The Frank Vectorcardiogram in Mitral Stenosis
A Study of 29 Cases

By Robert C. Taymor, M.D., Irwin Hoffman, M.D., and Edward Henry, M.D.

The cardiovascular effects of mitral stenosis are not static but vary considerably with the severity and duration of the lesion. The electrocardiogram and vectorcardiogram show a corresponding broad spectrum of findings. The QRS complexes of the electrocardiogram may be normal or show varying degrees of right ventricular hypertrophy. The pattern of left ventricular hypertrophy occurs rarely and generally only when other valvular lesions are present. A direct relation between the severity of the stenosis and of secondary pulmonary hypertension and electrocardiographic picture of right ventricular hypertrophy has been reported.

The vectorcardiogram has been shown to be a sensitive indicator of right ventricular hypertrophy, and several studies with the "cube" system of the vectorcardiogram in mitral stenosis have been published. Scherlis et al., Whipple et al., and Massie and Walsh found that right ventricular hypertrophy was the most common vectorcardiographic pattern associated with "pure" mitral stenosis. Less frequently, normal loops or a posteriorly, superiorly oriented appendage has been found. Donoso et al. found a higher incidence of normal vectorcardiograms in patients who underwent surgery for "pure" mitral stenosis. Nineteen of his 43 patients showed normal QRS loops; the remaining 24 had QRS loops of right ventricular hypertrophy.

Massie and Walsh noted the infrequent occurrence of posteriorly oriented, but otherwise normal appearing, loops in patients with mitral stenosis. More recently, Graf et al. reported seven cases of mitral stenosis with posterior QRS loops. Since this pattern resembles that seen in chronic pulmonary disease, the occurrence of this type of loop has been attributed, in part, to rotational or pulmonary factors. In our studies of the vectorcardiogram in mitral stenosis, a similar pattern was found frequently when the Frank electrode system was used. These loops varied from near normal to extreme posterior orientation and exhibited none of the generally accepted criteria for right ventricular hypertrophy. It is the purpose of this report to present our vectorcardiographic findings in 29 patients with mitral stenosis and to compare the data with those found in normal subjects. Particular attention is paid to the study of these posteriorly oriented loops and to the possible mechanisms involved in their production.

Materials and Methods

The vectorcardiographic data in 29 patients were studied. There were 22 women and seven men, and the ages ranged from 19 to 61 years. All these patients were considered to have "pure" mitral stenosis and to be in class 3 or 4. The patients were studied in the hospital just prior to mitral commissurotomy. No evidence of any other valvular lesion was present, either in the preoperative studies or at surgery. All of the patients were normotensive. Patients who had undergone prior cardiac surgery were excluded from this study.

The vectorcardiograms were recorded on a Sanborn vectorcardiographic amplifier and oscilloscope. The Frank lead system was employed. The oscilloscopic trace was interrupted every 2.5 milliseconds and modulated to indicate the direction of the sweep. A 1-millivolt tracing was placed on the Y axis to allow for voltage measurements. Permanent records of the tracings were made with a Polaroid camera.

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865
The following data were obtained in the various planes.

**Horizontal Plane**

The direction of the 20, 30, 40 millisecond, and maximum QRS vectors was obtained by direct (with use of a transparent protractor) measurement as were the duration of anterior forces (milliseconds anterior or MSA), maximum voltage anterior (MVA) and maximum voltage posterior (MVP). The half-area vector direction was determined by inspection of the loop. The voltage of the maximum vector (MV) was calculated by the equation

\[ MV = \frac{MVP}{\cos \alpha} \]

in which \( MV \) = voltage of maximum vector in millivolts, \( MVP \) = maximum posterior voltage in millivolts, \( \cos \alpha \) = cosine of angle between maximum vector and posterior Y axis.

**Right Sagittal and Frontal Planes**

The directions of the 20, 30, 40 millisecond and maximum vectors of the QRS loops were obtained in both planes.

Right ventricular hypertrophy was diagnosed as being evident in the vectorcardiogram when horizontal plane rotation was reversed or when anterior voltage equaled or exceeded posterior voltage. The remainder of the cases were compared statistically with the normal data obtained in other studies.9-11 Student's t-test was employed to determine the significance of the results; t values of less than 1.96 indicated no significant difference. Values of 1.96 to 2.58 indicated a significant difference with a 5-per cent level of confidence and above 2.58 a confidence level of 1 per cent.

