Evaluation of Electrocardiographic Diagnosis of Ventricular Hypertrophy Based on Autopsy Comparison

By Bertram J. Allenstein, M.D., and Hiroyoshi Mori, M.D.

RECENT advances in the field of cardiac surgery require greater precision in the diagnosis of early ventricular hypertrophy. Although many electrocardiographic criteria are proposed for the diagnosis of ventricular hypertrophy, only a few articles discuss their accuracy. Most studies apply criteria to either left or right ventricular hypertrophy as found in proved hypertrophy, but sufficient studies of the occurrence of false positives are lacking. It is the object of this study to analyze various criteria for ventricular hypertrophy, as found in isolated hypertrophy and in normal hearts.

Method

Five hundred and twelve consecutive cases autopsied between January 1954 and October 1956, at the City of Hope Medical Center, were studied. Excluded were cases under the age of 15, those in which an electrocardiogram had not been taken within 3 months prior to death, and those with myocardial infarction, myocardial fibrosis, advanced coronary sclerosis, or definite evidence of myocardial bleeding. Sixty-five cases remained for this study. Thirty-two had anatomic normal hearts, 17 had isolated left ventricular hypertrophy, and 16 had isolated right ventricular hypertrophy (table 1). The thickness of the ventricular wall was used as the indication of ventricular hypertrophy. According to Saphir,\(^1\) the thickness of the normal left ventricular wall should not exceed 10 mm. and that of the normal right ventricular wall should not exceed 3 mm. We considered a heart as normal when the thickness of the left ventricle was 10 mm. or less and the thickness of the right ventricular wall was 3 mm. or less. We used the term isolated right ventricular hypertrophy when the thickness of the right ventricular wall was 5 mm. or more and the thickness of the left ventricular wall was 10 mm. or less. All patients had electrocardiograms consisting of the standard limb leads, the augmented unipolar limb leads, the standard unipolar chest leads, \((V_{1,6})\) and the right precordial leads \(V_{4R}\) and \(V_{5R}\).

A direct-writing electrocardiographic machine was utilized with routine standardization. Upward deflections were measured from the top of the base line to the peak of the upstroke, and downward deflections were measured from the bottom of the base line to the nadir of the downstroke. The T-P level was used as the base line; when tachycardia made it impossible to measure the correct T-P level, the P-R segment was used as the base line. The time of onset of the intrinsicoid deflection in unipolar chest leads was measured from the beginning of the QRS to the top of the R, or to R, if present. The criteria studied for left ventricular hypertrophy were those of Gubner and Ungerleider;\(^2\) Katz;\(^3\) Schach, Rosenbaum, and Katz;\(^4\) Goldberger;\(^5\) Goulder and Kissane;\(^6\) Noth, Myers, and Klein;\(^7\) Wilson and co-workers;\(^8\)\(^-\)\(^11\) and Sokolow and Lyon.\(^12\)

The criteria used by these authors is listed below.

A. Left Ventricular Hypertrophy

1. Gubner and Ungerleider\(^2\)
   a) Left axis deviation, with \(R_1 + S_3\) exceeding 25 mm.
   b) Left axis deviation with depression of \(ST_1\) of 0.5 mm. or more.
   c) Left axis deviation, with \(T_1\) of less than 1 mm.
   [Note: Left axis deviation signifies that the maximum QRS is located between +30 and -90 degrees.]

2. Katz\(^3\)
   a) 1. Left axis deviation.
   2. ST-T normal. Lead II has small, equifusis QRS or deep S.
   b) 1. Left axis deviation.
   2. Depressed, upward-convexed S-T and inverted T wave in lead I.
   c) 1. Left axis deviation.

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Table 1

<table>
<thead>
<tr>
<th>Age (yrs.)</th>
<th>Normal Male</th>
<th>Normal Female</th>
<th>Left ventricular hypertrophy Male</th>
<th>Left ventricular hypertrophy Female</th>
<th>Right ventricular hypertrophy Male</th>
<th>Right ventricular hypertrophy Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>15—20</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>21—30</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>31—40</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>41—50</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>51—60</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>61—70</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>70 and over</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>16</td>
<td>10</td>
<td>7</td>
<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>

2. Lead II shows a small equiphase QRS or deep S wave.
3. Lead I shows the ST-T changes such as those seen in b.
   d) 1. QRS waves are concordant in standard limb leads.
   2. Depressed S-T and inverted T wave in lead I and depressed S-T in II, III.
   e) 1. CF3 shows QS pattern or an R wave of less than 1.5 mm., S-T elevation of more than 2.5 mm., and upward T wave.
   2. CF5 shows a depression of S-T segment and inversion of T wave.
[Note: We used the V lead instead of CF lead. S-T was considered depressed when it was 0.5 mm. or more below the isoelectric line.]

