Postoperative Changes in the Electrocardiogram in Congenital Heart Disease

I. Pure Pulmonary Stenosis

By Bernhard Landman, M.D.

Electrocardiograms of forty-six cases of pure pulmonary stenosis were analyzed before and after valvulotomy. The electrocardiograms taken at the last postoperative examinations (three months or longer after the operation) revealed significant changes as compared with the preoperative tracings. It is suggested that these changes may be due to the diminished load on the right ventricle and right auricle after the operation. Evidence is presented that electrocardiography offers a simple and valuable means for the evaluation of the result of valvulotomy in pure pulmonary stenosis.

Surgical advance in the correction of certain congenital cardiac defects renders an accurate diagnosis of these conditions important. In view of the fact that some malformations of the heart are associated with hypertrophy of the right ventricle whereas others are characterized by left-sided preponderance, a correct diagnosis often rests upon the evidence obtainable as to the relative amount of work demanded of these chambers. Consequently, the presence of right or left ventricular hypertrophy is one of the most important differential diagnostic signs. The difficulty, however, in the positive establishment of lesser degree of relative ventricular enlargement on clinical examination, including x-ray study, is well known and additional diagnostic procedures are often needed. Modern electrocardiography has increased the information derived from the electrocardiogram.

A considerable amount of statistical data has accumulated concerning the various intervals and deflections of the electrocardiogram in normal children.¹⁻⁷ The measurements obtained are, however, subject to a fairly wide range of variation which limits their value as normal standards in the study of specific cases.

During recent years, certain electrocardiographic criteria for right and left ventricular hypertrophy have been established.⁸⁻¹¹ Most of these observations have been made on adult patients and, therefore, the measurements obtained are not directly applicable to the study of children. Moreover, there is still a lack of agreement as to which electrocardiographic measurement gives the most valuable information in regard to right and left ventricular hypertrophy.

Cardiac surgery offers an opportunity for a new approach to the electrocardiographic study of ventricular preponderance. The present study was undertaken in order to determine what changes, if any, occurred in the electrocardiogram of patients operated upon because of congenital heart disease. Only uncomplicated cases were included in this study. The material comprised malformations characterized by an increased load on the right ventricle as well as those with left ventricular preponderance. Furthermore, the types of malformations were selected so that the factor which caused the strain on the heart could be eliminated or at least greatly decreased by the operation. A comparison between the electrocardiograms taken before and after the operation, when either normal or practically normal conditions had been created, seemed to offer indirect evidence of the electrocardiographic patterns in right and left ventricular preponderance. The studies
TABLE 1.—Forty-Six Cases of Pure Pulmonary Stenosis Studied before and after Pulmonary Valvulotomy

<table>
<thead>
<tr>
<th>Sex</th>
<th>Female</th>
<th>Age in Yrs. at Time of Operation</th>
<th>Postoperative Observation Period in Mos.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Under 1-5 6-10 11-15 16-25 26-35 36-46</td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>18</td>
<td>2 12 17 9 6 11 14 12 9</td>
<td></td>
</tr>
</tbody>
</table>

were carried out in the Cardiac Clinic of the Harriet Lane Home in 1952.

The Reported Electrocardiogram in Pure Pulmonary Stenosis

Pure pulmonary stenosis, according to modern nomenclature, refers to pulmonary stenosis with a closed ventricular septum. Since pulmonary stenosis has only recently been recognized as a relatively common clinical entity, detailed studies of this malformation are comparatively few and there is still a lack of agreement as to the significant electrocardiographic changes.

Several investigators have commented on the frequent occurrence of right axis deviation in the standard leads in pure pulmonary stenosis. Abrahams and Wood, in a series of 60 cases, found right axis deviation in every case. Götzschke and his group, on the other hand, reported right axis deviation in only 11 out of 21 cases of pure pulmonary stenosis all of which had been studied by cardiac catheterization. Likewise, Green and associates, in a series of eight cases, observed right axis deviation in only two instances.

