The Atrioventricular Conduction System in Persistent Common Atrioventricular Canal Defect

Correlations with Electrocardiogram

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

SUMMARY
Serial histologic sections of the atrioventricular (A-V) conduction system were studied in four hearts with persistent common A-V canal, and the anatomic findings were related to the abnormal ECG patterns. Two hearts were examples of the partial form and two of the complete form of A-V canal. The major anatomic abnormalities were: (1) postero-inferior displacement of the A-V node; (2) relatively short distances between the A-V node and the origin of the left bundle branching; (3) marked postero-inferior displacement of the left bundle branching system; and (4) relative hypoplasia of the anterior (superior) left bundle branches. The anatomic configuration of the A-V conduction system in A-V canal could result in relatively early impulse propagation to the posterior aspect of the ventricular septum as suggested by reported electrophysiologic studies. The anatomic findings are considered to be related closely to the known ECG patterns of A-V canal.

Additional Indexing Words:
Congenital heart disease
Left bundle branches

The electrocardiographic (ECG) and vectorcardiographic (VCG) patterns in patients with persistent common atrioventricular canal defects (A-V canal) are considered to be distinctive in the presence of a fully developed left ventricle.1-5 Although these patterns were once thought to be the result of left ventricular hypertrophy, experimental evidence6-9 suggests that they are the result of anomalous A-V conduction which might be related to anatomic abnormalities in the A-V conduction system. In this study, the morphologic configuration of the A-V conduction system of hearts with either partial or complete forms of A-V canal10 was studied in an effort to determine whether anatomic characteristics could be associated with the known electrophysiologic abnormalities.

Methods
Four examples of A-V canal were studied; two were the partial form and two were the complete form. In all four instances, schematic analysis of the scalar ECG revealed a superiorly oriented counterclockwise QRS loop or a figure-of-eight QRS loop lying on the isoelectric line in the frontal plane, the initial portion of which was counterclockwise in direction (fig. 1).

The morphology of the conduction system in each of the four cases was reconstructed by using a previously described11 technic of serial histologic sectioning. The blocks of tissue removed for study included parts of the atrial and ventricular...
Figure 1

Electrocardiograms and schematically reconstructed frontal plane QRS loops in four cases studied. Cases 1 and 2 (A and B) were complete forms of A-V canal. Cases 3 and 4 (C and D) were partial forms of the defect.

Figure 2

Schematic representation of A-V conduction system. AVN refers to A-V node. A represents length of common bundle prior to point at which left bundle branching begins. B represents length of common bundle from which left bundle branches (LB) are given off. C represents length of right bundle branch (RB) to point at which it takes a more or less abrupt inferior (apexward) course in the right side of the septa on each side of the A-V rings and included the A-V node, the bundle of His, and the left and right bundle branches.

The tissue blocks were sectioned serially at a thickness of 8 microns in a plane perpendicular or nearly so to the ventricular septum. Initially, every 40th section was stained with hematoxylin and eosin, and the next succeeding section was stained with the Mallory-Heidenhain stain. Additional intervening sections were prepared as needed for more detailed study. The actual and relative lengths of various portions of the A-V conduction system were measured by using a previously described method (fig. 2). The ratios...

ventricular septum. (From Feldt R H, DuShane J W, Titus J L: The anatomy of the atrioventricular conduction system in ventricular septal defect and tetralogy of Fallot: Correlations with the electrocardiogram and vectorcardiogram. Circulation 34: 774, 1966.)
were derived in an attempt to compare hearts of different sizes, since the comparison would be meaningless on the basis of absolute measurements.

**Results**

In all four specimens studied, the morphologic features and the size of the A-V node were similar to those described in other congenital cardiac defects. In all, the A-V node was displaced postero-inferiorly in the floor of the right atrium, as indicated by its relationship to the ostium of the coronary sinus (fig. 3A).

