The Deep S Wave in Leads V₁, V₂, and V₃ in Right Ventricular Hypertrophy

By Herbert Shubin, M.D., and David C. Levinson, M.D.

Six patients with mitral stenosis, 3 with pulmonic stenosis, and 1 with pulmonary hypertension are presented. All had isolated right ventricular hypertrophy and all had deep S waves in V₁, V₉, or V₄. In 3 cases the voltage of R in V₁ was less than 0.5 millivolt. In 3 cases R/S ratios in V₁ of less than 1.0 were present. Vectorcardiograms showed characteristic features and illustrated the reasons for the electrocardiographic findings.

The presence of a deep S wave in leads V₁ or V₂ is often interpreted as evidence suggesting left ventricular hypertrophy. Since the maximal electric force in left ventricular hypertrophy usually moves to the left and posteriorly, the presence of a deep S wave in leads V₁ or V₂ often correlates well with this condition.

In the interpretation of hypertrophies of congenital or acquired heart disease, the presence of a deep S wave in V₁ or V₂ may, however, not be due to left ventricular hypertrophy, either isolated, or in combination with right ventricular hypertrophy.

Ten cases of isolated right ventricular hypertrophy in which deep S waves were present in either V₁, V₂, or V₃ have been reviewed. There were 6 patients with pure mitral stenosis, 3 with isolated pulmonic stenosis, and 1 with "primary" pulmonary hypertension. The mitral stenosis cases were diagnosed by cardiac catheterization (table 1), and were confirmed at surgery in 4 instances. Subsequently one of these was also confirmed at autopsy and had right ventricular hypertrophy, but no left ventricular hypertrophy. Of the 3 cases with isolated pulmonic stenosis 2 were diagnosed at cardiac catheterization (table 1), and confirmed later at surgery. The third case of pulmonic stenosis was a relatively mild one and was diagnosed by cardiac catheterization alone (table 1). The single case of "primary" pulmonary hypertension was diagnosed at cardiac catheterization.

Electrocardiograms

The electrocardiograms on these patients are shown in figure 1. Noteworthy here are the deep S waves in V₁, V₂, or V₃. Of the 6 cases with mitral stenosis the R/S ratio in V₁, V₃R, and V₄R was greater than 1.0 in all instances. Of the 3 cases with pulmonic stenosis the R/S ratio in V₁ was less than 1.0 in 2 instances, but reached 1.0 in either V₃R or V₄R. Similarly in the case with "primary" pulmonary hypertension the R/S ratio, although less than 1.0 in V₁, was 1.0 in V₄R.

In 7 of the 10 cases the R wave in V₁ was

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**Table 1.—Hemodynamic Findings at Cardiac Catheterization**

<table>
<thead>
<tr>
<th>Case</th>
<th>Age</th>
<th>Diagnosis</th>
<th>Right ventricle</th>
<th>Main pulmonary artery</th>
<th>Peripheral pulmonary artery</th>
<th>Cardiac index</th>
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<tbody>
<tr>
<td>1</td>
<td>33</td>
<td>Mitral stenosis</td>
<td>115/10</td>
<td>115/55</td>
<td>—</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>52</td>
<td>Mitral stenosis</td>
<td>110/10</td>
<td>110/50</td>
<td>—</td>
<td>1.7</td>
</tr>
<tr>
<td>3</td>
<td>44</td>
<td>Mitral stenosis</td>
<td>104/16</td>
<td>104/52</td>
<td>25/22</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>Mitral stenosis</td>
<td>84/10</td>
<td>80/44</td>
<td>25/20</td>
<td>1.9</td>
</tr>
<tr>
<td>5</td>
<td>54</td>
<td>Mitral stenosis</td>
<td>60/6</td>
<td>60/25</td>
<td>25/18</td>
<td>1.9</td>
</tr>
<tr>
<td>6</td>
<td>49</td>
<td>Mitral stenosis</td>
<td>47/2</td>
<td>47/32</td>
<td>26/23</td>
<td>2.2</td>
</tr>
<tr>
<td>7</td>
<td>45</td>
<td>&quot;Primary&quot; pulmonary hypertension</td>
<td>125/10</td>
<td>130/50</td>
<td>11/7</td>
<td>2.9</td>
</tr>
<tr>
<td>8</td>
<td>11</td>
<td>Pulmonic stenosis-infundibular</td>
<td>120/6</td>
<td>22/17</td>
<td>—</td>
<td>3.3</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>Pulmonic stenosis-valvular</td>
<td>78/12</td>
<td>17/10</td>
<td>—</td>
<td>3.7</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>Pulmonic stenosis-valvular</td>
<td>40/4</td>
<td>15/5</td>
<td>—</td>
<td>3.1</td>
</tr>
</tbody>
</table>
greater than 0.5 millivolt. In 2 patients the R in V₁ was 0.25 millivolt and in another 0.30 millivolt. R waves in aVᵣ of more than 1 millivolt were present in only 5 of the 10 cases. In 3 cases there were no R waves in aVᵣ.
In all 4 of the cases with mitral stenosis in whom a sinus rhythm was present, the P waves in V1, V3R, and V4R were diphasic, with a plus minus configuration. In 1 instance (case 4), the amplitude of the P waves in V1 was greater than the RS. In the 3 cases of pulmonic stenosis, by contrast, only upright P waves were recorded in these leads. In the case with pulmonary hypertension only a negative P wave was recorded in V1, V3R, or V4R.

