Vectorcardiographic Studies in Acquired Valvular Disease with Reference to the Diagnosis of Right Ventricular Hypertrophy

By J. Cueto, M.D., H. Toshima, M.D., G. Armijo, M.D., N. Tuna, M.D., and C. Walton Lillehei, M.D.

The routine 12 lead electrocardiogram is not always reliable in demonstrating right ventricular hypertrophy (RVH), this is particularly true in patients with acquired valvular disease, or with mild or moderate RVH.1,2 Such discrepancies are understandable when one considers that the most commonly used criteria for RVH are based on voltages,3-5 and that only in cases of severe or massive RVH can the electromotive forces generated in the right ventricle (RV) counterbalance those produced in the left ventricle (LV).1,2

Our experience as well as that of several others6-9 has demonstrated the usefulness and merits of the orthogonal vectorcardiogram. Furthermore, Toshima et al.10 using the Schmitt-Simonson system (SVEC III) in patients with mitral and aortic valvular disease and left ventricular hypertrophy (LVH) not only were able to evaluate the hypertrophy more accurately but also in most cases were able to make a correct diagnosis of the specific valvular lesion causing it.

Mitral stenosis is known to produce pulmonary venous obstruction, left atrial enlargement, pulmonary hypertension, and ultimately RVH. The purpose of this paper is to report the vectorcardiographic findings, with use of the Schmitt-Simonson system (SVEC III) in 37 patients with proven "pure" mitral stenosis.

Methods

From the patients studied at the University of Minnesota Medical Center, 37 individuals were selected for this study. The criteria for selection of these patients were as follows: (1) clinical evidence of "pure" mitral stenosis, (2) right and left heart catheterization data, (3) cardioangiography, (4) operative evaluation, and (5) pathologic confirmation in those cases in which the patient died. All the patients in this series were operated on by the authors, and pathologic specimens were studied by Dr. J. E. Edwards.

There were 27 females with a mean age of 40 years, and 10 males with a mean age of 42.4 years, (table 1). All the patients were symptomatic and most of them were in or had been recently in congestive heart failure. Because these patients were receiving digitalis, it was not possible to study changes in the ST segments or the T waves with accuracy.

Scalar electrocardiograms and vectorcardiograms were taken within 1 week before or after catheterization, but always before operation. Vectorcardiograms were taken with the lead system described by Simonson and associates8 with the aid of a Sanborn oscilloscope, and permanent pictures of the loops were taken with a Polaroid camera. The three scalar leads X, Y, and Z were taken simultaneously at a speed of 50 mm./second and careful attention was paid to the point where the earliest activity could be detected. Cases with a QRS duration longer than 0.12 second

Table 1

Patients with "Pure" Mitral Stenosis Utilized for Study of Right Ventricular Hypertrophy

<table>
<thead>
<tr>
<th>Sex</th>
<th>No.</th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females</td>
<td>27</td>
<td>40.0</td>
<td>22-62</td>
</tr>
<tr>
<td>Males</td>
<td>10</td>
<td>42.4</td>
<td>17-57</td>
</tr>
<tr>
<td>Total</td>
<td>37</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Table 2

<table>
<thead>
<tr>
<th></th>
<th>Horizontal</th>
<th>Sagittal</th>
<th>Frontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Counter-clockwise</td>
<td>Fig. of 8</td>
<td>Clockwise</td>
</tr>
<tr>
<td>Group I</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(less than 400 dynes/sec./cm.(^{-5}))*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group II</td>
<td>10</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>(400-600 dynes/sec./cm.(^{-5}))*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group III</td>
<td>0</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>(above 650 dynes/sec./cm.(^{-5}))*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Total pulmonary resistance.

were considered to have a conduction disturbance and were not included in this study.

