Simple Quantitative Vectorcardiographic Criteria for the Diagnosis of Right Ventricular Hypertrophy

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SUMMARY
The vectorcardiogram is a useful supplement to the conventional electrocardiogram in the recognition of right ventricular hypertrophy. Many quantitative criteria have been proposed. However, they are often too complicated for routine clinical application. Based on the distribution of the QRS loop area in the various quadrants in the vectorcardiogram in 198 normal subjects, three simple criteria for diagnosis of right ventricular hypertrophy are derived: 1) the anterior and rightward QRS loop area in the transverse plane is greater than 70% of the total; 2) the QRS loop area in the right posterior quadrant of the transverse plane is greater than 20% of the total; 3) the QRS loop area in the right inferior quadrant in the frontal plane is greater than 20% of the total. Vectorcardiogram recordings in 97 patients with atrial septal defect, mitral stenosis, and chronic obstructive lung disease with pulmonary hypertension met one or more of the criteria in 80 (83%). The conventional electrocardiogram of these patients was suggestive of right ventricular hypertrophy in 64 (66%). It is concluded that the proposed vectorcardiographic criteria provide a sensitive means for the diagnosis of right ventricular hypertrophy. Their specificity however was not tested.

Additional Indexing Words:
QRS loop, Atrial septal defect, Mitral stenosis, Chronic obstructive lung disease

THE USEFULNESS OF THE vectorcardiogram as a supplement to the conventional electrocardiogram in the diagnosis of right ventricular hypertrophy has been generally recognized.1-4 Several types of QRS loop alterations have been described,5 and many quantitative criteria proposed.1-8 The application of these quantitative criteria often requires several measurements which are time consuming. The purpose of this article is to present a group of simple quantitative criteria which may be easily applied in the daily interpretation of the clinical vectorcardiograms. These criteria are based on the percentage of the QRS loop area in the various quadrants of the planar projections. The sensitivity of these criteria is tested against proven cases of right ventricular hypertrophy.

Methods and Materials
Normal vectorcardiograms were obtained from 198 healthy men. There were 50 subjects between the age of 20 and 29, 50 between 30 and 39, 50 between 40 and 49, and 48 between 50 and 59 years of age. All of the subjects were free of symptoms suggestive of cardiovascular or pulmonary disease. Their physical examination, chest X-ray, and electrocardiogram were within normal limits. The percentage of the QRS loop area in each quadrant in the three planes was determined by planimetry. The mean value and the 95% range for the entire group were calculated. The 2.5 and 97.5 percentile values of these areas were used as the lower and upper limits of normal. Three quantitative criteria for the diagnosis of right ventricular hypertrophy were derived from these measurements because of their potential usefulness on theoretical grounds.

The sensitivity of these criteria was tested with 41 cases of atrial septal defect, 41 cases of mitral stenosis, and 15 cases of chronic obstructive lung disease with pulmonary hypertension. The ages of the patients ranged from 17 to 67 years with a mean of 39. Forty-four were men and 53 were women. The diagnosis of all cases of atrial septal defect was established by cardiac catheterization. Patients with mitral stenosis had also
undergone hemodynamic studies to verify the significance of the stenotic lesion. Other valvar dysfunction, if present, was considered as mild from either the catheterization data or angiographic studies. All patients with chronic obstructive lung disease had undergone right heart catheterization after an informed consent was obtained. The study was performed at least two weeks after recovery from respiratory infection, if any. None of them had any evidence of heart disease due to other etiology. Only those patients whose right ventricular or pulmonary arterial systolic pressure exceeded 30 mm Hg at rest were included.

The sensitivity of the criteria was also analyzed in relation to right ventricular or pulmonary arterial systolic pressure in the three patient groups. Comparisons were made among cases with normal pressure (≤ 30 mm), mild to moderate hypertension (31–50 mm), and severe hypertension (> 50 mm Hg).

The Frank system of lead placement was used for the recording of the vectorcardiograms. The Helm's system of notation was employed. Patients with a QRS duration greater than 0.11 sec were excluded.

The conventional electrocardiograms of all the patients with atrial septal defect, mitral stenosis, and pulmonary emphysema with pulmonary hypertension were also examined for the signs suggestive of right ventricular hypertrophy. Right ventricular hypertrophy was considered to be present when one or more of the following criteria were met:

1) R in lead V1 7 mm or more
2) S in lead V1 less than 2 mm
3) R/S ratio in lead V1 greater than 1
4) R in lead V1 plus S in lead V5 or V6 greater than 10.5 mm
5) R/S ratio in lead V5 or V6 equal to 1 or less
6) Time of onset of the intrinsicoid deflection in lead V1 greater than 0.04 sec
7) R in lead aV1 5 mm or more
8) Right axis deviation of 110° or more

