The Anatomy of the Atrioventricular Conduction System in Ventricular Septal Defect and Tetralogy of Fallot: Correlations with the Electrocardiogram and Vectorcardiogram

By Robert H. Feldt, M.D., James W. DuShane, M.D., and Jack L. Titus, M.D.

In recent years the morphological features of the major portions of the atrioventricular (A-V) conduction system of human hearts that were afflicted with various congenital anomalies have been described.1–6 These reports have contrasted the anatomy of the A-V conduction system in examples of ventricular septal defect (VSD) and tetralogy of Fallot with that configuration found in defects of the persistent atrioventricular (A-V) canal type.7,8

The vectorcardiographic (VCG) pattern found in the A-V canal has been considered to be characteristic.9–12 It is now known, however, that various congenital heart defects have a similar vectorcardiographic pattern, including occasional examples of VSD and tetralogy of Fallot.13–15 Therefore, a study was made of the morphology of the A-V conduction system in instances of VSD and tetralogy of Fallot that had frontal plane VCG patterns similar to those usually found in the A-V canal. An effort was made to find a characteristic or characteristics of the anatomy of the conduction system that might be associated with the unusual VCG pattern observed in these examples.

Material

Tetralogy of Fallot

Of 78 examples of tetralogy in which autopsy was performed from 1958 through 1962, five (6.4%) were associated with preoperative VCG patterns similar to the A-V canal pattern, that is, an initially counterclockwise QRS loop in the frontal plane with the mean axis directed superiorly and to the left (fig. 1A). Two of these cases were studied; these were designated cases A1 and A2. Two other examples of tetralogy (cases A3 and A4), which had VCG patterns more representative of tetralogy, also were studied (fig. 1C).

None of the four examples selected had ventricular septal defects of the A-V canal type.8 The defects in all four cases were located in similar positions in the ventricular septum.

Ventricular Septal Defect

Seventy-nine examples of isolated VSD of the usual type came to autopsy from 1958 through 1962. Seven of the 79 (8.9%) had preoperative VCG patterns similar to the A-V canal pattern and two of these (cases B1 and B2) were studied (fig. 1B). Two other examples (cases B3 and B4) in which the VCG patterns were more typical of VSD also were studied (fig. 1D). None of these four examples had the morphological features of VSD of the A-V canal type.8

Methods

The morphology of the conduction system in each of the eight cases studied was reconstructed with the use of a previously established technique of multiple histological sections.5 The blocks of tissue for sectioning included the atrial and ventricular septa on each side of the atroventricular rings and included the atroventricular node, the common bundle of His, and the proximal portions of the right and left bundle branches. The more peripheral bundle branches were not studied.

The tissue blocks were sectioned at a thickness of 8 μm, and every twentieth or fortieth section was stained with hematoxylin and eosin and examined. The next succeeding section was stained with the Mallory-Heidenhain stain and examined. In each example, additional sections were stained and studied as needed to elucidate certain details. Approximately 300 sections were examined in each case.

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The lengths of various portions of the conduction system were measured (schematically represented in fig. 2). The length of the common bundle measured from its origin at the A-V node to the point at which left bundle branching began was termed "A." The length of the common bundle from which left bundle branches were given off was termed "B." The length of conduction fibers destined to become the right bundle branch but before they came to lie on the right side of the ventricular septum and to take an inferiorly (apexward) directed course was termed "C." ABC was the total length of the A-V conduction system studied, but in fact represented...
Figure 2

Schematic representation of the two configurations (1 and 2) of the conduction system found in this study. A represents the length of common bundle from its origin at the A-V node (AVN) to the point at which left bundle branching (LB) begins. B represents that portion of common bundle involved in left bundle branching. C represents the length of the fibers destined to become the right bundle branch (RB) but before they take a definite rightward and inferior course. D represents the distance from the A-V node to the point at which the right bundle branch took a definite rightward and inferior course in those examples in which the right bundle branch originated before left bundle branching was completed.

the length of conduction tissue from the A-V node to the point at which the right bundle branch assumed its usual anatomic relationships on the right side of the ventricular septum.

In instances in which the right bundle branch originated before left bundle branching was completed (configuration 2, fig. 2), the distance from the A-V node to the point at which the right bundle branch turned to the right side was called "D." In comparisons of various measurements, the ABC distance in configuration 1 of figure 2 was assigned the same meaning as the D distance in configuration 2. The actual measurements obtained for the eight specimens studied are listed in table 1.