In all but 2 instances the T waves in V1 were negative. Those with positive T in V1 were both in patients with pulmonic stenosis in whom the systolic pressure was less than 80 mm. Hg. Also noteworthy in these 2 cases was the age of the patients, one 10 years and the other 8 years, the youngest in the group. The 6 patients with mitral stenosis all had negative T waves in V1, but all were receiving digitalis.

The T waves in V6 were upright in 7 of the 10 cases. In the 2 cases where T in V6 was flattened or diphasic, both patients were receiving digitalis.

The electrocardiographic axis was +90° or greater in 9 of the 10 cases. In the 1 instance in which the electrocardiographic axis was normal, the right ventricular pressure was 40/4 mm. Hg.

**Vectorcardiograms**

The vectorcardiograms on these patients are shown in figure 2. These were recorded by the cube system.

In the horizontal plane clockwise rotation of the loop was present in all cases. In 2 cases there were figure-eight loops; however the inscription was predominantly in a clockwise direction. The loops were deviated anteriorly and to the right in all cases except 1 (case 9) in which both anterior and posterior deviation was present.

In the frontal plane there was clockwise rotation of the loop in all instances. In the 6 cases of mitral stenosis the mean frontal axis was greater than +110° in 3 cases. In the 3 cases of pulmonic stenosis the mean frontal axis was greater than +110° in 2.

![Fig. 2. Vectorcardiograms on cases 1-6 are on patients with mitral stenosis, case 7 is on a patient with pulmonary hypertension, and cases 8-10 are on patients with pulmonic stenosis. Arrow, direction of inscription of vectorcardiographic loops.](image-url)
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pertension the mean frontal axis was greater than +110°.

In the sagittal plane there was counterclockwise rotation in 6 cases and figure-eight loops in 4. Three of the mitral cases showed counterclockwise rotation of the loop, while 3 showed a figure-eight loop. In the pulmonary stenosis cases the loop rotated counterclockwise in 2 instances, and had a figure-eight configuration in the other. In the case with primary pulmonary hypertension the rotation was counterclockwise. The loop was deviated anteriorly in all cases except 1 (case 9) in which both anterior and posterior deviation were present.

The P wave is best shown in case 4, where it has been labeled (fig. 2). Here the loop lies posterior, predominantly to the left and inferior to the E point.

DISCUSSION

Electrocardiograms

The deep S wave in lead V1 may be found in left ventricular hypertrophy, in transmural septal myocardial infarction, and in chronic cor pulmonale.

The presence of a deep S in V1 is often found in left ventricular hypertrophy. To be diagnostic of left ventricular hypertrophy, however, the S in V1 voltage plus the R in V5 or V6 voltage should exceed 35 mm.1 In the present report a total combined voltage of this magnitude was not present in any of the cases.

Transmural septal myocardial infarction may also be associated with a small R wave in lead V1 and deep S waves in V1-3. The electrocardiogram here may closely resemble that of left ventricular hypertrophy.2

The presence of deep S waves in V1 and across the left precordium in chronic cor pulmonale has been stressed by Sodi-Pallares3 and Sokolow and Lyon.4 They note that the R wave may be small in all the precordial leads or may be absent in the right precordial leads. Sodi-Pallares attributes these R- and S-wave changes to the abnormal vertical and low position of the heart.

Aside from chronic cor pulmonale, the presence of a deep S wave in lead V1 or V2, usually is not associated with right ventricular hypertrophy although Lasser and co-workers5 and Donoso and associates6 noted its presence in the right ventricular hypertrophy of congenital heart disease. The criteria for right ventricular hypertrophy of a number of authors4,7,8 include an R/S ratio in V1 which is 1.0 or greater. By this criterion alone 30 per cent of the patients in this report would not have been diagnosed as having right ventricular hypertrophy. If an R/S ratio of 1.0 or greater in either V1, V3R, or V4R were regarded as evidence for right ventricular hypertrophy, then all 10 cases would have been so diagnosed. However, for reasons that are more apparent by vectorcardiographic analysis, it is quite possible that the R/S ratio in these leads may be less than 1.0 and right ventricular hypertrophy may still be present.