The obtained data were recorded on punch cards and a Control Data 1604 Computer was used to calculate the following information:

1. Magnitude of each instantaneous vector:

\[ V = \sqrt{X^2 + Y^2 + Z^2} \]

2. Azimuth = \( H^\circ = + \tan^{-1} \frac{Z}{X} \) of each instantaneous vector

3. Elevation of each instantaneous vector:

\[ V^\circ = + \tan^{-1} \frac{Y}{\sqrt{X^2 + Z^2}} \]

Regarding azimuth the zero degree was left lateral, +90° was anterior, −90° was posterior and ±180° was right lateral. Regarding elevation the zero was considered to be located at the horizontal level, −90° the vertical inferior, and +90° the superior vertical. In each one of the instantaneous vectors the mean and standard deviation were calculated and, to evaluate the significance of any differences, the student's t test was performed and interpreted according to the criteria previously outlined.\(^{11, 12}\)

Cardioangiography was performed and interpreted according to the criteria previously outlined.\(^{11, 12}\)

In an attempt to correlate the vectorcardiographic and hemodynamic data, the patients were divided into three groups upon the basis of their total pulmonary resistances (TPR). Group I included eight patients with a TPR of less than 400 dynes/sec./cm.\(^{-5}\). Group II included 15 patients with a TPR between 400 and 650 dynes/sec./cm.\(^{-5}\). Fourteen patients with a TPR in excess of 650 dynes/sec./cm.\(^{-5}\) were included in group III.

Results

Study of the loops. Table 2 shows the direction of inscription of the loops in the three planes for these three patients groups.

**Horizontal plane.** All patients in group I showed counterclockwise (CCW) loop. In group II, 10 patients showed a CCW loop, one a "figure 8," and four a clockwise (CW) loop. In group III, 10 of 14 patients showed a CW loop and four the "figure 8" type of loop.

**Sagittal plane.** In the sagittal plane, the normal pattern, namely, a CCW loop was observed in groups I and II, except for one case with a "figure 8" loop in each group. In group III five patients of 14 had a "figure 8" loop.

**Frontal plane.** In the frontal plane there were four cases of CW type of loop, three with CCW type of loop, and one with a "figure 8" type of loop in group I. Group II showed 10 instances of CW loop, one of "figure 8," and four of CCW loops. All cases included in group III showed CW loops.

We found two cases of the so-called "emphysematous loop," which is characterized by a marked posterior displacement of the loop, accompanied by deep S waves in the right precordial leads, which makes the electrocardiographic diagnosis of RVH particularly difficult.

**Frontal QRS axis.** Table 3 shows the mean axis of the QRS complex in the frontal plane. Group I showed slight right axis deviation; group II, moderate right axis deviation, the differences being statistically significant when
Table 3
Frontal Axis in Relationship to Total Pulmonary Resistance in Patients with Pure Mitral Stenosis*  

<table>
<thead>
<tr>
<th>Group</th>
<th>Degrees (Mean)</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>66.5</td>
<td>15.5</td>
</tr>
<tr>
<td>Group II</td>
<td>77.4</td>
<td>17.8</td>
</tr>
<tr>
<td>Group III</td>
<td>113.8</td>
<td>11.9</td>
</tr>
</tbody>
</table>

*p < 0.01 (N)  
*p < 0.001 (N, I, II)

*For normal data see reference 13.

compared with the normal\(^\text{13}\) \((p < 0.01)\). Group III showed the greatest degree of right axis deviation. This difference was significant when compared with the normal \((p < 0.001)\), with group I \((p < 0.001)\), and even with group II \((p < 0.001)\).

**Study of the scalar leads.** Table 4 shows the mean values of Q, R, and S waves in the three scalar leads, X, Y, and Z. These values were compared with normal data.\(^\text{14}\)

**Lead X.** A Q wave was recorded in eight instances only. Of these eight cases, one patient was in group I, three in group II, and the other patient in group III had what was called "a trace" of aortic or mitral insufficiency, or both, which had not been detected hemodynamically. The S wave in group III showed a marked increase in voltage, which was statistically significant when compared with the normal, group I and group II \((p < 0.001)\).

**Lead Y.** The QRS wave showed decreased voltage in all three groups. In lead Y any initial positivity was read as Q wave and the greatest negative deflexion as R wave.

