Postoperative Changes in the Electrocardiogram in Congenital Heart Disease

II. Coarctation of the Aorta and Patent Ductus Arteriosus

By Bernhard Landtman, M.D.

Electrocardiograms of 41 cases of coarctation and of 73 cases of patent ductus arteriosus were analyzed before and after surgical correction of the defect. The changes in the electrocardiogram which occurred after surgical repair of the coarctation were considered to be due to the diminished load on the left ventricle. In 65 of the cases of patent ductus arteriosus, electrocardiographic signs of left ventricular hypertrophy were recorded. Eight patients, seven of whom presented atypical murmurs, showed evidence of right ventricular or combined ventricular hypertrophy. Following ligation of the ductus, the electrocardiogram became normal in the majority of the cases.

In a previous communication,1 postoperative changes in the electrocardiogram were presented in 46 cases of pure pulmonary stenosis. The electrocardiographic changes which occurred after valvulotomy were considered due to the diminished load on the right ventricle and right auricle.

The present report deals with corresponding changes in the electrocardiogram in coarctation of the aorta and in patent ductus arteriosus. In each case, 60 electrocardiographic measurements were analyzed before and after the operation. The methods have been described in the first part of the study.1 Again, in the presentation of the results, only significant changes in the electrocardiogram will be discussed in detail.

Coarctation of the Aorta

The Reported Electrocardiogram in Coarctation of the Aorta

There is no uniform agreement as to the electrocardiographic changes produced by coarctation of the aorta. According to some observers, the electrocardiogram is usually normal in coarctation and, therefore, of little help in the recognition of this malformation.2-4 Several authors have, however, commented on the frequent occurrence of left axis deviation in the standard leads in coarctation,7-11 Rhodes and Durbin,12 in a group of 116 patients of all ages, reported left axis deviation in 57 instances.

Since the advent of unipolar electrocardiography, evidence has been presented that coarctation occasionally shows left ventricular hypertrophy pattern in the precordial leads. Sokolow and Edgar,13 in a study of 32 cases, found electrocardiographic signs of left ventricular hypertrophy in 19 instances. Likewise, Oglesby and associates14 reported that in 8 out of 11 cases of coarctation the precordial leads showed left ventricular hypertrophy pattern. Alimurung and Smith15 came to similar conclusions in an electrocardiographic study of 10 cases of coarctation. Most of these observations were made on adult patients and no details were given as to the electrocardiographic criteria of left ventricular hypertrophy or strain employed.

Most investigators agree that right axis deviation very rarely occurs in coarctation unless there are additional cardiovascular anomalies13, 14, 17 or signs of heart failure.18

Solitary cases of coarctation which showed right bundle-branch block in the electrocardiogram have been reported by different observers.13-15, 19

The writer has failed to find reports in the literature on postoperative studies of the electrocardiogram in coarctation of the aorta.

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TABLE 1.—Average, Minimum and Maximum Duration and Amplitude of the P Wave, P-R Interval and QRS Duration in 41 Cases of Coarctation of the Aorta (A) before and (B) after Surgical Correction of the Coarctation. 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>0.130/0.050/0.300/0.060/0.060/0.120/0.165/0.110/0.200/0.073/0.050/0.100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.112/0.050/0.200/0.075/0.050/0.160/0.147/0.110/0.200/0.069/0.050/0.090</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. The Q-T intervals were derived from Bazett's formula Q-T = 0.404 √R-R. Prior to operation (o), in 35 instances, the Q-T interval was above the range of variation as described in normal children. Following surgical correction of the coarctation, the Q-T interval decreased in 35 cases. In 27 instances, the Q-T interval was within normal limits at the last examination (*). The Q-T intervals in 41 cases of coarctation of the aorta are summarized in Table 1. In 17 cases a slight decrease occurred in the amplitude and the duration of the P wave after the operation. No significant changes were seen in the average P-R interval or in the QRS duration.

Material

The material comprised the electrocardiograms of 41 cases of uncomplicated coarctation of the aorta. There were 27 males and 14 females. The age of the patients ranged between 5 and 25 years. Thirty-seven of the patients were under 15 years of age at the time of the operation. The time interval between the operation and the last postoperative electrocardiogram ranged between three months and five years. In 31 cases the period of observation exceeded six months (average 15.2 months).

The operations were done by Dr. Blalock or by members of his surgical staff at the Johns Hopkins Hospital. In 37 cases, the surgical technic consisted of resection of the coarctation and end-to-end aortic anastomosis. In the four remaining cases, the coarctation was too long to permit such a procedure. In three of these cases, an anastomosis was created between the left subclavian artery and the aorta beyond the obstruction. In one case, after resection of the coarctation, an arterial homograft was inserted between the proximal and distal segments of the aorta.

