Normal Blood Supply to the Human His Bundle and Proximal Bundle Branches

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SUMMARY

The three major coronary arteries of 10 normal human hearts were injected with differentially colored gelatin mass for histologic determination of the blood supply to the His bundle and proximal bundle branches. The His bundle was dually supplied by the A-V node artery and the first septal branch of the left anterior descending artery in nine hearts, but entirely by the A-V node artery in one. The proximal right bundle branch was supplied by the A-V node artery and septal branch in five hearts, only the septal branch in four, and the A-V node artery alone in one. The anterior half of the left bundle branch was dually supplied by the A-V node artery and septal branch in four hearts, entirely by the septal branch in five, and the A-V node artery alone in one. The posterior half of the left bundle branch was supplied by the A-V node artery alone in five hearts, dually by the A-V node artery and septal branch in four, and by the septal branch alone in one. The blood supply to most of the human His bundle and its proximal branches is thus dual in origin, with anastomosis principally within the His bundle.

Additional Indexing Words:
Heart block  A-V node artery  Bundle-branch block  A-V node

Although general coronary anatomy has been studied in many ways for many years, the precise distribution in certain dually supplied regions of the human heart still requires better definition. One such region is the His bundle and the proximal few millimeters of its branches. A clearer understanding of the blood supply to this crucially important area of the heart should be helpful in understanding the pathophysiology of various forms of conduction disturbances in ischemic heart disease.

The blood supply to the human, canine, bovine, and lapine atrioventricular (A-V) node has been previously reported from this laboratory, but that to the His bundle was not a special focus of attention. Recent improvements in the use of coloring materials now make it possible to inject a colored barium gelatin mass which will withstand histologic processing and retain its original color. The present study was designed to utilize this new injectate to define precisely the normal blood supply to the human His bundle and the proximal portion of its two branches.

Materials and Methods

Ten normal human hearts were obtained at necropsy from subjects who died from various accidents and noncardiac diseases. Ages were evenly distributed between 13 and 46 years. The right and main left coronary arteries were cannulated with polyethylene tubing. In five hearts the circumflex branch of the left coronary artery was dissected and ligated directly at its origin. A small incision was made in the artery immediately distal to this ligature and a cannula was introduced and ligated in place. This procedure allowed separate perfusion of the circumflex branch, the anterior descending branch being perfused by the cannula in the main left coronary artery. In the five other hearts the left anterior descending branch was ligated and perfused from its origin in a similar manner, the circumflex branch in this instance being filled from the main left coronary artery.

This technic permitted simultaneous but separate perfusion of the three major coronary arteries of each heart. Stopcocks were attached at the proximal end of the polyethylene tubing, and the cannulae were kept filled with saline during the cannulation to prevent entry of air. The heart was immersed in a container of saline and warmed to 37°C just prior to injection. Each coronary cannula was connected to a separate perfusion bottle from which the coronary arteries were then simultaneously perfused initially with 100 cc of warm saline.

A barium gelatin mass was prepared according to the method of Hales and Carrington. After the heart had

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been preperfused with warm saline, the three colored gelatin injectates (red, blue, and yellow) were placed in the three bottles and then simultaneously injected into the coronary arteries. The pressure within the system was maintained at 80 mm Hg for 2 min while all small blood vessels on the cut surfaces were clamped. Pressure was then increased to 140 mm Hg for 8 min. The polyethylene cannulae were then tied and cut, and the heart was washed and immersed in a container of 10% formalin. The pigments are inert particles which maintain their color through histologic processing. The injection mass will penetrate vessels down to about 40 μ in diameter but will not pass the capillaries. Mixing of two colors in anastomosing channels is poor, producing a layered effect. This characteristic provided an advantage in the histologic identification of intercoronary anastomoses.

