Computer Diagnosis of Biventricular Hypertrophy from the Orthogonal Electrocardiogram

By Raul Gamboa, M.D., Jack D. Klingeman, M.S., and Hubert V. Pipberger, M.D.

SUMMARY

Orthogonal electrocardiograms obtained from 87 patients with necropsy evidence of biventricular hypertrophy (BVH) were compared to record samples obtained from normal subjects (N) and patients with left or right ventricular hypertrophy (LVH or RVH). From 333 different ECG measurements an attempt was made to select optimal discriminators of the various pathological entities. The best separation between the BVH sample and other entities was obtained by utilizing linear discriminant function analysis and a likelihood ratio test. By using a combined covariance matrix of BVH versus N, LVH, and RVH, 69% of the BVH sample was correctly classified, thus demonstrating that multivariate analysis can lead to a substantial improvement in diagnostic classification over previous studies reported in the literature.

To test the multivariate classification method against completely independent record samples, new series of LVH and RVH cases were compared to the BVH sample. The results were similar to those obtained against the original samples. When a "clinical" BVH sample was classified by the combined covariance matrix, 44% of the new cases were classified correctly.

A search was also made for optimal scalar and vectorial measurements that can be used in routine ECG interpretation without access to computer facilities. On using 96 percentile ranges, the separations were less efficient than those obtained by multivariate analysis but they still compared very favorably with previous reports.

Additional Indexing Words:
ECG classification
Vectorcardiography
Discriminant function analysis
Likelihood ratio test
Computer analysis

Characteristic electrocardiographic patterns of right and left ventricular hypertrophy have been extensively described in the past. The use of those patterns and the addition of quantitative criteria have established the definite value of the electrocardiogram in the diagnosis of left and right ventricular hypertrophy. On the other hand, the fruitful recognition of isolated left or right ventricular hypertrophy has not been matched with similar success when attempts were made to recognize combined ventricular hypertrophy. In fact, most clinicians have reserved only a supplementary role for the electrocardiogram in the diagnosis of biventricular hypertrophy.

The following investigation was undertaken to determine the accuracy of the corrected electrocardiogram and the usefulness of newer computational technics in the diagnosis of biventricular hypertrophy.

From the Veterans Administration Cooperative Study on Automatic Cardiovascular Data Processing, Veterans Administration Hospitals, Batavia, New York, Birmingham, Alabama, Durham, North Carolina, Houston, Texas, Minneapolis, Minnesota, San Francisco, California, Washington, D. C., and West Roxbury, Massachusetts, and the Department of Medicine, Georgetown University School of Medicine, Washington, D. C.

Work was supported in part by Research Grant HE-09696-03 from the National Heart Institute, U. S. Public Health Service and was carried out during Dr. Gamboa's tenure of an Advanced Research Fellowship from the American Heart Association.
BIVENTRICULAR HYPERTROPHY

Table 1

Clinical Diagnosis of BVH Cases Confirmed by Autopsy

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulmonary emphysema and other chronic pulmonary diseases</td>
<td>26</td>
</tr>
<tr>
<td>Mitral stenosis and mitral insufficiency</td>
<td>19</td>
</tr>
<tr>
<td>Hypertensive cardiovascular disease</td>
<td>16</td>
</tr>
<tr>
<td>Aortic stenosis, insufficiency, or both</td>
<td>8</td>
</tr>
<tr>
<td>Arteriosclerotic heart disease</td>
<td>13</td>
</tr>
<tr>
<td>Primary myocardial disease</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>87</td>
</tr>
</tbody>
</table>

Methods

The records used in the present study were obtained through a cooperative study by eight Veterans Administration Hospitals. The Frank lead system13 was used, with electrodes placed in the fourth intercostal space. Analog-to-digital conversion and details of the computational procedures have been reported previously.14

An autopsy sample of 87 cases considered to be representative of patients with biventricular hypertrophy (BVH 1) forms the basis for this study (table 1). Cases were accepted as BVH if they fulfilled the following criteria: (a) total heart weight > 400 g; (b) left ventricular wall thickness > 13 mm; and (c) right ventricular wall thickness > 4 mm.