Results of Present Study

Rhythm and Rate. A normal sinus rhythm was recorded in 40 of the cases. Prior to operation, one patient showed occasional extrasystoles; following surgery, the rhythm became normal. In some instances, arrhythmias, mostly extrasystoles, were recorded as transient phenomena during the early postoperative period. In one case occasional extrasystoles were recorded at the last postoperative examination.

Prior to operation, the average heart rate was 90.3 beats per minute. Following surgery, a slight decrease in the heart rate occurred in most of the cases. At the last postoperative examination, the average rate was 82.2 beats per minute.

P Wave, P-R Interval and QRS Duration. The pre- and postoperative measurements are summarized in Table 1. In 17 cases a slight decrease occurred in the amplitude and the duration of the P wave after the operation. No significant changes were seen in the average P-R interval or in the QRS duration.

Q-T Interval. Figure 1 illustrates the Q-T intervals before and after surgical correction of the coarctation. In 35 of the cases, the Q-T interval was above the normal range of variation. Following surgery, a decrease in the Q-T interval was recorded in 35 cases. At the last postoperative examination, the interval was within normal limits in 27 cases.

Electrical Axis of the QRS Complex and Electrocardiographic Position of the Heart. Prior to operation, a balanced axis was present in 25 of the cases. Left axis deviation, which ranged between −60 and +30 degrees, was recorded in 14 instances. Two patients showed right axis deviation. For the entire group, the average angle of the electrical axis was 15 degrees. Following operation, an increase in the angle was recorded in 22 instances. At the last postoperative examination the average angle was 23.2 degrees. At this time, left axis deviation was present in nine and right axis deviation in two instances.
Prior to operation, the electrocardiographic position of the heart was vertical or semiver- tical in 22 cases and horizontal or semihorizontal in 10 cases. An intermediate position was present in seven cases. In two instances, the position was indeterminate. Following surgery, in nine cases, the heart assumed a vertical or semivertical electrical position. At the last postoperative examination, a vertical or semivertical position was recorded in 31 cases and a horizontal or semihorizontal in five instances.

Q Wave. No significant changes were seen in the incidence or in the amplitude of the Q waves in the different leads. Lead I showed a Q wave in 14 cases. In lead II, the corresponding figure was 20. In lead III, a Q wave was present in 16 cases before and in 22 cases after the operation. None of the cases showed a Q wave in lead V1. In V5, a Q wave was recorded in 31 cases before and in 33 cases after the operation.

R Wave. Significant changes in the R waves were recorded in lead V5 (table 2). Following operation, a decrease in this measurement occurred in 35 instances. In leads I, II and aVL, a slight decrease in the amplitude of the R wave occurred in 28 instances. The other leads did not reveal any significant changes in the R waves. Figures 2 to 4 illustrate the postoperative changes in the R waves in the different leads.

S Wave. In lead III, a decrease in the amplitude of the S wave was recorded in 24 cases; the average pre- and postoperative measurements were 0.31 and 0.20 mv. A slight decrease in the average amplitude of the S wave was also recorded in leads II (from 0.32 to 0.18 mv.), in aVF (from 0.22 to 0.16 mv.) and in V1 (from 1.51 to 1.15 mv.).

R/S and R/Q Ratio. Following surgery, a decrease in the R/S ratio in lead I and a corresponding increase in this ratio in lead III was recorded in the majority of the cases. This was consistent with the slight shift of the electrical axis towards the right. In V1, the R/S ratio was less than unity in all the cases; an

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>aVL</th>
<th>aVF</th>
<th>V1</th>
<th>V5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Av. 1.32</td>
<td>0.20</td>
<td>2.10</td>
<td>1.45</td>
<td>0.40</td>
<td>2.20</td>
</tr>
<tr>
<td>B</td>
<td>Av. 0.93</td>
<td>0.20</td>
<td>2.00</td>
<td>1.28</td>
<td>0.40</td>
<td>2.20</td>
</tr>
</tbody>
</table>

Fig. 2. A. Electrocardiogram of a male, 21 years of age, with coarctation of the aorta. Slight depression of the S-T segments in leads I, II and aVF. Diphasic T wave in V5. The blood pressure was 190/100 mm. Hg. B. Twelve months after surgical correction of the coarctation. The S-T segments have become normal. In V5, time of onset of the intrinsicoid deflection has decreased, and the T wave has become positive. The blood pressure was 130/80 mm. Hg.
FIG. 3. A. Electrocardiogram of a girl, 8 years of age, with coarctation of the aorta. Slight depression of the S-T segments in leads I, II, aVF, and V5. The blood pressure was 165/80 mm. Hg. B. Three months after surgical correction of the coarctation. The S-T segments have changed towards normal. In V5 the time of onset of the intrinsicoid deflection and the amplitude of the R wave have decreased. The blood pressure was 125/85 mm. Hg.