**Results**

Of the 29 patients studied, only five showed obvious evidence of right ventricular hypertrophy in the vectorcardiogram; that is, anterior forces equal to or exceeding posterior forces, with or without reversal of rotation in

**Figure 1**

Examples of horizontal QRS loops found in this series of patients with mitral stenosis.
the horizontal plane. In the remaining 24 patients posterior forces exceeded anterior forces and horizontal plane rotation was normal in direction (counterclockwise). The data to be presented and the discussion that follows deal with an analysis of the vector loops in these latter 24 patients.

**Appearance of Vectorcardiographic Loops**

Inspection of the horizontal loops revealed an increased posterior orientation of the QRS forces. In this series of patients the degree of posterior variation extended over a considerable range. Figure 1 presents illustrative examples of the horizontal loops found in these patients with mitral stenosis. These loops varied from a normal appearance (1-A) to that demonstrating extreme posterior and rightward position (1-I). Only five of the 24 patients showed horizontal QRS loops that were considered normal on gross inspection. The remaining 19 loops demonstrated increased posterior orientation.

**QRS Voltage**

Table 1 summarizes the voltage data found in the 24 patients under analysis and compares the results with those found in studies of normal subjects by other investigators. The mean millivolt anterior (as measured in the horizontal plane) was 0.25 with a standard deviation of 0.11. These findings are close to the normal mean of 0.28 with a standard deviation of 0.14 and indicate that anterior voltage is normal in these cases. Measurements of posterior voltage directly along the “Y” axis of the horizontal plane showed a mean of 0.77 millivolt with a standard deviation of 0.21. This was of considerably greater magnitude than that found in normal subjects. In the normal series by Hoffman et al., this measurement was found to be 0.44 millivolt (S.D. = 0.21). On the other hand maximum voltage of the horizontal QRS vector was found to be diminished as compared to a normal series by Bristow et al. Our patients

**Table 1**

*Amplitude and Duration of Forces in Horizontal Plane Compared with Normal Series*

<table>
<thead>
<tr>
<th></th>
<th>Millivolt anterior</th>
<th>Millivolt posterior</th>
<th>Millivolt maximum</th>
<th>Millisecond anterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitral stenosis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.25</td>
<td>0.77</td>
<td>0.97</td>
<td>25.0</td>
</tr>
<tr>
<td>(S.D.)</td>
<td>(0.11)</td>
<td>(0.20)</td>
<td>(0.34)</td>
<td>(5.9)</td>
</tr>
<tr>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.28*</td>
<td>0.44*</td>
<td>1.58†</td>
<td>34.8*</td>
</tr>
<tr>
<td>(S.D.)</td>
<td>(0.14)</td>
<td>(0.21)</td>
<td>(0.37)</td>
<td>(5.5)</td>
</tr>
<tr>
<td>t test</td>
<td>1.0</td>
<td>6.6</td>
<td>6.8</td>
<td>7.0</td>
</tr>
</tbody>
</table>

* Hoffman et al.† Bristow et al.

**Table 2**

*Direction of 20, 30, 40 Millisecond and Maximum Instantaneous Vectors in Frontal Plane Compared with Normal Series*

<table>
<thead>
<tr>
<th></th>
<th>20 msec.</th>
<th>30 msec.</th>
<th>40 msec.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitral stenosis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>36.0</td>
<td>46.9</td>
<td>68.8</td>
<td>54.2</td>
</tr>
<tr>
<td>(S.D.)</td>
<td>(22.1)</td>
<td>(22.2)</td>
<td>(47.6)</td>
<td>(29.0)</td>
</tr>
<tr>
<td>Normal *</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>33.0</td>
<td>39.0</td>
<td>68.0</td>
<td>40.0</td>
</tr>
<tr>
<td>(S.D.)</td>
<td>(22.4)</td>
<td>(10.6)</td>
<td>(61.8)</td>
<td>(10.6)</td>
</tr>
<tr>
<td>t test</td>
<td>0.5</td>
<td>1.6</td>
<td>0.1</td>
<td>2.3</td>
</tr>
</tbody>
</table>

* Forkner et al.
Table 3
Direction of 20, 30, 40 Millisecond and Maximum Instantaneous Vectors in Right Sagittal Plane Compared with Normal Series

<table>
<thead>
<tr>
<th>Time (msec)</th>
<th>Mitral stenosis</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>44.8 (43.6)</td>
<td>29.0 (25.0)</td>
</tr>
<tr>
<td>30</td>
<td>95.8 (34.0)</td>
<td>78.0 (29.5)</td>
</tr>
<tr>
<td>40</td>
<td>128.8 (31.7)</td>
<td>115.0 (24.8)</td>
</tr>
<tr>
<td>Max</td>
<td>129.8 (30.4)</td>
<td>115.0 (31.2)</td>
</tr>
</tbody>
</table>

*Forkner et al.,9 corrected from left to right sagittal plane.