The electrocardiograms of the BVH sample were compared with those of a group of normals of comparable age. Two hundred twenty-nine records were selected from a larger normal sample (N) previously studied.12 Secondly, the BVH group was compared with an autopsy sample of 75 cases with anatomic left ventricular hypertrophy (LVH 1). Cases were accepted as LVH if the heart weight was > 350 g and the left ventricular thickness was > 13 mm. Thirdly, the BVH sample was compared with an autopsy sample of 33 cases with anatomic right ventricular hypertrophy (RVH 1). Cases were classified as RVH if the heart weight was > 350 g and the right ventricular thickness was > 3 mm.

To test the classification method against completely independent record samples, three new series of records were also classified: (a) a "clinical" BVH sample of 113 records from patients with both mitral stenosis and mitral insufficiency (BVH 2); (b) a "clinical" LVH sample of 77 records belonging to patients with an average blood pressure reading of 150/90 mm Hg, without cardiac enlargement on x-rays, no episodes of congestive heart failure, and a known history of hypertensive cardiovascular disease of more than 1 year duration (LVH 2); (c) a "clinical" RVH sample of 113 records obtained from patients with clinical and hemodynamic diagnosis of pure mitral stenosis.

The electrocardiographic measurements for separation of the groups were selected from a total of 333 items which included practically all scalar and vectorial parameters proposed in the past by various investigators.15 An attempt was made to determine the best discriminators of the various pathological entities. These discriminators were chosen first by selecting candidates by t-test. Only a crude selection can be obtained by this procedure: (1), The t-test is based on the assumption of normal distributions which are rarely found for ECG data. (2), The discriminative power of combinations of variables can be missed, as shown in figure 1B. For multivariate analysis the final selection of measurements was made, therefore, by linear discriminant function analysis.16, 17

To select single discriminators for use in sequence, as is commonly done in ECG analysis, a large number of candidates were compared side by side. Using 96 percentile ranges of normal, measurements were selected according to the number of abnormal records exceeding those ranges. In this side-by-side comparison it could be determined whether measurements contributed additional information or whether they were redundant.

When a large set of measurements is available, special attention must be paid to the adequacy of sample size. If the sample is not several times larger than the number of measurements, unrealistic discrimination rates will result. Previous studies14 have indicated that a number of discriminators greater than the square root of the sample size leads to overly optimistic results.

The first set of ECG items consisted of scalar measurements which can be reproduced by every electrocardiographer. The second set included, in addition, parameters derived from planar vectorcardiograms. By using the 96 percentile ranges of the comparative groups (N, LVH, and RVH), cases were classified as BVH when they were found to lie outside one or more of these limits. Finally, separation between the BVH samples and others was attempted by the likelihood ratio test.14

We shall outline briefly the method used for the multivariate analysis, and refer the reader to the "Appendix" for the mathematics of the procedure. Let us consider the case in which there are only two diagnostic groups as in figure 1A. If measurement X is going to be used for discrimination between the two groups, the members of both groups can be displayed in the form of histograms along the axis X. It can be visually
determined if the two groups have different distributions and we can select a discriminant, that is, a line f perpendicular to the X axis, which separates the two groups. If a patient's measurement falls to the left of f, it is classified as belonging to group a; to the right, as belonging to group b. If several measurements are available (X₁, X₂, . . . Xₙ), they can be considered one at a time, and we can select the one that discriminates best. If some of the measurements are correlated or redundant, it is certain that no efficient use of the data is being made. It is possible to improve the separation between both groups if two measurements are considered simultaneously. Suppose there are measurements, X₁ and X₂, on patients from groups a and b. Their distributions can be depicted in form of scatter diagrams in a two dimensional space as shown in figure 1B. Each patient can be defined by a vector. The tips of the vectors of each patient form a cluster for each group or sample representing the distribution of the cases. A mean vector (a' and b') is calculated for each group. An unknown vector or an unknown patient to be classified is treated as follows: The vector difference between the unknown and the various means is determined. The smaller the vector difference, the more likely it is that the unknown vector belongs to that group.

