Electrocardiographic Differentiation of the Causes of Left Ventricular Diastolic Overload*

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Left ventricular hypertrophy due to diastolic overload is characterized by the following in lead V₆: (a) tall R wave; (b) prominent initial Q wave; (c) minimally elevated concave-upward ST segment; and (d) relatively tall symmetrical T wave. Reciprocal deep S waves are seen in lead V₁. This study reflects a further evaluation of these parameters in the four main causes of left ventricular diastolic overload: mitral incompetence, aortic incompetence, patent ductus arteriosus, and ventricular septal defect. An S wave in lead V₆, which is equal to or greater than the R wave in lead V₁, excludes the diagnosis of mitral incompetence.

Left ventricular hypertrophy is classically represented by a deep S wave in lead V₁ and tall R wave in lead V₆. When, for example, the sum of these deflections exceeds 35 mm in the adult, the diagnosis of left ventricular hypertrophy is made. In 1956, Cabrera and Monroy further attempted to differentiate the electrocardiographic manifestations of left ventricular hypertrophy on the basis of the hemodynamic state. This heralded the overload concept.

Left ventricular systolic overload occurs with increased resistance to contraction during systole, as would occur with systemic hypertension and aortic stenosis. It is reflected electrocardiographically by the following (illustrated in diagram C of Fig 1):
- (1) A tall R wave in lead V₆.
- (2) A deep S wave in lead V₁.
- (3) A small or absent initial Q wave in lead V₆, probably the expression of an associated incomplete left bundle branch block.
- (4) An inverted T wave with asymmetrical limbs and a relatively blunt nadir in lead V₆.
- (5) A minimally depressed and slightly convex-upward ST segment in lead V₆.

Left ventricular diastolic overload is associated with increased distention and pressure during diastole. It occurs with increased filling of the left ventricle in conditions such as aortic incompetence, mitral incompetence, ventricular septal defect, and patent ductus arteriosus. Left ventricular diastolic overload is reflected electrocardiographically by the following (illustrated in diagram B of Fig 1):
- (1) A tall R wave in lead V₆, frequently taller than that which occurs with left ventricular systolic overload.
- (2) A deep S wave in lead V₁.
- (3) A prominent, relatively deep, initial Q wave in lead V₆.
- (4) Minimally elevated, concave-upward ST segment in lead V₆.
- (5) Relatively tall and symmetrical T wave in lead V₆.

The following study was undertaken to evaluate the further differentiation of left ventricular diastolic overload by a hitherto undescribed sign: the magnitude of the S wave in lead V₁. This enables the separation of the left ventricular diastolic overload of mitral incompetence from that of aortic incompetence, ventricular septal defect, and patent ductus arteriosus.

METHODS AND MATERIALS

The material comprised 106 cases of left ventricular diastolic overload which were collected consecutively, and consisting of 41 cases of mitral incompetence, 32 cases of aortic incompetence, 19 cases of patent ductus arteriosus, and 14 cases of ventricular septal defect. The diagnosis was made clinically and confirmed as follows:

Of the 41 cases with mitral incompetence, 26 were confirmed by cardiac catheterization as well as surgery, six by cardiac catheterization only, and nine by surgery only.

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Figure 1. Diagrams illustrating: A, normal ECG in lead V₆; B, left ventricular diastolic overload; and C, left ventricular systolic overload.
Table 1—Means and Standard Deviations of the R Wave Amplitude in Lead V6, The S Wave Amplitude in Lead V1, and the R:RS Ratios

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>N</th>
<th>RV₆</th>
<th>SV₁</th>
<th>RV₆/ (RV₆+SV₁)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitral incompetence</td>
<td>41</td>
<td>30.43±8.18</td>
<td>11.33±6.76</td>
<td>0.74±0.11</td>
</tr>
<tr>
<td>Aortic incompetence</td>
<td>32</td>
<td>28.17±9.51</td>
<td>24.94±8.70</td>
<td>0.75±0.09</td>
</tr>
<tr>
<td>Patent ductus</td>
<td>19</td>
<td>18.82±7.98</td>
<td>21.66±7.37</td>
<td>0.84±0.11</td>
</tr>
<tr>
<td>Ventricular septal</td>
<td>14</td>
<td>11.00±8.00</td>
<td>12.46±7.06</td>
<td>0.64±0.13</td>
</tr>
</tbody>
</table>

Of the 32 cases with aortic incompetence, ten were confirmed by cardiac catheterization as well as surgery, eight by cardiac catheterization only, five by surgery only, and nine by echocardiography. Of the 19 cases with patent ductus arteriosus, all were confirmed by cardiac catheterization, and 18 of these were submitted for surgical correction. Of the 14 cases with ventricular septal defect, all were confirmed by cardiac catheterization, and 11 of these were submitted for surgical correction. Cases with pulmonary hypertension were excluded from the study.