The common bundle of His passed through the fibrous A-V ring to reach the crest of the ventricular septum. In this location, the

![Image of microscopic anatomy of A-V conduction system in case 3 (partial form of A-V canal).](http://circ.ahajournals.org/)

Figure 3

Microscopic anatomy of A-V conduction system in case 3 (partial form of A-V canal). (A) Section through atrial and ventricular septa, showing location of A-V node (AVN) and its relationship to coronary sinus (CS). MV = mitral valve; TV = tricuspid valve. (Mallory-Heidenhain; × 5.) (B) Section through ventricular septum (VS) and A-V canal defect shows common bundle of His (CB) subjacent to defect on left side of ventricular septum and left bundle branching (LBB) from common bundle. This section is approximately 3.9 mm anterior to that shown in A. (Mallory-Heidenhain; ×5.) (C) Section through ventricular septum (VS) beneath defect shows origin of right bundle branch (RBB) and its relationship to left bundle (LBB) and A-V valves. (Mallory-Heidenhain; ×10.)
A-V conduction systems reconstructed from serial histologic sections and superimposed schematically on heart viewed from right side (showing opened right atrium, right ventricle, part of A-V valve, and defect). Cases 1 and 2 (A and B) are complete forms of A-V canal; cases 3 and 4 (C and D) are partial forms. A-V node (outlined in black) is close to ostium of coronary sinus in cases 1, 2, and 3. Broken lines outline common bundle and left bundle branch in left ventricular aspect of atrial and ventricular septa. Dotted single line in cases 1, 3, and 4 represents right bundle branch in right ventricular aspect of ventricular septum.

common bundle was close to the postero-inferior rim of the A-V canal and on the left ventricular aspect of the septum (fig. 3B).

In all four hearts, after the common bundle passed through the fibrous tissue onto the crest of the ventricular septum, large fascicles originated from it and streamed inferiorly (apexward) in the endocardial surface of the left ventricular side of the ventricular septum (fig. 3B). These fascicles, the left bundle branches, were given off in that area in which the common bundle was in approximation with the postero-inferior aspect of the defect. The left bundle branches were given off continuously; separation into anterior and posterior radiations could not be made at their origins from the common bundle. In all examples, fewer left bundle fascicles origi-
CONDUCTION SYSTEM IN A-V CANAL

Reconstructed A-V conduction system superimposed on same hearts as shown in figure 4 viewed from left side (showing opened left atrium, left ventricle, part of A-V valve, and defect). A-V node is outlined in black. Common bundle and left bundle branches in left side of septa are represented by solid white lines outlined in black. Common bundle is close to defect, and left bundle branches are located primarily in posterior portion of ventricular septum. Cases arranged as in figure 4.

The right bundle branch was identified in three specimens (cases 1, 3, and 4). It originated from the common bundle as a small number of fascicles which passed to the right side of the ventricular septum and then turned abruptly apexward. In some instances, the right bundle branch originated before all left bundle branches were given off (cases 1 and 4); in case 3 the right bundle branch was the continuation of the common bundle after left bundle branching was completed (fig. 3C).

Reconstruction of the A-V conduction system in the hearts studied (figs. 4 and 5) demonstrated that in comparison to the anatomic features of the A-V conduction system in normal hearts: (1) the A-V node was displaced postero-inferiorly; (2) the common bundle of His was displaced postero-inferiorly by the presence of the A-V canal.
Table 1

<p>| Heart Weights and Distance Measurements of A-V Conduction System in Cases of A-V Canal |
|---------------------------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Case</th>
<th>Type</th>
<th>Heart wt. (g)</th>
<th>Distances (mm)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Complete</td>
<td>65</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>Complete</td>
<td>55</td>
<td>10.0</td>
</tr>
<tr>
<td>3</td>
<td>Partial</td>
<td>120</td>
<td>4.5</td>
</tr>
<tr>
<td>4</td>
<td>Partial</td>
<td>150</td>
<td>3.2</td>
</tr>
</tbody>
</table>

*See figure 2 for definitions of A, B, and C.
†The right bundle branch was not identified in this heart.

The defect may extend into the postero-inferior part of the septum; and (3) the origin and course of the left bundle branches were markedly displaced postero-inferiorly, and the most anterior left bundle branches were fewer than in normal hearts.

In one example of the complete form (case 2), the common bundle skirted the postero-inferior rim of the defect in a circuitous manner and appeared to be markedly elongated as a result of this arrangement.

Measurements of the various parts of the A-V conduction system (table 1) and ratios of these measurements (table 2) supported the anatomic observations. When these measurements and ratios were compared to similar data reported in the literature for tetralogy of Fallot, a relatively short distance from the origin of the common bundle to the first left bundle branch (the A distance) was found in those hearts in which ECG patterns of the A-V canal type had been recorded during life (table 3). The exception (case 2) may be explicable on the basis of marked distortion of the entire common bundle and left bundle branching system due to the large defect.