The two dimensional approach can be extended to a multidimensional one if N-number of ECG measurements are considered as coordinates in a N-dimensional space. Figure 1C illustrates the use of a three-dimensional space, but no mathematical laws prevent an extension of the number of dimensions. In a three-dimensional space, groups a and b are clustered in two different regions in space. These regions are separated by decision surfaces which are defined by likelihood ratio test.

Results

Table 2 shows the results of comparing the BVH 1 sample with the N group, first using five simple ECG parameters, and second using eight items. It can be seen that 56% of the BVH sample are recognized with five measurements, and there are 9% of false positives. When eight measurements are used, the percentage of correctly classified records goes up to 73. The percentage of false positives is 15. As shown in table 2, the independent information obtained from each ECG param-

![Figure 1](http://circ.ahajournals.org/)

(A) Distribution of cases belonging to two diagnostic groups in the form of a histogram. X represents one ECG parameter and n represents number of cases.
(B) Two dimensional presentation of the distribution of two diagnostic groups. X₁ and X₂ represent the axes of two ECG parameters. Note that there is considerable overlap in both axes. A third axis can be computed which leads to optimal separation.
(C) Three dimensional presentation of the distributions of two diagnostic groups. The surface separates the two samples a and b on the basis of the density of findings. The likelihood of belonging to one of the groups is greater the nearer the cases are located to the center of the groups, with the surface itself representing equal likelihood for both.
BIVENTRICULAR HYPERTROPHY

Table 2
Comparison of BVH and Normals: Eight ECG Measurements Found Best for Separation of BVH from Normal

<table>
<thead>
<tr>
<th>Scalar ECG measurements</th>
<th>Cases recognized</th>
<th>Independent recognition, * recognition cases (%)</th>
<th>Scalar and vectorcardiographic ECG measurements</th>
<th>Cases recognized</th>
<th>Independent recognition, * recognition cases (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R/Sx ratio &lt;1.43</td>
<td>34</td>
<td>3</td>
<td>Spatial QRS magnitude &gt;2.49 mv</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>Rx amplitude &lt;0.51 mv</td>
<td>30</td>
<td>5</td>
<td>R/Sx ratio 1.43</td>
<td>34</td>
<td>1</td>
</tr>
<tr>
<td>R/Sy ratio &lt;1.11</td>
<td>10</td>
<td>5</td>
<td>Rx amplitude &lt;0.51 mv</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>Qz amplitude &lt;0.12 mv</td>
<td>5</td>
<td>3</td>
<td>R/Sy ratio &lt;1.11</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Q/Rz ratio &lt;0.10</td>
<td>5</td>
<td>2</td>
<td>Spatial max QRS azimuth angle &lt;259°</td>
<td>29</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Qz amplitude &lt;0.12 mv</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spatial T magnitude &lt;0.12 mv</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q/Rz ratio &lt;0.10</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

\*In the column for independent recognition only those cases are listed which were found abnormal with one measurement only.

†The percentages are cumulative.

eter varies and is not related to its recognition power. By independent information is meant the number of cases that would have been missed if such measurement was not used.

Table 3 shows the results of comparing the BVH 1 and the LVH 1 and LVH 2 samples. Using four simple ECG items, the percentage of correctly classified BVH cases was 39 against LVH 1 and 37 against LVH 2. The percentage of false positives against these samples was 8 and 10, respectively. Using seven measurements, the percentage of correct classifications improved up to 50 against LVH 1 and up to 47 against LVH 2. The percentage of false positives was 14 and 17, respectively.

The separation of BVH 1 from the RVH 1 and RVH 2 samples is shown in table 4. It is observed that four simple ECG items are able to classify correctly 52% and 46% of BVH records, respectively. When additional vectorcardiographic items were utilized, the percentage of correct classifications increased to 70 against RVH 1 and 65 against RVH 2. The percentages for false positives were 8 and 15 for four and eight items, respectively, against RVH 1, and 10 and 18 for four and eight parameters, respectively, against RVH 2.

When BVH 1 cases were differentiated stepwise (BVH-N, BVH-RVH, and BVH-LVH) and the misclassified cases were eliminated with each step, only 12% remained classified as BVH. The low recognition rate indicates that the stepwise procedure using 96 percentile ranges is certainly inefficient. However, if separation was established against N and LVH, or N and RVH only, the percentages of correctly classified BVH cases were 43 and 42, respectively.