FIG. 4. A. Electrocardiogram of a girl, 13 years of age, with coarctation of the aorta. Slight depression of the S-T segments in leads II, aVF and V5. The blood pressure was 180/100 mm. Hg. B. Nine months after surgical correction of the coarctation. Note the shift of the electrical axis towards right. The S-T segments have changed towards normal. A rSR’ pattern has appeared in V1. In V5, the amplitude of the R wave has diminished, and the time of onset of the intrinsicoid deflection has decreased. The blood pressure was 100/60 mm. Hg.

increase in this ratio was recorded in 28 instances. In V₅, the R/S ratio was greater than unity in all the cases. Following surgery a decrease in this ratio was recorded in 27 cases. It is worthy of note that in aVR the amplitude of the R wave never exceeded that of the main negative deflection. In this lead, 20 of the cases showed a QS pattern (figs. 2 and 3). An isolated Q wave was present in 16 cases (figs. 4 and 5) and a separate S wave in five instances.

Onset of the Intrinsicoid Deflection. Prior to operation, lead V₁ showed an average time of onset of the RS deflection of 0.018 second; this
TABLE 3.—The S-T Segments in Different Leads in 41 Cases of Coarctation of the Aorta (A) before and (B) after Surgical Correction of the Coarctation

<table>
<thead>
<tr>
<th>Normal S-T Segments in All the Leads, No. of Cases</th>
<th>S-T Depression or Strain, No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 20</td>
<td>I 5 II 9 III 4 aVR — aVL — aVF 5 V1 10</td>
</tr>
<tr>
<td>B 31</td>
<td>I 1 II 2 III 4 aVR — aVL — aVF 3 V1 1 V2 3</td>
</tr>
</tbody>
</table>

measurement did not change. An rSR' or RSR' pattern in V1, suggestive of partial right bundle-branch block, was recorded in three cases before and in four cases after the operation. In lead V5, the average time of onset of the intrinsicoid deflection was 0.035 second. Following surgery, this measurement diminished in 34 cases; the average measurement was 0.029 second at the last postoperative examination (figs. 2 to 4).

S-T Segment. Prior to operation, the S-T segments were normal in all the leads in 20 of the 41 cases (table 3). The remaining patients revealed S-T depression or strain in one or more leads. These changes were most frequently seen in leads V5, II, I and aVF. Following operation, in 11 cases the S-T segments became normal. Figures 2–4 show the postoperative changes in the S-T segments.

T Wave. The T waves were normal in the majority of the cases. Table 4 shows that the T waves were consistently positive in lead I and only exceptionally negative or diphasic in leads II, aVL, and V6. No significant changes occurred in the direction or in the average amplitude of the T waves after the operation.

Clinical Data

None of the patients showed signs of heart failure. Prior to operation, the average systolic pressure was 166 mm. Hg. In 32 cases, the systolic pressure exceeded 150 mm. Hg. Following surgical correction of the coarctation a decrease in the systolic blood pressure was recorded in 40 instances; the average systolic reading was 126.1 mm. Hg at the last examination. Prior to operation the average diastolic blood pressure was 99.3 mm. Hg. Following surgery, the diastolic pressure decreased in 38 instances. At the last postoperative examination the average diastolic pressure was 77.7 mm. Hg. Prior to surgery, the blood pressure was obtainable in the legs in only eight cases. Following surgery, the blood pressure was recorded in the legs in all the cases, the average systolic pressure at the last examination being 130.1 mm. Hg.
TABLE 4.—The Direction of the T Wave in Different Leads in 41 Cases of Coarctation of the Aorta (A) before and (B) after Surgical Correction of the Coarctation

<table>
<thead>
<tr>
<th>Direction of the T Wave</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>aV₁</th>
<th>aV₂</th>
<th>aV₃</th>
<th>VI</th>
<th>V₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>41</td>
<td>41</td>
<td>38</td>
<td>38</td>
<td>15</td>
<td>15</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>Isoelectric or diphasic</td>
<td>—</td>
<td>—</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Negative</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>1</td>
<td>19</td>
<td>16</td>
<td>41</td>
<td>41</td>
</tr>
</tbody>
</table>

There was a positive correlation between the postoperative fall in the blood pressure and the degree of the changes in the electrocardiogram towards normal (figs. 2 to 5).

The size of the heart, as determined by x-ray, was within normal limits in 32 cases. The remaining patients showed slight or moderate cardiac enlargement. Following surgery, the size of the heart decreased in 13 cases. At the last examination, seven patients still revealed slight cardiac enlargement. No significant correlation was seen between the size of the heart and the degree of the postoperative changes in the electrocardiogram.

