Arterial Supply to the Nodal Tissue in the Dog Heart

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A study of the hearts of 107 dogs revealed that the blood supply to the sinoatrial node was from three sources: right coronary artery, left coronary artery, and right internal mammary artery. A dominant pattern of supply was found in 90 hearts. Three variations are described. The importance of arterial anastomoses to the sinus node and their role in the formation of an extracardiac coronary arterial system are discussed.

The sinoatrial and atrioventricular nodes have been under investigation from many aspects, anatomic as well as physiologic. Many of these studies have been carried out on the dog, since it is the laboratory animal most commonly used in experimental procedures. The pattern of blood supply to the sinoatrial node in the dog has been described by Meek, Keenan and Theisen,1 Moore,2 Pianetto,3 and Kaznaz and Shanklin.4 Though there is general agreement as to which vessels of the coronary tree supply the sinoatrial node, the present author has found that the coronary system is not the only source of blood supply to this region. In the light of recent investigations on the sinoatrial node in other mammals (mouse, Nomura5, and rat, Halpern6) it might be expected that vessels from noncardiac sources would anastomose with the vessels that supply the sinoatrial node in the dog.

The purpose of this work is to point out the anastomotic connections, their extent, and their relations to the arterial supply of the sinus node region.

Material and Methods

For this study, the coronary arteries of 107 dog hearts were injected with latex, vinyl acetate, or nylon. Most of the animals were obtained from student laboratories in physiology and pharmacology, and nothing is known of their breed or age. However a few dogs that were obtained from other sources were of known age, ranging from newborn to 14 years.

In each heart the right coronary artery was injected with a red mass while the left coronary artery was injected with a blue mass. The isolated hearts were cleared either by the glycerine technic or by a modified Spalteholz method. All hearts were treated the same except where noted. The hearts were removed while beating and were placed immediately in warm saline containing 2 per cent each of magnesium sulfate and sodium citrate. After cessation of beating, the hearts were placed in fresh solution and refrigerated until rigor mortis passed. They were then flushed with tap water until the washings were clear. At this time the hearts to be injected with latex were filled by injecting each coronary artery separately through its origin from the aorta. A drop of concentrated hydrochloric acid was placed on this point after removal of the cannula. The acid coagulated and set the latex. After adequate fixation in 70 per cent alcohol acidified with hydrochloric acid, these hearts were transferred to fresh 70 per cent alcohol.

The vinyl acetate specimens, after washing with tap water, were flushed with acetone. The coronary arteries were then dried by blowing a gentle stream of compressed air (6 pounds pressure) through the vessels. Ethyl acetate was injected and the vessels dried again with compressed air. This was followed by the vinyl acetate injection, the procedure was the same as with the latex except that the plastic was set with water. These specimens were fixed in 70 per cent alcohol.

Those hearts to be injected with nylon were flushed with 70 per cent alcohol after tap water. The injection mass was prepared by dissolving nylon in hot 80 per cent ethanol until it had the consistency of cream. The mass was injected while hot and then hardened in cold water. Fixation was in 70 per cent alcohol, which did not affect the nylon once it had set.

After fixation in 70 per cent alcohol, all hearts were placed in a glycerine-potassium hydroxide clearing solution (20 per cent glycerine, 2 per cent
potassium hydroxide) until the tissues became jelly-like. Transfer was made to 70 per cent alcohol to which a few milliliters of hydrogen peroxide were added to bleach the remaining blood pigments. This bleaching-hardening solution was changed at frequent intervals. When the hearts were bleached, they were transferred to 95 per cent alcohol. After several days, a change was made to absolute alcohol except for the latex injected specimens. These were placed in a mixture of three parts 95 per cent alcohol and one part glycerine for a week. This mixture was replaced by one of equal parts alcohol and glycerine. After a week, a change was made into 1 part alcohol-3 parts glycerine mixture for final clearing. The specimens were stored in pure glycerine.

From absolute alcohol, the vinyl plastic and nylon hearts were carried into benzene. They remained here until cleared, changing the benzene whenever murky. The vinyl hearts were transferred to a mixture of one part toluene and three parts benzyl benzoate for final clearing and storage. Methyl salicylate should be avoided for it tends to dissolve the vinyl plastic. The nylon hearts, however, were placed in methyl salicylate from benzene. They may be stored here indefinitely. In six of the animals, the hearts remained in the thorax and the entire chest was injected with latex. These specimens were carefully dissected.

