Total Correction of Tetralogy of Fallot

II. Changes in the Electrocardiogram following Surgery

By Bernard Landtman, M.D., and Muriel D. Wolf, M.D.

The electrocardiogram in patients with tetralogy of Fallot usually shows right axis deviation and right ventricular hypertrophy. After creation of a systemic-pulmonary artery anastomosis, the work of the left ventricle increases, usually accompanied by a corresponding increase in the pattern of left ventricular loading.1,2 Following open-heart surgery, with closure of the ventricular septal defect and relief of the pulmonary stenosis, the load on the right ventricle decreases. Since main branches of the conduction system of the heart are located in the vicinity of the intracardiac defects, damage to the conduction system is often unavoidable. Electrocardiography offers a sensitive method for the study of resultant conduction disturbances.

This paper presents a brief analysis of the changes in the electrocardiogram following corrective surgery for tetralogy of Fallot. The clinical data of the patients and the operative results have been published previously.3,4

Material and Methods

The series comprised 146 patients who underwent corrective intracardiac surgery for tetralogy of Fallot at the Johns Hopkins Hospital from September 1956 to January 1962. Electrocardiograms were available before surgery in all 146 cases and postoperatively in 108 cases. One hundred and fifteen patients (79 per cent) were between 5 and 20 years of age at the time of operation. The follow-up time was less than 6 months in 29 patients and 6 months to 5 years in 79 patients.

All electrocardiograms were taken under the same conditions with a Sanborn direct-writing electrocardiograph. In each case, the following leads were recorded before and after surgery: I, II, III, aV_R, aV_L, aV_F, and V_1 through V_6. Additional precordial leads were recorded when indicated. As a rule, at least three cardiac cycles were studied and from these the average measurements were derived in tabular form. Calibration corrections were applied, if necessary, for accurate standardization (10 mm. = 1 mv.).

In each case, the electrocardiograms were analyzed for rate, rhythm, and mean frontal plane QRS axis. The amplitude of the P wave and the P-R interval were derived from lead II. The Q wave, QRS complex, ST segment and T wave were analyzed in each lead. Particular attention was directed to the pattern of the QRS complex in right and left precordial leads. In the presentation of the results only significant changes in the electrocardiogram will be discussed.

Temporary changes in the electrocardiogram occurring during operation were not included in the study. Following operation, transient changes in the electrocardiogram, suggestive of myocardial injury or pericarditis, were frequently recorded; these changes sometimes persisted for a few weeks. Therefore, postoperative changes in the electrocardiogram were studied by a comparison of the tracings obtained before surgery with those recorded on the last follow-up examination. A few patients were receiving digitalis at the time the electrocardiograms were taken. Changes in the electrocardiogram interpreted as digitalis effect were disregarded.

Results

Arrhythmias were recorded in eight of the 146 patients before operation (premature beats, five: Wenckebach block, two; and ectopic rhythm, one). Fourteen patients showed arrhythmias on the last follow-up examination. The arrhythmias included premature beats, six; ectopic rhythms, four; complete AV block, two; Wenckebach block, one; and atrial fibrillation, in one patient.

Atrioventricular conduction disturbances of various types frequently appeared during op-
operation and many of them persisted throughout the observation period. Seventeen patients developed complete AV block during operation and seven of them died. In eight of the surviving patients the block subsequently disappeared; two patients still showed complete heart block on the last follow-up examination. First-degree heart block (prolonged P-R interval) was present in only four patients before operation; following surgery, the P-R interval became normal in three patients and remained prolonged in one. Three patients developed first-degree heart block postoperatively.

The amplitude of the P wave in lead II was less than 2.5 mm. in 102 cases before operation (table 1). A moderately high amplitude was present in 33 cases, whereas in 10 instances the amplitude was above normal (more than 3 mm.). It is worthy of note that all the tracings with a P wave exceeding 3 mm. in height belonged to patients who had had previous shunt procedures. Following corrective surgery, the amplitude of the P wave decreased by 1 mm. or more in 32 cases, whereas an increase occurred in 10 instances. No changes were seen in 59 cases. None of the tracings showed an amplitude of the P wave exceeding 3 mm. on the last follow-up examination (table 1).