Several of these observers have noted that pure pulmonary stenosis is frequently associated with a high P wave in the electrocardiogram. Contrary to these reports, Dow and associates recorded prominent P waves only once in a series of eight cases of this malformation.

Opinions still differ as to the diagnostic value of unipolar leads in pure pulmonary stenosis. Götzschke and associates, in a series of 21 cases, claimed that these leads did not reveal any abnormal changes. Several investigators, on the other hand, have observed that pure pulmonary stenosis frequently shows signs of right ventricular hypertrophy in the precordial leads. The main changes described are high R waves and inverted T waves in right ventricular surface leads.

Blackford and Parker, in 1941, reported on a case of pure pulmonary stenosis in which the electrocardiogram showed complete right bundle-branch block. Subsequently, several investigators have commented on the occasional occurrence of complete or partial right bundle-branch block in pure pulmonary stenosis.

There are only very few reports on postoperative changes in the electrocardiogram in pure pulmonary stenosis. Brock and Campbell presented tracings of a case, limited to the standard leads, in which an inverted T became positive following pulmonary valvulotomy. Subsequently, they reported on postoperative changes in the electrocardiograms in 11 cases of pure pulmonary stenosis. They stated that some transient changes, suggestive of muscular injury or pericarditis, were occasionally registered during the early postoperative period. Similar observations have been made by Soulé and associates in a series of nine cases of pure pulmonary stenosis.

Material and Methods

The material comprised the electrocardiograms of 46 cases of pure pulmonary stenosis examined before and after valvulotomy (table 1). None of these patients has received digitalis or other drugs which might have affected the electrocardiogram.

All the electrocardiograms were taken under the same conditions with a Sanborn direct-writing cardiograph. The standard leads were recorded in the usual manner; unipolar precordial leads, V through V, were taken using the central terminal of Wilson as indifferent electrode. Augmented unipolar extremity leads, aV, aV, and aV, were recorded according to the technic described by Goldberger. Calibration corrections were applied, if necessary, for accurate standardization (10 mm. = 1 mv.). As a rule, at least three cardiac cycles were studied in each lead and from these the average measurements were derived in tabular form. A magnifying glass was often used to facilitate the study of individual measurements.

In each case the following electrocardiographic particulars were analyzed before and after the operation: Rate and rhythm were determined from any or all leads which were suitable. The duration
and the amplitude of the P wave, the P-R interval, the QRS duration and the Q-T interval were, according to standard procedures, obtained from standard lead II. The location of the electrical axis of the QRS complex was derived by algebraic addition from Einthoven's triangle. The relation between the electrical and the anatomic position of the heart was studied according to the criteria described by Wilson and associates.\(^1\) The amplitudes of the Q, R, S and T waves were measured in the three standard leads, in the unipolar limb leads and in the right (V₁) and left (V₅) ventricular surface leads. The shape of the S-T segments was studied in all these leads. The onset of the intrinsicoid deflection in V₁ and in V₅ was measured from the beginning of the Q wave to the peak of the R wave. Finally, the ratio between the positive and negative deflection of the QRS complex was determined in all these leads.

According to this procedure, 60 electrocardiographic particulars were analyzed in each of the cases before and after the operation. The average pre- and postoperative measurements were derived from all groups. In the presentation of the results, only significant changes in the electrocardiograms will be discussed in detail.

The surgical technic consisted in each case of pulmonary valvulotomy. The operations were done by Dr. Blalock or by members of his surgical staff at the Johns Hopkins Hospital. At the operation, the stenosed valve was palpated in each instance and the typical jetlike thrill was felt distal to the stenosis.

Prior to the operation, 34 of the patients revealed slight cyanosis which disappeared after valvulotomy. This was considered to indicate the presence of a foramen ovale. The remainder of the patients were acyanotic before, as well as after, the operation.