The performance of the items selected by the discriminant function analysis was evaluated first by independent comparisons of BVH 1 with N, LVH 1, and RVH 1 samples. The electrocardiographic parameters and the numerical values of the coefficients in the discriminant functions, as well as the results are given in tables 5 to 7. Eighty per cent of the BVH records were correctly classified against N, 68% against LVH, and 72% against RVH. When the process was repeated stepwise, 38% remained classified as BVH. If separation was established against N and LVH, or N and RVH only, the percentages of correct classification were 60 and 58, respectively, thus indicating a noticeable improvement over the percentages found through use of a series of single measurements.

The performance of a joint covariance matrix computed for N, LVH 1, and RVH 2
### Table 3

**Comparison of BVH and LVH**: Electrocardiographic and Vectorcardiographic Parameters Found Best for Separation of BVH from LVH

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Scalar ECG measurements</th>
<th></th>
<th></th>
<th>Total recognition (%)</th>
<th>Scalar and vectorcardiographic ECG measurements</th>
<th></th>
<th></th>
<th>Total recognition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LVH-1</td>
<td>LVH-2</td>
<td>LVH-1</td>
<td>LVH-2</td>
<td>LVH-1</td>
<td>LVH-2</td>
<td>LVH-1</td>
<td>LVH-2</td>
</tr>
<tr>
<td>Sx amplitude &gt;0.65 mv</td>
<td>17</td>
<td>18</td>
<td>4</td>
<td>5</td>
<td>19</td>
<td>20</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>R/Sx ratio &lt;0.66</td>
<td>20</td>
<td>23</td>
<td>10</td>
<td>9</td>
<td>31</td>
<td>31</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Qy amplitude &gt;0.34 mv</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>36</td>
<td>35</td>
<td>0.03 see after beginning</td>
<td></td>
</tr>
<tr>
<td>Sx duration &gt;56 msec</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>39</td>
<td>37</td>
<td>0.05 sec before end of QRS</td>
<td></td>
</tr>
</tbody>
</table>

*LVH-1 represents the autopsy sample; LVH-2 represents the clinical sample.
†The percentages in these columns are cumulative.

### Table 4

**Comparison of BVH and RVH**: Electrocardiographic and Vectorcardiographic Parameters Found Best for Separation of BVH from RVH

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Scalar ECG measurements</th>
<th></th>
<th></th>
<th>Total recognition (%)</th>
<th>Scalar and vectorcardiographic ECG measurements</th>
<th></th>
<th></th>
<th>Total recognition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RVH-1</td>
<td>RVH-2</td>
<td>RVH-1</td>
<td>RVH-2</td>
<td>RVH-1</td>
<td>RVH-2</td>
<td>RVH-1</td>
<td>RVH-2</td>
</tr>
<tr>
<td>Rx amplitude &gt;1.06 mv</td>
<td>36</td>
<td>30</td>
<td>5</td>
<td>4</td>
<td>41</td>
<td>35</td>
<td>36</td>
<td>30</td>
</tr>
<tr>
<td>R/Sx ratio &gt;5.17</td>
<td>11</td>
<td>9</td>
<td>4</td>
<td>6</td>
<td>46</td>
<td>41</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td>Ry amplitude &gt;1.07 mv</td>
<td>13</td>
<td>12</td>
<td>3</td>
<td>2</td>
<td>50</td>
<td>41</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Ry peak time &gt;52 msec</td>
<td>10</td>
<td>9</td>
<td>2</td>
<td>2</td>
<td>52</td>
<td>46</td>
<td>13</td>
<td>17</td>
</tr>
</tbody>
</table>

*RVH-1 represents the autopsy sample; RVH-2 represents the clinical sample.
†The percentages in these columns are cumulative.
Table 5
Measurements Found Best by Linear Discriminant Function Analysis for Separation of BVH and Normals *

