Laboratory Investigation

Anatomical Reasons for the Discrepancies in Atrioventricular Block

after Inferior Myocardial Infarction with and without Right Ventricular Involvement

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The incidence of arrhythmias after acute myocardial infarction of the inferior wall varies with the affected segment and increases when there is right ventricular involvement. This paper provides a clear review of the blood supply to the conduction system and gives an anatomic explanation of that supply.

We dissected 20 human hearts after anterograde and retrograde injection of latex. In every heart, we dissected the conduction system and its blood supply. Retrograde perfusion enabled proper injection of the atrial vessels that originate at the beginning of the coronary trunks.

We describe the 4 main arteries that supply blood to the conduction system. The classic concept included the atrioventricular node artery and the 1st septal artery. To that we add Kugel's artery and the right superior descending artery.

The incidence of arrhythmias after acute myocardial infarction of the inferior wall is greater when the occlusion of the coronary trunk is at or near the origin. This is due to the existence of the right superior descending artery, which is given off by the right coronary trunk less than 1 cm from the origin. The arrhythmias caused by the occlusion of the circumflex artery are due to the existence of Kugel's artery, which displays a peculiar anastomotic pattern. ***(Tex Heart Inst J 2009;36(1):8-11)***

Key words: *Atrioventricular node; cadaver; coronary vessels/anatomy & histology; heart atria; heart block/etiology; humans; heart conduction system; myocardial infarction, inferior/complications*

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Arrhythmias as a complication of acute myocardial infarction of the inferior wall vary in their occurrence, depending on the presence or absence of right ventricular involvement.[1-3] Many articles have made this observation, but, to the best of our knowledge, none has offered a clear morphologic explanation: that is, there have been few images of the heart's conduction system, particularly of the blood supply to the conduction system in the atrioventricular (AV) node and of the alternative blood supply to that conduction system (which has been shown in drawings and diagrams, but not in photographs). This paper reviews our present knowledge of the blood supply to the conduction system and supplements it with new findings that help to explain why the incidence of postinfarction arrhythmias is greater when there is right ventricular involvement. Two atrial arteries have been described[4] by the authors as sources of the blood supply to the conduction system: Kugel's artery (arteria anastomotica auricularis magna) and the right superior descending artery. These vessels, which appear to constitute the chief explanation for the phenomenon mentioned above, are thoroughly discussed herein.

Materials and Methods

For the present study, 20 hearts were removed from the cadavers of human subjects with and without coronary disease, who had ranged in age from 15 to 65 years at the time of death. Of these 20 hearts, 2 were dissected more than a decade ago and the results reported then.[4] These 2 hearts have the peculiarity of a "larger-than-usual" right superior septal artery. Accurate dissection of this vessel in new hearts has enabled us to discover more.

These 20 hearts were injected anterograde and retrograde via a technique described earlier[4] by the authors and then were dissected. The right coronary artery was dissected at the acute margin and cannulated anterograde and retrograde. The origins of

the right and left coronary artery were ligated, with care taken not to damage the 1st branches.

The anterior descending artery was cannulated anterograde and retrograde between the 1st and 2nd diagonal branches. Then, we began the latex injection (Noviplast; Buenos Aires, Argentina) and took great care to confirm our success through observation. If the circumflex did not fill, we injected more latex by means of a 3rd cannulation (of the obtuse marginal branch).

After leaving the heart in a formalin buffer for 2 days, we started the dissection with the aid of a Zeiss OPMI® 1 optical magnifier (Carl Zeiss Meditec, Inc.; Dublin, Calif) having lenses of 10× and 20× magnification. We first identified the conduction system, by starting its dissection at the anterior papillary muscle of the right ventricle in search of the right bundle branch. From there, the complete conduction system, including the bundle of His and the AV node, could be dissected and every single vascular structure tracked from the target to the origin.