The mean QRS axis in the frontal plane before operation is shown in table 2. Right axis deviation of varying degrees was present in the majority of cases. A balanced axis (−10 to +99°) was recorded in only three (8 per cent) of 38 cyanotic patients without a previous shunt procedure as compared with 14 (16 per cent) of 91 cyanotic patients who had had previous shunt procedures. Tracings of acyanotic patients showed the highest incidence of a balanced axis (41 per cent). Left axis deviation was present in only one cyanotic patient without a previous shunt procedure. This patient also had a large atrial septal defect that was closed at open-heart surgery. Following corrective surgery, right bundle-branch block frequently appeared, which prevented determination of the QRS axis. In a few electrocardiograms which showed little or no intraventricular conduction disturbances after surgery, the QRS axis usually showed a postoperative shift to the left (fig. 1).

Intraventricular conduction was normal in 109 patients before operation (table 3). It was normal postoperatively in only eight of the 82 patients in this group who survived surgery. Complete right bundle-branch block appeared at operation in 54 patients, and 20 patients developed incomplete right bundle-branch block.

Incomplete right bundle-branch block was present preoperatively in 37 patients; in the 26 who survived surgery the conduction pattern changed to complete right bundle-branch block in 20, and remained incomplete in six patients. The degree of the conduction defect, however, increased slightly after surgery in four of these patients (fig. 2).

Complete right bundle-branch block was characterized by a QRS duration equal to or

Table 1

<table>
<thead>
<tr>
<th>No. of Amplitude of P Wave in Lead II before (A) and after (B) Operation</th>
<th>Amplitude of P wave in mm.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 2.5</td>
</tr>
<tr>
<td>A</td>
<td>145</td>
</tr>
<tr>
<td>B</td>
<td>101</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Mean QRS Axis (degrees)</th>
<th>No.</th>
<th>−10 to + 99</th>
<th>+ 100 to + 119</th>
<th>+ 120 to + 149</th>
<th>+ 150 to + 179</th>
<th>± 180 to</th>
<th>− 90 to − 90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyanotic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No shunt</td>
<td>38</td>
<td>3</td>
<td>7</td>
<td>18</td>
<td>7</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Shunt</td>
<td>91</td>
<td>14</td>
<td>24</td>
<td>47</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Acyanotic</td>
<td>17</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>146</td>
<td>24</td>
<td>36</td>
<td>69</td>
<td>9</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

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greater than 0.12 second. The ventricular complex showed an rsR' pattern in V1 in 61 of 74 cases of complete right bundle-branch block (fig. 3). A qR pattern was present in seven tracings, and other patterns occurred in solitary cases. Notching or splitting of the positive deflection of the QRS complex in V1 and a QRS duration of less than 0.12 second were considered signs of incomplete right bundle-branch block. The shape of the QRS complex in V1 varied; an rsR', rSr', rR', and rR's pattern were, in that order, the commonest varieties of the block.

The postoperative intraventricular conduction defects persisted throughout the follow-up period. Only one patient showed slight regression of right bundle-branch block on repeated postoperative electrocardiographic examinations (fig. 4). Another patient who had incomplete right bundle-branch block developed complete right bundle-branch block. This latter patient died suddenly 28 months postoperatively.4

In cyanotic patients the use of an outflow patch appeared to have little influence on the conduction pattern postoperatively. Eight of 15 acyanotic patients who survived surgery (none of whom needed an outflow patch) had incomplete right bundle-branch block or a normal electrocardiogram, whereas only 26 of 89 (29 per cent) of the cyanotic patients had such an electrocardiogram.

The relative preponderance of the right and left ventricle was evaluated by an analysis of the absolute amplitude of the R and the S wave and the R/S ratio in leads V1 and V6.5

Prior to operation the highest incidence of right ventricular hypertrophy occurred in patients without previous shunts, and the lowest incidence in the acyanotic groups of patients (table 4). Thus, 28 (75 per cent) of 38 cyanotic patients without a previous shunt showed evidence of right ventricular hyper-

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![Image of electrocardiograms](image_url)

**Figure 1**

A. Electrocardiogram of a girl, 8 years of age, with tetralogy of Fallot. No previous cardiac surgery. Right axis deviation, right ventricular hypertrophy, and good left ventricular potential. B. Ten months after corrective cardiac surgery. The tracings are almost normal.