III. Schach, Rosenbaum, and Katz
a) Main negative deflection in aV_L more than 14 mm.
   b) R wave more than 12 mm. in aV_L (horizontal electrical position) R wave more than 19 mm. in aV_F (vertical electrical position).
   c) Sum of the main negative deflection in aV_R and the positive deflection in aV_L or aV_F exceeds the maximum found normally in the respective “electrical” position, (29 mm. in vertical heart, 23 mm. in semivertical heart, 26 mm. in intermediate position of the heart, 22 mm. in semihorizontal heart, and 21 mm. in horizontal heart.)

IV. Goldberger
a) High voltage of QRS complex.
   1. In horizontal heart, the R wave 13 mm. or more in aV_L.

2. In vertical heart, the R wave of 20 mm. or more in aV_F.
   b) Left ventricular strain.
   Depression of S-T segment of 0.5 mm. or more or inverted T waves in aV_L in horizontal heart, or in aV_F in vertical heart. Depression of S-T segment of 0.5 mm. or more in V5 and V6 or inversion of T waves in V5 and V6.
   c) Left ventricular hypertrophy and strain: a combination of a and b.

V. Gauloir and Kissane
a) In horizontal or semihorizontal heart, R wave in aV_L more than 11 mm., with or without a T:R ratio of less than 10 per cent.
   b) In horizontal or semihorizontal heart, an R wave of 10 mm. with a T:R ratio of less than 10 per cent.

VI. Noth, Myers, and Klein
a) Time interval from the onset of QRS to peak of R is 0.05 second or more in V5 and V6.
   b) Time interval from the onset of R to its peak is 0.04 second or more in V5 and V6.

VII. Wilson and co-workers
a) Absence of R wave or abnormally small R wave in V1 (1 mm. or less). Abnormally large S wave in V1 (24 mm. or more).
   b) Left shift of transitional zone.
[Note: In our study this placed the transitional zone in V3 or V6.]
   c) Delay of peak of R in V5 and V6 (0.05 second or more).
   d) Abnormally tall R wave (33 mm. or more in V5. 26 mm. or more in V6).
   e) Inverted T wave in V5 and V6.
   f) QRS interval of 0.10 or 0.11 second.

VIII. Sokolow and Lyon
a) Standard limb leads
   1. Voltage R5 + S3 = 25 mm. or more.
   2. RS-T1 depressed 0.5 mm. or more.
   3. T1 flat, diphasic, or inverted, particularly when associated with (2) and a prominent R wave.
   4. T2 and T3 diphasic or inverted in the presence of tall R waves and (2).
   5. T3 greater than T1 in the presence of left axis deviation and high voltage QRS complex in leads I and III.

b) Precordial leads
   1. Voltage of R wave in V5 or V6 exceeds 26 mm.
   2. RS-T segment depressed more than 0.5 mm. in V1, V5, or V6.
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3. A flat, diphasic, or inverted T wave in leads V4 through V6 with normal R and small S waves and (2).
4. Ventricular activation time in V5 or V6 0.06 second or more, especially when associated with a tall R1 wave.

c) Unipolar limb leads
1. RS-T segment depressed more than 0.5 mm. in aVL or aVF.
2. Flat, diphasic, or inverted T wave, with an R wave of 6.0 mm. or more in aVL or aVF and (1).
3. Voltage of R wave in aVL exceeds 10.0 mm.

In addition to these they found that the ratio of R/S in V5 was below 100 (mean 32.0) in normal cases, but found above 100 (mean 98.0) in 33 per cent of the cases of left ventricular hypertrophy in which this ratio could be determined. Therefore, they also added this ratio of above 100 into the criteria of Sokolow and Lyon. The term flat T was used when the amplitude of the T wave in lead I was 1 mm. or less, or R: T ratio was 10 or less in lead aVL, aVF, V4, V5, and V6.

The criteria for right ventricular hypertrophy studied were those of Sokolow and Lyon; Myers, Klein, and Stofer; and Goldberger. B. Right Ventricular Hypertrophy

I. Sokolow and Lyon
a) Voltage of the R and S waves and various ratios:
1. The R wave in V1 is 7.0 mm. or more.
2. The S wave in V1 is less than 2.0 mm.
3. The S wave in V5 or V6 is 7.0 mm. or more.
4. The sum of the amplitudes of the R wave in V1 and the S wave in V5 and V6 exceeds 10.5 mm., in individuals over 5 years of age.
5. The R wave in V5 or V6 is less than 5.0 mm.
6. The ratio of the R to the S wave in V5 or V6 is 1.0 or less.
7. The R wave in aVR is 5.0 mm. or more.
8. The ratio of R/S in V5 is 0.4 or less.
9. The ratio of the R wave in V1 to the S wave in V1 exceeds 4.0 in individuals under the age of 5.
10. The ratio of the R wave to the S wave in V1 exceeds 1.0 in individuals over the age of 5 years.

