The Electrocardiogram and Ventricular Gradient in Isolated Congenital Pulmonary Stenosis

By Nicholas DePasquale, M.D., and G. E. Burch, M.D.

A SPECTS of the electrocardiogram in isolated congenital pulmonary stenosis have been described previously by others.1-6 This report is concerned with a study of the electrocardiograms and ventricular gradients of 41 patients from the Charity Hospital and Tulane Medical School at New Orleans, Louisiana, who had proved isolated congenital pulmonary stenosis. The diagnoses for the 41 patients were established by cardiac catheterization; 10 were confirmed at surgery and 2 at autopsy.

Methods and Materials

The 41 patients varied in age from 3 to 38 years, the mean being 14 years. Their distribution according to age, sex, and race is shown in table 1. The patients were studied by cardiac catheterization and by conventional clinical and electrocardiographic methods. The electrocardiograms were recorded within 2 or 3 days of cardiac catheterization.

Results

The results are summarized in tables 2 to 4 and figures 1 to 8.

There was electrocardiographic evidence of right ventricular hypertrophy in all but 2 patients and right deviation of the electrical axis of the QRS complex in all patients. Typical examples of 4 types of patterns found are shown in figure 1. In general, however, in all of the electrocardiograms the ratio of the amplitude of the R wave to that of the S wave in lead V1 was directly related to the pressure recorded in the right ventricle (figs. 2 and 7). The S wave was large and the R wave small in leads recorded to the left of the transition zone, e.g., V5 and V6 (fig. 1). The duration of the QRS complex was not affected by age nor by increase in right ventricular pressure.

Table 1

<table>
<thead>
<tr>
<th>Age</th>
<th>Sex</th>
<th>Race</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>11-20</td>
<td>21-30</td>
</tr>
<tr>
<td>21</td>
<td>13</td>
<td>4</td>
</tr>
</tbody>
</table>

The P wave tended to be prominent in leads II, III, and V1 but its magnitude showed no significant relationship to the pressure recorded in the right ventricle (fig. 3), the correlation coefficient being 0.12.

\( \hat{A}_{QRS} \) was oriented to the right in the frontal plane (figs. 4, 5, and table 2). The degree of orientation of \( \hat{A}_{QRS} \) to the right in the frontal plane varied directly with the right ventricular systolic pressure (figs. 6 and 7).

\( \hat{A}_{R} \) was oriented more to the left in the frontal plane than \( \hat{A}_{QRS} \) (fig. 4, table 2). The angle between \( \hat{A}_{QRS} \) and \( \hat{A}_{R} \) was greater than normal in 28 of the 41 patients (68 per cent) due to rightward deviation of \( \hat{A}_{QRS} \) without an associated change in \( \hat{A}_{R} \), or to rotation of \( \hat{A}_{R} \) to the left (fig. 4).

\( \hat{A} \) had a mean direction in the frontal plane of +65° and a mean magnitude of 54 \( \mu \)v.s., (fig. 4, table 2). The angle between \( \hat{A}_{QRS} \) and \( \hat{A} \) was greater than normal in 26 patients (63 per cent) (table 3). \( \hat{A}_{QRS} \) was located to the right of \( \hat{A} \) in 38 of the 41 patients (93 per cent) and to the left of \( \hat{A} \) in 3 patients (7 per cent).

Surgical reduction of the pulmonary stenosis resulted in migration of \( \hat{A}_{QRS} \), \( \hat{A}_{R} \) and \( \hat{A} \) toward normal locations and magnitudes in the frontal plane projection. The only exception was in a patient in whom the right ventricular pressure failed to decrease after surgery (patient 6, table 4). \( \hat{A}_{QRS} \) rotated to the left, \( \hat{A}_{R} \) to the right, and \( \hat{A} \) to a more normal direction with respect to \( \hat{A}_{QRS} \) and \( \hat{A}_{R} \) (table 4, fig. 8). The mean magnitude of \( \hat{A}_{QRS} \) de-
Figure 1

Four types of electrocardiographic patterns in 41 cases of isolated pulmonary stenosis.
creased, that of \( \hat{\alpha} \) increased, and that of \( \hat{A}_T \) remained essentially the same after surgery.

