Tetralogy of Fallot

Postoperative Electrophysiologic Studies

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SUMMARY Electrophysiologic studies performed during postoperative cardiac catheterization in 51 patients following repair of tetralogy of Fallot (TF) were compared with studies performed in a control group of 30 patients. These studies include His bundle electrograms, measurement of atrioventricular (A-V) conduction at progressively increasing atrial pacing rates, and evaluation of sinus node recovery time.

More postoperative TF patients (20%) had prolonged H-V intervals compared to the controls (7%). With atrial pacing, no patient in the control group developed second degree A-V block below 160 beats/min, while 23% of the postoperative TF patients developed block below this level. Half of these patients had normal His bundle studies. Stress of the A-V conduction system by atrial pacing may unmask conduction abnormalities not present on the surface electrocardiogram or on His bundle electrogram. Two-thirds of the patients had some form of conduction abnormality on the basis of evaluation of one or more parameters but about half of the patients with a given abnormality had normal findings in other areas.

The high incidence of electrophysiologic abnormalities following TF repair may have future prognostic significance. Systematic evaluation of atrioventricular conduction during preoperative and postoperative cardiac catheterization may be of value.

A control group was composed of 30 patients who also had electrophysiologic studies at the time of hemodynamic investigation. Their ages ranged from 10 months to 15-8/12 years (mean 5-8/12 years). Fifteen were preoperative TF, 12 patients had transposition of the great arteries with intact interventricular septum (five preoperative, seven postoperative) and three had miscellaneous defects. The criteria for inclusion in the control group were 1) adequate His bundle electrocardiography (HBE) and complete atrial pacing study; 2) no evidence of atrioventricular (A-V) conduction abnormality on surface electrocardiogram; 3) no cardiac medications being taken at the time of cardiac catheterization.

All inpatient and outpatient records, ECGs, previous cardiac catheterization data and operative reports were reviewed. The clinical, hemodynamic, and anatomic follow-up data were then tabulated and correlated with the results obtained from the electrophysiologic studies.

A protocol for a series of electrophysiologic studies was set up to screen for the presence of A-V conduction abnormalities. The entire screening protocol added 20 to 30 min to the cardiac catheterization and could be performed with a single venous catheter. A #5 or 6 French bipolar electrode catheter, with an electrode 1 cm proximal to a distal tip electrode, was used for most studies. In some cases a hexapolar electrode catheter was used with a 0.5 cm interelectrode distance between the distal three electrodes and a 1.0 cm interelectrode distance between the remainder of the proximal electrodes. The catheter was positioned under fluoroscopic control in all cases.

His bundle electrocardiography was performed using previously reported techniques. Recordings were made on photographic paper at a paper speed of 100 mm per second with 20 msec timelines. A simultaneous surface ECG lead II was also recorded. The conduction intervals, in milliseconds, were measured from the HBE as follows:

1) The A-H interval was measured from the onset of atrial activation (A) to the first rapid deflection of the His bundle potential (H).
2) The H-V interval was measured from the first rapid
deflection of the His bundle potential (H) to the onset of ventricular activity on either the surface ECG or the HBE, whichever came first.

A sequence of atrial pacing studies was performed with the electrode catheter positioned in the high right atrium near the superior vena cava-right atrial junction. A Medtronics Model 5837 pulse generator was used to deliver rectangular pulses of 2 msec duration with the current set at approximately twice the threshold level (2-3 milliamps). Atrioventricular conduction was evaluated by determining the heart rate at which 2° A-V block (AVB) occurred during progressively increased atrial pacing at rates from 120 to 200 beats/min in 20 beat/min increments. The A-V conduction time during atrial pacing (P'R interval) was measured from the pacing artifact to the beginning of the QRS complex in two simultaneously recorded standard ECG leads (fig. 1). This was then expressed as a percentage increase over the baseline P-R interval recorded in the same leads. In some patients a second venous electrode catheter was utilized so that simultaneous atrial pacing and His bundle electrocardiography could be performed (fig. 2).

Sinus node function was also evaluated by measuring the

![P'R Interval](https://example.com/pic1.png)

**Figure 1.** Determination of P'R interval. Two surface electrocardiogram leads and a His bundle electrocardiogram (HBE) at a paper speed of 100 mm/sec (timelines 20 msec) The P'R interval is measured from the pacing artifact (P') to the beginning of the QRS complex. An increase in the P'R interval due to prolongation of the A-H interval is seen. A = atrial activity; H = His bundle spike; V = ventricular activity; SR = sinus rhythm; HR = heart rate; AP = atrial pacing.