b) Delayed onset of the intrinsicoid deflection (delayed ventricular activation time) 0.04 to 0.07 second in V1 or V2, or in both.

c) Depression of the RS-T segment and inversion of T wave in:
1. V1, less often V2 and V6 when the R wave equals or exceeds 5.0 mm.
2. aVL or aVF, when the R wave equals or exceeds 5.0 mm.

d) Marked right axis deviation, greater than 110 degrees suggests, but is not in itself diagnostic of, right ventricular hypertrophy. [Note: Their subjects included 40 per cent infants under the age of 5. The cases in which V1 showed M-shaped QRS complexes with prominent R wave and a ventricular activation time exceeding 0.07 second in lead V1 were all excluded.]

II. Myers, Klein, and Stofer
They studied the 40 cases of preponderant right ventricular hypertrophy proved by autopsy, and classified them into the following 6 groups. Among these cases lead V3R was taken in 8 cases. The unipolar limb leads were taken in 35 cases. Electrocardiograms diagnostic for right ventricular hypertrophy are as follows:

a) 1. Reversal in the R/S ratio in V1 and V6 characterized by an abnormally large R in contrast to S in V1, a diminution in ratio in leads further to the left, and a prominent S in V6.
2. The delay of the time of the onset of the intrinsicoid deflection in V1 (generally between 0.03 and 0.05 second) and greater than in V5 or V6.
3. Tendency to a small Q wave in V1.
4. Tendency to inversion of the T wave in V1 and to upright T wave in V6.
5. QRS interval of less than 0.12 second.
6. Absence of notching or double peaking of the R wave in lead V1.

b) Typical pattern of right ventricular hypertrophy or incomplete right bundle-branch block in lead V3R.

c) Right ventricular hypertrophy is presumed from lead V6 and aVR without confirmatory signs in V1, or V2: abnormally large S wave in V6 with an abnormally tall R in aVR, which was 4 to 10 times the amplitude of the downward deflection in the same lead.

III. Goldberger

a) Atrial hypertrophy (large biphasic P in...
Table 2
Criteria of Gubner and Ungerleider for Left Ventricular Hypertrophy

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Left axis deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of cases</td>
</tr>
<tr>
<td>Normal</td>
<td>32</td>
</tr>
<tr>
<td>LVH</td>
<td>17</td>
</tr>
<tr>
<td>RVH</td>
<td>16</td>
</tr>
</tbody>
</table>

$V_{1}$, $V_{2}$, or $aV_{R}$, 0.11 second or more wide, 2.5 mm. or more tall.)
If $aV_{R}$ in these cases shows a QR or QR pattern, and if $aV_{R}$ revealed rS pattern, and if lead $aV_{L}$ showed rS, or QR and downward T, right ventricular hypertrophy can be suspected.

b) Marked clockwise rotation.
1. If $V_{1}$ through $V_{6}$ shows rS pattern and R/S in $V_{5}$ or $V_{6}$ is $1/2$ or less.
2. If $aV_{R}$ shows qR pattern and R is 3 or more times higher than q.
3. Extreme clockwise rotation: $aV_{R}$, $V_{1}$ show qR pattern and inverted T wave.
4. Tall R in $V_{1}$, or $V_{1}$ and $V_{2}$ (R is 3 or more times larger than the S). QRS interval is less than 0.12 second. $V_{5}$ and $V_{6}$ show rS pattern.
5. Right bundle-branch block.

We applied these criteria of both left ventricular and right ventricular hypertrophy to all our cases. We considered a positive finding, the presence of one or more of those criteria set forth by the authors above.

Results

**A. Criteria for the Diagnosis of Left Ventricular Hypertrophy**

I. Gubner and Ungerleider\(^2\) (table 2)

a) Of 17 cases with left ventricular hypertrophy, 6 were positive, and 11 were false negatives.
b) There were no false positives among the 16 cases of right ventricular hypertrophy.
c) Among the 32 normal hearts there were 6 false positives, mostly due to the presence of left axis deviation with flat $T_{1}$ of less than 1 mm.

II. Katz\(^3\) (table 3)

a) Only 7 of the 17 cases with left ventricular hypertrophy were positive, 10 being false negatives.
b) Three of the 16 cases of right ventricular hypertrophy yielded false positives for left ventricular hypertrophy.
c) Among the 32 normal hearts there were 10 false positives for left ventricular hypertrophy.

III. Schach, Rosenbaum and Katz\(^4\) (table 4)

a) Two of 17 cases of left ventricular hypertrophy were positive, leaving 15 cases of false negatives.
b) One false positive was present among the 32 normal cases.
c) There were no false positives among the cases of right ventricular hypertrophy.