Results

Morphological Findings

In all eight examples, the A-V node appeared to be formed by the fusion of finger-like fascicles of atrial myocardium in the region of the artery to the node (fig. 3A and B). The majority of these fibers entered the region of the node from the posterior aspect of the septum, with lesser numbers from the region of the atrial septum superior to the node. In two examples, cases A2 and B2, the node was situated more posteriorly relative to the coronary sinus ostium than in the others.

In all examples, the common bundle (bundle of His) was identifiable in the floor of the right atrium for only a short distance before it penetrated the atrioventricular ring and central fibrous body (fig. 4A). It was situated on the left endocardial surface of the ventricular septum after passing through the fibrous tissue.

The left bundle branching in each case consisted of a series of fascicles given off the common bundle in a continuous fashion (fig. 4B). In none of the examples could

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yr)</th>
<th>Heart weight (g)</th>
<th>Tetralogy of Fallot</th>
<th>Distances (mm)</th>
<th>ABC</th>
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<tbody>
<tr>
<td>A1</td>
<td>18</td>
<td>640</td>
<td>2.0</td>
<td>4.8</td>
<td>10.0</td>
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<tr>
<td>A2</td>
<td>17</td>
<td>460</td>
<td>2.0</td>
<td>3.6</td>
<td>7.0</td>
</tr>
<tr>
<td>A3</td>
<td>9</td>
<td>207</td>
<td>3.6</td>
<td>4.4</td>
<td>1.0</td>
</tr>
<tr>
<td>A4</td>
<td>5</td>
<td>184</td>
<td>5.6</td>
<td>6.4</td>
<td>1.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yr)</th>
<th>Heart weight (g)</th>
<th>Distances (mm)</th>
<th>ABC</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>2</td>
<td>109</td>
<td>2.0</td>
<td>2.3</td>
</tr>
<tr>
<td>B2</td>
<td>2½</td>
<td>81</td>
<td>2.8</td>
<td>8.4</td>
</tr>
<tr>
<td>B3</td>
<td>5/12</td>
<td>62</td>
<td>3.6</td>
<td>5.6</td>
</tr>
<tr>
<td>B4</td>
<td>7</td>
<td>186</td>
<td>1.8</td>
<td>12.5</td>
</tr>
</tbody>
</table>

*See text and figure 2 for definitions.
Figure 3

Histology of the conduction system. AS designates the atrial septum; VS, the ventricular septum; MV, the mitral valve; TV, the tricuspid valve; VSD, the ventricular septal defect; CB, the common bundle; LB, a left bundle branch; RB, the right bundle branch. All figures represent sections stained with hematoxylin-eosin. (A) Region of the artery to the node (arrow) showing fibers destined to enter the A-V node (×10). (B) Region of the A-V node (arrow) (×10).

these fascicles be separated into distinct radiating bands in their proximal 1 to 2 mm. In each case the right bundle branch was a discrete bundle of fascicles (fig. 4C).

Conduction System in Tetralogy of Fallot

The four examples of tetralogy were similar in that conduction tissue was in close approximation to the postero-inferior rim of the septal defect (fig. 5A and C). Cases A1 and A2, the examples with a VCG pattern similar to the A-V canal pattern, differed from cases A3 and A4, the examples with the usual VCG pattern of tetralogy of Fallot, in that the fascicles destined to become the right bundle branch took an elongated and circuitous course. In case A2 this abnormal course appeared to result from the position of the septal defect, but in case A1 this explanation did not pertain.
In addition, in cases A1 and A2 the left bundle branching (the A distance) began a shorter distance from the A-V node than in cases A3 and A4. The actual measurements (table 1) of this distance were 2.0 mm in both A1 and A2, whereas in cases A3 and
Figure 5

Schematic representation of the conduction system. CS indicates the coronary sinus; TV, the tricuspid valve; VSD, the ventricular septal defect. The AV node is a white oval; the common bundle before left bundle branching is represented by a bar line with close interruptions; the common bundle with left bundle branching is the bar line with longer interruptions; the solid white or black bar lines represent the course of the right bundle branch. (A) The configuration found in an example of tetralogy with a representative VCG pattern. (B) The configuration in an example of VSD with a representative VCG pattern. (C) The configuration in an example of tetralogy with a VCG pattern similar to the AV canal pattern. (D) The configuration in an example of VSD with a VCG pattern similar to the AV canal pattern.