**Table 3**

<table>
<thead>
<tr>
<th>Right Ventricular Conduction Defects before (A) and after (B) Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>No block</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>No block</td>
</tr>
<tr>
<td>146</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>108</td>
</tr>
</tbody>
</table>

*Circulation, Volume XXXI, March 1965*
TOTAL CORRECTION OF TETRALOGY OF FALLOT

I II III AVR AVL AVF VI V6

Figure 2
A. Electrocardiogram of a boy, 12 years of age, with tetralogy of Fallot. No previous cardiac surgery. Incomplete right bundle-branch block and evidence of right ventricular hypertrophy with good left ventricular potential.
B. Eighteen months after corrective cardiac surgery. Increase of incomplete right bundle-branch block which now shows an rSr' pattern in V1.

I II III AVR AVL AVF VI V6

Figure 3
A. Electrocardiogram of a man, 21 years of age, with tetralogy of Fallot. A shunt operation was performed at the age of 11 years. Right axis deviation and right ventricular hypertrophy. Notching of the R wave in V6.
B. One year after corrective cardiac surgery. Complete right bundle-branch block with an rsR' pattern in V1.

trophy as compared with 54 (59 per cent) of 91 cyanotic patients with previous shunt procedures. Only two (12 per cent) of acyanotic patients revealed right ventricular hypertrophy. The incidence of electrocardiographic changes suggestive of combined ventricular hypertrophy was highest in acyanotic patients and higher in cyanotic patients with prior shunt procedures than in those without such shunt procedures. It is of interest that 10 of 38 cyanotic patients without a previous shunt showed good left ventricular potentials with right ventricular hypertrophy. Two patients, one cyanotic with a previous shunt and the other acyanotic, showed evidence of left ventricular hypertrophy mainly characterized by a tall R wave and absence of S wave in V6 and by an R/S ratio of less than one in V1.

Right bundle-branch block occurred so frequently after operation that no estimation of ventricular preponderance by standard electrocardiographic criteria was possible. Fifty-five patients, however, showed an increase of 5 mm. or more of the R wave in V6; a decrease was recorded in six, whereas no change occurred in 41 cases. Eight patients showed
block and 26 showed incomplete right bundle-branch block after operation; in these the postoperative electrocardiograms usually revealed definite signs of a decreased load on the right ventricle and a corresponding increase in the left ventricular activity (fig. 1). The onset of the intrinsicoid deflection was not a reliable electrocardiographic criterion of ventricular hypertrophy. Moreover, the frequent occurrence of right bundle-branch block prevented the use of the intrinsicoid deflection in the analysis of the tracings.

Anomalous coronary arteries crossed the outflow tract of the right ventricle in 14 patients. They were divided at operation in five patients, all of whom died. Evidence of postoperative myocardial infarction, characterized by diminution or loss of R waves in several precordial leads, was present in two of nine surviving patients in whom a small coronary artery was known to have been divided at surgery (fig. 5). Two patients showed similar changes in one precordial lead that, however, were not considered sufficient for an electrocardiographic diagnosis of infarction. The remainder of the surviving

![Figure 4](image)

**A.** Electrocardiogram of a girl, 12 years of age, with tetralogy of Fallot. No previous cardiac surgery. Right axis deviation and right ventricular hypertrophy. **B.** Three weeks after corrective cardiac surgery. Right bundle-branch block with an rsRR' pattern in V1. **C.** Two years postoperatively. The block has decreased and V1 now shows a different pattern of the QRS complex.

**Table 4**

**Ventricular Preponderance in the Electrodiagram before Operation**

<table>
<thead>
<tr>
<th></th>
<th>RVH</th>
<th>RVH &amp; LVH</th>
<th>LVH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyanotic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No shunt</td>
<td>38</td>
<td>28</td>
<td>10</td>
</tr>
<tr>
<td>Shunt</td>
<td>91</td>
<td>54</td>
<td>36</td>
</tr>
<tr>
<td>Acyanotic</td>
<td>17</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>146</td>
<td>84</td>
<td>60</td>
</tr>
</tbody>
</table>

*Criteria:

RVH
a) R in V1 > 5 mm.

b) R/S in V1 > 1

c) R/S in V6 < 1

RVH & LVH
a) RVH
b) R/S in V6 > 1
c) Tall R wave in V6

LVH
a) R/S in V1 < 1
b) R/S in V6 > 1

with tall R waves in V6 (> 25 mm.)
patients had no signs of infarction in postoperative electrocardiograms.