IV. Goldberger\(^5\) (table 5)

a) Of 17 cases of proved left ventricular hypertrophy only 6 were positive. If the cases in which digitalis was used are excluded, only 2 of 13 cases were positive.
b) Of 32 normal cases there were 6 false positives for left ventricular hypertrophy.
c) Among the cases of right ventricular hypertrophy there were 3 false positives for left ventricular hypertrophy.

V. Goulde and Kissane\(^7\) (table 6)

a) Only 2 of the 17 cases of left ventricular hypertrophy were positive. If the cases in which digitalis was used are excluded only 1 of 13 cases were positive.
b) There were 4 false positives among the normal cases.
c) There were no false positives among the cases of right ventricular hypertrophy.

VI. Noth, Myers, and Klein\(^8\) (table 7)

a) Three of the 17 cases of left ventricular hypertrophy were positive. If the cases in which digitalis was used are excluded, 2 of 13 cases are found to be positive.
b) One of the 32 normal cases was positive.
c) There were no false positives among the cases of right ventricular hypertrophy.
VII. Wilson and co-workers⁹⁻¹¹ (table 8)
  a) Sixteen of the 17 cases of left ventricular hypertrophy were positive. If the cases in which digitalis was given are excluded then only 5 of 13 cases are found to be positive.
  b) False positives were found among 25 of the 32 normal cases.
  c) Twelve of the 16 cases of right ventricular hypertrophy were false positives. According to Scott and his co-workers,¹⁵,¹⁶ the presence of a Q wave in V₅ and V₆ is included in the above mentioned criteria. However, this is not reasonable because small Q waves are usually seen in the left-sided chest leads in normal subjects. If we exclude the Q waves, only 7 of the 17 cases of left ventricular hypertrophy are positive and the false positives are reduced to 14 in the normal cases and 7 in the cases of right ventricular hypertrophy. Furthermore, if we eliminate the cases in which digitalis was given then the false positives are only 13 of the 32 cases among the normal subjects and 6 of 13 cases of right ventricular hypertrophy.

VIII. Sokolow and Lyon¹²,¹³ (tables 9, 10, 11, and 12)
  a) Fifteen of 17 cases of left ventricular hypertrophy were positive.
  b) There were 17 false positives among the 32 normal subjects.
  c) There were 10 false positives among 16 cases of right ventricular hypertrophy.

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**Table 3**
Criteria of Katz for Left Ventricular Hypertrophy

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Number of cases</th>
<th>QRS concordant</th>
<th>CF₅ (V₅):QS or v</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST-T</td>
<td>ST-T</td>
<td>ST-T</td>
<td>RS-T I</td>
</tr>
<tr>
<td>ST↓</td>
<td>T↓</td>
<td>T↑</td>
<td>&lt;1.5 mm. ST♀</td>
</tr>
<tr>
<td>ST-T</td>
<td>ST-T</td>
<td>ST-T</td>
<td>&gt;2.5 mm. T♀</td>
</tr>
<tr>
<td>ST-T</td>
<td>ST-T</td>
<td>ST-T</td>
<td>CF₅ (V₅)</td>
</tr>
<tr>
<td>ST↓</td>
<td>T↓</td>
<td>T↑</td>
<td>+</td>
</tr>
<tr>
<td>ST-T</td>
<td>ST-T</td>
<td>ST-T</td>
<td>-</td>
</tr>
</tbody>
</table>

| Normal | 32 | 7 | 2 | 1 | 16 | 0 | 0 | 0 | 1 | 0 |
| LVH | 17 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| RVH | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

---

**Table 4**
Criteria of Schach, Rosenbaum, and Katz for Left Ventricular Hypertrophy

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Number of main neg. deflection</th>
<th>R aV₅ or aV₆</th>
<th>Neg. aV₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>aV₅</td>
<td>19 mm.*</td>
<td>+ pos.</td>
<td>aV₅ or aV₆</td>
</tr>
<tr>
<td>R aV₅</td>
<td>&gt;14 mm.</td>
<td>&gt;12 mm†</td>
<td>normal</td>
</tr>
<tr>
<td>Normal</td>
<td>32</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>LVH</td>
<td>17</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>RVH</td>
<td>16</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Vertical electrical position.
†Horizontal electrical position.

**B. Criteria for the Diagnosis of Right Ventricular Hypertrophy**

I. Myers, Klein, and Stofer¹⁴ (table 13)
  a) Eight of 16 cases of right ventricular hypertrophy were positive.
  b) One false positive was found among the 32 normal hearts.
  c) One false positive occurred in the 17 cases of left ventricular hypertrophy.
  d) If the cases in which digitalis was used are omitted, then where were 6 positives among the 14 cases of right ventricular hypertrophy and no false positives among the cases of left ventricular hypertrophy.