A4 the distances were 3.6 and 5.6 mm. Specimens in cases A1 and A2 were larger than in cases A3 and A4.

In order to compare measurements among different sized hearts, various ratios were calculated (table 2). These ratios represented the length of a portion of the conduction system to the total length of the system as defined.

Comparisons of the ratios obtained from measurements of length indicated differences in cases A1 and A2 from cases A3 and A4 (table 2): The ratios of B to ABC were relatively smaller in cases A1 and A2 than in cases A3 and A4. This indicated that the length of common bundle involved in left bundle branching was relatively smaller in A1 and A2. The relatively larger ratios of C to
**Table 2**

**Measurement Ratios**

<table>
<thead>
<tr>
<th>Case</th>
<th>A/ABC</th>
<th>B/ABC</th>
<th>C/ABC</th>
<th>AB/ABC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.12</td>
<td>0.29</td>
<td>0.60</td>
<td>0.40</td>
</tr>
<tr>
<td>A2</td>
<td>0.16</td>
<td>0.29</td>
<td>0.56</td>
<td>0.44</td>
</tr>
<tr>
<td>A3</td>
<td>0.40</td>
<td>0.49</td>
<td>0.11</td>
<td>0.89</td>
</tr>
<tr>
<td>A4</td>
<td>0.43</td>
<td>0.49</td>
<td>0.08</td>
<td>0.92</td>
</tr>
<tr>
<td>Bi</td>
<td>0.38</td>
<td>0.43</td>
<td>0.19</td>
<td>0.81</td>
</tr>
<tr>
<td>B2</td>
<td>0.23</td>
<td>0.69</td>
<td>0.08</td>
<td>0.91</td>
</tr>
<tr>
<td>B3</td>
<td>1.0</td>
<td>1.56</td>
<td>1.0</td>
<td>2.56</td>
</tr>
<tr>
<td>B4</td>
<td>0.3</td>
<td>2.0</td>
<td>1.0</td>
<td>2.38</td>
</tr>
</tbody>
</table>

*See text and figure 2 for definitions.

ABC in cases A1 and A2 substantiated the impression that the right bundle branch was elongated in these cases in comparison to cases A3 and A4. The relatively smaller A to ABC ratios in cases A1 and A2 reflected the differences already noted in actual measurements.

**Conduction System in VSD**

All four examples of VSD studied were similar to the examples of tetralogy of Fallot in that conduction tissue was in close approximation to the edge of the ventricular septal defect. Two different morphological configurations were observed (fig. 5 B and D). One pattern (cases B1 and B2) was similar to that observed in the cases of tetralogy, whereas the other configuration resulted from the fact that the right bundle branch originated from the common bundle before left bundle branching was completed (cases B3 and B4).

Comparisons of the actual measurements of the A distances (table 1) did not show consistent differences between those cases with a vectorcardiographic pattern similar to that of A-V canal (cases B1 and B2) and those with representative vectorcardiographic patterns of VSD (cases B3 and B4). Although the A distances in cases B1 and B2 were less than in case B3, this measurement in case B4 was less than that of any of the others.

The ratio of AB to ABC or AB to D was the only measurement ratio that appeared to distinguish cases B1 and B2, the examples with VCG patterns similar to the A-V canal pattern, from cases B3 and B4. The ratios indicated that cases B1 and B2 had a relatively longer distance from the A-V node to the point at which the right bundle actually turned to the right than cases B3 and B4.

**Discussion**

The source of the fibers contributing to the formation of the A-V node was similar to that previously reported. The position of the A-V node was normal in all but one example of tetralogy of Fallot and one of VSD. The close relationship of the major A-V conduction tissue and the posterior rim of the ventricular septal defect has been reported many times in tetralogy of Fallot and the usual variety of VSD.

The finding of a distinct, compact right bundle branch is well known. Its apparent “early” origin (cases B3 and B4) has been reported previously in VSD and has been considered a variant of normal.