**Lead Z.** In all three groups there was a tendency for tall R waves and small S waves, these changes being more pronounced in group III.

**Study of the instantaneous vectors.** Eight vectors were measured in each case; their strength, azimuth and elevation were determined. The results in each group were compared with normal data\(^\text{15}\) and with the other two groups (table 5 and figs. 1-3).

**0.01-Second vector.** The strength was increased in all three groups. The azimuth was significantly abnormal in groups II and III...
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Magnitude of instantaneous vectors in the three groups studied.

(p < 0.01) as compared with normal, with the vectors being directed to the left, while the normal and those in group I were directed anteriorly or to the right. Elevations were normal.

0.02-Second vector. The strength was increased in all three groups. In each group the differences were statistically significant when compared with normal (p < 0.001). The vectors in group III continued to point abnormally to the left and downwards.

0.03-Second vector. The magnitude was increased in groups II and III. The azimuth in group III was markedly abnormal, having a mean value -156°, compared to the mean of -58° (group II), -62° (group I), and -93° (normal data). This difference was highly significant when compared with groups I, II, and normal controls. Elevations continued to show the same abnormal changes in all three groups.

0.02-Second vector. Strengths were found to be augmented in all three groups. The also showed abnormal azimuth with the vectors pointing more posteriorly than with the normal. Vectors in group III continued to be more anteriorly oriented. Elevations were again abnormal and showed the same alterations present in the .03-second vector.

Maximal spatial vector. The greatest magnitude occurred in group III, whereas the least was found in group I (fig. 1).

-0.03-Second vector. The magnitude was increased in groups II and III. The azimuth in group III was markedly abnormal, having a mean value -156°, compared to the mean of -58° (group II), -62° (group I), and -93° (normal data). This difference was highly significant when compared with groups I, II, and normal controls. Elevations continued to show the same abnormal changes in all three groups.

-0.02-Second vector. Strengths were found to be augmented in all three groups. The

Azimuth of instantaneous vectors in the three different groups.
Table 5

Magnitude, Azimuth and Elevations of Instantaneous Vectors in Patients with Mitral Stenosis in Relation to Their Total Pulmonary Resistance

<table>
<thead>
<tr>
<th>Group</th>
<th>0.01 Sec.</th>
<th>0.02 Sec.</th>
<th>0.03 Sec.</th>
<th>0.04 Sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.156</td>
<td>95.7</td>
<td>-0.8</td>
<td>0.107</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>(N)</td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>II</td>
<td>0.151</td>
<td>71.8</td>
<td>-1.9</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.01</td>
<td>(N)</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>0.146</td>
<td>66.6</td>
<td>10.4</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Normal</td>
<td>0.114</td>
<td>115.0</td>
<td>4.1</td>
<td>0.292</td>
</tr>
<tr>
<td></td>
<td>(N)</td>
<td>(N)</td>
<td>(N)</td>
<td>(N)</td>
</tr>
</tbody>
</table>

*Maximal spatial vector.

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Figure 3

Elevations of instantaneous vectors in the three groups studied.

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Vectors in group III showed a marked rightward orientation as compared with the normal (p < 0.001), group I (p < 0.001), and group II (p < 0.01). Elevations were abnormal in group I as compared with group III, showing vectors pointing abnormally downwards in the former groups.

-0.01-Second vector. Magnitudes were again increased in all three groups when compared with the normal controls. The azimuth showed no significant alterations among the three groups. Groups I and III showed significant difference when compared with the normal, namely, that vectors in these groups had a marked rightward orientation, (p < 0.05; p < 0.001). Elevations were within normal limits.

Study of the electrocardiograms. The electrocardiograms were analyzed by the criteria described by Milnor. Table 6 summarizes the findings in each group. Positive criteria for RVH were found in only one case in group I, in seven cases in group II, and in all the cases in group III.