II. Sokolow and Lyon¹²,¹³ (table 14)
  a) Twelve positives were present among the 16 cases of right ventricular hypertrophy.
  b) Sixteen false positives were found in the 32 normal subjects.
Criteria of Normal RVH

1. LVH

Hypertrophy

Table 5
Criteria of Goldberger for Left Ventricular Hypertrophy

<table>
<thead>
<tr>
<th>Number of cases</th>
<th>Horizontal</th>
<th>Vertical</th>
<th>ST-T V₃, V₅</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R aV₃ ≥13 mm.</td>
<td>ST aV₁ or T aV₁ ≥20 mm.</td>
<td>aV₁ ≤0.1</td>
</tr>
<tr>
<td>Normal</td>
<td>32</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>LVH</td>
<td>17</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RVH</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 6
Criteria of Goulder and Kissane for Left Ventricular Hypertrophy

<table>
<thead>
<tr>
<th>No. of cases</th>
<th>R aV₁ ≥10 or 11 mm.</th>
<th>T/R ≥11 mm.</th>
<th>aV₁ ≤0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>32</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>LVH</td>
<td>17</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RVH</td>
<td>16</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

c) Four of 16 cases of left ventricular hypertrophy were positive.
d) If the cases in which digitalis was given are excluded, there are 10 positives among the 14 cases of right ventricular hypertrophy, 16 false positives in the 31 normal hearts and 4 of 12 cases of left ventricular hypertrophy.

III. Goldberger⁵, ⁶ (Table 15)
a) There were 11 positives among the 16 cases of right ventricular hypertrophy.
b) Two false positives in the 32 normal subjects were found.
c) Five of the 17 cases of left ventricular hypertrophy were positive. Note: These criteria include atrial hypertrophy (0.11 second or more wide or 2.5 mm. or more tall) but this is an indirect sign. If this is omitted, only 6 positives occurred among the 16 cases of right ventricular hypertrophy with 2 false positives in the normal subjects and 1 of the 2 cases of left ventricular hypertrophy.
d) If the cases in which digitalis was used are excluded, there are 9 positives among 14 cases of right ventricular hypertrophy, 2 false positives among 3 normal subjects and 2 of 13 cases of left ventricular hypertrophy. If the criteria of atrial hypertrophy is omitted in addition, then there are 4 positives among 14 cases of right ventricular hypertrophy.

Table 7
Criteria of Noth, Myers, and Klein for Left Ventricular Hypertrophy

<table>
<thead>
<tr>
<th>No. of cases</th>
<th>V₁ and V₅</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R intrinsicoid deflection ≥0.04</td>
</tr>
<tr>
<td>Normal</td>
<td>32</td>
</tr>
<tr>
<td>LVH</td>
<td>17</td>
</tr>
<tr>
<td>RVH</td>
<td>16</td>
</tr>
</tbody>
</table>

trophy, 2 false positives among 3 normal subjects and 2 of 13 cases of left ventricular hypertrophy. If the criteria of atrial hypertrophy is omitted in addition, then there are 4 positives among 14 cases of right ventricular hypertrophy.

Discussion

Electrocardiography is a diagnostic means to estimate a state of myocardium by analyzing the action current produced by heart muscle. Therefore, an electrocardiogram is an electrodynamic expression of the function of heart muscle, not a pathologic, static expression. Even the tension of the muscle fibers of the heart may change the electrocardiographic findings.¹⁷ It is well known that there is a discrepancy between the anatomic position of the heart and the electrical axis of the heart defined by electrocardiograms.¹⁸ Therefore, some disagreement between anatomic and electrocardiographic findings is inevitable.

Compared to the days in which only the standard limb leads were used, the clinical application of the unipolar limb and multiple

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chest leads made clinical electrocardiography much more accurate. Concomitantly, the accurate determination of ventricular hypertrophy has become important in clinical medicine. In advanced cases of ventricular hypertrophy, the diagnosis may be made easily by x-ray or by physical examination. In less advanced cases, however, which usually occur in the early stages of cardiovascular diseases, the accurate diagnosis of ventricular hypertrophy is often difficult by these means. The electrocardiographic method has been used to detect early pathologic changes of myocardium. There are many criteria for the diagnosis of the ventricular hypertrophy proposed by different authors\textsuperscript{2-10, 12-14} but there are only a few papers\textsuperscript{15, 16} about the comparative study of these criteria. Good criteria for the diagnosis of ventricular hypertrophy should have a good positivity and few or no false positives.