Pathologic changes in the ST segments and T waves were rare in the absence of intraventricular conduction defects. One patient with an anomalous coronary artery crossing the right ventricular outflow tract showed elevation of the ST segment in several leads prior to surgery. At operation the ventricular septal defect was repaired through an atriotomy, and the infundibular resection was done through a small ventriculotomy, which did not injure the coronary artery. Postoperatively the ST segments were normal, although there was complete right bundle-branch block.

Following corrective cardiac surgery, inversion of the T wave in $V_6$ was present in three cases, having been present in one patient prior to surgery. These changes were interpreted as signs of relative myocardial ischemia.

Discussion

A decrease in the amplitude of the P wave frequently occurred after corrective cardiac surgery. The same phenomenon has been observed in patients with tetralogy of Fallot following shunt operations.$^6,7$ It seems reasonable to assume that the postoperative decrease in the amplitude of the P wave reflected a diminished load on the right atrium.

Preoperatively the electrocardiogram showed right axis deviation and right ventricular hypertrophy in most cases. A balanced axis and evidence of combined ventricular hypertrophy were more common in acyanotic patients and in cyanotic patients who had had previous shunt procedures. Some of the cyanotic patients without a previous shunt, however, showed biventricular hypertrophy; in some of these there was a mild degree of pulmonic stenosis, and as a group they are comparable to the patients described by Pileggi and associates.$^8$ One may hypothesize that in the other patients with severe pulmonic stenosis, the good left ventricular potentials were related to a good collateral circulation. These interesting variations in the electrocardiographic pattern seem to be consistent with the prevailing anatomic and hemodynamic conditions in the different groups of patients. Similar observations have been made by other investigators in electro-
cardiographic studies of patients with tetralogy of Fallot.\textsuperscript{1, 6, 8-11}

Two patients showed evidence of left ventricular hypertrophy in the electrocardiogram. One of the patients in the present series had had one previous shunt procedure, which possibly explained the left ventricular preponderance in the electrocardiogram. The other patient was a 10-year-old acyanotic girl. Preoperative cardiac catheterization revealed a right ventricular pressure of 95/0 mm. Hg and a pressure of 30/6 mm. Hg in the pulmonary artery, with a 1.5-volume per cent oxygen step-up at the right ventricular level. No explanation could be offered for the unusual electrocardiographic pattern in this case. It is possible that the amount of left ventricular hypertrophy overshadowed the right ventricular hypertrophy on the electrocardiogram.

After corrective cardiac surgery, the electrocardiogram showed definite signs of a diminished load on the right ventricle and a corresponding increase in left ventricular activity in the few cases in which intraventricular conduction defects did not appear. The frequent occurrence of right bundle-branch block after operation prevented estimation of relative ventricular preponderance by standard electrocardiographic criteria. It is, however, worthy of note that the amplitude of the R wave in V\textsubscript{6} increased in most of the cases showing right bundle-branch block. This possibly reflected increased left ventricular activity after surgery.

The evidence is strong that the postoperative conduction defects were mainly caused by mechanical injury to the conduction system. Right ventricular conduction disturbances have been induced in experimental animals by severing or by tapping the right bundle,\textsuperscript{12, 13} and similar blocks have been observed as transient phenomena during right heart catheterization.\textsuperscript{14} It is also possible that the postoperative blocks may in part have been induced by circulatory disturbances. This view is supported by observations by Reemtsma et al.\textsuperscript{15} that the conduction system is supplied by branches from the coronary arteries that may be damaged during open-heart operations.

The frequent development of right bundle-branch block after surgical correction of tetralogy of Fallot and ventricular septal defects is well recognized.\textsuperscript{16-20} Postmortem studies have shown that the right bundle-branch is usually located in the posteroinferior margin of high ventricular septal defects.\textsuperscript{21, 22} It is therefore possible that the right bundle-branch block may have been caused by injury to the conduction system in closing the ventricular septal defect. The incidence of right bundle-branch block is higher after repair of a ventricular septal defect with infundibular pulmonary stenosis than with repair of an isolated ventricular septal defect.\textsuperscript{10} This evidence suggests that complete right bundle-branch block may occur as a result of injury to the bundle in the infundibular resection. Lesser degrees of right ventricular conduction disturbances could also be caused by damage to peripheral ramifications of the right bundle-branch during ventriculotomy. Postoperatively the incidence of incomplete right bundle-branch block on a normal electrocardiogram was higher in the group of acyanotic patients than in the group of cyanotic patients. This finding would correlate with the fact that the acyanotic patients had a less severe degree of pulmonic stenosis and thus needed less infundibular resection. The use of an outflow patch had little influence on the postoperative electrocardiogram.

