

## A concise review on the anatomy of the atrioventricular node in mammals

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Received: May 7, 2009

Accepted: July 18, 2009

### Abstract

Cardiac conduction system enables the heart to pulsate continuously by producing electric impulse and conducting it. As the anatomical information about cardiac conduction system in human being and other mammals needed in various fields of sciences, such as anatomy, histology, physiology, pathology and cardiology, the present review article intends to provide this basic information about an important part of this system; the atrioventricular node. The histological structure and blood supply of the node and also the internodal pathways which conduct impulse from the sinus node to the AV node will be discussed.

**Key words:** atrioventricular node (AV node), heart, blood supply, internodal pathways

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## مروری مختصر بر کالبدشناسی گره دهلیزی - بطنی در پستانداران

ابوالقاسم نبی پور

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پذیرش نهایی: ۸۸/۴/۲۷

دریافت مقاله: ۸۸/۲/۱۷

### چکیده

سیستم هدایتی قلب از طریق ایجاد مداوم امواج الکتریکی و هدایت آن، قلب را قادر به ضربان منظم می نماید. از آنجائیکه اطلاعات بافت شناسی سیستم هدایتی قلب در انسان و سایر پستانداران در زمینه‌های مختلف علمی مانند بافت شناسی، کالبدشناسی، آسیب شناسی و کاردیولوژی مورد نیاز می‌باشد، مقاله مروری حاضر بر آن است تا اطلاعات پایه در مورد بخش مهمی از این سیستم یعنی گره دهلیزی- بطنی را فراهم آورد. ساختار بافت شناسی و عرضه خونی در این گره و نیز مسیرهای بین گره‌ای که امواج الکتریکی را از گره سینوسی به گره دهلیزی- بطنی هدایت می‌کنند، مورد بحث قرار خواهد گرفت.

واژه‌های کلیدی: گره دهلیزی- بطنی، قلب، عرضه خونی، مسیرهای بین گره‌ای

## Introduction

In the evolutionary development of the vertebrate heart, the specialized atrioventricular conducting system appears as a phylogenetically new structural entity, which, to date, has been documented only in mammalian and birds (Szabo et al., 1986). In the lower vertebrates the atria and ventricular muscle fibers establish direct contact, thereby making the electrical pathway for conduction of the contractile impulse between the chambers. Although a number of investigators have described morphologically specialized fibers in the hearts of Reptilia (Prakash, 1960, Robb, 1953), their finding do not have universal acceptance, although Cranefield (1965) on physiological grounds has postulated the necessity of the existence of an atrioventricular junction possessing specialized properties.

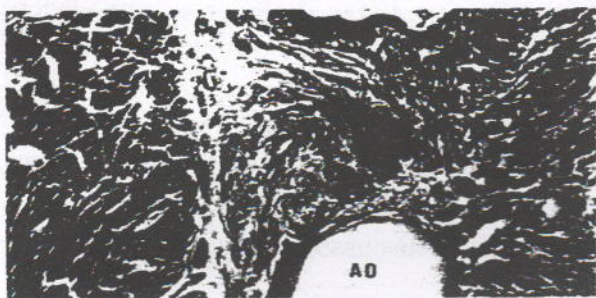


Figure. 1: Photomicrograph showing the location, color difference and shape of the AV node in the heart of four-month ovine fetus. AV node (AVN), interatrial septum (IAS), interventricular septum (IVS), aorta (AO). Green Masson's trichrome staining  $\times 64$ .

Cardiology is not about recognizing stamps in a collection; cardiology is the art of understanding the (patho) physiology of the heart and circulation and, if possible, correcting abnormalities. The atrioventricular node (AV node) and AV conduction in mammals are prominent parts of this puzzle (Meijler and Strackee, 2006). The microscopic anatomy of the normal AV node may help explain certain aspects of the electrophysiology of the AV conduction.

## A few physiological characteristics of the AV node

Human's circulation distributes oxygen to and removes metabolic waste from the tissues of our body. To keep all our cells freshly oxygenated, our hearts pump about 350 L of blood an hours, over 8000 L every day, three million L in a year-enough to fill four Olympic-sized swimming pools. This is at rest. During exercise, e.g., race rowing, the young and healthy human left ventricle may deliver 25 L of blood per minute against a pressure of 100 mm Hg on the average. The performance of the healthy human heart is prodigious-and it has to do.