Transient changes in the electrocardiogram, suggestive of myocardial injury or pericarditis, frequently occurred immediately after the operation, and these changes sometimes persisted during the subsequent few weeks. These changes, which were similar to those described by Brock and Campbell,\(^2\) mainly affected the T waves. Figure 1 illustrates one of these cases. In addition, transient arrhythmias, mostly extrasystoles, were occasionally recorded.

**Fig. 1.** A. Electrocardiogram of a girl, 9 years of age, with pure pulmonary stenosis. Marked right axis deviation. Peaked P wave in lead II. T-wave inversion in leads III, aV₂, aV₅, and V₅. Depression of the S-T segment in V₅. Cardiac catheterization revealed a right ventricular pressure of 200/10 mm. Hg. B. Two weeks after pulmonary valvulotomy. T-wave inversion, suggestive of myocardial injury, has appeared in leads I, II, aV₁, and V₅. These changes persisted for three additional weeks. C. One year after pulmonary valvulotomy. Note the decrease in the amplitude of the P wave in lead II and the decrease in the angle of the electrical axis. The T wave has become positive in leads I, II, III, aV₁, and V₅. The R/Q and the R/S ratios have changed in aV₁, V₁ and V₅. At this time, the right ventricular pressure was 65/0 mm. Hg.
during the early postoperative period. Therefore, only those records of patients who had been followed for at least three months after the operation were included in this study. Table 1 shows that the postoperative observation period, that is, the time interval between the operation and the last postoperative electrocardiogram, was more than six months in 35 of the 46 cases. The average period was thirteen and one-half months.

**RESULTS OF PRESENT STUDY**

*Rhythm and Rate.* Arrhythmias were not recorded in a single case before the operation or at the last postoperative examination. Prior to the operation, the average heart rate was 100.4 beats per minute. Following valvulotomy, a slight decrease in the heart rate was observed as a rule. The average rate was 90.1 beats per minute at the last examination.

**P Wave, P-R Interval and QRS Duration.** Following surgery, a significant decrease in the amplitude of the P wave was recorded in 40 of the 46 cases (table 2). Figure 2 illustrates a case in which the amplitude of the P wave in lead II decreased from 0.7 to 0.2 mv. A decrease in the duration of the P wave occurred after the operation in 33 instances. The average P-R interval and the average QRS duration showed no significant changes. Only occasionally was a significant decrease in the QRS duration recorded postoperatively (fig. 3). Table 2 shows that the different measurements were subject to a fairly wide range of variation before as well as after the operation.

**Table 2.—Average, Minimum and Maximum Duration and Amplitude of the P Wave, P-R Interval and QRS Duration in Forty-Six Cases of Pure Pulmonary Stenosis (A) before and (B) after Pulmonary Valvulotomy. The Measurements Were Derived from Lead II**

<table>
<thead>
<tr>
<th></th>
<th>P Wave</th>
<th>P-R Interval</th>
<th>QRS Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.32 ± 0.10</td>
<td>0.09 ± 0.11</td>
<td>0.15 ± 0.23</td>
</tr>
<tr>
<td>B</td>
<td>0.19 ± 0.05</td>
<td>0.08 ± 0.09</td>
<td>0.15 ± 0.21</td>
</tr>
</tbody>
</table>

**Fig. 2.** A. Electrocardiogram (lead II) of a girl, 7 years of age, with pure pulmonary stenosis. High P wave, depression of the S-T segment and diphasic T wave. B. Two and a half years after pulmonary valvulotomy. Note the decrease in the amplitude of the P wave and the change to normal of the S-T segment and the T wave.

**Fig. 3.** A. Electrocardiogram of a girl, 15 years of age, with pure pulmonary stenosis. Marked right axis deviation. QRS duration of 0.10 second. S-T depression and delayed onset of the intrinsicoid deflection in V1. B. Nine months after pulmonary valvulotomy. The electrical axis has become balanced. Note the decrease in the QRS duration. In V1, the R wave and the S-T segment have changed towards normal. The R/Q and R/S ratios have changed in aVR and V1.
Fig. 4. The Q-T and R-R relationship (o) before and (x) after pulmonary valvulotomy were derived from Bazett's formula $Q-T = 0.404 \times E.R.$ The middle curve represents the mean values of the corresponding Q-T intervals obtained by Alimurung and associates in 517 normal children; the area covered by the dotted lines included 95.6 per cent of their cases.