The following day, photographs and X-rays of the intact heart were made. These initial X-ray films were reviewed to rule out unsuspected vascular disease and to document complete filling of the coronary tree. The free walls of both atria and ventricles were then cut away leaving only the interatrial and interventricular septum. The crista supraventricularis was cut transversely, leaving a short stub of it attached to the ventricular septum. X-rays of the septum were then taken in the horizontal, sagittal, and frontal planes (fig. 1). These septal views demonstrated not only the origin and distribution of the anterior septal and A-V node artery branches, but also the blood supply of the crista supraventricularis and the degree to which these cristal branches may penetrate the ventricular septum.1

The block of tissue containing the A-V node, His bundle, and the proximal portion of its two bundle branches was prepared by trimming away the lower two thirds of the ventricular septum and the upper half of the atrial septum. This block included at least 2 cm each of interatrial and interventricular septa. Thus, at least 20 mm of each bundle branch was available for study. Histologic sections were cut perpendicular to the junction of the interatrial and interventricular septa at 2-3-mm intervals, beginning anterior to the crista supraventricularis and continuing posteriorly to the epicardium at the crux of the heart. Each subserial block was embedded in paraffin and sectioned at 6–8 μ. At least 10 slides from each block were prepared with the Goldner trichrome stain and Verhoeff-van Gieson elastic stain. Because of the color retention by the injection mass, the blood supply to the His bundle and the proximal portion of its two bundle branches could be precisely determined by microscopic examination of these histologic sections.

Results

In general terms there are two primary sources of blood supply to the human His bundle and the proximal portion of its two branches: the A-V node artery and the first septal branch of the left anterior descending coronary artery (fig. 2). Secondary sources of supply which provide important anastomoses include: (1) Kugel’s artery (arteria anastomotica auricularis magna); 3,7 (2) the first few septal branches of the posterior descending artery, the A-V node artery (fig. 3) usually being the uppermost of this group; (3) the second septal branch of the left anterior descending artery; (4) posterior left atrial and right atrial arteries; and (5) branches into the crista supraventricularis from the right coronary artery. Kugel’s artery may be one or more vessels originating from either the proximal right or proximal left coronary artery and coursing back into the junction of atrial and ventricular septa. There are important comparative anatomic differences in coronary distribution in this region, as will be discussed later.

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**Figure 1**

X-ray of one of the studied cases includes the interatrial and interventricular septa but the free ventricular walls have been cut away. The rectangle outlines the region excised for histologic examination in each heart. The crista supraventricularis (CrS) lies directly beneath the origin of the right coronary artery, seen with cannula in place, and marks the anterior margin of the study block. The two principal sources of blood supply to the His bundle and its branches are the A-V node artery (AVNA) and the first septal branch (Sep) of the left anterior descending artery (LAD). Note the characteristic right-angle termination of the A-V node artery.
The blood supply to the human His bundle (figs. 4, 5) and its proximal bundle branches in these 10 hearts is shown in table 1. The His bundle in nine hearts received a dual supply of blood from both the crux and the anterior septum. In four of these the dual supply overlapped and was identified in each microscopic section of His bundle. In the remaining five, the two arteries met near the midpoint of the His bundle but did not overlap significantly, the posterior portion of His bundle being supplied by the A-V node artery and the anterior portion of His bundle by the anterior septal branch. In one heart, the A-V node artery penetrated sufficiently anterior to supply the entire His bundle and proximal bundle branches, without meeting or visibly anastomosing with communicating branches from the anterior septum. The undivided His bundle (posterior to the initial portion of the left bundle branch) was always supplied by the A-V node artery.

The initial parts of the right bundle branch and of the anterior half of the left bundle branch were supplied in an almost identical fashion (figs. 6, 7). In nine of 10 hearts both were supplied by the anterior septal branch, in five of the hearts exclusively by it, and in the other four jointly with the A-V node artery. In one heart, however, both the right and left bundle branches proximally were entirely supplied by the A-V node artery. The proximal portion of the posterior half of the left bundle branch differed significantly, being supplied entirely by the A-V node artery in five hearts, receiving a dual supply in four, and being supplied exclusively by the anterior septal branch in only one heart. The His bundle itself was never supplied solely by the anterior septal branch.