PATENT DUCTUS ARTERIOSUS

The Reported Electrocardiogram in Patent Ductus Arteriosus

Many investigators agree that the electrocardiogram is normal in the majority of patients with uncomplicated patent ductus arteriosus. More recently, however, evidence has been brought forward that patent ductus arteriosus may occasionally show signs of left ventricular hypertrophy in the precordial leads. Sokolow and Edgar, in a study of 39 cases, found electrocardiographic evidence of left ventricular hypertrophy in the precordial leads in 17 instances. The main changes described are high and delayed R waves and inversion of the T waves in left ventricular surface leads.

It has been said that the presence of electrocardiographic evidence of right ventricular hypertrophy is so rare in patent ductus arteriosus as to practically exclude an uncomplicated lesion. Gross in a series of 526 cases, found right ventricular preponderance in the electrocardiogram in only six instances. Occasionally, however, patent ductus arteriosus may show electrocardiographic evi-

dence of right ventricular or combined ventricular hypertrophy especially in young infants and in patients with pulmonary hypertension.

Cabrera and his associates, in 1952, reported on postoperative changes in the electrocardiogram in 33 cases of patent ductus arteriosus. Changes such as a decrease in the duration of the P wave, diminution of the amplitude of the R and the T waves in lead V₅, and changes in the S-T segments were recorded in a number of cases. In many instances, the electrocardiograms were taken a few hours after the operation; in the entire group the average period of observation was only 30 days.

Solitary cases of patent ductus arteriosus which showed postoperative changes in the electrical axis in the standard leads have been reported by different authors.

Material

Electrocardiograms of 73 cases of uncomplicated patent ductus arteriosus were included in the study. There were 28 males and 45 females. At the time of the operation, the age of the patients ranged between 5 months and 28 years. Sixty-two of the patients were under 10 years of age.

In all the cases, the ductus was closed by means of the suture ligation technic described by Blalock. The time interval between the operation and the last postoperative electrocardiogram ranged between three months and five years. In 55 cases the time interval exceeded six months (average 14 months).

Results of Present Study

Rhythm and Rate. Prior to operation, 70 of the patients showed a normal sinus rhythm. Occasional extrasystoles were recorded in three instances. Transient arrhythmias, mostly extrasystoles, frequently occurred during the early postoperative period. At the last ex-
amination all the patients showed a normal sinus rhythm.

Prior to operation, the average heart rate was 100.6 beats per minute. Following ligation of the ductus, a slight decrease in the heart rate usually occurred; the average rate was 92.2 beats per minute at the last examination.

**P Wave, P-R Interval and QRS Duration.**

Following surgery, a slight diminution in the amplitude of the P wave was recorded in 35 instances (table 5). A slight decrease in the duration of the P wave occurred in 45 instances. A slight decrease in P-R interval and in the QRS duration was found in 35 instances.

**Q-T Interval.** Figure 6 shows that the Q-T interval was within normal limits in 25 instances. The remaining cases exhibited a prolonged Q-T interval. Following ligation of the ductus, a decrease in the Q-T interval was recorded in 30 instances. At the last examination, the Q-T interval was normal in 52 instances.

**Electrical Axis of the QRS Complex and Electrocardiographic Position of the Heart.** In 54 cases, the QRS complexes showed a balanced axis. Left axis deviation, which ranged between -60 and +30 degrees, was present in 13 cases. Five patients revealed right axis deviation between +90 and +150 degrees. Extreme right axis deviation with negative main deflections in the standard leads was recorded in one case (fig. 10). For the entire group, the average electrical angle was 52.2 degrees. Following ligation of the ductus, a slight increase in the electrical angle occurred in 40 instances. At the last postoperative examination the average angle was 60 degrees.

**Table 5.** Average, Minimum and Maximum Duration and Amplitude of the P Wave, P-R Interval and QRS Duration in 75 Cases of Patent Ductus Arteriosus (A) before and (B) after Ligation of the Ductus. 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></td>
<td>Amplitude, mV</td>
<td>Duration, sec.</td>
<td>Duration, sec.</td>
</tr>
<tr>
<td>A</td>
<td>Av. 0.120, Min. 0.050, Max. 0.200</td>
<td>Av. 0.146, Min. 0.040, Max. 0.190</td>
<td>Av. 0.105, Min. 0.040, Max. 0.100</td>
</tr>
<tr>
<td>B</td>
<td>Av. 0.098, Min. 0.050, Max. 0.200</td>
<td>Av. 0.132, Min. 0.100, Max. 0.170</td>
<td>Av. 0.065, Min. 0.040, Max. 0.100</td>
</tr>
</tbody>
</table>

At this time, 58 of the cases showed a balanced axis. Left and right axis deviation were present in respectively 11 and 4 cases.