Table 4
Direction of 20, 30, 40 Millisecond, Maximum, and Half-area Instantaneous Vectors in Horizontal Plane Compared with Normal Series

<table>
<thead>
<tr>
<th>Time (msec)</th>
<th>Mitral stenosis</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>34.8 (39.3)</td>
<td>50.0 (24.2)</td>
</tr>
<tr>
<td>30</td>
<td>337 (40.5)</td>
<td>8.0 (15.6)</td>
</tr>
<tr>
<td>40</td>
<td>300 (35.3)</td>
<td>343 (25.0)</td>
</tr>
<tr>
<td>Max</td>
<td>294 (32.6)</td>
<td>346 (30.5)</td>
</tr>
<tr>
<td>Half-area</td>
<td>304 (23.1)</td>
<td>331 (18.0)</td>
</tr>
</tbody>
</table>

*Forkner et al.9

with mitral stenosis showed the mean voltage of the maximum instantaneous horizontal vector to be 0.97 millivolt. The standard deviation was 0.34. The normal series showed a mean voltage for this vector to be 1.58 millivolts and a standard deviation to be 0.37.

QRS Time Anterior

In general, patients with right ventricular hypertrophy exhibit increased duration, as well as magnitude, of anterior forces. As can be seen in table 1, this group of patients with mitral stenosis had distinctly diminished duration of the time anterior. The mean anterior duration was 25.0 milliseconds with a standard deviation of 5.9, whereas the normal series showed a mean of 34.8 milliseconds and a standard deviation of 5.5.

Direction of Instantaneous Vectors

Table 2 summarizes the data for the direction of the 20, 30, 40 millisecond and maximum instantaneous vectors in the frontal plane. Except for the maximum vector, the findings are not significantly different from those in normal subjects. The maximum instantaneous frontal vector had a mean direction of 54.2 degrees. This is a slightly more vertical location than the normal mean of 40.0 degrees.

The direction of these instantaneous vectors in the sagittal plane can be seen in table 3. The results are of borderline significance when compared with a normal series. However, it is apparent that these patients with mitral stenosis have more posteriorly oriented vectors.

In the horizontal plane a marked variation from the normal could be noted. The data for the horizontal plane are presented in table 4 and figure 2. The angles for the 20, 30, and 40 millisecond instantaneous vectors are located more posteriorly than normal. In addition, this posterior variation appears to increase as the QRS loop progresses.
in time. When the location of the 20, 30, and 40 millisecond vectors are compared with a normal series the values obtained for the Student's t test are 2.7, 4.3, and 5.4, respectively. The maximum and half-area instantaneous vectors were found to be even more posteriorly located as compared to the normal series. The mean maximum vector had a location of 294 degrees (S.D. = 32.6), the normal mean being 346 degrees (S.D. = 30.5). The direction of the half-area vector in the patients with mitral stenosis had a mean of 304 degrees (S.D. = 23.1); the normal mean half-area vector was located at 331 degrees (S.D. = 18.0). The t test for these two measurements showed the highly significant values of 8.1 and 9.0 respectively.

Discussion

In the published series of patients with mitral stenosis, the ratio of vectorcardiograms that are normal to those demonstrating right ventricular hypertrophy varies considerably. When preoperative patients are selected, the current indications for mitral commissurotomy will influence this ratio. The earlier in the course of the disease that patients are selected for surgery, the less will be the incidence of overt right ventricular hypertrophy in the vectorcardiogram. This would probably account for relatively low occurrence (five of 29 patients) of this finding in the vectorcardiograms of our patients. On the other hand, the vector loops of 19 of the remaining 24 patients could not be considered normal. The principal abnormality in these loops was an accentuated posterior, and sometimes rightward, position of the QRS loop. This shift was most marked in the midportion of the loop (40 millisecond, maximum, and half-area instantaneous vectors).

Similar loops have been described as occurring occasionally in patients with mitral stenosis, and more frequently in patients with chronic pulmonary disease. Rotation of the heart into a more posterior and vertical position associated with selective hypertrophy of the right ventricular outflow tract has been offered as an explanation for this change in QRS orientation. Such a change in the intrathoracic anatomic relation may occur with the overdistention of the lung and low diaphragmatic position of chronic pulmonary disease. However, in mitral stenosis, left atrial enlargement is the principal early gross anatomic change. This chamber is generally the most posterior structure of the heart, and it is difficult to visualize rotation resulting from its dilatation or hypertrophy. Patients with massively enlarged left atria do not show proportionately increased posterior orientation of the QRS complex. This latter situation, is generally associated with equally extensive ventricular hypertrophy, which might overshadow any positional effects on the QRS vector.