In general, the electrocardiographic patterns found in this congenital anomaly tended to be of 4 types (fig. 1):

**Type A**

This type of electrocardiogram had a small to absent R wave and a deep S wave in lead I, and a high R wave and a small to absent S wave in lead V1, and was obtained from patients in whom the right ventricular systolic pressure was greater than 100 mm. of mercury.

**Type B**

This electrocardiographic pattern was obtained when the right ventricular systolic pressure was between 75 and 100 mm. of mercury. The R wave in lead I was more prominent in type B than in type A but was of less magnitude than the S wave in lead I, whereas the R wave in V1 was greater in magnitude than the S wave although the S wave in V1 was moderately deep.

**Type C**

When the right ventricular systolic pressure was less than 75 mm. of mercury, an electrocardiogram of type C was obtained in which the R wave in lead I was equal to or greater in magnitude than the S wave in lead I and the magnitude of the S wave in V1 was equal in magnitude to the R wave in V1.

**Type D**

This type of tracing was of normal configuration. Two of the 41 patients had a normal electrocardiogram even though the right ventricular systolic pressure was 75 and 105 mm. of mercury, respectively.
### Table 4

**Electrocardiographic Data before and after Surgical Reduction of Pulmonary Stenosis in Ten Patients**

<table>
<thead>
<tr>
<th>Patient number</th>
<th>Months after surgery</th>
<th>Height of R in V1 (mm.)</th>
<th>Height of PII, or PIII (mm.)</th>
<th>Location degree</th>
<th>Magnitude μv.s.</th>
<th>Location degree</th>
<th>Magnitude μv.s.</th>
<th>Location degree</th>
<th>Magnitude μv.s.</th>
<th>Location degree</th>
<th>Magnitude μv.s.</th>
<th>RV systolic pressure mm. Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>117</td>
<td>24</td>
<td>110</td>
<td>14</td>
<td>70</td>
<td>54</td>
<td>46</td>
<td>34</td>
</tr>
<tr>
<td>2</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>155</td>
<td>62</td>
<td>120</td>
<td>24</td>
<td>0</td>
<td>28</td>
<td>57</td>
<td>44</td>
</tr>
<tr>
<td>3</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>193</td>
<td>16</td>
<td>-102</td>
<td>8</td>
<td>-30</td>
<td>44</td>
<td>14</td>
<td>66</td>
</tr>
<tr>
<td>4</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>140</td>
<td>40</td>
<td>120</td>
<td>14</td>
<td>75</td>
<td>60</td>
<td>53</td>
<td>54</td>
</tr>
<tr>
<td>5</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>125</td>
<td>38</td>
<td>67</td>
<td>42</td>
<td>65</td>
<td>40</td>
<td>90</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>103</td>
<td>9</td>
<td>160</td>
<td>6</td>
<td>5</td>
<td>25</td>
<td>91</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>168</td>
<td>16</td>
<td>63</td>
<td>11</td>
<td>40</td>
<td>26</td>
<td>40</td>
<td>60</td>
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<tr>
<td>8</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>111</td>
<td>45</td>
<td>60</td>
<td>28</td>
<td>60</td>
<td>40</td>
<td>5</td>
<td>32</td>
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<tr>
<td>9</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>129</td>
<td>24</td>
<td>121</td>
<td>42</td>
<td>0</td>
<td>20</td>
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<td>26</td>
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<tr>
<td>10</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>Before After</td>
<td>180</td>
<td>12</td>
<td>-120</td>
<td>23</td>
<td>70</td>
<td>41</td>
<td>6</td>
<td>31</td>
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<tr>
<td>Mean</td>
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<td></td>
<td></td>
<td></td>
<td>+142</td>
<td>29</td>
<td>+59</td>
<td>21</td>
<td>+35</td>
<td>38</td>
<td>+42</td>
<td>40</td>
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</table>