![Site of atrioventricular block with atrial pacing](https://example.com/pic2.png)

**Figure 2.** Site of atrioventricular block with atrial pacing. Simultaneous recording of two surface electrocardiogram leads and a His bundle electrocardiogram at a paper speed of 100 mm/sec (timelines 20 msec). Upper Tracing) Second degree A-V block (Wenckebach) at a pacing rate of 120 beats/min. Progressive prolongation of the P-R interval is seen due to a decrease in A-H interval. The third beat is not conducted to the His bundle. Lower Tracing) 2° A-V block (Wenckebach) at a pacing rate of 100 beats/min. Progressive prolongation of the P-R interval is seen due to an increase in the H-V interval. The fourth beat is not conducted below the bundle of His. A = atrial activity; H = His bundle spike; V = ventricular activity; P' = pacing artifact; A-H = A-H interval; H-V = H-V interval.
Table 1. His Bundle Studies: A-H Intervals

<table>
<thead>
<tr>
<th></th>
<th>A-H interval (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;80</td>
</tr>
<tr>
<td>TF-P/O</td>
<td>51†</td>
</tr>
<tr>
<td>Control</td>
<td>30</td>
</tr>
</tbody>
</table>

*Includes 1 patient with infra His A-V block and an artificial pacemaker (A-H = 110 msec).
†Maximum upper range of normal.
TF-P/O = postoperative tetralogy of Fallot.

Table 2. His Bundle Studies: H-V Intervals

<table>
<thead>
<tr>
<th></th>
<th>H-V interval (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td>TF-P/O</td>
<td>50†</td>
</tr>
<tr>
<td>Control</td>
<td>30</td>
</tr>
</tbody>
</table>

*One additional patient had infra His Block and an artificial pacemaker.
†Maximum upper range of normal.
TF-P/O = postoperative tetralogy of Fallot.

Results

The A-H and H-V intervals for the control and study groups are shown in Tables 1 and 2. In our laboratory the maximum upper limits of normal for A-H and H-V intervals are 140 and 50 msec respectively. There is some disagreement among studies in the literature as to the normal range for A-H intervals or even which point to take as the onset of atrial activity. Since the intervals reported in this series are absolute values and not corrected for age or heart rate, very generous upper limits were set for A-H intervals in the tables and figures so that values beyond this level were unquestionably abnormal. The mean values for A-H and H-V intervals were similar in the groups evaluated (postop TF: A-H, 94 msec; H-V, 44 msec; control group: A-H, 79 msec; H-V, 39 msec). More postoperative TF patients had prolonged A-H and H-V intervals than did the controls. Although no statistically significant difference between the mean A-H intervals was found, the mean H-V intervals were significantly different (P < 0.025).

The absolute values for SNRT showed a wide range of variation. When expressed as a percentage of the resting P-P interval, the corrected SNRT decreased at faster atrial pacing rates. The mean corrected SNRT was similar at each rate of atrial pacing for both 1 min and 5 min durations. Since these findings in this study and in others suggested that SNRT could be accurately determined at lower atrial pacing rates of short duration, the latter 20% of patients in this series had SNRT measured at an atrial pacing rate of 140 beats/min for 1 min duration. The corrected sinus node recovery time was slightly prolonged in only four patients in the overall series, two in the postoperative TF group, and two in the control group.

Atrioventricular conduction was evaluated by progressive atrial pacing in all patients in the control group and in 48 of the 51 patients in the postoperative TF group. With the exception of two patients in the postoperative TF group all patients in both the control and study groups maintained a normal systemic blood pressure throughout the pacing study. The study was not terminated because of hypotension or any other serious problem in any patient. Although all patients in the control group maintained 1:1 A-V conduction until at least 160 beats/min, 11 of 48 patients in the postoperative TF group developed 2° A-V block below 160 beats/min and were considered to have an abnormal atrial pacing/A-V conduction study (table 3). There was no relationship between the age of the patient at the time of catheterization and the rate at which 2° A-V block appeared in either the control or the study group. Of the 11 patients who developed A-V block below 160 beats/min in the postoperative TF group, six were less than 12 years of age. Twenty of the 48 patients in the postoperative TF group were over 12 years of age at the time of catheterization. Of these, five patients developed 2° A-V block at pacing rates below 160 beats/min and 15 had normal A-V conduction.