The electrical position of the heart was vertical or semivertical in 60 cases. A horizontal or semihorizontal position was present in four cases. In seven instances, the position was intermediate. No significant changes occurred in the electrocardiographic position of the heart after the operation.

**Q Wave.** No significant changes were seen in the Q waves. In lead I, an isolated Q wave was present in 10 cases before and in 12 cases after the operation. Lead II and III showed a Q wave in respectively 34 and 44 cases. A slight increase in the amplitude of the Q wave was recorded in lead III; the average pre- and postoperative measurements were 0.178 and 0.205 mV. In leads V1 and V5, an isolated Q wave was recorded in 4 and in 68 cases, respectively; no changes occurred after operation.

**R Wave.** Following surgery, a decrease in the amplitude of the R wave in V5 occurred in 66 cases (table 6). A slight decrease in the amplitude of the R wave usually occurred in the three standard leads and in aVF. Figures 7 to 10 illustrate the postoperative changes in the R waves.

**S Wave.** In V1, a significant decrease in the
amplitude of the S wave occurred in 55 instances; the average pre- and postoperative amplitudes were 1.58 and 1.04 mv. A corresponding increase in the amplitude of the S wave was registered in V₅. A slight decrease in the average amplitude of the S wave occurred in aVR (from 1.13 to 0.89 mv.).

R/S and R/Q Ratio. A decrease in the R/S ratio in lead I and a corresponding increase in lead III were recorded in most of the cases. This was consistent with the slight postoperative shift of the electrical axis towards the right. In V₁, the R/S ratio was less than unity in 65 cases before and in 72 cases after operation. In V₅, the amplitude of the R wave exceeded that of the S wave in all the cases. Following ligation of the ductus, the R/S ratio in V₅ decreases in 53 instances. In aVR, the amplitude of the R waves was greater than that of the main negative deflection in only four cases before and in three cases after operation. This lead showed a QS pattern in 39 cases (figs 7–9), an isolated Q wave in 21 cases (fig. 10) and an S wave in 13 instances. Following operation, a slight increase in the ratio between the positive and the negative
deflection in aVR was recorded in 47 of the cases. Figures 7 to 10 illustrate the changes in the R/S ratios.

Onset of the Intrinsicoid Deflection. Prior to operation, V₅ showed an average time of onset of the intrinsicoid deflection of 0.038 second. Following surgery, a decrease in this measurement was recorded in 55 of the cases; the average measurement was 0.025 second at the last postoperative examination. No changes were seen in the time of onset of the intrinsicoid deflection in V₁ which was 0.022 second. An rSR' or RSR' pattern in V₁ suggestive of partial right bundle-branch block was re-
POSTOPERATIVE ELECTROCARDIOGRAM IN HEART DISEASE. II

Fig. 10. A. Electrocardiogram of a male, 7 months of age, with patent ductus arteriosus. The infant was in cardiac failure. The electrocardiogram exhibits signs of right ventricular hypertrophy. Extreme right axis deviation. High R waves in aVR and V1. The diameter of the ductus was 8 mm. B. Eighteen months after ligation of the ductus. Left axis deviation. In aVR and V1, the ratios between the positive and the negative deflections of the QRS complex have decreased. The tracing is within normal limits.

TABLE 7.—The S-T Segment in Different Leads in 73 Cases of Patent Ductus Arteriosus (A) before and (B) after Ligation of the Ductus

<table>
<thead>
<tr>
<th>Normal S-T Segments in All Leads, No. of Cases</th>
<th>S-T Depression or Strain. No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>I  II  III  aVR  aVL  aVF  V1  V5</td>
<td></td>
</tr>
<tr>
<td>A  48  13  8  3  1  4  10  —  17</td>
<td></td>
</tr>
<tr>
<td>B  66  2  3  1  1  —  2  1  2</td>
<td></td>
</tr>
</tbody>
</table>

recorded in three cases before and in four cases after the operation (fig. 4).

S-T Segment. Prior to operation, 48 of the patients showed normal S-T segments in all the leads (table 7). The remainder of the patients revealed S-T depression or strain in one or more leads. These changes were most frequently recorded in leads V5, I, and aVF. The S-T segments frequently became normal after the operation. At the last postoperative examination, the S-T segments were normal in all the leads in 66 instances. Figures 7 and 8 illustrate the postoperative changes in the S-T segments.

T Wave. Changes in the direction of the T waves were occasionally recorded (table 8). There was a slight postoperative increase in the average amplitude of the T wave in lead I. A slight decrease in this measurement was recorded in leads III, aVF and V5. Figures 7 to 10 illustrate the changes in the T waves.

Clinical Data

In 65 of the cases, a typical continuous murmur and electrocardiographic evidence of left ventricular preponderance was recorded. The remaining eight cases which presented atypical murmurs were confined to the youngest age groups. Prior to operation, seven of these patients showed electrocardiographic evidence of right ventricular or combined ventricular hypertrophy (fig. 10). Three of these patients showed signs of heart failure.