<table>
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<th>RV systolic pressure mm. Hg</th>
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<tr>
<td>175</td>
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<tr>
<td>160</td>
</tr>
<tr>
<td>165</td>
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<tr>
<td>146</td>
</tr>
<tr>
<td>105</td>
</tr>
<tr>
<td>134</td>
</tr>
</tbody>
</table>

**Discussion**

Of the 21 patients whose electrocardiograms were of type A only 1 had a right ventricular systolic pressure of 135 mm. of mercury and an electrocardiographic pattern of type C, while another patient had a right ventricular systolic pressure of 90 mm. of mercury and an electrocardiogram of type A. One patient had a right ventricular systolic pressure of 135 mm. of mercury and an electrocardiographic pattern of type C, while another patient had a right ventricular systolic pressure of 69 mm. of mercury and an electrocardiogram of type A. The lead with the highest P wave was selected for analysis.

**Figure 3**

Relationship of right ventricular systolic pressure to the R/S ratio in lead V1. When a diphasic R wave was present the highest wave was selected.

**Figure 2**

Relationship of right ventricular systolic pressure to the R/S ratio in lead V1.
CONGENITAL PULMONARY STENOSIS

Figure 4
\[ \hat{A}_{QRS}, \hat{A}_T, \text{and } \hat{G} \text{ in 41 cases of isolated pulmonary stenosis.} \]

68 mm. of mercury and complete right bundle-branch block. This was the only instance of complete bundle-branch block in this series.

The ventricular gradient of Wilson and associates, an expression of the variations in the duration of the excited state, has been studied by us in patients with congenital and acquired heart disease as well as in normal children.\(^8\)-\(^10\). \(^{13}\) Ashman analyzed the electrocardiograms of 164 normal adults and found the mean \(\hat{A}_{QRS}\) to have a direction of +41.7° (range, -21.5° to +104.9°) and a mean magnitude of 21.8 μV.s. (40.6 to 3.1 μV.s.) in the frontal plane projection, whereas \(\hat{G}\) had a mean direction of +39.2° (+72.2° to +2.2°) and a mean magnitude of 46.2 μV.s. (78.9 to 13.5 μV.s.). In 77 children (2 to 14 years of age) he found \(\hat{A}_{QRS}\) to have a mean direction of +61.1° (+102° to +20.1°) and a mean magnitude of 16.6 μV.s. in the frontal plane projection, whereas in 78 children the \(\hat{G}\) had a mean direction of 48.0° (+73.1° to +22.9°) and a mean magnitude of 46.6 μV.s. (72.2 to 16.6 μV.s.). In our study of the ventricular gradients of 172 normal infants and children from birth to 16 years of age,\(^{10}\) we found that, except for a decrease in the mean magnitude of \(\hat{A}_{QRS}\) and to a lesser extent of \(\hat{G}\), during the first 3 years of life and a shift of \(\hat{A}_{QRS}\) to the right during the first year of life, the values for children were the same as Ashman’s values for adults.\(^{11}\)

There were abnormally wide angles (>30°) between \(\hat{A}_{QRS}\) and \(\hat{G}\) in the frontal plane projection in 26 patients (63 per cent) (table 3). In addition, the \(\hat{A}_{QRS}\) in 29 patients (71 per cent) was deviated more to the right than the normal (fig. 4), and \(\hat{G}\) was abnormal in direction in 22 patients (54 per cent) (fig. 4). The magnitude of \(\hat{A}_{QRS}\) was abnormal in 9 patients (22 per cent) and the magnitude of \(\hat{G}\) was abnormal in 4 patients (10 per cent). The mean \(\hat{G}: \hat{A}_{QRS}\) ratio was 2.7; however, in 9 patients the ratio was less than 1.0. In 4 other patients the ratio was greater than 3.0 because of a \(\hat{G}\) of unusually great magnitude. Normally, the magnitude of \(\hat{G}\) is essentially twice the magnitude of \(\hat{A}_{QRS}\).\(^{12}\)

The abnormal ventricular gradient indicates functional electrical changes in the myocardium other than those due to right ventricular hypertrophy. The ventricular gradient was abnormal in 26 patients (63 per cent), in 22 because of its direction and in 4 because of its magnitude, whereas 39 patients (95 per cent) had electrocardiograms that were not considered to indicate myocardial disease other than ventricular hypertrophy. These
changes apparently are reversible in large part as is indicated by the reversion of the gradient toward the normal following surgery (table 4, fig. 8).