<table>
<thead>
<tr>
<th>ECG measurements</th>
<th>Coefficients of the discriminant functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Spatial magnitude 3/8 ST-T</td>
<td>1.00</td>
</tr>
<tr>
<td>2. Spatial magnitude 4/8 ST-T</td>
<td>-0.46</td>
</tr>
<tr>
<td>3. Ry amplitude</td>
<td>-0.11</td>
</tr>
<tr>
<td>4. Spatial QRS magnitude</td>
<td>0.09</td>
</tr>
<tr>
<td>5. R/Sx ratio</td>
<td>-0.05</td>
</tr>
<tr>
<td>6. Rx amplitude</td>
<td>-0.05</td>
</tr>
<tr>
<td>7. T Magnitude horizontal plane</td>
<td>-0.04</td>
</tr>
<tr>
<td>8. Spatial max QRS azimuth</td>
<td>-0.03</td>
</tr>
<tr>
<td>9. QRS magnitude frontal plane</td>
<td>-0.02</td>
</tr>
</tbody>
</table>

Likelihood ratio test
Correctly classified 80%
False positives 12%
False negatives 20%

*The coefficients of the discriminant functions are multiplied by the magnitude of the measurements, and the products are added. Note that measurements of small amplitude, such as ST-T, have frequently a large coefficient and those of greater amplitude may have small ones. The product of the two determines the true weight of the parameter.

Table 6
Measurements Found Best by Linear Discriminant Function Analysis for Separation of BVH and LVH (for Explanation See Table 5)

<table>
<thead>
<tr>
<th>ECG measurements</th>
<th>Coefficients of the discriminant functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 0.03 sec after beginning of QRS elevation angle</td>
<td>1.00</td>
</tr>
<tr>
<td>2. Sx amplitude</td>
<td>-0.38</td>
</tr>
<tr>
<td>3. Time QRS max spatial magnitude</td>
<td>-0.19</td>
</tr>
<tr>
<td>4. R/Sx ratio</td>
<td>-0.07</td>
</tr>
<tr>
<td>5. Sx duration</td>
<td>-0.03</td>
</tr>
<tr>
<td>6. Spatial max QRS azimuth</td>
<td>-0.02</td>
</tr>
<tr>
<td>7. 0.05 sec before end of QRS elevation angle</td>
<td>-0.02</td>
</tr>
<tr>
<td>8. Time QRS max magnitude of frontal plane</td>
<td>-0.02</td>
</tr>
</tbody>
</table>

Likelihood ratio test
Correctly classified 68%
False positives 12%
False negatives 32%

Table 7
Measurements Found Best by Linear Discriminant Function Analysis for Separation of BVH and RVH (for Explanation See Table 5)

<table>
<thead>
<tr>
<th>ECG measurements</th>
<th>Coefficients of the discriminant functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Spatial magnitude 3/8 ST-T</td>
<td>1.00</td>
</tr>
<tr>
<td>2. Spatial magnitude 4/8 ST-T</td>
<td>-0.41</td>
</tr>
<tr>
<td>3. Ry amplitude</td>
<td>-0.24</td>
</tr>
<tr>
<td>4. Spatial QRS magnitude</td>
<td>0.20</td>
</tr>
<tr>
<td>5. Rx amplitude</td>
<td>-0.08</td>
</tr>
</tbody>
</table>

Likelihood ratio test
Correctly classified 72%
False positives 15%
False negatives 28%

Table 8
Measurements Found Best by Linear Discriminant Function Analysis for Separation of BVH and One Covariance Matrix for the Combination of N, LVH, and RVH (for Explanation See Table 5)

<table>
<thead>
<tr>
<th>ECG measurements</th>
<th>Coefficients of the discriminant functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Spatial magnitude 3/8 ST-T</td>
<td>1.00</td>
</tr>
<tr>
<td>2. Spatial magnitude 4/8 ST-T</td>
<td>-0.38</td>
</tr>
<tr>
<td>3. Ry amplitude</td>
<td>-0.19</td>
</tr>
<tr>
<td>4. T magnitude horizontal</td>
<td>-0.09</td>
</tr>
<tr>
<td>5. Spatial QRS magnitude</td>
<td>0.07</td>
</tr>
<tr>
<td>6. QRS magnitude sagittal plane</td>
<td>-0.05</td>
</tr>
<tr>
<td>7. Rx amplitude</td>
<td>-0.05</td>
</tr>
<tr>
<td>8. 0.03 sec after beginning of QRS azimuth angle</td>
<td>-0.05</td>
</tr>
<tr>
<td>9. 0.04 sec after beginning of QRS elevation angle</td>
<td>-0.03</td>
</tr>
</tbody>
</table>

Likelihood ratio test
Correctly classified 69%
False positives 18%
False negatives 31%

The discrimination was 69. Testing the same procedure with the BVH 2 sample, a reduction in correct classification to 44% was observed.

