
</tr>
<tr>
<td>R&lt;sub&gt;V&lt;/sub&gt; &lt; R&lt;sub&gt;V&lt;/sub&gt;</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>R + S &gt; 45 mm</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>ST depression</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>T wave inversion</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flat T waves</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>T&lt;sub&gt;V&lt;/sub&gt; &lt; T&lt;sub&gt;6&lt;/sub&gt;</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Activation time</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>V&lt;sub&gt;5&lt;/sub&gt; or V&lt;sub&gt;6&lt;/sub&gt; ≥ 0.05 sec</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>QRS ≥ 0.10 sec</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Left axis deviation</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Transitional zone</td>
<td>1</td>
<td>11</td>
</tr>
</tbody>
</table>

See table 6 for abbreviations.
Table 9

Prevalence of Electrocardiographic Diagnostic Items and Their Relationship to Possible Causes of Anatomic Left Ventricular Enlargement Among Women, 50 or More Years of Age

<table>
<thead>
<tr>
<th>Diagnostic items</th>
<th>49 women with high amplitude R waves</th>
<th>49 control women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>R1, RII, III &gt; 20 mm</td>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td>R1 + SIII &gt; 25 mm</td>
<td>32</td>
<td>65</td>
</tr>
<tr>
<td>Q or SaV_R &gt; 14 mm</td>
<td>15</td>
<td>31</td>
</tr>
<tr>
<td>RaV_L &gt; 11 mm</td>
<td>36</td>
<td>73</td>
</tr>
<tr>
<td>RaV_L &gt; 12 mm</td>
<td>33</td>
<td>67</td>
</tr>
<tr>
<td>RaV_R &gt; 13 mm</td>
<td>29</td>
<td>59</td>
</tr>
<tr>
<td>RaV_R &gt; 19 mm</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>RaV_R &gt; 20 mm</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Ra1 &lt; 1 mm + Sa1 &gt; 24 mm</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sa1 &gt; 24 mm</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Ra5 &gt; 26 mm</td>
<td>16</td>
<td>33</td>
</tr>
<tr>
<td>Ra5 &gt; 33 mm</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Ra6 &gt; 26 mm</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>Sa1 + Ra5 or v6 &gt; 35 mm</td>
<td>17</td>
<td>35</td>
</tr>
<tr>
<td>Ra6 &gt; Ra5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>R + S &gt; 45 mm</td>
<td>14</td>
<td>29</td>
</tr>
<tr>
<td>ST depression</td>
<td>14</td>
<td>29</td>
</tr>
<tr>
<td>T wave inversion</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Flat T waves</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>TV1 &gt; TV6</td>
<td>19</td>
<td>39</td>
</tr>
</tbody>
</table>

See table 6 for abbreviations.
at all ages and among both sexes. Probably the most practical approach is a crude separation on the basis of several relatively sensitive items, such as the Minnesota criteria, and then a more precise classification based upon items of greater specificity. Among young men with high-amplitude complexes there seems to be a greater probability of anatomical left ventricular hypertrophy if the electrical position is horizontal and the criteria, $R_t + S_{III} > 25$ mm or $R$ a $V_L > 11$, 12, 13 mm, are fulfilled. The presence of ST-segment depression, flat T waves or inverted T waves among persons of any age with high-amplitude QRS items increases the specificity. Among older women such ST-segment or T-wave changes should suggest the possibility of enlargement even without high QRS amplitudes. High-amplitude activation waves in the chest leads of women are infrequent, but, when present, they appear to be specific for left ventricular hypertrophy. Occasionally prolongation of the ST-segment depression time or QRS interval or left axis deviation increases the specificity of diagnosis among older persons of each sex with high-amplitude QRS complexes.

When it occurs with QRS amplitude changes, the $Tv_1 > Tv_6$ criterion appears to increase the specificity of diagnosis among young and old persons of both sexes.

Although the amplitude criteria are only gross indications of left ventricular hypertrophy, the recognition of age and sex variations and the appropriate application of a variety of differential items should improve the specificity and at times the sensitivity of electrocardiographic diagnosis.

An accurate diagnosis of left ventricular hypertrophy requires more than high amplitude QRS complexes without other clinical or electrocardiographic findings. It is particularly important to avoid overdiagnosis in routine health examinations or other work involving predominantly healthy people.

Conversely, the diagnosis should not be abandoned in individuals with other clinical evidence of enlargement whose QRS complexes are of insufficient amplitude to fulfill accepted criteria for left ventricular hypertrophy.

The electrocardiogram provides only limited diagnostic aid in equivocal cases and its limitations must be taken into account if the various criteria are to be applied intelligently.

**Summary**

Electrocardiograms from 5,129 examined persons, 2,449 men and 2,680 women, 16 years of age or older, were classified according to the Minnesota code of Blackburn and associates. The R wave amplitude criteria for possible left ventricular hypertrophy were fulfilled in 193 tracings from 135 men and 58 women. Age and sex matched controls were randomly selected from the remainder of the examined population for similar measurement. Those with high amplitude R waves and their controls were grouped according to age, sex, and possible cause for anatomical left ventricular enlargement. Precise measurements were made of all the amplitudes and intervals necessary for the application of a variety of other differential items from current diagnostic criteria. The prevalence of the various differential items in the high amplitude and control groups and the frequency with which each was associated with a cause for enlargement indicated their relative sensitivity and specificity.

Among the individuals with electrocardiographic evidence of left ventricular hypertrophy according to the Minnesota criteria, there were more persons in the upper and lower quintiles of the relative weight distributions, more hypertensives, more persons with roentgenographic evidence of cardiomegaly, and fewer persons in congestive heart failure than among the controls, but the differences were slight.

Most QRS amplitude items were too nonspecific to be of much diagnostic value among young men, and the same items apparently lack sensitivity when applied to the tracings from older women. The items which constitute the Minnesota criteria are useful for screening purposes.

Single items are unreliable for the detection
of left ventricular hypertrophy and certain combinations are suggested to improve diagnostic accuracy. Still the electrocardiogram is often an inexact method for the recognition of left ventricular hypertrophy and the diagnosis should be based on careful physical and roentgenographic examinations as well.

Acknowledgment
The author is grateful to Dr. Frederick H. Epstein for his helpful suggestions.

References
"It Was Decided I Should Become a Doctor"

For here I was in contact with what I most wanted, life in the raw. In those three years I must have witnessed pretty well every emotion of which man is capable. It appealed to my dramatic instinct. It excited the novelist in me. Even now that forty years have passed I can remember certain people so exactly that I could draw a picture of them. Phrases that I heard then still linger on my ears. I saw how men died. I saw how they bore pain. I saw what hope looked like, fear and relief; I saw the dark lines that despair drew on a face; I saw courage and steadfastness. I saw faith shine in the eyes of those who trusted in what I could only think was an illusion and I saw the gallantry that made a man greet the prognosis of death with an ironic joke because he was too proud to let those about him see the terror of his soul.—W. SOMERSET MAUGHAM. In FABRICANT, N. D. (Editor): Why We Became Doctors. New York, Grune & Stratton, 1954, p. 7.
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LEON D. OSTRANDER, JR.

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