**Table 3.—Electrical Axis of the QRS Complex and Electrical Position of the Heart in Forty-Six Cases of Pure Pulmonary Stenosis (A) before and (B) after Pulmonary Valvulotomy.**

<table>
<thead>
<tr>
<th>Electrical Axis in Degrees</th>
<th>Electrical Position</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vertical</td>
</tr>
<tr>
<td>60-90</td>
<td>91-120</td>
</tr>
<tr>
<td>A</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>6</td>
</tr>
</tbody>
</table>

**Table 4.—Average, Minimum and Maximum Amplitude of the R Wave in Millivolts in Forty-Six Cases of Pure Pulmonary Stenosis (A) before and (B) after Pulmonary Valvulotomy. Leads Showing Significant Postoperative Changes in the R Wave Are Presented.**

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>III</th>
<th>$aV_R$</th>
<th>$aV_F$</th>
<th>$V_1$</th>
<th>$V_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0.33</td>
<td>0</td>
<td>1.2</td>
<td>1.92</td>
<td>0.4</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>0.90</td>
<td>0</td>
<td>2.4</td>
<td>1.65</td>
<td>0.1</td>
<td>3.50</td>
</tr>
<tr>
<td></td>
<td>2.53</td>
<td>0.6</td>
<td>4.0</td>
<td>1.27</td>
<td>0.2</td>
<td>3.0</td>
</tr>
<tr>
<td>B</td>
<td>0.48</td>
<td>0</td>
<td>1.3</td>
<td>1.56</td>
<td>0.2</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>0.40</td>
<td>0</td>
<td>2.2</td>
<td>1.26</td>
<td>0.1</td>
<td>2.80</td>
</tr>
<tr>
<td></td>
<td>1.48</td>
<td>0.2</td>
<td>2.8</td>
<td>1.72</td>
<td>0.2</td>
<td>2.1</td>
</tr>
</tbody>
</table>

**Q-T Interval.** The Q-T intervals, plotted against the corresponding R-R measurements are presented in figure 4. The Q-T intervals were within normal limits in 35 cases and slightly increased in 11 cases. Following pulmonary valvulotomy, the Q-T interval decreased in 16 instances, the postoperative measurements being within normal range of variation in 41 instances.

**Electrical Axis of the QRS Complex and Electrical Position of the Heart.** Right axis deviation was present in all the cases before the operation; the average angle was 134.5 degrees (table 3). Extreme right axis deviation, with negative main deflections in the three standard leads, was recorded in one case. There was a decrease in the angle of the electrical axis in 41 cases after the operation (figs. 1, 3, 6 and 7). The average postoperative angle was 110.3 degrees.

Prior to operation, the electrical position of the heart was vertical or semivertical in 41 of the cases (table 3). No significant change in the electrical position of the heart was recorded after the operation.

**Q Wave.** In most of the leads, no significant changes were seen in the amplitude of the Q wave. An isolated Q wave was present in lead I in six cases pre- and postoperatively. In lead II, a Q wave was recorded in 18 cases before and in 16 cases after the operation. Lead III showed a Q wave in 33 cases. With regard to the unipolar limb leads and the precordial leads significant changes in the Q waves were recorded postoperatively only in lead $aV_R$ (figs. 1, 3, 5 and 6).