Previous studies have indicated that the left bundle-branch system is a continuous sheet of fascicles leaving the common bundle as observed herein. We were unable to recognize the division of these left bundle-branch fibers in their proximal 1 to 2 mm into specific anterior and posterior radiations as has been described previously.

Although apparent elongation of the major A-V conduction tissue has been reported previously in A-V canal defects and was presumably due to distortion by the defect itself, previous studies have not indicated that similar elongation may occur in tetralogy of Fallot. It seems significant that both examples of tetralogy with VCG patterns similar to the A-V canal pattern had elongation of the course of the fibers destined to become the right bundle branch. If this elongation were not related necessarily to the position of the septal defect, which appeared to be the situation in case A1, it might be considered to be a specific anomaly per se. Conceivably, the anomaly might exist without a septal defect at all and thus suggest an
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explanation for the finding of an abnormal VCG in normal relatives of children with A-V canal defects.\textsuperscript{19}

The course of the fibers destined to become the right bundle branch was not obviously elongated in any of the examples of VSD studied; however, comparison of the measurement ratios indicated differences similar to those found in the cases of tetralogy of Fallot. Thus, the distance from the A-V node to the origin of the right bundle branch was relatively greater in the two examples of VSD with VCG patterns similar to the A-V canal pattern than in the examples with the usual VCG pattern.

Comparisons of the actual lengths of the major portions of the A-V conduction system in different hearts revealed that, with one exception, short A distances were associated with vectorcardiographic patterns similar to those seen in A-V canal. The converse situation would be expected if heart size had been the determining factor; that is, the A distance would have been longer in cases A1 and A2 than in cases A3 and A4. In recognition of the relationship between heart size and such measurements, the measurement ratios were defined to permit comparisons between various specimens. The actual linear measurements were readily verified in each instance since the thickness of each histological section and the exact number of sections were known.

Relative elongation of the right bundle branch, in combination with a short distance from the A-V node to the start of left bundle branching noted in instances of tetralogy of Fallot and in one of two examples of VSD that had VCG patterns similar to A-V canal, was considered to have created an anatomic situation in which the left bundle branches could have received a conducted impulse relatively earlier than in the normal heart.

This anatomic configuration is compatible with the findings of Roos and Durrer\textsuperscript{20} in which epicardial excitation times were measured in examples of ostium primum defects. They found that the posterobasal portion of the septum, presumably supplied by the initial branches of the left bundle, was excited earlier than normal. In addition, the anatomic configuration found in this study would permit early excitation of the left bundle as suggested by Grant and associates\textsuperscript{21} to occur in pre-excitation syndrome. In regard to Grant's hypothesis, however, our findings indicated that the impulse may not reach the left bundle branch earlier because of an anomalous route of excitation as has been suggested to occur in pre-excitation, but rather because the conduction system was anatomicallly suited for relatively early impulse conduction to the left bundle branches.

Burchell and associates\textsuperscript{22} had suggested earlier that the abnormal vectors observed in A-V canal may result from an imbalance of the electric forces which might be related to an anatomic abnormality of the left bundle system. Since our study did not include the peripheral portions of the left bundle branching system, we cannot comment on this possibility as an alternate view to that suggested above.

Summary

The atrioventricular conduction system was studied by a technique of selected serial histological sections in examples of tetralogy of Fallot and ventricular septal defect to correlate the anatomic findings observed with the electrophysiological findings as manifested by the vectorcardiographic pattern. Eight hearts were studied; two examples of each anomaly had electrocardiographic and VCG patterns in the frontal plane similar to A-V canal defects and two examples of each had ECG and VCG patterns usually associated with these lesions.

Of the four examples of tetralogy, the two examples with VCG patterns similar to the A-V canal pattern differed from the other examples in that the distance between the A-V node and the origin of left bundle branching was shorter and the fibers destined to become the right bundle branch took an elongated course. The VSD examples offered less striking differences. A short distance from the A-V node to the onset of left bundle branching was seen in both examples with

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VCG patterns similar to the A-V canal pattern, but one example of VSD with a representative VCG pattern had a similar anatomic configuration. When measurement ratios were compared, the right bundle took its origin at a relatively greater distance from the A-V node in the examples with VCG patterns similar to the A-V canal pattern.

The anatomic configuration of those examples of tetralogy and VSD with VCG patterns similar to the A-V canal pattern was such that relatively early conduction to the left bundle branch system could occur.

References


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