In addition to the A-V node artery and first major anterior septal branch, several other arteries were notable potential sources of collateral circulation. The numerous anastomotic connections from the A-V node artery to both the atrial and ventricular septum were readily identified. Branches of the right coronary artery to the crista supraventricularis often additionally penetrated the ventricular septum a short distance, anastomosing with the anterior septal branches. In one heart a large cristal branch penetrated deep toward the membranous septum, anastomosing freely with septal branches of the left anterior descending, the posterior descending, and the A-V node artery. This branch was in close proximity to the right bundle branch but did not actually furnish the primary blood supply to this structure; however, it was an excellent source of collateral blood supply. The anterior septal branch providing primary blood supply to the region of the His bundle and proximal bundle branches always originated from the left anterior descending artery, but in one case there was also a large septal branch originating from the circumflex artery. This unusual vessel passed downward and backward below the membranous septum to provide a secondary source of blood to the anterior His bundle, proximal right bundle branch, and the proximal anterior half of the left bundle branch. Occasionally, a small septal branch of the left anterior descending artery may arise proximal to the first major septal branch. This serves as another inconsistent source of blood to the conduction system.1, 8

The crux of the heart was supplied by the right coronary artery in five hearts, by the circumflex in three, and by both in two hearts. In both of the latter cases the circumflex was the larger vessel, but it gave rise to the A-V node artery in only one. The origin of the A-V node artery, therefore, was from the right coronary in six cases and from the circumflex in four. This represents a slightly greater percentage of circumflex origin than is usually the case.1, 9, 10

Discussion

While 10 specially selected hearts comprise the central portion of this study, the interpretation of these observations is aided by considerable prior experience with anatomy of the coronary arteries and the cardiac conduction system.1-8, 11 Thus, variants in distribution are more readily recognized in this comparatively small sample. It may also be noted that earlier studies have established that the primary blood supply to the human A-V node is from the A-V node artery virtually exclusively.1, 2, 9, 10, 12, 13

Figure 2

Vinylite casts of human coronary arteries illustrating details of the anatomy in the region studied. The area of crista supraventricularis is seen as a void in the cast of the right ventricular cavity. (Top) Rectangle indicates most of the section removed for histologic examination. Abbreviations same as in figure 1. (Bottom) Same image. The unshaded region outlines the superimposed His bundle and a proximal portion of its left branch, schematically cut off at its lower margin.

Circulation, Volume XLVII, January 1973
Photomicrographs illustrate the right-angle termination of the A-V node artery, which typically turns toward the interventricular septum near the midportion of the A-V node. Both sections are from the same heart about 3 mm apart, with A posterior to B. (A) The arrow indicates the A-V node artery within the A-V node. (B) The artery (arrow) turns down into the septum. This sharp turn is a useful anatomic landmark, since it does not occur within the His bundle but always within the A-V node. (Goldner trichrome stain; × 10.)

It has previously been reported\(^1,\ 2,\ 9,\ 12\) that the human His bundle and the proximal bundle branches were supplied by the A-V node artery, although Haas (as quoted by Gross\(^9\)) noted that the right bundle branch lay just on the border between the regions of arborization of the right and left coronary arteries in the septum. Gross,\(^9\) Lascano,\(^12\) and Lumb and Singletary,\(^13\) however, described anastomosing channels directly through the His bundle from the anterior septal branches to the A-V node artery. The present study demonstrates that certain segments of the His bundle and proximal bundle branches receive a relatively constant or specific blood supply, while the supply to other segments is variable. The His bundle clearly received a primary dual blood supply in the majority (90\%) of these normal hearts.