Results

The mean value and the 95 percentile range of the QRS loop area in each quadrant of the three planes expressed as the percentage of the total area in the 198 normal subjects are indicated in figure 1. Since an increase of the rightward QRS forces represents the most important finding in right ventricular hypertrophy, only the transverse and frontal planes were used. Abnormal increase in the anterior forces, often seen in patients with right ventricular hypertrophy, can also be detected with the transverse plane projection. The following criteria were derived based on the normal limits for the area in the anterior and rightward directions (fig. 2):

1) The anterior and rightward QRS loop area in the transverse plane is greater than 70% of the total or the area in the left posterior quadrant is less than 30% of the total

\[ \text{QRS LOOP AREA} \]

\[ \text{NORMAL} \]

\[ \text{TRANSVERSE PLANE} \]

\[ \text{R. SAGITTAL PLANE} \]

\[ \text{FRONTAL PLANE} \]

\[ \text{Figure 1} \]

\[ \text{The mean value of 95 percent range (in parenthesis) of the percentage of QRS loop area in the various quadrants in 198 normal subjects. P = posterior; R = right; L = left; A = anterior; S = superior; I = inferior.} \]

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the vectorcardiogram met one or more of the criteria in 40 (96%). Criterion 1 was most useful and was applicable in 30 patients. Thirty-two of the 41 cases (78%) met one or more of the electrocardiographic criteria for the diagnosis of right ventricular hypertrophy. The difference in the sensitivity of the vectorcardiographic and electrocardiographic criteria was statistically significant ($P < 0.01$).

In the 41 cases of mitral stenosis 29 (71%) met the vectorcardiographic criteria. Criterion 1 alone was again useful in diagnosis of the majority (22) of the cases. Twenty-four patients (59%) met the electrocardiographic criteria. In the 15 patients with chronic obstructive lung disease and pulmonary hypertension, 11 (73%) met one or more of the vectorcardiographic criteria. In contrast to the other two disease entities, criteria 2 and 3 were most helpful in this instance. The electrocardiogram was positive in eight cases (53%). In both groups, although the vectorcardiogram appeared more sensitive than the electrocardiogram, the differences did not reach the level of statistical significance.

When the entire group of 97 patients was considered, the vectorcardiogram was able to identify right ventricular hypertrophy or pulmonary hypertension in a significantly larger number of patients than the electrocardiogram (80 patients or 83% vs 64 patients or 66%, $P < 0.01$). In no instance did the vectorcardiogram fail to detect right ventricular hypertrophy when it was suggested by the electrocardiogram. An example is given in figure 3 to illustrate the increased sensitivity of the vectorcardiographic display.

The sensitivity of the vectorcardiographic criteria in relation to the right ventricular or pulmonary arterial systolic pressure in the three groups of patients is depicted in table 2. In patients with atrial septal defect, right ventricular hypertrophy was recognized in all but one patient regardless of

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**Figure 2**

Proposed quantitative vectorcardiographic criteria for the diagnosis of right ventricular hypertrophy based on the QRS loop area. (See figure 1 for explanation of abbreviations.)

2) The QRS loop area in the right posterior quadrant (transverse plane) is greater than 20% of the total

3) The QRS loop area in the right inferior quadrant (frontal plane) is greater than 20% of the total.

The effectiveness of these criteria in the recognition of right ventricular hypertrophy or pulmonary hypertension in the 97 patients is summarized in table 1. In the 41 patients with atrial septal defect

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*For the sake of simplicity the values 70 and 30% in criterion 1 are used instead of 72 and 28% respectively. In criterion 3, 20% is used instead of 22%.

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**Table 1**

| Number of Patients Who Met One or More of the Vectorcardiographic and Electrocardiographic Criteria for the Diagnosis of Right Ventricular Hypertrophy |
|---|---|---|---|---|
| | Total no. of patients | VCG Criteria | Electrocardiographic Criteria | |
| | | Criterion 1 | Criterion 2 | Criterion 3 |
| | | One or more (% of total) | One or more (% of total) |
| ASD | 41 | 30 | 14 | 27 | 40 (96) | 32 (78) |
| Mitral stenosis | 41 | 22 | 13 | 17 | 29 (71) | 24 (59) |
| COPD | 15 | 2 | 9 | 10 | 11 (71) | 8 (53) |
| Total | 97 | | | | 80 (83) | 64 (66) |

Abbreviations: ASD = atrial septal defect; COPD = chronic obstructive pulmonary disease.
The tracings were obtained from a 31-year-old woman with proven atrial septal defect. The transverse plane QRS loop area in the anterior and right-sided quadrants is greater than 70% of the total (or the area of the left posterior quadrant is less than 30% of the total). The electrocardiogram is not diagnostic of right ventricular hypertrophy.

The presence or absence, or the degree, of pressure overload. In patients with mitral stenosis, recordings from a significantly higher percentage of patients with severe hypertension met one or more of the criteria than those with mild or moderate hypertension \( (P < 0.025) \). In patients with chronic obstructive lung disease recordings from six of ten patients with a pressure of 31-50 mm Hg and all of
five with a pressure of greater than 50 mm Hg met one or more of the criteria.