**R Wave.** Significant changes in the amplitude of the R waves were recorded in lead $V_1$ (table 4). Following pulmonary valvulotomy, a decrease in this measurement occurred in 40
Fig. 5. The shape of the QRS complex in aVR in 46 cases of pure pulmonary stenosis (A) before and (B) after pulmonary valvulotomy. In lead aVR, the R wave was greater than the Q wave in 41 patients before the operation. Note the decrease in the R/Q ratio after the operation. At the last postoperative examination the positive deflection of the QRS complex was greater than the negative in only 14 cases.

the changes in the R waves after the operation.

S Wave. There was as a rule a diminution in the amplitude of the S waves in lead I after the operation (average amplitudes 1.49 and 0.98 mV.). In lead III, an S wave was present in 10 cases before and in 6 cases after the operation. An S wave was recorded in lead II in 32 cases before and in 27 cases after the operation. The unipolar limb leads did not reveal any significant changes in the S waves. In aVR, a separate S wave was not recorded in a single instance before or after the operation (fig. 5). S waves were present in all the cases in aVL. Lead V₁ showed an S wave in only five cases before and after the operation. In V₅, an S wave was recorded in 42 cases before the operation. Following pulmonary valvulotomy, the amplitude of the S wave in V₅ decreased in 36 instances. Figures 1, 3, 6 and 7 illustrate the postoperative changes in the S waves.

R/S and R/Q Ratio. In many leads, changes in the ratio between the amplitude of the R wave and that of the main negative deflection were recorded after the operation. An increase in this ratio was usually seen in lead I and a corresponding decrease in lead III; this was consistent with the shift of the electrical axis towards the left. Significant changes also occurred in aVR (figs. 1, 3, 5 and 6). Figure 5 shows that the positive deflection in aVR was greater than the negative in 41 cases before the operation. Following pulmonary valvulotomy, this ratio decreased in 41 cases and in only 14 instances was the positive deflection bigger than the negative at the last examination. A postoperative increase in the R/S ratio in V₅ was recorded in 31 instances.

Onset of the Intrinsicoid Deflection. In lead V₁, the average time of onset of the intrinsicoid deflection before the operation was 0.048 second. A decrease in this measurement was recorded in 35 cases; the average postoperative measurement was 0.033 second. Lead V₅ did not show any changes in the time of onset of the intrinsicoid deflection; the average pre- and postoperative values were 0.024 second.

An rSR' or RSR' pattern in V₅, suggestive of partial right bundle-branch block, was recorded in five cases before the operation. Four of these cases showed evidence of patency of the foramen ovale. In three instances, an rSR' or RSR' pattern appeared in V₃ following pulmonary valvulotomy. Figure 6 illustrates one of these cases.

S-T Segment. The S-T segments were normal in all the leads in 8 of the 46 cases. Table 5 shows that the remaining patients presented S-T depression or strain in one or more leads. These changes were most frequently seen in leads III, aVR and in V₁. Lead V₅ revealed changes in the S-T segments in four cases; in all of these, there was a marked clockwise rotation of the heart with right ventricular surface pattern recorded from V₅ through V₇. Following pulmonary valvulotomy, in 20 instances the S-T segments became normal in all the leads. Figures 1, 2, 3, 6 and 7 illustrate the changes of the S-T segments after the operation.

T Wave. Table 6 illustrates the direction of the T waves in the different leads before and after the operation. In lead I, a diminution in the amplitude of the T wave was recorded in 31 instances; the average pre- and postoperative measurements were respectively 0.287 and 0.197 mV. In V₁, the average amplitude of the T wave was -0.403 mV. Following surgery, the average amplitude was -0.360 mV; thus, there was a slight decrease in the
negativity of the T wave in this lead. Figures 1, 2, 3, 6 and 7 illustrate the postoperative changes in the T waves.

**CLINICAL DATA**

The exercise tolerance was within normal limits in four cases before the operation; the remainder of the patients showed varying degrees of incapacity. Following surgery, the exercise tolerance improved in 43 cases and at the last postoperative examination it was considered normal in 38 instances.