Discussion

Previous anatomic-electrocardiographic correlations have shown that the ECG diagnosis of BVH is rather a difficult one. Pagnoni and Goodwin reported that, from an autopsy sample of 51 cases of BVH, ECG recognition of both left and right ventricular hypertrophy could be made in 25% of the samples against BVH 1 was also found to be considerably more efficient than what has been previously reported (table 8); in this process the percentage of correct BVH clas-
cases only. Lipsett and Zinn\textsuperscript{18} studied an autopsy sample of 73 cases of BVH and found that the electrocardiogram was diagnostic of BVH in only 14\% of the cases. Recently, Wolff and associates\textsuperscript{12} concluded that only in 4\% of their autopsy-proven cases of BVH could the ECG diagnosis of combined ventricular hypertrophy be made. The percentages of correct classifications were better in studies including nonautopsy material. Rosenman and associates\textsuperscript{10} were able to recognize 42\% of their BVH sample. Other investigators have reported percentages between 13 and 30.\textsuperscript{19-21} More recently Hattori\textsuperscript{22} has shown that in cases of BVH established by angiography, the diagnosis of BVH was made from the electrocardiogram in only 6\%. In general these results indicate that the ECG recognition of BVH is far from ideal.

The factors contributing to the low recognition rate of BVH in previous ECG studies are manifold. Among them, the selection of the lead system to be used may play a significant role. The intra-individual and inter-individual variability of the lead-fields of the conventional 12-lead ECG might contribute to a low diagnostic classification. Secondly, it can be postulated that the simultaneous hypertrophy of both ventricles may lead to a pseudo-normalization of the ECG,\textsuperscript{12} making its recognition among normals rather difficult. Besides these considerations, as is well known, BVH may develop in the later phases of almost any type of heart disease regardless of whether LVH or RVH was present in the early phase of the disease, thus, presenting a wide spectrum of ECG characteristics.

The results of the present investigation demonstrate that a substantial improvement in the electrocardiographic recognition of BVH is feasible. Two factors are the main contributors to this improvement over results

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{figure2.png}
\caption{Discrimination between BVH and normals using 96 percentile ranges. It is observed that eight measurements gave a discrimination power of 73\%. Thereafter, the curve levels off and no new ECG items, among 25 best discriminators, contribute to increase the percentage of correct classifications.}
\end{figure}
BIVENTRICULAR HYPERTROPHY

reported by others. In conventional electrocardiography only a limited number of measurements can be tested by visual procedures, whereas a set of N-number of criteria can be selected by computer out of 333 measurements. Secondly, the use of more complex and efficient classification procedures through automatic data processing has been shown to be of definite value for ECG classification.

Differential Diagnosis of BVH from Normals

Although the computer analysis of the ECG permits use of a large number of parameters, many measurements proved redundant, that is, no new or additional cases were recognized by adding more measurements. One measurement by itself may be fairly efficient in the separation of BVH and N, but unless new cases are recognized, it may be abandoned. As observed in Table 2, eight measurements led to a recognition of 73% of the BVH sample. No additional measurements were able to add new cases, and as a consequence, any other ECG parameter could be considered redundant (Fig. 2). The use of simple scalar ECG parameters, namely QRS amplitudes and ratios, demonstrates that five items are the maximal number that will provide independent information. Using these five ECG parameters, 56% of the BVH sample was correctly classified. To our knowledge, these are the highest figures hitherto reported in the literature. It is noteworthy that in a comparison of a clinically selected BVH sample and a normal group, Kovats-Hopf and Wyss, using eight vectorcardiographic parameters, were able to recognize only 46% of their cases.