Scott et al.\textsuperscript{15} studied 100 cases of pure left ventricular hypertrophy proved by autopsy. They concluded that the criteria of Sokolow and Lyon, Wilson et al., Goldberger, and Katz give, in order, the most accurate electrocardiographic diagnosis of left ventricular hypertrophy, obtaining 85 per cent accuracy using Sokolow and Lyon's criteria. They did not, however, determine the occurrence of false positives. As shown in table 16, the occurrence of false positives is important in the evaluation of these criteria. In the application of these criteria, cases that show one or more of the items listed in each table were considered positive, as Scott et al. did. There are 2 criteria (i.e., those of Wilson, and of Sokolow and Lyon) that show a high correlation with

Table 8
Criteria of Wilson and His Co-workers for Left Ventricular Hypertrophy

<table>
<thead>
<tr>
<th></th>
<th>V\textsubscript{1}</th>
<th></th>
<th>V\textsubscript{5}</th>
<th></th>
<th>V\textsubscript{6}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of cases</td>
<td>Rs \textsubscript{1}</td>
<td>Rs \textsubscript{3}</td>
<td>Rs \textsubscript{5}</td>
<td>Rs \textsubscript{6}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S\textsubscript{1}</td>
<td>S\textsubscript{3}</td>
<td>S\textsubscript{5}</td>
<td>S\textsubscript{6}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rs \textsubscript{5}</td>
<td>T\textsubscript{5}</td>
<td>Rs \textsubscript{6}</td>
<td>T\textsubscript{6}</td>
</tr>
<tr>
<td>Normal</td>
<td>32</td>
<td>11</td>
<td>0</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>LVH</td>
<td>17</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>RVH</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 9
Criteria of Sokolow and Lyon for Standard Limb Leads for Left Ventricular Hypertrophy

<table>
<thead>
<tr>
<th>Number of cases</th>
<th>Rs \textsubscript{1} + S\textsubscript{1} \geq 25 mm.</th>
<th>Rs \textsubscript{5} + S\textsubscript{5} \geq 0.5 mm.</th>
<th>Rs-T\textsubscript{5} \downarrow \geq 0.5 mm.</th>
<th>Left axis deviation high voltage (I, III)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>32</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>LVH</td>
<td>17</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>RVH</td>
<td>16</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Circulation, Volume XXI, March 1960
### Table 10

**Criteria of Sokolow and Lyon for Unipolar Limb Leads for Left Ventricular Hypertrophy**

<table>
<thead>
<tr>
<th>Number of cases</th>
<th>T aVL↑</th>
<th>R &gt; 11 mm.</th>
<th>T low or ↓ ST-T + R ≥ 6 mm. &gt; 0.5 mm.</th>
<th>TRS-T↓</th>
<th>R &gt; 20 mm. &gt; 0.5 mm.</th>
<th>T low or ↓ RS-T↓ + R ≥ 6 mm. TRS-T↓</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>32</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>LVH</td>
<td>17</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>RVH</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

### Table 11

**Criteria of Sokolow and Lyon for Unipolar Chest Leads for Left Ventricular Hypertrophy**

<table>
<thead>
<tr>
<th>Number of cases</th>
<th>V5</th>
<th>V6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R &gt; 0.5 mm.</td>
<td>R &gt; 0.5 mm.</td>
</tr>
<tr>
<td>Normal</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>LVH</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>RVH</td>
<td>15</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 12

**Criteria of Sokolow and Lyon for Left Ventricular Hypertrophy**

<table>
<thead>
<tr>
<th>Standard limb leads only</th>
<th>Standard limb leads + AV</th>
<th>Standard limb leads + chest leads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>LVH</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>RVH</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Lyon’s criteria, when applied to our normal cases and the cases of pure right ventricular hypertrophy, had a high rate of false positives. From this point of view each item of the criteria was reviewed. If the items causing a high incidence of false positives, listed below, are omitted from the criteria, the positivity for left ventricular hypertrophy is 71 per cent (12 of 17 cases) and the false positives are 19 per cent (6 of 32 cases) in the normal subjects and 13 per cent (2 of 16 cases) in pure right ventricular hypertrophy.

The items responsible for a high incidence of false positives are as follows:

1. Depression of RS-T segment in lead I more than 0.5 mm.
2. Depression of RS-T segment in lead aVL or aVF over 0.5 mm.
### Table 13
**Criteria of Myers, Klein, and Stofer for Right Ventricular Hypertrophy**

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of cases</td>
<td>Reversal of V1</td>
<td>S1 &gt; 4 mm.</td>
<td>V1 + S1 &gt; 10.5 mm.</td>
<td>R/S v. V4 &lt; 1</td>
</tr>
<tr>
<td>Normal</td>
<td>32</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LVH</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>RVH</td>
<td>16</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

*Intrinsicoid deflection.