**Table 5.—The S-T Segments in Forty-Six Cases of Pure Pulmonary Stenosis (A) before and (B) after Pulmonary Valvulotomy**

<table>
<thead>
<tr>
<th>Normal S-T Segments in All Leads</th>
<th>S-T Depression or Strain. No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>I</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>28</td>
</tr>
</tbody>
</table>

**Table 6.—Direction of the T Wave in Different Leads in Forty-Six Cases of Pure Pulmonary Stenosis (A) before and (B) after Pulmonary Valvulotomy**

<table>
<thead>
<tr>
<th>Direction of T Wave</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>aVR</th>
<th>aVL</th>
<th>aVF</th>
<th>V1</th>
<th>V5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>45</td>
<td>45</td>
<td>23</td>
<td>36</td>
<td>7</td>
<td>22</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Isoelectric or diphasic</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>10</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Negative</td>
<td>—</td>
<td>17</td>
<td>5</td>
<td>14</td>
<td>37</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

The average preoperative systolic blood pressure was 105.5 mm. Hg. This pressure did not change. The diastolic blood pressure slightly decreased in 23 instances following pulmonary valvulotomy. The average pre- and postoperative diastolic blood pressures were 70.5 and 65.5 mm. Hg.

Cardiac catheterization was carried out in 30 cases preoperatively. In 26 cases the right ventricular systolic pressure exceeded 100 mm. Hg, the average systolic pressure being 144 mm. Hg. Twelve patients were recatheterized after the operation; in these cases the systolic pressure in the right ventricle had decreased by an average of 60.2 mm. Hg. There was a positive correlation between the degree of this pressure fall and the degree of the changes in the electrocardiogram (figs. 1 and 7).

The size of the heart, as determined by x-ray films, was within normal limits in 21
cases before the operation. Cardiac enlargement, with a cardiothoracic ratio between 45 and 55 per cent, was present in 18 cases, and in seven cases the ratio exceeded 55 per cent. During the early postoperative period, an increase in the size of the heart often occurred. At the last postoperative examinations, 23 of the patients still revealed various degrees of cardiac enlargement. As compared with the preoperative measurements, the size of the heart had decreased in 19 cases; the most marked decrease usually occurred in the younger age groups. In 24 instances there was no obvious difference between the size of the heart before and after the operation. In three instances, the last examination showed that the heart had increased over its preoperative size. No significant relation was observed between the size of the heart and the degree of the postoperative changes in the electrocardiogram. Thus, in many instances, although after operation the size of the heart had remained unchanged, there was a marked change of the electrocardiogram towards normal combined with a fall in the right ventricular pressure.

Discussion

Significant changes, which followed a uniform trend, were recorded in the electrocardiograms after pulmonary valvulotomy. Inasmuch as the electrocardiograms had remained unchanged on repeated preoperative examinations, the assumption is justified that the vast majority of these changes were a direct result of the operation on the heart.

A slight decrease in the heart rate occurred, as a rule, after the operation. This change may have been a direct effect of the valvulotomy on the heart action. The possibility, however, that the decrease in the heart rate was in part a physiologic phenomenon due to increasing age should also be borne in mind.

The average amplitude of the P wave before the operation was about twice as high as that described in normal children. It is generally agreed that a high P wave suggests right auricular enlargement. The significant diminution in the amplitude of the P waves after the operation, the average measurement being within normal limits on the last postoperative examination, therefore, suggests a lessening of the load on the right auricle.

The Q-T interval was slightly increased in 14 cases before the operation, and a decrease in this measurement was recorded in 16 instances postoperatively. In this connection it is of interest that Alexander and associates found the Q-T intervals to be within normal limits in 13 adult patients with right ventricular hypertrophy.

High R waves in proportion to the S waves in V1 have been considered by many authors one of the most important electrocardiographic evidences of right ventricular hypertrophy. In the present study, the
average amplitude of the R waves in V1 was about three times greater than that in normal children, and an S wave was recorded in this lead in only five instances. Following pulmonary valvulotomy, a decrease in the amplitude of the R waves in V1 was observed in 40 of the 46 cases. Indeed, the average amplitude of the R waves after the operation was about half of that before the operation. Therefore, it seems safe to assume that the decrease in the amplitude of the R waves in V1 reflected the diminished load on the right ventricle after the operation.