Discussion

Scott and others have stated that the accuracy of the electrocardiogram in determining RVH is poor, especially when one is dealing with acquired valvular disease or when the
Table 6
Results of the Study of the 12-Lead Electrocardiogram in 37 Patients with RVH in Relation to Total Pulmonary Resistances by Using Milnor's Criteria

<table>
<thead>
<tr>
<th>Group</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>1 (12.5)</td>
<td>7 (87.5)</td>
</tr>
<tr>
<td>II</td>
<td>7 (46.6)</td>
<td>8 (53.4)</td>
</tr>
<tr>
<td>III</td>
<td>14 (100)</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>59.5%</td>
<td>40.5%</td>
</tr>
</tbody>
</table>

RVH is only of mild or moderate degree.\textsuperscript{1, 2} This may be explained by the fact that in the normal adult the left ventricle is three times thicker than the right, thus contributing the major part of the detectable electrical activity, and rarely does the right ventricle reach a thickness equal to or greater than that of the left ventricle.\textsuperscript{16}

The QRS interval is usually within normal limits, since the pathway of activation of the heart is not very prolonged in cases of mild or moderate RVH, unless there is an associated conduction disturbance.\textsuperscript{16}

Grant\textsuperscript{17} stated that right axis deviation of marked degree produced by RVH occurs more frequently in young patients as compared to older patients, who show a definite tendency toward horizontalization of the heart.

All the patients included in this study had "pure" mitral stenosis, were symptomatic, and had radiologic and anatomic evidence of RVH. Most of them were or had been in congestive heart failure. However, the electrocardiogram showed RVH according to Milnor's criteria in only 59 per cent of the cases (all the cases in group III, half of the cases in group II, and only one in group I). This is in agreement with the results collected by Scott.\textsuperscript{1} It should be pointed out, however, that all the vectorcardiograms were abnormal if the instantaneous vectors were taken as the most important criteria.

In the normal heart the initial forces originate in the left side of the middle third of the septum, producing a vector oriented toward the right, forward, and slightly upward.\textsuperscript{18} In our study we found that the vectors in groups II and III had abnormal magnitude and were directed toward the left as compared with the normal and group I. This might be explained on the basis of hypertrophy of the right side of the septum, which produces a vector of greater magnitude and different direction.\textsuperscript{19} The concomitant clockwise rotation of the heart tends to bring the septum to a more sagittal position, thus also modifying the direc-
V.K., female, 52 years. Mitral valvular area, 1.5 cm², right ventricular pressure 30/0, total pulmonary resistance 540 dynes/sec./cm⁻⁵. ECG: atrial fibrillation, normal frontal axis, digitalis effect. VCG: notice anterior displacement of the loop in the horizontal and sagittal planes. Study of instantaneous vectors revealed RVH.

As described by Penaloza, in RVH the 0.02-second vector is directed forwards, to the left, and downwards. This observation could also be explained on the basis of hypertrophy of the lower septal mass originating forces that predominate over the ones generated in the left ventricle. In the 0.03-second vector the findings recorded in group III are readily explained when one considers that the right ventricle, which is hypertrophied, is laying anterior and also to the right and inferior in relation to the left ventricle. The 0.04-second vector showed decreased voltage in group I, for which we have no reasonable explanation other than at this time depolarization of the free wall of the left ventricle produced vectors of greater magnitude and opposite direction, leading to cancellation of the right ventricular forces.

As expected, the maximal spatial vector occurred in group III, which showed also to have the greatest degree of RVH. The terminal forces represented by the −0.03, −0.02, and −0.01 vectors were abnormally oriented to the right, a finding that is in agreement with the work of others. This has been called the basal vector. The postero-basal areas of both ventricles are the last ones to be activated, and in RVH they are the origin of these abnormal forces.