Table 2

<p>| Ratios of Measurements* of A-V Conduction System in Cases of A-V Canal |
|------------------|------------------|------------------|------------------|</p>
<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>1</td>
<td>0.13</td>
<td>0.63</td>
<td>0.24</td>
<td>0.76</td>
</tr>
<tr>
<td>3</td>
<td>0.24</td>
<td>0.19</td>
<td>0.57</td>
<td>0.43</td>
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<tr>
<td>4</td>
<td>0.14</td>
<td>0.41</td>
<td>0.44</td>
<td>0.56</td>
</tr>
<tr>
<td>Mean</td>
<td>0.17</td>
<td>0.41</td>
<td>0.42</td>
<td>0.58</td>
</tr>
</tbody>
</table>

*See figure 2 for definitions and table 1 for individual values.

Discussion

The ECG and VCG patterns seen in patients with A-V canal have been considered to be distinctive based on clinical experience and the fact that these patterns are not greatly altered by successful complete surgical repair of the defect.1-5 Surface ECG and VCG mapping studies6 have suggested anomalous A-V conduction in patients with A-V canal. Direct epicardial surface recording of A-V conduction potentials in A-V canal showed relatively early impulse propagation to that portion of the left ventricle in closest proximity to the posterior (initial) left bundle branches.7 Previous morphologic studies11-16 of the A-V conduction system in A-V canal and related defects revealed an apparent posterior displacement of the A-V conduction system by the defect. Direct endocardial staining of the heart with iodine6 showed apparent posterior displacement of the left bundle branches. To our knowledge, a detailed histologic study of the left bundle branches in A-V canal has not been reported.

The postero-inferior displacement of the A-V node in its relationship to the ostium of the coronary sinus in the four examples of A-V canal studied herein has been observed previously.18 A circuitous course of the bundle of His about the postero-inferior rim of the defect also has been reported previously.13-15, 17

This circuitous course was greatly exaggerated in our case 2 and was similar to the anatomic configuration reported in ventricular septal defect of the A-V canal type.15 The location of the bundle of His in these hearts—on the left ventricular aspect of the...
CONDUCTION SYSTEM IN A-V CANAL

Table 3

Comparison of Mean Ratios of Measurements of A-V Conduction System in Cases of A-V Canal and Tetralogy of Fallot

<table>
<thead>
<tr>
<th>Defect</th>
<th>Mean values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A/ABC</td>
</tr>
<tr>
<td>A-V canal (present study)</td>
<td>0.17</td>
</tr>
<tr>
<td>Tetralogy</td>
<td></td>
</tr>
<tr>
<td>With ECG of A-V canal*</td>
<td>0.14</td>
</tr>
<tr>
<td>With typical ECG*</td>
<td>0.42</td>
</tr>
</tbody>
</table>

*Means calculated from data reported by Feldt and associates.11

The crest of the ventricular septum—has been described in other congenital cardiac defects and in some normal hearts.11, 12, 17, 18

The relatively early origin of the left bundle branches from the common bundle has been reported previously in examples of ventricular septal defect and tetralogy of Fallot which had frontal plane VCG patterns of the A-V canal defect type.11 The measurements and the ratios of the various lengths of the components of the A-V conduction system suggest an anatomic configuration that could allow relatively early impulse propagation to the left bundle branches. Whether these relative lengths of the components of the A-V conduction system are related directly to electrophysiologic events occurring with impulse propagation cannot be proved by this study.

Relative hypoplasia of the more anterosuperior left bundle branches was found in this study, as in others.6, 13 and is considered to be an important anatomic feature which could affect electrophysiologic events. Marked posterior displacement of the left bundle branches was present in all four hearts, as reported previously,6 and may be the most significant anatomic basis for the electrophysiologic abnormalities present in A-V canal.

From consideration of these findings, we believe that the anatomic configuration of the A-V conduction system in A-V canal could result in relatively early impulse propagation to the posterior aspect of the ventricular septum and left ventricle; this correlates with the known electrophysiologic abnormalities and the anomalous ECG patterns.

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