The results of resting His bundle electrocardiography were compared with the A-V conduction studies. No

Table 3. A-V Conduction during Atrial Pacing

<table>
<thead>
<tr>
<th></th>
<th>Heart Rate at 2° A-V block (beats/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td>TF-P/O</td>
<td>48</td>
</tr>
<tr>
<td>Control</td>
<td>30</td>
</tr>
</tbody>
</table>

*2° A-V block below this level is abnormal.
A-V = atrioventricular; TF-P/O = postoperative tetralogy of Fallot.
Atrial relationship was found between the heart rate at which 2° A-V block occurred and the resting A-H or H-V intervals (table 4). The A-H and H-V intervals obtained in the 11 postoperative TF patients with abnormal atrial pacing/A-V conduction studies are demonstrated in figure 3. One patient had an abnormal A-H but normal H-V interval. Two patients had normal A-H but abnormal H-V intervals while in two others both intervals were abnormal. Six patients had normal A-H and H-V intervals on His bundle electrocardiography. Table 5 summarizes the His bundle and atrial pacing/A-V conduction studies. Of the 48 patients who had complete HBE and atrial pacing studies, 32 (67%) had normal findings.

Simultaneous HBE and atrial pacing studies were performed in three of the 11 patients in this series who developed 2° A-V block at atrial pacing rates under 160 beats/min (fig. 2). In one patient the block was proximal to the His bundle and in the other two it was distal. Only one of the three patients had an abnormal resting HBE (slightly prolonged H-V interval).

The A-V conduction times during atrial pacing (P'R intervals) for patients in the control group were compared with those of patients in the postoperative TF group who had normal atrial pacing and did not develop A-V block until a pacing rate greater than 160 beats/min (fig. 4). Prior to atrial pacing the heart rate for control patients ranged from 70 to 130 beats/min (mean 107 beats/min) as compared to 55 to 130 beats/min (mean 85 beats/min) for this portion of the postoperative TF group. The baseline P-R intervals were 100 to 200 msec (mean 141 msec) and 100 to 220 msec (mean 143 msec), respectively. The P'R interval in each patient was expressed as a percentage increase over the baseline P-R interval recorded in the same lead, thus correcting the P'R interval for age and heart rate. When the mean P'R intervals were compared between the control and postoperative TF groups, no significant difference was found at a low atrial pacing rate. However, with more rapid atrial pacing the mean P'R interval was significantly greater in patients in the postoperative TF group than in the controls.

The P'R interval includes an isoelectric period between the pacing stimulus and the onset of atrial depolarization (P'P). In all patients in this series the P'P interval remained constant at each atrial pacing rate. Simultaneous HBE and atrial pacing studies were performed in 20% of patients in the control and normal postoperative TF groups. In each instance prolongation of the P'R interval was due to an increase in the A-H interval.

The ECG data of the 51 postoperative TF patients are summarized in table 6. Preoperatively, the pattern of left anterior hemiblock (Lah) was present in two patients while the others had either right axis deviation (41 patients) or a balanced axis (eight patients). All patients had normal A-V conduction and a QRS duration less than 80 msec. The QRS morphology was normal in two patients, 47 had right ventricular hypertrophy, and two had biventricular hypertrophy. No preoperative patient had right bundle branch block (RBBB) or prolonged A-V conduction. Postoperatively, ten patients who previously had right axis deviation or a balanced axis developed a pattern of LH and RBBB. Nine patients currently have sinus rhythm with 1° A-V block, and one additional patient has intermittent 2° A-V block (Wenckebach). Another patient has 3° A-V block and has an artificial pacemaker since operation.

![Figure 3](https://example.com/figure3.png)

**Figure 3.** His bundle intervals in patients with an abnormal atrial pacing study. Postoperative tetralogy of Fallot, N = 11. The dotted line represents the maximum upper limits of normal.

### Table 4. A-V Conduction during Atrial Pacing vs H-V Intervals (postop TF)

<table>
<thead>
<tr>
<th>H-V (msec)</th>
<th>&lt;120</th>
<th>120</th>
<th>140*</th>
<th>160</th>
<th>180</th>
<th>200 or &gt;</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>35</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>40</td>
<td>1</td>
<td>-</td>
<td>3</td>
<td>1</td>
<td>-</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>45</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>50†</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>55</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>60 or &gt;</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Totals</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td>4</td>
<td>12</td>
<td>21</td>
<td>48</td>
</tr>
</tbody>
</table>

*2° A-V block below this level is abnormal.
†Maximum upper range of normal HV.
A-V = atrioventricular; TF = tetralogy of Fallot.