The findings related to the Q amplitude and Q/R amplitude ratio in lead Z deserve special comment. It is known that in children with high-flow ventricular septal defects, the evidence for BVH is given by the increased magnitude of the R wave in both, right and left precordial leads. Similarly, Rosenman and associates, studying patients with BVH due to rheumatic heart disease, pointed out that "in records primarily indicative of left ventricular strain, changes due to concomitant right heart strain, that is, tall R waves in V1 and V2, are diagnostic of BVH." On the other hand, in our series, composed of patients above 40 years of age with a variety of cardiac diseases, the mean value for Q amplitude as well as the Q/R amplitude ratio in lead Z was below the normal control values. These differences call our attention to the particular ECG characteristics of certain cardiac abnormalities even though under the common denominator of BVH, and to the necessity of larger and more homogeneous groups for ECG classification.

The subsequent use of a multivariate analysis, thus using more fully the capacity of the computer to perform complex statistical operations, led to a further improvement in the separation of normals and BVH records. An improvement of 7 percentage points leading to 80% in correct classification, and a reduction by 3% of false positives indicate the advantages of the new procedure.

Differential Diagnosis of BVH from RVH and LVH

From a practical standpoint it is not sufficient to separate BVH records from normals. A separation from RVH and LVH has also to be included to make the differentiation clinically meaningful.

As shown before in the BVH-N classification, the separation between BVH and LVH, and between BVH and RVH using 96 percentile ranges was better when vectorcardiographic in addition to scalar parameters were considered. Fifty per cent of the BVH sample was correctly classified when compared with LVH, and 70% when compared with RVH. When the process was repeated stepwise (BVH-N, BVH-RVH, and BVH-LVH) eliminating the misclassified cases with each step, the percentage of the sample correctly classified was reduced to 12%.

An improvement in BVH-LVH and BVH-RVH classifications could be obtained by multivariate analysis. Compared to the 96 percentile range procedure, the improvement in correct classification averaged 18% against LVH (68% correctly classified), and 2%
against RVH (72% correctly classified). Once again, a stepwise procedure led to a deterioration in the diagnostic recognition rate. By this method only 38% of the cases remained classified as BVH. It must be realized however that a stepwise procedure for ECG classification is unrealistic from a clinical standpoint and does not favor a practical separation. Dealing with the particular problem of BVH, there are at the most two questions: (1) Is the record normal or abnormal? (2) Does the record represent BVH or LVH? or Does the record represent BVH or RVH? The two possibilities of the second question depend upon the underlying cardiac disease, for example, systemic hypertension for the left side, or cor pulmonale for the right one. Using a multivariate analysis, 60% and 58% of the cases would be classified as BVH if the final separation could be established against LVH or RVH, respectively. On the other hand, using scalar and vectorial analyses, 43% and 42% of the cases would be correctly classified against LVH and RVH, respectively. It must be emphasized that the recognition rates obtained through both procedures, either the multivariate analysis or the scalar and vectorial analysis, compare favorably with results previously reported in the literature.

These findings indicate that, for a clinician who does not have access to computer facilities, the two-step procedure represents a realistic approach to correct classification of BVH in clinical electrocardiography. If computer facilities are available, the results of the linear discriminant function analysis may be used in statistical methods for discriminating between BVH and a group comprised of N, LVH, and RVH. These groups are used to calculate a combined covariance matrix which leads to further improvement in diagnostic classification to the correct classification of 69% of cases.

The question may be raised whether the samples used in the present investigation are truly representative of the different diagnostic groups. In regard to the normal sample, previous evidence from our laboratory indicates that it can be considered large enough to represent an average normal population.17 The similarity in percentage classifications when comparisons were made against completely independent record samples of LVH and RVH indicates that the original samples were good representatives of those groups. However, when a clinical BVH sample (BVH 2) obtained from rheumatic patients with both mitral stenosis and insufficiency was tested against the N-LVH-RVH groups using the original combined covariance matrix, only 44% of the new sample were classified as BVH whereas 69% were so classified against the original BVH sample (BVH 1). Differences in sample material and sample size may account for this deterioration. This final result emphasizes the necessity of selecting new discriminators for each type of cardiovascular abnormality. New evidence collected in our cooperative study indicates that the BVH classification may be improved if diagnostic groups are established in terms of “BVH in systemic hypertension,” “BVH in cor pulmonale,” and others. The general approach to search for optimal discriminators in the BVH classification has also been rather successful in identifying other ECG abnormalities.