Prior to operation, the average systolic blood pressure was 108.3 mm. Hg, and no significant changes occurred. The diastolic pressure, on the other hand, increased in 62 cases; the average pre- and postoperative readings were 41.2 and 66.2 mm. Hg.

The size of the heart was within normal limits in 54 cases. Cardiac enlargement, with a cardiothoracic ratio between 45 and 60 per cent, was present in 14 instances. In five patients, all of whom were small children, the ratio exceeded 60 per cent. Following ligation of the ductus, a decrease in the size of the heart occurred in 16 cases. The most marked diminution in the size of the heart was usually seen in the youngest age groups. At the last postoperative examination, 10 patients revealed a moderate enlargement of the heart.

TABLE 8.—The Direction of the T Wave in Different Leads in 73 Cases of Patent Ductus Arteriosus (A) before and (B) after Ligation of the Ductus

<table>
<thead>
<tr>
<th>Direction of the 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>64</td>
<td>72</td>
<td>70</td>
<td>70</td>
<td>63</td>
<td>54</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Isoelectric or diphasic</td>
<td>3</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>6</td>
<td>12</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>Negative</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>—</td>
<td>4</td>
<td>7</td>
<td>68</td>
<td>71</td>
</tr>
</tbody>
</table>

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No significant correlation was observed between the size of the heart and the degree of the electrocardiographic changes after the operation.

The diameter of the ductus varied between 5 and 19 mm. In 11 cases, the diameter exceeded 10 mm. There was as a rule a positive correlation between the size of the ductus and the changes in the electrocardiogram. Thus, the most marked changes were seen in patients with large ductuses, whereas the changes were less conspicuous in patients in whom the ductus was small (figs. 7 to 10).

**DISCUSSION**

Coarctation of the aorta causes an increased load on the left side of the heart. Hence, in the present series, the changes in the electrocardiogram that occurred after surgical correction of the coarctation offered indirect evidence of the electrocardiographic pattern which occurs with left ventricular preponderance.

The electrocardiographic changes in coarctation were not, as a rule, as conspicuous as those seen in right-sided heart strain produced by pure pulmonary stenosis. In many instances, the effect of the left ventricular strain on the electrocardiogram could be appreciated only by comparing the pre- and postoperative tracings.

Prior to operation, the average amplitude and duration of the P wave were within the normal limits as described in healthy young subjects. Following surgery, a slight decrease in these measurements was recorded in about half of the cases. This decrease probably reflected a lessening of work required of the left auricle.

It is worthy of note that the Q-T interval was prolonged in the majority of cases of coarctation. This observation is in keeping with reports according to which a prolonged Q-T interval frequently occurs in adult patients with hypertensive heart disease. As long ago as in 1892, Lüderitz made an observation which is of considerable interest. In pulse tracings made on experimental animals, he registered a prolongation of the systole duration by compressing the aorta. It is, therefore, possible that the marked postoperative decrease in the Q-T intervals which was observed in the present series was not necessarily a sign of diminished cardiac hypertrophy but rather due to a shorting of the phase of contraction of the left ventricle.

Prior to operation, the electrocardiographic position of the heart was horizontal or semi-horizontal in about one-fourth of the cases of coarctation. Yu and associates, in an electrocardiographic study of 100 normal children, did not record a horizontal position in a single case, nor was this position observed in pure pulmonary stenosis. Thus, a horizontal position of the heart in children seems to be suggestive of left ventricular preponderance. This assumption is supported by the fact that a shift of the electrical axis towards the right frequently occurred in coarctation after reduction of the work required of the left ventricle.

High voltage in the standard leads and high R waves in V and V have been considered electrocardiographic evidence of left ventricular hypertrophy. In the present series of coarctation the average amplitude of the R wave in the standard leads was at the upper limits of normal recorded for healthy children. Following surgery, a decrease in the amplitude of the R wave was recorded in leads I, II, aV, and in particular in V. Thus, the effect on the R waves of the diminution of the left ventricular load was best seen in these leads.

It is worthy of note that in aVR the amplitude of the R wave was less than that of the main negative deflection in all the cases of coarctation. In pure pulmonary stenosis the R/S or R/Q ratio in aVR was as a rule more than unity. Thus, although an R/S or R/Q ratio of less than unity is generally considered merely to indicate counterclockwise rotation of the heart, it seems to offer indirect evidence of left ventricular preponderance.