### Table 5. A-V Conduction Studies (postoperative TF)

<table>
<thead>
<tr>
<th>Pacing studies</th>
<th>HBE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>Normal</td>
<td>32</td>
</tr>
<tr>
<td>Abnormal</td>
<td>7</td>
</tr>
<tr>
<td>Total*</td>
<td>39</td>
</tr>
</tbody>
</table>

*Two additional patients had an incomplete pacing study (HBE: 1 normal, 1 abnormal); one additional patient had an artificial pacemaker. Abbreviations: A-V = atrioventricular; HBE = His bundle electrocardiography; TF = tetralogy of Fallot.
The QRS duration is slightly prolonged in five of the 51 patients and is greater than 100 msec in 34 patients. About 80% of the postoperative patients have RBBB with or without voltage criteria for right ventricular hypertrophy. One patient has a normal QRS duration but QRS morphology that suggests an anterosetal myocardial infarction. Atroventricular conduction abnormalities other than RBBB or LAH were present intraoperatively in 18 patients and persisted in the early postoperative period in all (fig. 5). These problems have all subsequently resolved except for the two patients described above. Of the nine patients who currently have sinus rhythm with 1º A-V block, only two manifested higher degrees of A-V block in the early postoperative period.

The relationship between abnormal A-V conduction on atrial pacing, the surface ECG, and history of postoperative conduction disturbances is shown in table 7. Five of the 11 patients with an abnormal atrial pacing study currently have abnormal A-V conduction on the surface ECG. None of these patients had a history of postoperative conduction disturbances. Four of the remaining patients who have no current A-V conduction abnormality on the surface ECG had a conduction abnormality in the postoperative period. Thus, nine of the 11 patients with an abnormal pacing study have demonstrated abnormal A-V conduction on the surface ECG.

An overall evaluation of the A-V conduction abnormalities demonstrated by surface electrocardiogram, evaluation of postoperative electrocardiograms, His bundle electrophysiology, and atrial pacing studies is shown in figure 6. Although there is some overlap in the abnormality of A-V conduction as determined by any of the parameters evaluated, approximately 1/3 to 1/2 of the patients with each type of A-V conduction abnormality were abnormal in only that parameter. In the overall series only 17 patients (34%) had normal A-V conduction (excluding RBBB), either historically or on the basis of all of the parameters evaluated at the time of postoperative cardiac catheterization.

**Discussion**

In this study as well as in others, the majority of patients who underwent correction of TF developed RBBB postoperatively.1-6 The significance of this abnormality remains unclear since it may occur as a result of one or more of several mechanisms. Right bundle branch block has been attributed to injury of the proximal portion of the specialized conduction system7-10 or to peripheral interruption of the conduction fibers at the time of ventriculotomy.11,12 The possibility of multiple sites of involvement in the A-V conduction system is supported by the conflicting reports of both favorable14-18 and poor prognosis1-3 in patients with bifascicular block following TF repair. Although this may explain the different clinical course in these groups of patients, the presence of RBBB with or without LAH on the surface electrocardiogram does not adequately identify those patients with significant damage to the proximal portion of the conduction system who may have a poor long-term prognosis.

This study was designed to provide additional information about the A-V conduction system through the use of intracardiac electrophysiologic techniques. The electrophysiologic procedures performed were simple, were accomplished with a single venous catheter in the majority of cases, and

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**Table 6. Tetralogy of Fallot Electrocardiographic Data (N = 51)**

<table>
<thead>
<tr>
<th>Axis</th>
<th>A-V Block</th>
<th>QRS Duration (sec)</th>
<th>QRS Morphology</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAD</td>
<td>Bal</td>
<td>LAH</td>
<td></td>
</tr>
<tr>
<td>Preop</td>
<td>None</td>
<td>1º 2º 3º</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;0.08 0.08-0.10 &gt;0.10</td>
<td></td>
</tr>
<tr>
<td>Post*</td>
<td></td>
<td>Normal RVH BVH RBBB ± RVH</td>
<td></td>
</tr>
</tbody>
</table>

---

**Table 7. TF - Abnormal Atrial Pacing Study (N = 11)**

<table>
<thead>
<tr>
<th>Abnormal A-V conduction (EGC)*</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAH</td>
<td>1</td>
</tr>
<tr>
<td>1º AVB</td>
<td>2</td>
</tr>
<tr>
<td>LAH + 1º AVB</td>
<td>2</td>
</tr>
<tr>
<td>Normal A-V conduction (EGC)*</td>
<td>6</td>
</tr>
<tr>
<td>No postoperative conduction abnormality</td>
<td>2</td>
</tr>
<tr>
<td>Postoperative conduction disturbance</td>
<td>4</td>
</tr>
</tbody>
</table>

| Intraoperative 3º AVB | 2 |
| Junctional rhythm     | 1 |
| 2º AVB                | 1 |

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*Other than RBBB.