Vectorcardiograms

The orientation and direction of inscription of the vectorcardiographic loops are of considerable assistance in determining the presence of hypertrophy, either right, left, or combined.

Horizontal Plane

Clockwise or figure-eight rotation of the horizontal loop usually indicates right ventricular hypertrophy provided the QRS duration is less than 0.12 second. Clockwise or figure-eight rotation may occur with myocardial infarction,8 especially when the duration of the QRS is 0.12 second or more. In our series clockwise rotation of the horizontal loop was present in all but 2 cases, where there was a figure-eight configuration. In no instance did the duration of the QRS exceed 0.12 second.

The deep S waves in V1, V2, or V3, which characterized this series, need not be present in all stages of right ventricular hypertrophy. Figure 3 shows the vector loops in varying degrees of right ventricular hypertrophy. The relationship of the V1, V2, or V3 electrodes to the E point, illustrates why the depth of the S wave varies so considerably. V1 and V2 are essentially anterior to the usual
Fig. 3. The vectorcardiographic loops A through E are on cases with progressively more marked right ventricular hypertrophy. Arrow, direction of inscription of the vectorcardiographic loop.

location of the E point, but lie 10° to either side of the midline of the chest. Thus displacement of the vector loop anteriorly, as occurs in early right ventricular hypertrophy, will be associated with increased positive voltage in V1 and V2. S waves will occur if the vector loop moves posteriorly, as occurs in more advanced right ventricular hypertrophy.

The areas of positivity and negativity may be determined in the following manner (fig. 4): a line is drawn from the V1 position through the E point (X line or axis of derivation). A second line (Y line) is drawn at a right angle to the X line, through the E point. Points that lie on the far side of this Y line are in the zone of negativity, and on the proximal side of the Y line in the zone of positivity. The solid vector loop in figure 4, which is taken from case 8, lies entirely on the positive side of the Y line, and thus only an R wave would be recorded in V1. The dotted vector loop, which is taken from case 9, lies on both the positive and negative sides of the Y line and thus both R and S waves would be recorded in V1 with this loop.

In all 6 mitral stenosis cases there is an abrupt increase in the size of the S wave between leads V1 and V2. From the V2 position a much larger portion of the vector loop lies on the negative side of the Y line, than in V1. The reason for this is illustrated in figure 5. Here the axis of derivation from the V1 position is labeled X and the axis of derivation from the V2 position X’. The corresponding Y and Y’ lines are drawn at right angles to the X and X’ lines, through the E point. The vector loop, which is taken from case 8, lies entirely on the positive side of the Y line, and thus only an R wave is recorded from the V1 position. The same vector loop, however, lies on both the positive and negative sides of the Y’ line, and thus both R and S waves are recorded from the V2 position.

The depth of the S wave from the V2 position thus depends on the amount of the vector loop that lies both to the right and posteriorly. If the vector loop is deviated markedly to the right and anteriorly, the S wave in V2 may be very small, since only a small part of the vector loop would lie on the negative side of the Y’ line.

Similarly, it is possible to have marked rightward deviation of the vector loop and a small R wave in V3R or V4R, provided the loop is inscribed significantly posteriorly. This is illustrated in case 9, where the posterior location of the loop largely cancels out the large positive wave that would be expected from its marked rightward location.

The presence, in 3 cases, of R (or R’) in V1 less than 0.5 millivolt in amplitude, is at variance with one of Milnor’s criteria for right ventricular hypertrophy. In case 7 the R wave in V1 is 0.25 millivolt. The evidence for right ventricular hypertrophy in this case is (1) the presence of ventricular lift at the left sternal margin, (2) a pulmonary artery pressure of 130/50 mm. Hg, (3) a horizontal vector loop with clockwise inscription and with deviation to the right and anteriorly, (4) a frontal vector loop with clockwise inscription and a mean axis of +110°, (5) a sagittal vector loop with counterclockwise inscription and anterior deviation.

Inspection of the horizontal vector loop in
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This case (case 7) shows the reason for the small R wave in V1. Although the loop is inscribed in a clockwise direction, and far to the right, it lies only slightly anterior to the E point, hence the relatively small R in V1. The placement of the electrodes in the various systems currently in use in vectorcardiography does not represent an ideal method for the evaluation of the electric forces of the heart. But even with such deficiencies as are present with the various vectorcardiographic electrode-placement methods, the inscription and location of the loops help to clarify puzzling electrocardiographic variations.

Thus, even in the presence of large electric forces to the right, if these forces are sufficiently posterior, the R wave in V1, V3R, and V4R may remain sufficiently small, or the S wave in these leads sufficiently large so that an R/S ratio of 1.0 or greater is never reached. From analysis of such vector loops, it is our opinion that an R/S ratio of 1.0 or greater in V1, V3R, or V4R need not always be present for an electrocardiographic diagnosis of right ventricular hypertrophy.