According to Veasy and Adams, the time of onset of the intrinsocid deflection in V in normal young subjects varies between 0.020 and 0.040 second. An increase in this measurement is considered by many authors a highly suggestive electrocardiographic sign of left ventricular hypertrophy.
present series of coarctation, the average ventricular activation time in V₅ was 0.035 second. Following surgery, a decrease in this measurement occurred in the majority of the cases; this suggested a lessening of the work required of the left ventricle. No corresponding changes were recorded in V₁ in which the average onset of the intrinsicoid deflection was normal before as well as after the operation. This suggests that the load on the right ventricle, contrary to that on the left ventricle, did not diminish after surgical correction of the coarctation.

Depression of the S-T segments and T-wave inversion in lead I²⁷-⁻³⁰ and in V₅⁽⁵²-⁻⁵⁴⁾ have been considered electrocardiographic signs of left ventricular hypertrophy and strain. In the present series of coarctation, S-T depression or strain was recorded in leads II and V₅ in about one quarter of the cases whereas the remaining leads rarely revealed such changes. Following surgery, the S-T segments usually became normal.

It is worthy of note that inversion of the T waves was never recorded in lead I and only exceptionally in leads II and V₅. Prior to operation, the average amplitude of the T wave in leads I, II, aVF and V₅ was slightly less than the corresponding measurements in normal children. On the whole, however, the results are in keeping with observations according to which changes in the S-T segments and in the T waves are relatively rare in children with left ventricular hypertrophy in contrast to adult patients with hypertensive heart disease.

In the series of patent ductus arteriosus which presented a typical continuous murmur, the electrocardiograms showed a basic pattern similar to that recorded in coarctation. As a rule, however, the electrocardiographic changes indicating left ventricular preponderance were more conspicuous in patent ductus arteriosus than in coarctation. Insofar as the electrocardiographic signs of left ventricular strain diminished after ligation of the ductus, the same comments as outlined in coarctation apply to the majority of the cases of patent ductus arteriosus.

Seven of the patients with patent ductus arteriosus exhibited an electrocardiographic pattern indicative of right ventricular or combined ventricular hypertrophy. Cardiac catheterization, performed in four of these cases, revealed an elevated pressure in the pulmonary artery. It has been suggested⁴⁸, ⁴⁰ that pulmonary hypertension occurring in patients with patent ductus arteriosus may occasionally be due to changes in the pulmonary vascular bed. In the present series, the electrocardiographic signs of right ventricular hypertrophy markedly decreased after ligation of the ductus. Thus, it appears as if the increased load on the right ventricle in these seven cases was not primarily due to permanent structural changes in the pulmonary vascular bed.

Mannheimer and associates⁴¹ have noticed that patients with patent ductus arteriosus frequently show a positive result of the hypoxia tolerance test. The electrocardiographic changes recorded during hypoxia were similar to those seen in coronary insufficiency. Following ligation of the ductus, the result of the test frequently became negative. This observation possibly suggests that the postoperative changes in the electrocardiogram which occurred in the present series may in part have been due to an improved coronary circulation.

The positive correlation which was found between the diameter of the ductus and the degree of the changes in the electrocardiogram is in keeping with observations made by Sokolow and Edgar.¹⁵ Likewise, several authors have commented on the fact that the pulse pressure usually decreases after ligation of patent ductus arteriosus.⁴⁹, ⁶²-⁻⁶⁴

It is worthy of note that the size of the heart did not decrease in a substantial number of the cases after ligation of the ductus. This phenomenon has previously been observed by different authors.⁴⁹, ⁵⁰ In the present series, the electrocardiogram usually revealed signs of a diminished load on the heart after ligation of the ductus. This observation, in conjunction with the corresponding observation made in pure pulmonary stenosis and in coarctation of the aorta, offers further evidence that electrocardiography is a sensitive means for measuring the degree of ventricular preponderance and, consequently, for the evaluation of the
benefits derived from surgical correction of cardiac defects.

Summary

Electrocardiograms of 41 cases of coarctation and of 73 cases of patent ductus arteriosus were analyzed before and after surgical correction of the defect. The majority of the patients were children. The time interval between the pre- and postoperative electrocardiograms varied between three months and five years.

Coarctation of the Aorta

Following surgery, a slight decrease in the heart rate occurred in the majority of the cases.

Prior to operation, the Q-T interval was prolonged in 35 of the cases. A decrease in the Q-T interval was recorded in 35 cases after the operation.

Twenty-five of the patients showed a balanced axis. Left axis deviation was present in 14 and right axis deviation in two instances. Postoperatively, a slight shift of the electrical axis towards the right occurred in the majority of the cases.

Following surgery, there was a slight decrease in the average amplitude of the R wave in leads I, II, aV₆, and V₅.

In all the cases, the R/S ratio was less than unity in V₁ and greater than unity in V₅. Following surgery, there was an increase in the R/S ratio in V₁ and a corresponding decrease in the ratio in V₅.

The onset of the intrinsicoid deflection in V₅ was slightly delayed in the majority of the cases. Following surgery, this measurement usually decreased.