The dual blood supply to the His bundle helps explain certain events seen in posterior myocardial infarction complicated by heart block.\(^11\) The A-V
Figure 4

In this photomicrograph the arteries supplying undivided His bundle (AVB) are clearly visualized. All these vessels are from the A-V node branch of the right coronary artery. (van Gieson stain; × 50.)

node is regularly supplied by the A-V node branch arising from the coronary artery crossing the crux of the heart, this being the right coronary artery in 90% of human hearts.\(^1,2\) Posterior infarction caused by an occlusion proximal to the origin of the A-V node artery results in A-V node ischemia and often heart block.\(^11\) The degree of block may vary from slight P-R interval prolongation through the various forms of second-degree to complete heart block.\(^11,14\) When complete heart block occurs, it is frequently associated with narrow QRS complexes, suggesting an escape pacemaker focus proximal to the bifurcation of the His bundle.\(^15,16\) Therefore, the A-V node ischemia, while of sufficient magnitude to impair conduction there, need not involve as severely the dually supplied His bundle.

Posterior infarction with complete block is sometimes associated with widened QRS complexes.\(^14,17,18\) Ischemia of the A-V node and the entire His bundle is implied here, and can be explained in two ways. First, the entire His bundle may be supplied by the A-V node artery without sufficient collateral flow to prevent the ischemia. However, such an anatomic configuration was
present in only one of 10 hearts in the present study. The second and more likely explanation, considering the His bundle’s dual primary blood supply, implies narrowing disease of both systems. An acute posterior infarction superimposed on older anterior septal arterial disease places both the A-V node and entire His bundle in jeopardy.

Complete heart block following anteroseptal myocardial infarction may be analyzed in much the same way. The anterior infarct in such cases is usually very large, indicating occlusion of the left anterior descending artery near its origin. There is often preceding right bundle-branch block rather than P-R prolongation, and the QRS complexes of the eventual escape rhythm are wide. The heart block has generally been attributed to an interruption of the peripheral segments of both bundle branches secondary to a large septal infarction. However, in almost all cases there has been associated severe coronary disease proximal to the A-V node artery, so that there must be A-V node ischemia as well. Judging by the normal dual blood supply to the His bundle and proximal bundle branches, it seems unlikely that an anterior infarction alone would produce heart block by affecting these structures at their
Table 1
Normal Blood Supply to His Bundle and Proximal Bundle Branches in Ten Normal Human Hearts

<table>
<thead>
<tr>
<th>Origin of blood supply</th>
<th>His bundle</th>
<th>Prox RBB</th>
<th>Ant half</th>
<th>Post half</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-V node artery only</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>A-V node artery plus ant septal branch</td>
<td>9</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Ant septal branch only</td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 6
Photomicrographs showing the branching portion of the His bundle (arrow) with filled arteries easily visualized in two different hearts (A and B). (A) The right subendocardial course of two major septal arteries is seen, with mixing of two different color injection masses readily identified even in the black-and-white picture. (van Gieson stain; × 8.)

Arteries to His Bundle and Branches

However, in one heart in the present study both bundle branches proximally were primarily supplied by anterior septal branches, suggesting that bilateral bundle-branch block may be the explanation in rare cases of complete heart block occurring with isolated anteroseptal infarction.

Anteroseptal infarction would most commonly affect a portion of the blood supply to the proximal right bundle branch and the anterior half of the left bundle branch, since both of these structures...
receive essentially the same primary blood supply. The normal blood supply to the posterior half of the left bundle branch, which is from the A-V node artery, would be maintained in this circumstance. Such an infarct may result in right bundle-branch block and, depending on the extent of injury, various degrees of altered activation of the left bundle-branch system. Complete left bundle-branch block occurring during acute myocardial infarction requires multiple coronary lesions, since the primary blood supply to the left bundle-branch system is clearly of dual origin. It is unsurprising that left bundle-branch block seldom occurs in posterior myocardial infarction, and similarly that complete block of the left bundle branch is unusual in uncomplicated anteroseptal infarcts (although left-axis deviation and incomplete left bundle-branch block are not uncommon).