In aVR, the positive deflection of the QRS complex was greater than the negative deflection in 41 cases before the operation. It is worthy of note that Goodwin, in a study of 53 healthy children, never observed the positive deflection to be greater than the negative deflection in aVR. Children with right ventricular hypertrophy, on the other hand, frequently showed a relatively high R wave in this lead. Thus, although an R/Q ratio of more than unity in aVR, according to a general concept, merely indicates clockwise rotation of the heart, it appears to be a suggestive indirect sign of right ventricular preponderance. This assumption is supported by the fact that a significant decrease in the R/Q ratio in aVR was observed in the majority of the cases after the operation.

Depression of the S-T segments and T-wave inversion in leads II and III, especially when combined with right axis deviation, have been considered signs of right ventricular hypertrophy according to a concept advanced by Barnes and Whitten. In the present study, S-T depression or strain was recorded before the operation in the majority of the cases in leads II, III, aVF, or V1. Following pulmonary valvulotomy, these changes usually disappeared, which suggests a diminished load on the right ventricle. The same applies to the T waves, which, prior to operation, were inverted in leads II, III and aVp, and frequently became positive after the operation.

The upper limit of the time of onset of the intrinsicoid deflection V1 in normal children is estimated at approximately 0.030 second. An increase in this measurement is considered by many investigators a strongly suggestive sign of right ventricular hypertrophy. In the present study, the average time of onset of the intrinsicoid deflection in V1 was 0.048 second. Following pulmonary valvulotomy, a decrease in this measurement was recorded in 35 instances. No corresponding changes were recorded in V5 in which the onset of the RS deflection was within normal limits before the operation as well as postoperatively. This observation suggests that the left ventricular load, contrary to that of the right ventricle, was not diminished by the operation.

An rsR' or RSR' pattern in V1, suggestive of partial right bundle-branch block, was recorded in five cases before the operation. Opinions still differ as to whether partial bundle-branch block, per se, represents a mild conduction defect or whether it is a sign of ventricular hypertrophy. It is noteworthy that, in the present study, partial right bundle-branch block appeared in three cases following pulmonary valvulotomy. Since, in these cases, the electrocardiograms revealed evidence of a diminished load on the right ventricle combined with a fall in the right ventricular pressure, it seems reasonable to assume that the bundle-branch block which appeared after the operation was a conduction defect rather than a sign of ventricular hypertrophy.

As a rule, the postoperative changes in the electrocardiogram had stabilized about three months after pulmonary valvulotomy, and thereafter the tracings did not significantly change.

It is worthy of note that in a substantial number of the cases, the size of the heart did not diminish after surgery even in instances which showed a marked drop in the right ventricular pressure. The discrepancy between the marked clinical improvement and the failure of the heart to decrease in size following pulmonary valvulotomy has been observed by several investigators. In the present study, the electrocardiograms as a rule revealed signs of diminished load on the right ventricle after the operation even in those cases in which the size of the heart had re-
remained unchanged. These findings indicate that electrocardiography is a sensitive method for measuring the degree of right ventricular strain. Therefore, comparative electrocardiograms taken before and after operation offer a simple and useful means for the evaluation of the result of valvulotomy in pure pulmonary stenosis.

**Summary**

Forty-six cases of pure pulmonary stenosis were studied before and after pulmonary valvulotomy. The majority of the patients were children. In each case, 60 electrocardiographic measurements were studied pre- and postoperatively.