### Table 14
**Criteria of Sokolow and Lyon for Right Ventricular Hypertrophy**

|   | Number of cases | RV1 > 17 mm. | SY2 > 2 mm. | SY3 > 2 mm. | RV1 + SV1 > 10.5 mm. | R/S v. V4 < 1 | R/S v. V5 > 5 mm. | v. neg. | v. neg. | R/S in V1 > 1 | v. neg. | R/S in V1 > 0.04 | v. neg. | v. neg. | RV1 > 17 mm. | v. neg. | Right axis deviation > 10° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Normal | 32 | 3 | 0 | 1 | 10 | 1 | 0 | 2 | 1 | 0 | 1 | 16 | 16 |
| LVH | 16 | 0 | 1 | 0 | 3 | 1 | 0 | 0 | 0 | 1 | 0 | 4 | 12 |
| RVH | 16 | 2 | 4 | 0 | 6 | 6 | 3 | 1 | 1 | 7 | 4 | 8 | 12 |

3. Criterion 2 and flat, diphasic, or inverted T wave with R wave of over 6 mm.
4. Depression of RS-T segment in leads V4, V5, and V6 over 0.5 mm.
5. Criterion 4 and flat, diphasic, or inverted T wave with Rs pattern.
6. R/T ratio of more than 10 in leads V5 and V6.
7. R/S in V5 ratio of more than 100.
   R/S in V1

Generally speaking, the changes of the RS-T segment and of the T wave show a high incidence of false positives when used as a criterion of left ventricular hypertrophy. Myocardial ischemia of varying etiology and electrolyte imbalance, which is observed in many conditions especially near terminus, will be causes of this false positivity.

In right ventricular hypertrophy, Walker

### Table 15
**Criteria of Goldberger for Right Ventricular Hypertrophy**

<table>
<thead>
<tr>
<th></th>
<th>Number of cases</th>
<th>Atrial hypertrophy</th>
<th>Marked clockwise rotation</th>
<th>Extreme clockwise rotation</th>
<th>Right bundle-branch block</th>
<th>Tail RV1 (m)</th>
<th>Right bundle-branch block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>32</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>LVH</td>
<td>17</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>RVH</td>
<td>16</td>
<td>6</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>11</td>
</tr>
</tbody>
</table>
Table 16

<table>
<thead>
<tr>
<th>Criteria for LVH</th>
<th>Normal 32</th>
<th>Isolated LVH 17</th>
<th>Isolated RVH 16</th>
<th>Walker et al. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gubner, Ungerleider</td>
<td>6 18.8 %</td>
<td>6 35.3 %</td>
<td>36.0 %</td>
<td>0 0 %</td>
</tr>
<tr>
<td>Katz</td>
<td>10 31.3 %</td>
<td>7 41.2 %</td>
<td>59.0 %</td>
<td>3 18.8 %</td>
</tr>
<tr>
<td>Schach, Rosenbaum, Katz</td>
<td>1 3.1 %</td>
<td>2 11.8 %</td>
<td>21.9 %</td>
<td>0 0 %</td>
</tr>
<tr>
<td>Goldberger</td>
<td>6 18.8 %</td>
<td>6 35.3 %</td>
<td>68.0 %</td>
<td>3 20.0 %</td>
</tr>
<tr>
<td>Gould, Kissane</td>
<td>4 12.5 %</td>
<td>2 11.8 %</td>
<td>27.0 %</td>
<td>0 0 %</td>
</tr>
<tr>
<td>Noth, Myers, Klein</td>
<td>1 3.1 %</td>
<td>3 17.6 %</td>
<td>28.0 %</td>
<td>0 0 %</td>
</tr>
<tr>
<td>Wilson</td>
<td>(14) **</td>
<td>(17)</td>
<td>(41.2)</td>
<td>(7)</td>
</tr>
<tr>
<td>Sokolow, Lyon</td>
<td>17 53.1 %</td>
<td>15 88.2 %</td>
<td>85.0 %</td>
<td>10 66.7 %</td>
</tr>
</tbody>
</table>

Criteria for RVH

| Myers, Klein, Stofer | 1 3.1 % | 1 5.9 % | 8 50.0 % | 13.6 % |
| Sokolow, Lyon | 16 50.0 % | 42 25.0 % | 12 75.0 % | 22.7 % |
| Goldberger* | 2 6.3 % | 5 29.4 % | 11 68.7 % |

* Result when the atrial hypertrophy was omitted.
† Number out of 15 cases.
‡ Number out of 16 cases.
** Figures in parentheses are result when the presence of Q wave in Lead V₅ and V₆ was omitted.

et al. reported that they found only 23 per cent (5 of 22 cases) positivity using Sokolow and Lyon's criteria and 14 per cent (3 of 22 cases) positivity by using the criteria of Myers and his co-workers. They concluded that frequently the electrocardiogram will not be diagnostic in the presence of anatomic right ventricular hypertrophy.