Right bundle-branch block described with anteroseptal rather than posterior infarction is associated with proximal occlusion of the anterior descending coronary artery. This association may be explained by the small size of the right bundle branch and the frequency with which it is supplied primarily by anterior septal branches. Blondeanu found necrosis of the right bundle branch to be a relatively frequent feature of anteroseptal infarction complicated by heart block. Transient right bundle-branch block is also often seen as an isolated finding in posterior infarctions. Anatomically, this can best be explained on the basis of transient but unequal ischemia of the A-V node and proximal His bundle, selectively inhibiting conduction to the right branch, the conduction to the left branch being relatively unaffected. It may also be noted that right bundle-branch block is sometimes difficult to distinguish from delayed activation of the posterior left ventricular wall, as may occur during its infarction. The possibility of selective involvement of the proximal portion of the right bundle branch secondary to a posterior infarction, without also producing some form of A-V block or left bundle-branch block, seems remote in view of the patterns of the normal blood supply.

_Circulation, Volume XLVII, January 1973_
ARteries to His Bundle and Branches

One of the most familiar observations in clinical electrocardiography, the Q wave of posterior myocardial infarction, may now be considered in light of the present findings. Although this Q wave is often considered to represent the loss of electrical activity in the free ventricular wall, the free wall usually infarcted is among the ventricular segments normally activated rather late.\(^4\) Thus, one might anticipate terminal but not proximal QRS deformation on this basis. In the present study it was found that the initial portion of the posterior half of the left bundle branch was supplied by the A-V node artery in nine of 10 hearts, and exclusively by this artery in five of these nine. One may thus suspect that altered activation of the posterior portion of the left bundle branch may account for the Q-wave abnormality in posterior infarct. There is a necessary qualification in this reasoning, however, and that concerns the required additional assumption that the A-V node (but not the His bundle) was as ischemic as the posterior half of the left bundle branch. If the A-V node was as ischemic, it would explain the transient A-V block so often seen in posterior infarcts, but the Q wave often persists in surviving patients while the A-V block seldom does.

Our suggested explanation is as follows. The Q wave of posterior infarcts means that a sufficiently large component of the A-V junction was affected to place all A-V conduction in immediate jeopardy. This fits with the familiar stormy nature of the clinical course in such patients, particularly when seen very early. The persistence of Q waves but transience of A-V block is most likely due to adequate collateral circulation to the A-V node and main His bundle, but not to the posterior portion of the left bundle branch.

These observations are in human heart and can not be readily extrapolated to other animals, where most experimental electrophysiology is conducted. The dog and rabbit hearts are the most frequent choices for such experiments, and, in both, the septal arterial circulation is grossly different from that in man.\(^3,4\) In contrast to the four to six major septal branches in man, both the dog and rabbit have a single major septal branch of the left anterior descending artery. In the beef heart a single major septal branch comes from the proximal segment of the right coronary artery.\(^4\) Although it is widely believed that pork hearts closely resemble human ones, there is an important difference caused by normal persistence of the left superior vena cava and a consequently large coronary sinus through which it drains. The location of the porcine A-V node and His bundle is comparatively closer to the membranous septum and further from the epicardium of the crux than in man, and this “displacement” influences the sources of its primary blood supply.

More needs to be known about the influence of ischemia on physiologic behavior of the His bundle and its proximal branches\(^25\) for better interpretation of the consequences of arterial disease. For example, the concept of normal longitudinal dissociation of conduction in the human His bundle\(^26,27\) inevitably leads to the possibility that electrocardiographic bundle-branch block need not be due to an anatomic lesion in a bundle branch. Any reported demonstration of such lesions in a bundle branch thus requires careful additional assessment of integrity or disease of “upstream” structures such as the His bundle. However, whatever the functional interpretation of such lesions may ultimately prove to be, detailed knowledge of the anatomy of their blood supply will be essential to an understanding of their pathogenesis.

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Correction

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