The amplitudes of the S wave in lead V₁ and the R wave in lead V₆ were measured and their relationship expressed in the form of the following ratio:

\[
\frac{RV₆}{RV₆+SV₁}
\]

This will be referred to as the R:RS ratio and is an adaptation of the ratio developed by Cabrera et al to express the R to S relationship in lead V₁, i.e.,

\[
\frac{RV₁}{RV₁+SV₁}
\]

This ratio was devised because a simple R to S ratio becomes meaningless if the S wave is 0, since the R:S ratio would be infinity, and a mean of the ratios cannot then be expressed.

Using the R:RS ratio, an absent S wave would result in an index of 1. All other indices would be less than 1. An R wave that is equal to the S wave would result in an index of 0.5. An R wave greater than the S wave would result in an index between 0.5 and 1. A simple R to S ratio of 2:1 or higher would result in R:RS ratios between 0.66 and 1. An R wave less than the S wave would result in an R:RS ratio of less than 0.5.

**Statistical Methods**

The data were analyzed by means of a one way analysis of variance. This analysis was followed by a pairwise Student's t-test procedure where the test level was adapted according to the principles laid down by Bonferroni: a p value of <0.0167 was required to achieve the 0.05 confidence level; p<0.0033 for the 0.01 confidence level, and p<0.0003 for the 0.001 confidence level.

**Results**

The amplitudes of the S wave in lead V₁ and the R wave in lead V₆ as well as the R:RS ratios are depicted in Table 1. The pairwise comparisons between the means of these variables for the four groups are depicted in Table 2. A graph reflecting the R:S relationship is shown in Figure 2.

**Discussion**

This study clearly shows that the electrocardiographic presentation may differ in all the four cited examples of left ventricular diastolic overload with respect to:

1. The amplitude of the R wave in lead V₆ considered in isolation.
2. The amplitude of the S wave in lead V₁ considered in isolation.
(3) The relationship of the amplitude of the R wave in lead V₆ to the S wave in lead V₁.

The R Wave in Lead V₆

The R wave amplitude in lead V₆ of mitral incompetence was significantly taller than those of patent ductus arteriosus (p<0.001), and ventricular septal defect (p<0.001). The R wave amplitude in lead V₆ of aortic incompetence was significantly taller than those of patent ductus arteriosus (p<0.002) and ventricular septal defect (p<0.001). Furthermore, the R wave in lead V₆ of patent ductus arteriosus was significantly taller than that of ventricular septal defect (p=0.018).

The S Wave in Lead V₁

The amplitude of the S wave in lead V₁ of mitral incompetence was very significantly less than those associated with aortic incompetence (p<0.001), patent ductus arteriosus (p<0.001), and ventricular septal defect (p<0.001). Aortic incompetence was associated with the largest S waves in lead V₁ (a mean of 24.94 mm). In ten of the 32 cases, the S wave in lead V₁ was larger than the R wave in lead V₆. A typical example of the electrocardiographic presentation of aortic incompetence is illustrated in Figure 3.

The S wave amplitude in lead V₁ of aortic incompetence was significantly greater than that of a ventricular septal defect (p<0.001).

The R to S Relationship

The most important differentiating feature for separating mitral incompetence from the other causes of left ventricular diastolic overload was the R to S relationship. Thus, in mitral incompetence, the R wave in lead V₆ was always taller than the S wave in lead V₁ (Fig 2 and 3 and Table 1).

The R:RS ratio of mitral incompetence was significantly higher than those of aortic incompetence (p<0.001), patent ductus arteriosus (p<0.001), and ventricular septal defect (p<0.001) (Table 2).

In 33 of the 41 cases of mitral incompetence, the R wave in lead V₆ was two or more times greater than the S wave in lead V₁ (Fig 2). An example of the classic electrocardiographic presentation of mitral incompetence is illustrated in Figure 4. This is also evident from Figure 2 where 33 of the 41 cases of mitral incompetence are located on or above the axis depicting the 2:1 RS ratio. Indeed, the mean R:RS ratio of 0.74 is significantly higher (p<0.001) than 0.66 (a figure which is equivalent to a simple R:S ratio of 2:1). It is also evident that no case of mitral incompetence occurs on or below the Y=X axis. This indicates that there are no case of mitral incompetence where the S wave in lead V₁ was equal to or greater than the R wave in lead V₆. With aortic incompetence, patent ductus arteriosus, and ventricular septal defect, however, the cases were almost equally distributed on either side of