Results

We have previously described 2 patterns of blood supply to the conduction system: the classic one, in which the AV node artery and the 1st septal artery are the only responsible conduits, and the new one, which includes Kugel's artery and right superior descending artery, commonly called the ramus cristae.[4] The description of these 2 vessels could be achieved by means of the retrograde cannulation and injection technique described above and in our 1998 article.[4] In any event, a careful review of the blood supply to the conduction system must include at least 4 arteries (Fig. 1), before further conclusions can be drawn:

1) *AV Node Artery.* This vessel, which originates at the right coronary artery or at the circumflex artery, at the level of the crux cordis, is found in the Koch triangle right below the coronary sinus. This conduit, usually of a large size, goes straight to the AV node and is the main source of blood supply to the node. However, there are some few cases in which this vessel is not so relevant: it may have a much smaller caliber, in which event the AV node artery is a small recurrent branch that runs along the insertion of the septal leaflet of the tricuspid valve.

It is important to remark that the origin of this vessel does not depend upon left or right coronary dominance, as stated by several authors.[5] Moreover, there are some cases in which the AV node is supplied by 2 "AV node arteries"—one from the right coronary artery and the other from the circumflex. This strange pattern makes the AV node resistant to ischemic events.

2) *First Septal Artery.* From its origin at the anterior descending coronary artery, the 1st septal artery reaches the right side of the interventricular septum. The fact that the 1st septal artery runs directly below the pulmonary extension of the moderator band can indeed be taken as a reference, which is important at the time of obtaining the autograft pulmonic valve in the Ross procedure.[6-9] The 1st septal artery passes near the crista supraventricularis en route to supply the right bundle branch and the AV node itself (Fig. 2). The importance of the 1st septal artery as a supply source for the interventricular septum varies. The right superior septal artery (see below) supplies the same territory (the upper ventricular septum) when the 1st septal artery is small. This new morphologic finding surprises us, because we are accustomed to speaking of "septal dominance" by the right or the left septal artery.

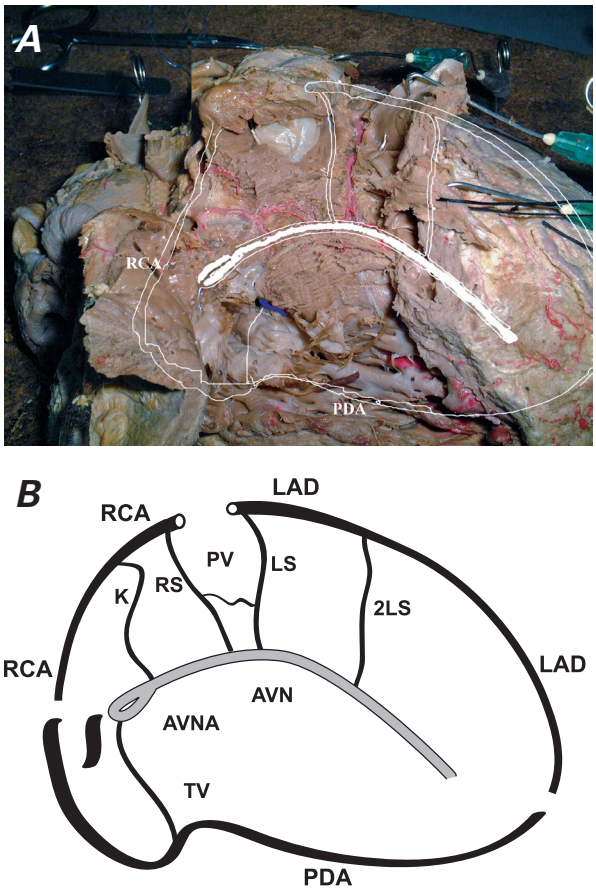

Fig. 1 ***A****) Photograph of the 4 sources of blood supply to the atrioventricular node, with partial schematic overlay.* ***B****) Diagram illustrates the 4 sources of blood supply to the atrioventricular node.*

AVN = atrioventricular node; AVNA = atrioventricular node artery; K = Kugel's artery; LAD = left anterior descending coronary artery; LS = 1st left septal; 2LS = 2nd left septal; PDA = posterior descending coronary artery; PV = pulmonary valve; RCA = right coronary artery; RS = right superior septal artery; TV = tricuspid valve