An additional six hearts from newborn pups were fixed in Bouin's fixative and serially sectioned. Two of these hearts were stained with Goldner's modification of Masson's technic; four of the hearts were stained with hematoxylin and eosin.

**Observations**

Careful examination of 107 dog hearts by means of dissection and clearing reveals a dominant pattern of blood supply to the sinoatrial node. The right coronary artery gives off three major right atrial arteries: a ventral right atrial artery, an intermediate right atrial artery, and a dorsal right atrial artery. The ventral right atrial artery is the first large atrial branch arising from the right coronary artery under cover of the auricle. This vessel passes to the deep surface (aortic side) of the right auricle where it ramifies to supply this structure (fig. 1).

The intermediate right atrial artery arises from that portion of the right coronary artery coursing around the lateral part of the heart in the atrioventricular sulcus (fig. 2). This atrial branch begins at a point opposite the junction of the right auricle with the right atrium. It continues onto the lateral surface of the right atrium, dorsal to the junction of the atrium with its appendage, and its terminal branches spread over the lateral portion of the right atrium. Some branches extend onto the external surface of the auricle (fig. 2).

The dorsal right atrial artery is the last significant atrial branch from the right coronary artery. This vessel arises from the right coronary artery ventral to the point of junction of the inferior vena cava with the right atrium. It curves over the dorsal and lateral parts of the right atrium giving off branches in course (fig. 2). Reaching the dorsal portion of the right
atrium it runs to the sulcus terminalis where it penetrates the epicardial tissue to run lengthwise through the crista terminalis, as shown in microscopic section (fig. 3). This portion of the dorsal right atrial artery, coursing through the crista terminalis, is known as the cristal branch. Before the dorsal right atrial artery goes deep to become the cristal artery, it gives off several branches some of which pass caudally along the inferior vena cava. Others run dorsally to go into the interatrial septum or ramify over the dorsal parts of the right and left atria. From the cristal artery, branches ascend along the superior vena cava, others proceed around the caval funnel to reach the aortic surface of the right atrium, while still others pass onto the cranial portion of the right auricle (figs. 1 and 2).

The cristal artery and its branches, on and around the superior vena cava, are of considerable importance in the blood supply to the sinoatrial node. These will be discussed in more detail below.

The left coronary artery gives off left atrial arteries which correspond to those named on the right. These vessels have been described and figured by Meek, Keenan and Theisen.1

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**Fig. 2.** Right lateral view of the dog heart showing the atrial branches of the right coronary artery.

**Fig. 3.** Projection drawing of a frontal section of a pup heart through the superior vena cava and right atrium. The head of the sinus node is shown at the auriculocaval junction.

Since there are no differences in the present series, the reader is referred to the earlier work. However, the ventral left atrial artery is of importance in the present investigation. As described by the above authors, it originates from the circumflex branch of the left coronary artery.
artery. The stem of origin almost immediately breaks up into many branches (fig. 1). Several branches ramify over the undersurface (aortic face) of the left auricle. A single branch runs deep in the sulcus between atria and aorta whence it turns deep to send branches into the base of the interatrial septum and tissue of that region. The main branch of the ventral left atrial artery passes to the right across the aortic face of the left and right atria (fig. 1). It veers toward the superior vena cava where its branches anastomose with those from the dorsal right atrial artery (cristal branch) that passed around the caval funnel (fig. 1). These points of anastomoses are easily demonstrated since the vessels from the right coronary artery have a red mass in them and those from the left coronary have a blue mass in them. The site where these two colors fuse is taken to be the point of anastomosis.

The location of the sinoatrial node in the dog has been described as lying at the junction of the superior vena cava and right auricle.8, 9 It lies lengthwise in the sulcus terminalis on the caval side of the crista terminalis (fig. 3). Its head is at the auriculocaval junction and its tapering tail extends almost to the inferior vena cava. The blood supply to this region is by the crista artery, a branch of the dorsal right atrial artery. However, this simple pattern is not the complete picture. There are important anastomoses that probably account for a large share of the blood supply. In 90 of the 107 hearts studied, the crista artery is a branch of the dorsal right atrial artery (fig. 5A). This branch supplies the crista terminalis and neighboring area, it also supplies the sinus node (fig. 3) as demonstrated by serial microscopic sections. On the ventral wall of the right atrium, visible anastomoses occur between the dorsal right atrial artery and ventral left atrial artery.