In Goldberger's criteria we included the item of atrial hypertrophy (0.11 second or more wide, 2.5 mm. or more tall) as one item of the criteria of right ventricular hypertrophy. If this is omitted, the positivity decreases markedly, as does the false positivity. Sokolow and Lyon's criteria show high positivity (75 per cent) in right ventricular hypertrophy, but also show a high incidence of false positives, 50 per cent (16 of 32 cases) of the normal subjects and 25 per cent (4 of 16 cases) of the cases of the left ventricular hypertrophy. Among each item of Sokolow and Lyon's criteria, the following items are responsible for the high incidence of false positivities:

1. S V₁ < 2 mm.
2. S V₅, V₆ > 7 mm.
3. R V₅, V₆ < 5 mm.
4. R/S V₅, V₆ < 1

If these items are omitted from these criteria, the positivity for the diagnosis of right ventricular hypertrophy is 63 per cent (10 of 16 cases) and the false positivity is 9 per cent.
VENTRICAL HYPERTROPHY

(3 of 32 cases) in the normal cases. In this instance there is no false positivity in the cases of left ventricular hypertrophy. The reason for this, a clockwise rotation along its longitudinal axis which is frequently observed normally, is one of the important factors of the false positivity when applying Sokolow and Lyon’s criteria.

Myers’ criteria show very few false positives, but the positivity for right ventricular hypertrophy is only 50 per cent. Applying these criteria, we strictly followed the criteria for incomplete right bundle-branch block proposed by him; so atypical incomplete right bundle-branch block such as rSr’ pattern in the right-sided chest leads was not considered as significant.

If this kind of incomplete right bundle-branch block is considered as significant, their positivity increases to 88 per cent (14 of 16 cases), but the false positivities increase to 22 per cent (7 of 32 cases) in normal subjects, and 24 per cent (4 of 17 cases) in cases of left ventricular hypertrophy. The reason for this is the heterogeneous origins for incomplete right bundle-branch block as emphasized by Allenstein.19

Conclusions

Several criteria for the diagnosis of left ventricular hypertrophy and right ventricular hypertrophy were studied referring to positivity as well as false positivity.

Criteria for the diagnosis of left ventricular hypertrophy proposed by Gubner, Ungerleider; Katz; Schach, Rosenbaum, and Katz; Gouder and Kissane; and Noth, Myers, and Klein, showed a low incidence of positivity, under 50 per cent. The criteria of Wilson and co-workers, and Sokolow and Lyon, showed relatively high positivities, but they also had a high incidence of false positives. The reason for the high false positivities of these 2 criteria was evaluated.

The criteria for the diagnosis of right ventricular hypertrophy as proposed by Goldberger; Myers, Klein, and Stofe; and Sokolow and Lyon, were studied. They had a high incidence of false positives and a poor incidence of positive correlation.

These findings indicate that great caution must be taken in applying these criteria in clinical practice.

Summario in Interlingua

Plure criterios electrocardiographic pro le diagnose de hypertrophia sinistro-ventricular e hypertrophia dextero-ventricular eseva studiate con attention prestate al procentages de positivitate si ben como de positivitate false.

Le criterios pro le diagnose de hypertrophia sinistro-ventricular proponite per Gubner e Ungerleider, per Katz, per Schach, Rosenbaum, e Katz, per Goulder e Kissane, e per Noth, Myers, e Klein mostrava un basse incidentia de positivitate, amontante a minus que 50 pro cento. Le criterios de Wilson, Rosenbaum, e Johnston e de Sokolow e Lyon monstравa relativamente alte valores de positivitate, sed illos etiam resultava in un alte incidentia de positivitate false. Le rationes pro le alte false positivitate in iste duo casos es evulate.

Esva studiate le criterios pro le diagnose de hypertrophia dextero-ventricular proponite per Goldberger, per Myers, Klein, e Stofe, e per Sokolow e Lyon. Illos ha un alte incidentia de false positivitate e un basse incidentia de correlation positive. Le constatationes indica que le uso de iste criterios in le practica clinique require le plus meticulose precaution.

References

8. NOTH, P. H., MYERS, G. B., and KLEIN, H. A.:


A study based on data from the files of life insurance policyholders is reported. The persons in question were required to pay increased insurance premium rates because at least one blood pressure reading had been found to be above 136 mm. Hg systolic or 88 mm. Hg diastolic. Otherwise the individuals were in good health. The data offered no evidence that lability of the blood pressure was a significant factor in the moderately increased mortality. The observed fluctuations in blood pressure did not indicate that the life span in these persons was greater than that of persons with constantly observed hypertension. Therefore, it would seem proper to include a proportionate number of elevated readings with the normal ones in the determination of the average blood pressure for an individual person. These data also supported the generally accepted conclusion that the significance of hypertension becomes less important as the age of the person advances. Finally, the results of this study suggested the desirability for early recognition of temporary elevations in blood pressure and their importance in otherwise healthy persons.

Krause
Evaluation of Electrocardiographic Diagnosis of Ventricular Hypertrophy Based on Autopsy Comparison
BERTRAM J. ALLENSTEIN and HIROYOSHI MORI

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