Table 2—P Values for Comparison of the Diagnostic Groups with Respect to the Amplitudes of the R Wave in Lead V₆, the S Wave in Lead V₁, and RV₆ + SV₆

<table>
<thead>
<tr>
<th>Diagnostic Comparison</th>
<th>R Wave Amplitude in V₆</th>
<th>S Wave Amplitude in V₁</th>
<th>RV₆ + SV₆ Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>MI with AI</td>
<td>NS</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MI with PDA</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MI with VSD</td>
<td>&lt;0.001</td>
<td>NS</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>AI with VSD</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>NS</td>
</tr>
<tr>
<td>AI with PDA</td>
<td>&lt;0.002</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>PDA with VSD</td>
<td>&lt;0.002</td>
<td>&lt;0.001</td>
<td>NS</td>
</tr>
</tbody>
</table>

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the Y = X axis, e.g., 30 below and 35 above in aortic incompetence (Fig 2). Furthermore, only two of 32 cases of aortic incompetence were associated with a simple R:S ratio greater than 2:1 (Fig 2).

Sensitivity, Specificity and Predictive Accuracy

The presence of an R:S ratio of 2:1 or higher can be used to diagnose mitral incompetence with a sensitivity of 75.6 percent, a specificity of 95.4 percent, and a predictive accuracy of 91.2 percent. The manifestation of an S wave in lead V₁ of lesser amplitude than the R wave in lead V₆ can be used to diagnose mitral incompetence with a sensitivity of 49.2 percent and a predictive accuracy of 56.2 percent.

Mechanisms

The normal horizontal plane QRS axis is directed to

![Figure 4. Electrocardiogram showing the features of left ventricular diastolic overload due to mitral incompetence.](image)

the left and slightly posteriorly (as illustrated in diagram A of Fig 5). It is thus usually directed to a region midway between the V₆ and V₁ lead axes. The impression on these leads is consequently about equal, i.e., the R wave in lead V₆ is of approximately the same amplitude as the S wave in lead V₁. It must be borne in mind that the horizontal plane axes cannot be localized with the same accuracy or fineness as the frontal plane axes. This is due to the variability which occurs with body build and electrode placement, and which are easily reflected on the proximity leads of the horizontal plane when compared with the relatively remote leads of the frontal plane.

With left ventricular hypertrophy due to systolic overload, the magnitude of the QRS vector is increased but the direction is usually maintained so that the amplitude of the deep S wave in lead V₁ is approximately that of the tall R wave in lead V₆ (diagram A of

![Figure 5. Diagrams illustrating the horizontal plane QRS vector in: A, aortic incompetence, patent ductus arteriosus, and ventricular septal defect; and B, mitral incompetence.](image)
Fig 5). With left ventricular diastolic overload due to aortic incompetence, the horizontal plane QRS axis is similarly directed and increased in magnitude. It is, however, commonly a little more anteriorly placed so that, although both deflections are increased in magnitude, the R wave in lead V₆ is often slightly greater than the S wave in lead V₁, but this is not invariably so. This occurred in 21 of the 32 cases (Fig 2).

With mitral incompetence, the R wave in lead V₆ was always larger than the S wave in lead V₁, and usually appreciably so. This is due to important anterior displacement of the left ventricle, and hence, the QRS axis as a result of the enlarged left atrium (diagram B of Fig 5). When this occurs, the horizontal plane QRS axis will be closely aligned with the V₆ lead axis and will tend to be perpendicular to the lead V₁ axis. The impression will thus be far greater on the V₆ lead axis than on the V₁ lead axis. Furthermore, the deflections will be of large amplitude in lead V₆ for the following reasons:

1. There is left ventricular hypertrophy.
2. The QRS axis is more aligned with lead V₆. Hence, its impression is greater on this lead. Compare the impression on lead V₆ in diagrams A and B of Figure 5.
3. The anterior displacement will cause the ventricle to be closer to the precordial electrodes which will consequently result in larger deflections. This hypothesis was previously put forward by Grant.⁴

CONCLUSIONS

If, in left ventricular diastolic overload, the amplitude of the S wave in lead V₁ is equal to or greater than the R wave in lead V₆, the diagnosis of mitral incompetence can be excluded (p<0.001). If, in left ventricular diastolic overload, the ratio of the R wave in lead V₆ to the S wave in lead V₁ is 2:1 or greater, the diagnosis of mitral incompetence is most likely (p<0.001), but may very occasionally be associated with aortic incompetence. If, in left ventricular diastolic overload, both the R wave in lead V₆ and the S wave in lead V₁ are of large magnitude, the most likely diagnosis is aortic incompetence.

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REFERENCES

1. Cabrera CE, Monroy JR. Systolic and diastolic loading of the heart. Am Heart J 1952; 43:661