The degree of right ventricular hypertrophy was dependent upon the magnitude of the right ventricular pressure, a finding already indicated by others.\(^6\) The age of the patient was not found to be so important a factor in the production of an abnormal electrocardiogram in congenital pulmonary stenosis as it was in congenital atrial septal defect.\(^13\) Nevertheless, the duration of hypertension in the right ventricle must be a factor in importance in determining the degree of right ventricular hypertrophy. The reason for the absence of a significant relationship of right ventricular hypertrophy to age of the patient is not known.

An interesting aspect of the electrocardiographic pattern in pure pulmonary stenosis was the failure of the QRS complex to become abnormally prolonged with age. Atrial septal defect, on the other hand, is characteristically associated with progressive widening of the QRS complex.\(^18\) The mechanisms responsible for this difference are not clear. In both types of cardiac defects the work of the right ventricle is increased but in atrial septal defect the increase in work is due to an increase in volume output of the heart, whereas in pure pulmonary stenosis the increase in work is due to increase in right ventricular pressure. Anatomically, there is predominantly hypertrophy of the crista supraventricularis in atrial septal defect, whereas in pure pulmonary stenosis there is generalized hypertrophy of the right ventricle. Cabrera and Monroy\(^14\) have already discussed this problem. The precise mechanisms for these differences in anatomic changes remain to be explained. Regardless of the mechanism, these observations demonstrate again the significant relationship of the electrocardiogram to the normal and abnormal functional and anatomic state of the heart.

With the accumulation of more detailed data in future years the role of the electrocardiogram in the clinical diagnosis of congenital cardiac defects should be improved.
Summary
The electrocardiogram and ventricular gradient were studied in 41 patients with isolated congenital pulmonary stenosis. The ventricular gradient was abnormal in 26 of the 41 patients (63 per cent). The $A_{QRS}$ migrated to the right in the frontal plane and $A_T$ migrated to the left. Following surgical reduction of the stenosis these vectors rotated rapidly toward the normal position.

The electrocardiographic pattern in isolated congenital pulmonary stenosis tended to be of 4 types that were generally related to the right ventricular systolic pressure. The electrocardiographic changes associated with this defect, in which the work of the right ventricle was increased because of right ventricular hypertension, were different from those associated with atrial septal defect in which right ventricular work was increased because of high volume output. The duration of the QRS complex was not prolonged in the electrocardiograms of patients with pulmonary stenosis, whereas it was characteristically prolonged in those with atrial septal defect.

Summario in Interlingua
Le electrocardiogramma e le gradiente ventricular esseva studiate in 41 patientes con isolate congenite stenosis pulmonar. Le gradiente ventricular esseva anormal in 26 del 41 (63 pro cento). $A_{QRS}$ migrava verso le dextera in le plano frontal, e $A_T$ migrava verso le sinistra. Post reduction chirurgic del stenosis, iste vectores rotava rapidamente verso lor positiones normal.

Le patrono electrocardiographic in isolate congenite stenosis pulmonar tendeva a gruppars se in un de 4 typos que esseva generalmente relacionate al tension systolic dextero-ventricular. Le alterationes electrocardiographic associate con iste defecto, in que le labor del ventriculo dextere esseva augmentate a causa del presentia de hypertension dextero-ventricular differeva ab le alterationes electrocardiographic associate con defecto atrio-septal in que le labor del ventriculo dextere esseva augmentate a causa de un alte volumine del rendimento. Le duration del complexo QRS non esseva prolongate in le electrocardiogrammas de patientes con stenosis pulmonar, durante que illo esseva characteristicamente prolongate in patientes con defecto atrio-septal.

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