Mention has been made of branches from the crista artery that ascend on the superior vena cava. In order to check the extent of these ascending vessels, the intact thorax was dissected in six dogs. Most of the ascending ves-

![Diagram of the dog heart](http://circ.ahajournals.org/)

**Fig. 4.** Right lateral view of the dog heart within the thorax. The pericardium is reflected to show the extent of the extracardiac arterial anastomoses.
Vessels, as well as the descending branches found on the inferior vena cava, are vasa vasorum to the caval veins. But some of these vessels anastomose with pericardial arteries. In addition to these, in the region of the middle one third of the superior vena cava, small branches from the right pericardiacophrenic artery extend onto the superior vena cava to anastomose with some of the ascending vessels (fig. 4). These anastomotic connections between the right pericardiacophrenic artery and the ascending branches of the cristal artery together form an extracardiac (collateral) coronary arterial system. The ascending portion of the cristal artery is seen in all hearts studied, but the extracardiac anastomoses with the branch from the right internal mammary artery is seen only in the dissected thorax with the heart injected in situ.

The cristal artery is not always a branch of the dorsal right atrial artery as depicted in figure 5A. In some instances, the cristal artery is of dual origin. (1) The portion of the crista terminalis at the auriculocaval junction and the head of the sinus node are supplied by a branch of the ventral left atrial artery. (2) The portion of the crista near the inferior vena cava and the tail of the sinoatrial node are supplied.

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**Fig. 5.** Diagrammatic representation of the four patterns of blood supply to the sinus node. The nodal region is stippled. The dorsal right atrial artery and right coronary artery are black, the ventral left atrial artery has alternating black and white blocks, the ventral right atrial artery is in fine stipple.
by a branch from the dorsal right atrial artery (fig. 5B). This configuration was found in six hearts of the 107 examined. When this pattern occurred, the ascending branches on the superior vena cava came from that part of the crista artery which supplied the head of the node, that is, from the ventral left atrial artery.

In other instances, the dorsal right atrial artery is reduced or missing. When present in the reduced form it supplies a small caudal portion of the dorsolateral wall of the right atrium close to the atrioventricular sulcus. The crista artery is then formed entirely from the ventral left atrial artery (fig. 5C). The ventral left atrial vessel coursed through the notch formed by the superior caval vein and the right atrium. It then proceeded deep in the sulcus terminalis to become the crista branch. The crista terminalis and the sinus node were thus supplied by this vessel (fig. 5C'). This arrangement has been seen in 10 of the 107 hearts. No anastomotic connections were found with the dorsal right atrial artery in this case. The ascending crista branches were present but were derived from the ventral left atrial artery.

In one isolated case out of 107, the crista artery was formed by the ventral right atrial artery. This vessel extended across the ventral wall of the right atrium, passed around the caval funnel and ramified over the lateral surface of the right atrium (fig. 5D). The dorsal right atrial artery was poorly developed.

The sinoatrial node has an extensive blood supply from many sources as a result of the abundant anastomoses between vessels. The right coronary artery (via the dorsal right atrial branch), the left coronary artery (via the ventral left atrial branch), and the right internal mammary artery (via the pericardiacophrenic anastomoses upon the superior vena cava) all contribute to the vascularization of the crista terminalis region and to the blood supply of the sinus node.

**DISCUSSION AND CONCLUSIONS**

These observations on the distribution of blood vessels to the sinus node are in substantial agreement with the views of other workers. In the present investigation, the blood supply to the atrioventricular node has been purposely deemphasized at this time. No discrete set of vessels specific to this node has been observed. However, the atrioventricular blood supply seems to be by those atrial branches of the right and left coronary arteries that pass into the interatrial septum. Moore noted that the A-V node is supplied by branches of the right and left atrial arteries. Hasa and Kalm, quoted in Condorelli's work, stated that a small branch from the circumflex left coronary artery nourishes the atrioventricular node and the bundle of His. The septal branch of the left coronary artery which runs in the interventricular septum sends twigs which also supply parts of the interatrial septum. The septal artery and its branches have been described by Moore and Pianetto. Pianetto stated that all of the atrioventricular conduction system could receive its blood supply from the septal artery. Glomset and Glomset stated that a "good-sized artery" runs through the atrioventricular node in the dog. It was a branch of the septal artery. Nonidez in his figure 1B showed a vessel passing through the A-V node of the pup which was labelled the "nodal artery." Copenhaver and Truex stated that the A-V nodal region lacks a recognized nodal artery but contains arterioles and venous sinusoids.