Abbreviations: A-V = atrioventricular; AVB = atrioventricular block; LAH = left anterior hemiblock; RBBB = right bundle branch block pattern; TF = tetralogy of Fallot.
did not greatly prolong the overall cardiac catheterization. This serves as an effective screening procedure and if any abnormality is found, a second venous catheter can then be used to perform simultaneous atrial pacing and His bundle studies. The importance of intracardiac electrophysiology in the evaluation of postoperative patients is demonstrated by the fact that some patients may have abnormal A-H or H-V intervals but still have a normal P-R interval on the surface ECG. In this study, although 10 of 50 postoperative TF patients had prolonged H-V intervals, only three had evidence of first degree A-V block on surface electrocardiogram. The other six patients with 1° A-V block had either a prolonged A-H interval, or had A-H and H-V intervals that were both in the upper range of normal. The latter combination resulted in a prolonged P-R interval.

Stress of the A-V conduction system by atrial pacing may unmask conduction abnormalities that are not present on the surface ECG or on the HBE. An increase in heart rate by atrial pacing usually results in prolongation of the P-R interval, with 2° A-V block occurring at rapid pacing rates. The P-R interval during atrial pacing (P'R interval) includes an isoelectric interval between the pacing stimulus and atrial depolarization, the intra-atrial conduction time, the A-V nodal conduction (A-H interval), and the His-ventricular conduction time (H-V interval). In all patients in this series, the isoelectric or P-P interval remained constant at each atrial pacing rate. Prolongation of the P'R interval due to an increase in the A-H interval was found in those patients with normal atrial pacing studies who had HBE and atrial pacing performed simultaneously.

Unlike adults, children can maintain 1:1 conduction at atrial pacing rates of 160 beats/min or greater. With rapid atrial pacing, 2° A-V block occurs proximal to the His bundle in individuals with normal A-V conduction, and either proximal or distal to the His bundle in patients following TF repair. In this series no patient in the control group developed 2° A-V block at atrial pacing rates less than 160 beats/min while 11 of 48 patients in the postoperative TF group developed block below this level. In three of these 11 patients simultaneous HBE and atrial pacing studies demonstrated the site of the A-V block to be either proximal (one patient) or distal (two patients) to the His

Figure 5. Perioperative atrioventricular conduction disturbances following repair of tetralogy of Fallot. A-V = atrioventricular.

Figure 6. Overall atrioventricular conduction abnormalities following tetralogy of Fallot repair. Abbreviations: AVB = atrioventricular block; HBE = His bundle electrocardiography; LAH = left anterior hemiblock; RBBB = right bundle branch block pattern. *one additional patient has 3° AVB and an artificial pacemaker.
bundle. Since simultaneous studies were not performed in the other eight patients, no definite conclusions can be made about the site of the A-V block in this group. No relationship was found between the heart rate at which 2nd A-V block occurred and the resting A-H or H-V intervals or the patient's age at the time of catheterization.

A recent report demonstrated experimentally that transection of approximately 50% of the cross-sectional area of the His bundle on either the right or left side did not affect bundle branch conduction at pacing rates below 100 beats/min. However, conduction disturbances were seen at faster pacing rates. This phenomenon could explain the high percentage of patients in this series with a normal resting HBE but an abnormal atrial pacing study. Even in the group of postoperative TF patients with normal atrial pacing, the mean P'R interval became significantly greater than controls at high atrial pacing rates. These findings suggest that some patients have latent A-V conduction abnormalities after repair of TF that are evident only with rapid atrial pacing.

Only 22 patients in the overall series had no evidence of abnormality, other than RBBB, on the surface ECG, HBE, or at atrial pacing, and five of these 22 had a history of early postoperative conduction abnormality (fig. 6). Thus, two-thirds of the patients had some form of conduction abnormality on the basis of evaluation of one or more parameters. Although some patients had more than one conduction abnormality, about 50% of the patients with a given abnormality had normal findings in other areas.

Conclusions

In this series abnormal A-V conduction was present in a significant number of patients following repair of TF. The significance of these electrophysiologic abnormalities is unknown since all patients are currently asymptomatic and doing well. However, these data suggest that after TF repair there may be more damage to the A-V conduction system than is suspected on the basis of evaluation of only the surface ECG or HBE. Thus some patients may be at risk for the late development of progressive A-V conduction abnormalities or complete heart block. Since the A-V conduction abnormalities demonstrated in this group of patients may, therefore, have some future prognostic significance, it is recommended that electrophysiologic studies be performed on all patients with TF at the time of both preoperative and postoperative hemodynamic investigation. These should include His bundle electrocardiography and atrial pacing, with simultaneous two catheter studies performed in those patients with any evidence of abnormality. It is only by further prospective series of electrophysiologic studies, combined with long-term follow-up, that the significance of these abnormalities will become known.

References