3) *Arteria Anastomotica Auricularis Magna, or Kugel's Artery.* Many anatomists have debated the morphology or the very existence of this vessel, which was first described by Kugel in 1927.[10] Some authors[11] have maintained that Kugel's artery is not a single artery but a

bunch of atrial vessels that anastomose with one another at random. In fact, we can observe a truly anastomotic pattern only in the variants that Kugel calls "A" and "B," among the 3 varieties that he describes in his 1st report. Despite these varieties, we can state that the artery exists: we first found it in *Balaenoptera acutorostrata* (the Minke whale),[12] which suggests that this vessel is genetically encoded in mammals. However, the significance does not rest on our finding the artery in a species other than man. It rests in the 1st objective evidence that Kugel's artery supplies the AV node (Fig. 3). Provided that the anastomotic pattern is properly developed, the AV node is not very vulnerable to ischemic events. The 1st variety of Kugel's artery (variant A) arises from both the right coronary artery and the circumflex artery and runs from the interatrial bundle, near the aortic sinuses, making several anastomoses at the level of the interatrial bundle and in the atrial wall. Kugel never stated that this vessel reaches the conduction system of the heart. The 2nd variety of Kugel's artery (variant B) arises from the circumflex coronary artery and ends near the nadir of the noncoronary sinus. The 3rd variety is similar to the 1st, but no macroscopic anastomoses are seen, as Kugel stated.

4) *Right Superior Descending.* This atrial vessel originates at the very beginning of the right coronary artery, at the sinoatrial node artery or even at the aorta.[13] The vessel originates from the right coronary artery and reaches the interventricular septum from the right side, near the aortic and pulmonary valve insertions. It is important to remark that when this vessel is large, the 1st septal branch is small, because the right superior descending artery occupies the territory of the 1st septal.

In other specimens, the right superior descending artery runs along the right coronary sinus until it penetrates the right atrium and then follows the anterior limb of the fossa ovalis up to the AV node. This vessel has both clinical and surgical significance as an additional blood supply[14]; in Figure 4, the right superior descending artery can be as a source of supply to the AV node.

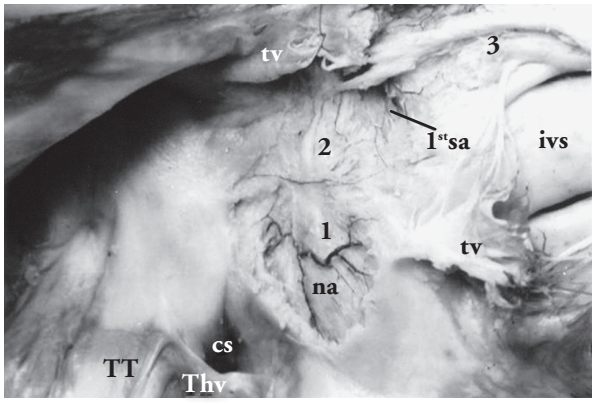

Fig. 2 *Photograph shows the blood supply (via the atrioventricular node artery and the 1st septal artery) to the atrioventricular node and the bundle of His.*

1 = atrioventricular node; 2 = bundle of His; 3 = right bundle branch and moderator band; 1st sa = 1st septal artery; cs = coronary sinus; ivs = interventricular septum; na = atrioventricular node artery; Thv = Thebesian valve; TT = Todaro tendon; tv = tricuspid valve

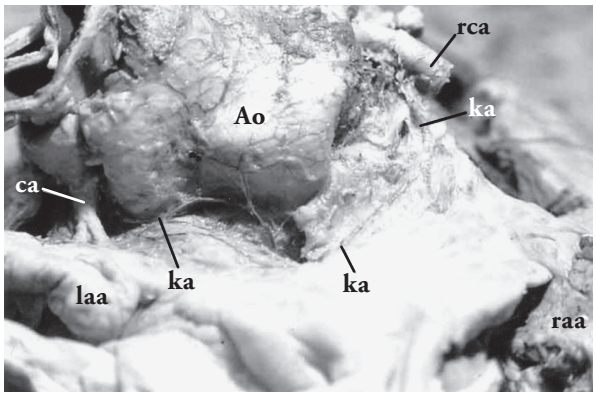

Fig. 3 *Photograph shows the truly anastomotic pattern of Kugel's artery in front of the anterior wall of the atria.*