The development of conduction disturbances after corrective cardiac surgery may shed some light on the nature and clinical significance of so-called bundle-branch blocks. For instance, opinions still differ as to whether incomplete right bundle-branch block, per se, represents a mild conduction defect or an electrocardiographic sign of right ventricular hypertrophy. The results of the present study favor the former concept. Moreover, no correlation was observed between the development of right bundle-branch block and the size of the heart after surgery.

The postoperative right ventricular conduction defects have not caused any symp-
toms or discomfort to the patients. Although the defects persisted in all cases, the vast majority of the patients were leading a perfectly normal life at the end of the follow-up period, up to 5 years after surgery. The long-term outlook of these blocks is not yet known but it is hoped that it is different, and possibly much better, than the prognosis of acquired right bundle-branch blocks due to other causes such as coronary artery disease.

Summary

The material comprised the data of 146 patients with tetralogy of Fallot treated by corrective intracardiac surgery. Electrocardiograms were recorded in all cases before and in 108 cases after operation. The majority of the patients were between 5 and 20 years of age at the time of surgery and have been followed for an average of 1.5 years.

Arrhythmias, mostly extrasystoles, were recorded in eight cases before operation and in 14 cases on the last follow-up examination. The amplitude of the P wave in lead II decreased by 1 mm. or more after surgery in one third of the cases.

Seventeen patients developed complete AV block postoperatively, seven died; of the 10 who survived operation, in all but two the electrocardiogram reverted to normal sinus rhythm.

The electrocardiogram showed right axis deviation and right ventricular hypertrophy in the majority of cases. A balanced axis and signs of combined ventricular hypertrophy were commonest in cyanotic patients and more common in cyanotic patients who had had previous shunt procedures than in cyanotic patients who had had no previous shunt. Two patients showed electrocardiographic signs of left ventricular hypertrophy. After corrective cardiac surgery, the mean electrical axis and the pattern of the QRS complex in V₁ and V₆ changed toward normal in the eight patients in whom intraventricular conduction defects did not appear and in the 26 patients with incomplete right bundle-branch block.

Two of nine surviving patients in whom a small coronary artery was divided at surgery developed the pattern of myocardial infarction in the postoperative electrocardiogram.

Conduction disturbances frequently appeared during operation; they were considered to be caused mainly by direct trauma to the conduction system during closure of the ventricular septal defect or during infundibular resection. Complete right bundle-branch block appeared in 74 (69 per cent) and incomplete right bundle-branch block developed in 20 (19 per cent) of surviving patients. Only eight patients showed no disturbances of conduction after surgery. The right bundle-branch blocks persisted throughout the follow-up period. The conduction disturbances have not adversely affected the postoperative course, nor have they caused any discomfort to the patients.

Acknowledgment

The authors gratefully acknowledge the help and advice of Dr. Helen B. Taussig and Dr. Catherine A. Neill in the preparation of this manuscript.

References


8. Pileggi, F., Bocanegra, J., Tranches, J., Ma-

Circulation, Volume XXXI, March 1965
How Medicine Became a Science

If I were asked to give a definite date for the birth of modern scientific medicine I should unhesitatingly choose the year 1858. In that year Virchow published his Cellular Pathology, which is regarded as the beginning of modern pathology; in the same year a new world in organic chemistry was opened by the work of Couper and Kekule, who proved the quadrivalency of the carbon atom with the possibility of chain formation in the molecule. In 1858 Pasteur published his paper on the fermentation of lactic acid which has been acclaimed as the beginning of modern bacteriology; while at that time Claude Bernard was at the height of his career as experimental physiologist; he had just demonstrated the glycogenic function of the liver, in that year he showed the vaso-constrictor effect of stimulation of the sympathetic, and he was soon to publish his Introduction to the Study of Experimental Medicine, a medical classic. In 1858 Darwin had just completed his Origin of Species which was published in the following year. From the British point of view the year 1858 is of importance because it was in that year that the General Medical Council was set up and the Medical Register started. There is clearly some justification for marking that date as important in the history of scientific medicine. —ZACHARY COPE, KT. Some Famous General Practitioners and other Medical Historical Essays. London, Pitman Medical Publishing Co., Ltd., 1961, p. 191.
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_Circulation_. 1965;31:394-402
doi: 10.1161/01.CIR.31.3.394

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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