Representative tracings of each of the studied groups can be seen in figures 4 to 7. It is again emphasized that the careful analysis of the instantaneous vector is the most important single criterion for the diagnosis of RVH.
I.P., female, 46 years. Mitral valvular area, 1.0 cm², right ventricular pressure 56/0-2, total pulmonary resistance 680 dynes/sec./cm.⁻⁵. ECG: atrial fibrillation, mild right axis deviations, digitalis effect. VCG: notice the marked anterior displacement of the loop in the horizontal and sagittal planes with terminal forces oriented to the right. Horizontal loop shows a “figure 8” type of loop, whereas the frontal plane shows CW rotation, supporting the diagnosis of RVH.

Although a number of studies have been made in mitral stenosis, the investigators have used the 12-lead electrocardiogram²²-²⁵ or the cube system,²⁶-²⁹ and until recently there have been very few using the orthogonal lead systems. Taymor et al.³⁰ reported the results of their vectorcardiographic studies in mitral stenosis using the Frank system. Their findings were similar to the data obtained in group I of our series. They found that the 0.04-second vector is oriented more posterior than normal and also that the strength of this vector was reduced. However, in group I, considered to have mild or moderate mitral stenosis and early RVH, we found significant alterations in the magnitude, strength, and elevation of the initial, middle, and terminal forces, which Taymor et al. did not detect, since they did not analyze the terminal forces nor the elevation of the instantaneous vectors. These changes have proved to be very important in the diagnosis of RVH in each of our three groups. On the other hand, they thought that the increased voltage in the posterior area of the loop (exception made when this voltage was over 1.5 mV.) and the posterior orientation of the 0.03-second and 0.04-second vectors could be used as criteria for RVH. Both of these factors may also be present in LVH and in biventricular hypertrophy, whereas abnormal inferior orientation of the vectors is more specific for hypertrophy of the right ventricle.¹⁰

The “emphysematous loops,” although rarely found, must be kept in mind, since in such cases the diagnosis of RVH is obscured by the presence of deep S waves in the right precordial leads. These are similar to those present in chronic cor pulmonale.³¹ Recently Graf et al.,³² while discussing this type of loop, concluded that pulmonary changes such as those present in mitral stenosis could lead to the development of this special type of loop. We have one other case with this pattern.
that was not included in this study because of concomitant mitral regurgitation but in a recent review in over 150 cases of aortic valvular disease we did not find a single example of this type of loop, thus suggesting that this type of loop may be specific for mitral valve disease when chronic cor pulmonale can be ruled out.

Summary

The orthogonal vectorcardiogram described by Schmitt and Simonson has been studied in 37 patients with "pure" mitral stenosis.

The diagnosis of right ventricular hypertrophy (RVH) could be established from changes in the magnitude, azimuth, and elevations of the initial, middle, and terminal forces, which could not be detected by the routine 12-lead electrocardiogram. This type of recording has proved to be of great value in the diagnosis of right ventricular hypertrophy, particularly when the hypertrophy is of mild or moderate degree. Analysis of the instantaneous vectors has proved to be the single most important criterion in the electrocardiographic diagnosis of right ventricular hypertrophy.

References


Figure 6

M.P., female, 36 years. Mitral valvular area, 0.62 cm.², right ventricular pressure 75/2, total pulmonary resistance 860 dynes/sec./cm.-5. ECG: atrial fibrillation, RVH, digitalis effect. VCG: notice marked anterior displacement of the loop in horizontal and sagittal planes. The horizontal and frontal planes show CW rotation, whereas a "figure 8" type of loop is seen in the sagittal plane, consistent with marked RVH.
Figure 7

L.W., male, 51 years. Mitral valvular area 0.92 cm.$^2$, right ventricular pressure 45/0, total pulmonary resistance 680 dynes/sec./cm.$^{-2}$. ECG: atrial fibrillation, right axis deviations, deep S waves over precordium. VCG: notice the posterior displacement of the loop in horizontal and sagittal planes with right axis deviations in the frontal plane which also show CW rotations.

The study of instantaneous vectors showed RVH.


14. NAKAGAWA, H., ET AL.: Quoted by Simonson, E., p. 279.$^{13}$

15. MORI, ET AL.: Quoted by Simonson, E., p. 270.$^{13}$


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