Ao = aorta; ca = circumflex artery; ka = Kugel's artery; laa = left atrial appendage; raa = right atrial appendage; rca = right coronary artery

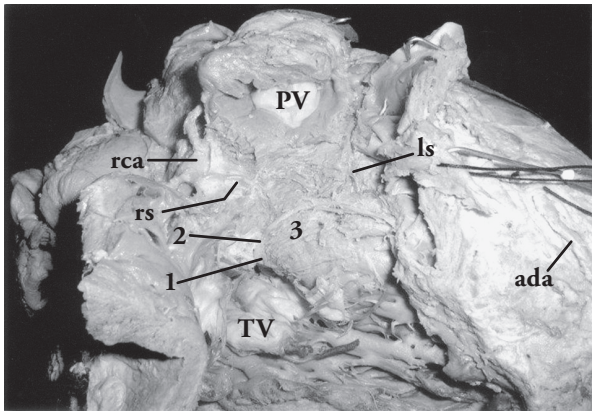

Fig. 4 *Right superior descending artery: this atrial vessel originates at the very beginning or the first 3rd of the right coronary artery, reaching the atrioventricular node and sending an anastomotic branch to the atrioventricular node artery. In the example shown, this vessel has a diameter of 2 mm and replaces the role of the 1st septal branch of the left anterior descending artery, because it supplies the crista supraventricularis and the superior septum.*

1 = atrioventricular node; 2 = bundle of His; 3 = right bundle branch and moderator band; ada = anterior descending artery; ls = left septal artery; PV = pulmonary valve; rca = right coronary artery; rs = right superior descending artery; TV = tricuspid valve

Discussion

Since the time of the creation of the coronary care unit, patients with ischemic heart disease have been classified by the kind of disease, the affected anatomy, the

pathophysiology, and the pathology laboratory results. The introduction of coronary angiography subsequently enabled better correlation of the electrocardiographic findings, the coronary disease diagnoses, and the pathology reports. However, in regard to the AV block index after inferior-wall infarction with and without right ventricular involvement, the anatomy did not quite explain the figures.

According to the angiographic findings, when a right coronary artery occlusion is at the origin of that vessel, the percentage of patients who experience AV block is somewhere between 18% and 24%. On the other hand, when the lesion is found near the bifurcation of the right coronary artery, that percentage drops to 13% to 15%. Therefore, there must be an intervening vessel responsible for these findings. In our judgment, the presence of the right superior descending coronary artery clearly explains why the incidence of AV block after inferior-wall infarction with right ventricular involvement is higher when the occlusion is at the origin of the right coronary artery. In consideration of this new anatomic information, one should take great care in performing alcohol septal ablation for hypertrophic cardiomyopathy.

Furthermore, the presence of Kugel's artery explains why AV block sometimes occurs after occlusion of the circumflex coronary artery. Although this fact has been reported before, a morphologic explanation has not been given until now. Our finding could be achieved only by means of the method of injection and dissection that we used, because only retrograde injection could fill the coronary vessel with latex.

In our early experiments with injection methods, we attempted many times to opacify the atrial arteries, but the high variability of our injection results was unacceptable. The cause of this variability was that we performed injections by cannulating the coronary arteries at their origins. In doing this, we inadvertently occluded the origins of the atrial vessels with the walls of the cannula, so that these arteries could not be injected.

In conclusion, we have objectively described 2 new vascular sources of blood for the AV node. In the particular case of the right superior artery, we have demonstrated with these new dissections that the vessel not only supplies the atrioventricular node, but that it also supplies the right and left bundle branches. These new findings pertaining to the left-bundle-branch blood supply will be elaborated upon in the near future.

We believe that these atrial vessels are highly relevant to the understanding of complications that ensue from acute myocardial infarction of the inferior wall.

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