APPENDIX

Linear discriminant function analysis may be used to select from a very large set of ECG measurements a subset to use for discriminating between groups. The measurements from the sample population are projected onto an axis which maximizes separation of the groups in the sense that the ratio A/W is maximized (fig. 1B). In this ratio A represents a measure of the “between group variation,” and W, a measure of the “within group variation.” The calculation of the relative contribution of each measurement to this projection allows one to determine which measurements contribute to the separation of the groups.

The computational procedure is briefly outlined below. A more detailed discussion has been given elsewhere.26 27

We assume the total variation of our sample population is comprised of between group variation and within group variation. A weighted dispersion matrix is calculated for each group. These matrices are added, and their sum, W, is used to estimate the within group variation. The total
BIVENTRICULAR HYPERTROPHY

variation of the sample population, \( T \), is estimated by the dispersion matrix calculated from the entire sample population. The measure of the between group variation, \( A \), is the total variation minus the within group variation. The ratio \( A/W \) is maximized along the axis defined by the eigenvector corresponding to the largest eigenvalue of the matrix equation:

\[
(W^{-1} A - \lambda I) V = 0
\]

where
- \( A = T - W \)
- \( I \) = identity matrix
- \( V \) = eigenvector
- \( \lambda \) = eigenvalue

The components of the eigenvector derived from equation 1 are the coefficients for our linear discriminant function. The coefficients of the linear discriminant function are used to project the patients’ measurements onto an axis of maximal separation as follows (fig. 1B):

\[
X_i' = x V
\]

where
- \( X = \) vector of measurements from \( i^{th} \) patient
- \( V = \) vector of linear discriminant function coefficients
- \( X_i' = \) position of \( i^{th} \) patient along the axis.

References

1. Lewis, T.: Observations upon ventricular hypertrophy, with special reference to preponderance of one or other chamber. Heart 5: 365, 1914.


22. Hattori, M.: Study of correlation between ECG findings and ventricular wall thickness based on cardio-synchronous angiocardiography: II.


300 Years Ago
Red Colour From Air In The Lungs

It is certain, then, that the difference in colour, which is found between venous and arterial blood, is quite independent of the heating of the blood in the heart (even if such some heating must be conceded there); for, granted that heating does occur chiefly in the heart, then, as the function of both ventricles is the same, and they do not differ in any other respects than, as stated above, in the strength and thickness of their fibres, why should the colour not undergo a similar change in the right ventricle? But it is quite certain that blood withdrawn from the pulmonary artery is similar in all respects to venous blood, and is only reddish on the surface. Indeed, it will be shown by a very convincing experiment that this fresh red colour is not conferred on the blood by the left ventricle either. For, if the trachea is exposed [p. 165] in the neck and divided, a cork inserted, and the trachea ligatured tightly over it to prevent any ingress of air into lungs, then the blood flowing from a simultaneous cut in the cervical artery (or, at least, such blood as comes out some time after the asphyxiation of the lung) will be seen to be as completely venous and dark in colour, as if it had flown from a wound in the jugular vein. I have tried this fairly often, and the same truth is more evident still from the fact that the blood within the left ventricle of the heart and the trunk of the aorta of an animal, which has been strangled or has died a natural death, and in which air is prevented from passing into the blood, is found to be entirely akin to venous blood.—Richard Lower: Tractatus de Corde item de Motu & Colore Sanguinis et Chyli in eum Transitu. (1669) Translated by K. J. Franklin. In: R. T. Gunther: Early Science in Oxford, vol. 9. Oxford, University Press, 1932, ch. 3.
Computer Diagnosis of Biventricular Hypertrophy from the Orthogonal Electrocardiogram
RAUL GAMBOA, JACK D. KLINEMAN and HUBERT V. PIPBERGER

Circulation. 1969;39:72-82
doi: 10.1161/01.CIR.39.1.72
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1969 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/39/1/72

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org/subscriptions/