The patients showed a uniform electrocardiographic pattern before the operation. Right axis deviation was present in all the cases. The electrical position of the heart was classified as vertical or semivertical in 41 instances. The average amplitude of the P waves was considerably greater than normal. The R waves in V1 were high and delayed and S waves were present in this lead in only five instances. In aV1, the R/Q ratio was greater than unity in 41 cases. Normal S-T segments in all the leads were recorded in only eight cases; the remainder of the patients showed S-T depression in one or more leads. These changes were most frequently seen in leads II, III, aVf and V1. In addition, these leads frequently showed T-wave inversion.

After pulmonary valvulotomy, transient changes in the electrocardiogram, mainly T-wave inversion and extrasystoles, suggestive of myocardial or pericardial involvement, frequently occurred during the early postoperative period.

The electrocardiograms taken at the last postoperative examinations (three months to four years after the operation) revealed significant changes as compared with the preoperative tracings.

A slight decrease was recorded in the average heart rate.

The amplitude of the P waves diminished in 40 instances. A decrease in the duration of the P wave occurred in 33 instances.

The Q-T interval decreased slightly in 16 cases.

A decrease in the angle of the electrical axis occurred in 41 instances.

The amplitude of the R waves in V1 decreased in 40 cases. In three instances signs of partial right bundle-branch block appeared after the operation. In V1, the onset of the intrinsicoid deflection diminished in 35 cases.

The R Q ratio in aV1 decreased in 41 cases. In V1 an increase in the R/S ratio was recorded in 31 instances.

The S-T segments frequently became normal in leads II, III, aVf and V1; in these leads, the T waves frequently became positive.

The postoperative changes measured in the electrocardiogram were considered to be due to the diminished load on the right side of the heart.

The size of the heart frequently remained unchanged after surgery even in cases which showed significant changes in the electrocardiogram towards normal and a marked postoperative drop in the right ventricular pressure.

**Sumario Español**

Cuarenta y seis casos de estenosis pulmonar pura fueron estudiados antes y después de valvulotomía pulmonar. La mayoría de los casos fueron niños. En cada caso, 60 medidas electrocardiográficas fueron estudiadas antes y después de la operación.

Los pacientes mostraron un patrón electrocardiográfico uniforme antes de la operación. Desviación del eje estuvo presente en todos los casos. La posición eléctrica del corazón clasificada como vertical o semivertical en 41 casos. La amplitud promedio de la onda P fue considerablemente más grande que lo normal. Las ondas R en V1 fueron altas y tardías y las ondas S estuvieron presentes en esta derivación en solo cinco casos. En aV1 la proporción R/Q fue mayor que unidad en 41 casos. Segmentos S-T normales en todas las derivaciones fueron registrados en solamente ocho casos; el restante de pacientes mostraron depresión del segmento S-T en una o más derivaciones. Estos cambios fueron más frecuentemente ob-
servados en las derivaciones II, III, aVF y V1. En adición estas derivaciones frecuentemente mostraron inversión de las ondas T.

Luego de la valvulotomía pulmonar en el período temprano postoperatorio se observaron cambios transitorios en el electrocardiograma, principalmente inversión de las ondas T y extrasístoles, sugestivos de daño al miocardio o pericardio.

Los electrocardiogramas tomados en el último examen postoperatorio (de tres meses a cuatro años después de la operación) revelaron cambios significativos al ser comparados con los trazados preoperatorios.


La proporción R/Q en aVR disminuyó en 41 casos. En V5 un incremento en la proporción R/S se registró en 31 casos.

Los segmentos S-T frecuentemente se normalizaron en las derivaciones II, III, aVF y V1; en estas derivaciones, las ondas T frecuentemente se tornaron positivas.

Los cambios postoperatorios determinados en el electrocardiograma fueron considerados ser causados por la disminución en el trabajo del lado derecho del corazón.

El tamaño del corazón frecuentemente permaneció inalterado después de la operación aún en los casos que mostraron cambios significativos en el electrocardiograma hacia lo normal y una marcada disminución en la presión del ventrículo derecho.

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Postoperative Changes in the Electrocardiogram in Congenital Heart Disease: I. Pure Pulmonary Stenosis

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