S-T depression or strain was recorded in leads II and V₅ in approximately one quarter of the cases. Following surgery, these changes disappeared in most of the cases.

The postoperative changes in the electrocardiogram were considered to be due to the diminished load on the left ventricle.

The size of the heart frequently remained unchanged even in cases which showed a marked postoperative drop in the blood pressure combined with electrocardiographic evidence of a diminished load on the left ventricle.

Patent Ductus Arteriosus

Prior to operation, three patients showed occasional extrasystoles. At the last postoperative examination, a normal sinus rhythm was recorded in all the cases. Following ligation of the ductus, there was a slight decrease in the average heart rate.

Sixty-five of the patients presented typical continuous murmurs. These patients revealed a basic electrocardiographic pattern similar to that in coarctation. The electrocardiographic changes indicative of left ventricular preponderance, however, were more conspicuous in the cases of patent ductus arteriosus than in coarctation.

Seven of the patients showed electrocardiographic evidence of right ventricular or combined ventricular hypertrophy. All of these patients presented atypical murmurs.

Following ligation of the ductus, the electrocardiogram became normal in the majority of the cases. A positive correlation was found between the size of the ductus and the changes in the electrocardiogram.

The size of the heart frequently remained unchanged even in cases which showed electrocardiographic evidence of a diminished load on the heart.

SUMARIO ESPAÑOL

Los electrocardiogramas en 41 casos de coarctación y en 73 casos de conducto arterioso patente fueron analizados antes y después de corrección quirúrgica del defecto. La mayoría de los pacientes fueron niños. El intervalo de tiempo entre los estudios electrocardiográficos pre y postoperatorios varió entre tres meses y cinco años.

Coarctación de la Aorta

Después de la operación ocurrió un ligero decremento en el pulso en la mayoría de los casos.

Antes de la operación, el intervalo Q-T estaba prolongado en 35 casos. Un decremento en el intervalo Q-T se registró en 35 casos luego de la operación.
Veinte y cinco de los pacientes mostraron un eje balanceado. Desviación de eje hacia la izquierda estuvo presente en 14 y desviación hacia la derecha en dos casos. Después de la operación un ligero cambio del eje eléctrico hacia la derecha ocurrió en la mayoría de los casos.

Después de la operación, hubo un ligero decremento en la amplitud promedio de la onda R en las derivaciones I, II, aVL y V6.

En V1, la proporción R/S fue menos que unidad y en V6 mayor que unidad en todos los casos. Después de la operación, por regla general ocurrió un incremento en la proporción de R/S en V1 y un correspondiente decremento en la proporción en V6.

El comienzo de la desviación intrínsecoide en V1 estuvo ligeramente retardado en la mayoría de los casos. Luego de la operación, esta medida usualmente disminuyó.

Depresión del segmento S-T o esfuerzo fué registrado en las derivaciones II y V6 en aproximadamente una cuarta parte de los casos. Después de la operación, estos cambios desaparecieron en la mayoría de los casos.

Los cambios postoperatorios en el electrocardiograma fueron considerados debido a la disminución en trabajo del ventrículo izquierdo.

El tamaño del corazón frecuentemente permaneció inalterado aún en los casos que mostraron una caída marcada en la presión arterial acompañada de evidencia electrocardiográfica de disminución de esfuerzo del ventrículo izquierdo.

**Conducto Arterioso patente.**

Antes de la operación, tres pacientes mostraron extrasístoles ocasionales. En el último examen postoperatorio se registró un ritmo sinusal normal en todos los casos. Luego de la ligadura del conducto hubo un ligero decremento en el pulso promedio. Sesenta y cinco pacientes presentaron soplos continuos típicos. Estos pacientes revelaron un patrón electrocardiográfico básico similar a aquel de la coartación. Los cambios electrocardiográficos indicativos de preponderancia ventricular izquierda, sin embargo, fueron más conspicuos en los casos de conducto arterioso patente que en los de coartación.

Siete de los pacientes mostraron evidencia electrocardiográfica de hipertrofia ventricular derecha o de hipertrofia ventricular combinada. Todos estos pacientes presentaron soplos atípicos. Después de la ligadura del conducto, el electrocardiograma se tornó a lo normal en la mayoría de los casos. Una correlación positiva se encontró entre el tamaño del conducto y los cambios en el electrocardiograma.

El tamaño del corazón frecuentemente permaneció inalterado aún en los casos que mostraron evidencia electrocardiográfica de disminución de esfuerzo en el corazón.

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POSTOPERATIVE ELECTROCARDIOGRAM IN HEART DISEASE. II


Postoperative Changes in the Electrocardiogram in Congenital Heart Disease: II. Coarctation of the Aorta and Patent Ductus Arteriosus

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