**Discussion**

It is generally agreed that the accuracy of the electrocardiogram in the recognition of mild or moderate degree of right ventricular hypertrophy is poor. This is particularly true when one is dealing with acquired heart disease. This finding is not surprising as the electrical potential from the left ventricle is normally much greater than that from the right ventricle. A mild, or even moderate degree of right ventricular hypertrophy may not necessarily result in noticeable changes in the QRS forces. Because of the better method of display, the vectorcardiogram has been found more sensitive than the electrocardiogram in the detection of minor abnormalities. Both qualitative and quantitative criteria have been proposed for the vectorcardiographic diagnosis of right ventricular hypertrophy. The limitation of the qualitative criteria is obvious. The quantitative criteria suggested includes the use of the following:

1) The maximum rightward voltage
2) The ratio of the rightward forces to the left posterior forces
3) The direction of the half-area QRS vector
4) The direction of the maximum QRS vector
5) The direction of the tangent to the terminal forces
6) The maximum rightward spatial vector
7) The sum of certain selected rightward spatial vectors
8) The direction and magnitude of various instantaneous vectors
9) The percentage of loop area in the right posterior quadrant in the transverse plane

Although each of the above criteria has been found useful in the diagnosis of right ventricular hypertrophy, various combinations of three or more of the criteria have been employed to improve the accuracy of recognition. Many measurements may be needed, and the procedure often proves to be too time consuming and too complicated for routine clinical application.

In our proposed criteria the relative size of the QRS loop area in the different quadrants alone is utilized. Although the criteria have been simplified, the sensitivity of the method is not reduced. This is due to the fact that selected loop area represents the sum of all the instantaneous vectors in that direction. By expressing the loop area as the percentage of the total the relationship between the various forces is obtained. Similarly, the ratio will also indicate indirectly the direction of the maximum or half-area QRS vector. Alterations of either the initial, mid, or late QRS forces are equally effective in modifying the distribution of the loop area. Finally, by using two planar projections, the spatial characteristics of the vectors are also taken into consideration. Therefore it is apparent that practically all of the information sought by the previously described criteria may be obtained from the loop area alone.

In the great majority of instances the estimation of the percentage of the loop area for clinical use can be made by simple inspection alone. Planimetry is not necessary. In doubtful cases a transparent plastic sheet marked with grid may be superimposed on the vectorcardiogram. The relative size of the area in each location may be determined by counting the number of squares it contains which is in turn compared with the number for the entire QRS loop.

It should be emphasized that the specificity of the proposed criteria has not been tested. It is well

### Table 2

<table>
<thead>
<tr>
<th>RV or PA Systolic pressure</th>
<th>No. of patients</th>
<th>No. met VCG Criteria (% of total)</th>
<th>No. of patients</th>
<th>No. met VCG Criteria (% of total)</th>
<th>No. of patients</th>
<th>No. met VCG Criteria (% of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤30 mm Hg</td>
<td>22</td>
<td>21 (95)</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31-50 mm Hg</td>
<td>11</td>
<td>11 (100)</td>
<td>17</td>
<td>9 (53)</td>
<td>10</td>
<td>6 (60)</td>
</tr>
<tr>
<td>&gt;50 mm Hg</td>
<td>8</td>
<td>8 (100)</td>
<td>23</td>
<td>20 (87)</td>
<td>5</td>
<td>5 (100)</td>
</tr>
<tr>
<td>Total</td>
<td>41</td>
<td>40</td>
<td>41</td>
<td>29</td>
<td>15</td>
<td>11</td>
</tr>
</tbody>
</table>

Abbreviations: ASD = atrial septal defect; COPD = chronic obstructive pulmonary disease.
known that true posterior myocardial infarction and left posterior hemiblock may mimic right ventricular hypertrophy both electrocardiographically and vectorcardiographically. The separation often can only be made on clinical grounds.

Although patients with a QRS duration greater than 0.11 sec have been excluded, the presence of incomplete right bundle branch block in these patients cannot be ruled out. This is particularly true in patients with atrial septal defect. Marked slowing of the inscription of the terminal portion of the QRS loop was however not observed in any of our cases.

All of the patients with chronic obstructive lung disease included in this report had elevated right ventricular pressure. The incidence of false positive diagnosis in patients with normal right ventricular pressure is therefore unknown. Three such patients have thus far been studied and none of their vectorcardiograms met the suggested criteria. The number of patients is too small to evaluate the specificity of the criteria. They are therefore not included in this series.

In conclusion the currently available quantitative vectorcardiographic criteria for the diagnosis of right ventricular hypertrophy may be effectively replaced by three simple signs. They are sensitive and are easily applicable for routine clinical use.

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