The anastomotic connections between the vessels that supply the sinus node are of interest. These connections introduce the problem of extracardiac coronary arteries and collateral circulation of the heart. The fact that there exists an extracardiac coronary arterial system was first recognized in the rat. Cardiac veins that drained the heart to an extracardiac site were described by Halperm who illustrated extracardiac coronary arteries without labelling them. Additional investigations on the coronary arteries of the rat revealed that the extracardiac coronary arteries supplied nodal tissue. In the mouse, Nomura noted a vessel from the right subclavian artery that supplied the sinoatrial node. The relationship of this vessel to the node in the mouse was similar to that of the crista artery to the sinus node in the dog. The anastomosis between the pericardiacophrenic artery and the ascending branches of the crista artery forms an extracardiac coro-
nary system. If the extracardiac coronary arteries, as occur in rat and mouse, are a primitive characteristic a similar condition is retained in the dog as illustrated in figure 5. This system is augmented by anastomoses between pericardial arteries and other branches of the dorsal right atrial artery. No difficulty was encountered in filling these vessels with the injection mass.

The concept of the persistence of an extracardiac source of blood supply to the heart is important in the light of the current attempts at revascularization of the heart by cardiopericardiopexy. It is the aim of this procedure to establish a collateral (extracardiac) circulation to the heart. Such a circulation exists normally in the dog. The extent of such an extracardiac coronary system in the normal heart of man remains unknown. Such investigations on the human heart are now in progress by the author.

The amount of blood that collateral vessels carry to the heart of the dog is not known. The presence of extensive anastomoses between the right and left coronary arteries indicates a vast blood supply to the sinus node. This observation also indicates that there is little possibility of vascular occlusions affecting the sinoatrial node. This idea was also advanced by Meek, Keenan and Theisen who stated that "the sinus node is furnished with an abundant and sure blood supply," and that it is "extremely difficult to reduce its circulation sufficiently to cause injury. Likewise auricular (atrial) thrombi are seldom if ever found in the region of the sulcus terminalis. The explanation for both facts is readily found in the anastomosing blood supply." Moore found it impossible to delineate definite areas of blood supply in the atria because of the abundant anastomoses. He pointed out that though the sinus node receives its blood supply from the right distal atrial artery (dorsal right atrial artery), there is, however, abundant anastomoses with other atrial arteries. In his series, Moore observed the injection mass to flow from the left coronary artery to the right coronary artery through the anastomoses between the right and left atrial vessels. In the horse Sabathie and Pianetto found that the sinus node had a double blood supply: from the left circumflex and right coronary arteries. From these facts, it may be stated with assurance that occlusive vascular changes are of little consequence in affecting the sinus node in its role as pacemaker of the heart. In experimental procedures on the sinus node, cognizance should be taken of the fact that the node and its blood supply form an intimate morphologic unit.

**Summary**

1. Examination of 107 dog hearts revealed that the sinoatrial node received a blood supply from three sources; right coronary artery, left coronary artery, and right internal mammary artery.

2. A dominant pattern of supply was found in 90 hearts. Three variations in the pattern were described and the incidence of each was noted.

3. The importance of the arterial anastomotic connections to the sinus node is discussed. These anastomoses form an extracardiac coronary arterial system. The implications of this system are described.

**Sumario Español**

1. Examen de 107 corazones caninos reveló que el nódulo sinuauricular recibe su circulación sanguínea de tres fuentes; la arteria coronaria derecha, la arteria coronaria izquierda y la arteria mamaria interna derecha.

2. Un patrón dominante de abastecimiento se encontró en 90 de los corazones. Tres variaciones del patrón fueron descritas y la incidencia de cada una se notó.

3. La importancia de las conexiones anastomóticas arteriales al nódulo sinuauricular se discuten. Estas anastomosis forman un sistema arterial coronario extracardíaco. Las implicaciones de este sistema se describen.

**References**


ARTERIAL SUPPLY TO NODAL TISSUE


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Circulation. 1954;9:547-554
doi: 10.1161/01.CIR.9.4.547

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1954 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/9/4/547

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