Deep S waves in leads V1 or V2 may be produced by vectors oriented to the left, or to the left and posteriorly. Figure 6 illustrates the electrocardiogram and vectorcardiogram of a patient with isolated left ventricular hypertrophy due to a systemic hypertension. The deep S waves in V1, V2, or V3, which are present here, may also be found in right ventricular hypertrophy. The tall R waves in V5 and V6 however are characteristic of left ventricular hypertrophy.

Diphasic P waves in leads V1 or V2 are found in certain cases of mitral stenosis (fig. 1, cases 1, 2, and 5). The diphasic P waves in these instances are due to hypertrophy of the left atrium, which causes the P vector loop to move posteriorly and to the left from its normal position. This is illustrated in case 4 (fig. 2), where the P vector loop has been labeled.

Frontal Plane

In right ventricular hypertrophy the mean frontal plane axis may commonly be between +110° to ±180° or −91° to ±180°. A mean frontal plane axis of less than +110°, however, does occur in right ventricular hypertrophy, and was present in 40 per cent of the patients in this report. Clockwise rotation of the frontal loop was present in all instances.

A tall R wave in lead aVR is found when a significant part of the vector loop lies on the positive side of a line extending from +120° through the E point to −60°. Case 9 illustrates this point. The major part of the loop lies at about −150° (i.e. on the positive side of the Y line for lead aVR) and the R wave in aVR measures 8 mm.
In 3 of the cases there is no R wave in aVR. The evidence for isolated right ventricular hypertrophy in 2 of these, (case 5 and 6) is (1) the presence of the diastolic rumbling apical murmur of mitral stenosis and of a mitral opening snap, (2) the absence of the systolic murmur of mitral insufficiency, (3) an accentuated P₂, (4) an elevated wedged pulmonary artery pressure, (5) the absence of a regurgitant V wave in the wedged pulmonary artery pressure tracing, (6) the presence of moderate pulmonary hypertension, (7) left atrial and pulmonary artery enlargement by x-ray, (8) tall R waves in lead V₁ and with R/S ratios greater than 1.0, (9) horizontal vector loops with clockwise inscription and with deviation to the right and anteriorly, (10) sagittal vector loops with counterclockwise inscription and anterior deviation. The evidence for right ventricular hypertrophy in the third case (case 7, “primary” pulmonary hypertension) has been previously presented in detail.

The findings in these 2 cases of mitral stenosis and in the single case of “primary” pulmonary hypertension provide pertinent evidence for right ventricular hypertrophy, despite the absence of R waves in lead aVR.

SUMMARY

Six cases with mitral stenosis, 3 with pulmonary stenosis, and 1 with pulmonary hypertension have been described. In all 10 cases there was isolated right ventricular hypertrophy, and in all of them deep S waves were present in V₁, V₂, or V₃.

R/S ratios of less than 1.0 in V₁ were present in 3 cases. The voltage of R in V₁ was less than 0.5 millivolt in 3 cases. R waves were absent in aVR in 3 instances.

Vectorcardiograms on these patients showed right ventricular hypertrophy and illustrated the reasons for the electrocardiographic findings.

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SUMMARIO IN INTERLINGUA

Es describite 6 casos con stenosis mitral, 3 con stenosis pulmonar, e 1 con hypertension pulmonar. In omne le 10 il habeva isolate hy-
pertrophia dextero-ventricular, e in omnes profunde undas S esseva presente in V₁, V₂, o V₃.

Proportiones R/S de minus que 1,0 in V₁ esseva presente in 3 casos. Le voltage de R in V₁ esseva infra 0,5 millivolt in 3 casos. Undas R in aV₃ esseva absente in 3 casos.

Le vectocardiogrammas de iste patiente indicava hypertrophia dextero-ventricular e illustrava le rationes pro le constatationes electrocardiographic.

REFERENCES


Atrial fibrillation appeared following mitral valvulotomy in 47 per cent of 77 patients who had a normal sinus rhythm prior to surgery. Fibrillation appeared most frequently on the second postoperative day and rarely on the day of surgery. Spontaneous resumption of sinus rhythm occurred in 10 patients, and quinidine restored sinus rhythm in 16 patients, leaving 10 who had persistent postoperative atrial fibrillation. Since the ventricular rate is high in patients not receiving digitalis, and since additional digitalis was needed to slow the ventricular rate of most patients who developed postoperative atrial fibrillation, all patients should probably be fully digitalized prior to valvulotomy. Since spontaneous resumption of sinus rhythm occurs in many patients, quinidine may be withheld until the seventh postoperative day. It also may be more effective at that time, since factors responsible for the onset of atrial fibrillation have by then apparently diminished.

Simon
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