In this series of patients with mitral ste-
nosis variations other than in orientation of the instantaneous vectors were noted in the horizontal QRS loops. Maximum voltage was diminished as compared with a normal series, while posterior voltage along the Y axis of the reference plane was increased. Simple rotation of the QRS loop posteriorly would increase posterior voltage. In an orthogonal lead system, however, maximum voltage should be unaffected. In the normal vectorcardiogram, leftward voltage is the chief component of the maximum horizontal vector. Diminution of leftward, or an increase in rightward, forces will result in a decrease in the maximum voltage of QRS loop in this plane.

If cardiac rotation can be excluded as a significant factor in mitral stenosis, the findings in this series of patients with mitral stenosis strongly suggest that early right ventricular hypertrophy may produce accentuated right and posterior forces. If the normally predominant leftward forces are only partially counterbalanced, the resultant horizontal loop may appear to have normal configuration with increased posterior orientation. This can be distinguished from the posterior position frequently associated with left ventricular hypertrophy by the voltage of the maximum instantaneous vector in the horizontal plane. As rightward forces increase, the midportion of the loop migrates further to the right to assume a right and posterior position that has been more commonly associated with right ventricular hypertrophy. In severe right ventricular hypertrophy, right forces completely predominate, and the horizontal loop assumes that classic anterior and right position with clockwise rotation.

An attempt was made to establish criteria by which QRS loops of the type described might be accurately identified. No single criterion will adequately separate the normal from the mitral stenosis cases. For example, the posterior orientation of horizontal plane 30 and 40 millisecond, maximum, and half-area instantaneous vectors occurs also in left ventricular hypertrophy. However, multiple criteria, useful in the diagnosis of dorsal myocardial infarction, may be used to good advantage in mitral stenosis cases as well. The multiple criteria shown in Table 5 reflect decreased duration of anterior forces, posterior position of the later vectors, and increased posterior voltage. Anterior voltage is normal and maximum QRS voltage diminished.

**Summary**

The vectorcardiographic findings in 29 patients with mitral stenosis are presented.

Five patients had normal QRS loops, and five had classical loops of right ventricular hypertrophy with predominant anterior forces. The remaining 19 patients had posteriorly oriented loops with normal rotation. The characteristics of these latter loops were an-

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Criteria for Recognition of Posterior QRS Loop in Mitral Stenosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description of vectorcardiogram findings</td>
<td>Proposed criteria</td>
</tr>
<tr>
<td>Decreased duration of anterior forces</td>
<td>30 msec. vector in horizontal plane at or posterior to X axis</td>
</tr>
<tr>
<td>Posterior orientation of 40 msec., maximum, and half-area vectors</td>
<td>All vectors should be located at 315° or less in the horizontal projection</td>
</tr>
<tr>
<td>Increased posterior QRS voltage</td>
<td>Posterior voltage 0.8 mV, but not exceeding 1.5 mV</td>
</tr>
<tr>
<td>Normal or diminished magnitude of anterior and maximum QRS voltage</td>
<td>Anterior voltage less than 0.5 mV. and maximum QRS voltage less than 1.75 mV</td>
</tr>
</tbody>
</table>
alyzed in detail and compared with the findings in series of normal subjects.

The midportions of the horizontal plane QRS loops were found to be significantly more posterior in orientation. Posterior voltage was increased while maximum QRS voltage was decreased.

It was thought that the findings represent early right ventricular hypertrophy, and quantitative criteria to differentiate these loops from normal are suggested.

References

Pathologic Physiology of Angina Pectoris

The explanation of the causation of angina pectoris by coronary disease was, as pointed out by Osler, given by Allan Burns (1781-1813), the Glasgow anatomist and surgeon, who in 1809 ascribed the symptoms to anaemia, or as it might now be expressed anoxaemia, of the heart muscle resulting from coronary obstruction. This conception is now known as intermittent claudication—a term introduced by Bouley in 1831 in regard to horses and applied to man by Charcot in 1858—and perhaps more intelligibly as intermittent limp.—Sir Humphry Davy Rolleston. The Harveian Oration. Great Britain, Cambridge University Press, 1928, p. 88.
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