Several factors enable the mammalian heart to do its duty at low energetic cost. One of those factors is the fine-tuning of the time lapse between the contractions of atria and ventricles. The AV delay represents the time taken by the electric impulse generated in the sinus node to propagate from the atria to the ventricles. It consists of 1) the time to conduct the electric impulse over the atrial myocardium; 2) the transmission time of the impulse through the AV node; and 3) the time for conduction of the impulse over the His-purkinje system. The major part of AV delay takes place within the AV node (Meijler and Strackee, 2006). Because of the profuse interconnections of the normal AV node fibers, the suggestion is made that the slight delay in impulse conduction observed in this region may be a multiple cancellation effect within the node (James, 1961).

The AV node plays a vital role in health and disease:

- \* It warrants an optimal efficacy of cardiac output by fine-tuning the delay between atrial and ventricular contraction.

- \* It protects the ventricles and thus life itself against the effects of high-rate atrial arrhythmias, such as atrial fibrillation. For instance, without this protection, in patients with Wolff-Parkinson-White syndrome the accessory pathway may act as a short circuit between atria and ventricles, which may result

in high-frequency ventricular rhythms and even ventricular fibrillation.

\* It serves as a back-up pacemaker in case of atrial arrest of whatever origin or AV block.

In fact, The AV node controls the electric and mechanical functions of the heart and thus of the circulation of every mammal. As such, it also plays a fundamental role in the survival strategy of all mammalian species (Meijler and Strackee, 2006).

Among the more important factors in autonomic control of the heart is the cholinergic innervation of the AV node.

The AV node may also act as a substitute pacemaker, but is normally more important as a filter system feeding signals from the sinus node into His bundle for distribution into the ventricles; it is well known that vagal stimulation will decrease the speed of AV conduction (including production of AV block) (James and Spence, 1966).

### Embryology of the AV node

There is little question that the AV node migrates inward from an original epicardial location. The primitive AV node comes to lie deep within the heart as the dorsal endocardial cushion invaginates during the formation of the atrioventricular valves. These gross anatomic features suggest that, as the dorsal endocardial cushion moved inward, it carried the AV node and the artery with it. One may consider that the primitive AV node began its existence at junction of the left cranial cardinal vein with sinus venosus and then, in the development of the body of the left atrium and incorporation of the sinus venosus into the atria, the AV node may either have moved to its adult location or may have remained more or less in the same site while the atria developed around it (James 1970).

### Anatomical location and shape of the AV node

The AV node is oval or fan shaped in human being (Titus et al., 1963). The canine AV node, like that of man, lies just anterior to

the ostium of the coronary sinus and just above the septal attachment of the tricuspid valve. It is in the right half of the interatrial septum, being located 1 mm or less beneath the endocardium, to which it presents a convex surface. The shape of the AV node resembles a tiny spleen, with the concave surface resting on the central fibrous body and base of the mitral annulus. Viewed from the right atrial side the AV node is oblong in shape and tilts down, with the anterior end lower than the posterior (James, 1964).

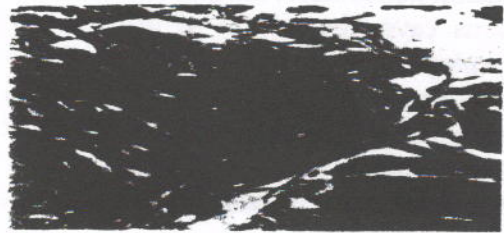


Figure. 2: Microphotograph of the AV node in the heart of goats: Note to twisting interlacing fibers of the node. AV node (AVN), collagen fibers (cf), interventricular septum (IVS). Green Masson's trichrome staining  $\times 64$ .

Grossly, the AV node cannot be adequately dissected in the equine heart. Histologically, the AV node lies in the dorsal portion of the fibrous septum adjacent to the right atrium, just anterior to the orifice of the coronary sinus and about 0.6 cm above the attachment of the septal leaflet of the tricuspid valve in adult horse. It is covered by the endocardium and 1.0-1.5 mm of atrial fibers, many of which connect dorsally and laterally with the AV node, while others sweep past to the base of the tricuspid valve. The AV node has a flattened oblong shape (Bishop and Cole, 1967).



Figure.3: Microphotograph of the para-sympathetic ganglion related to the AV node of goats heart showing capsule (C), nerve fibers (nf), perikaryon (P), nucleus and nucleolus (arrows). Green Masson's trichrome staining  $\times 640$ .

The anatomical location of the AV node of goat (Nabipour, 2002), cattle (James, 1965) and sheep (Frink and Merrick, 1974) is also beneath the endocardium, at the lower right side of interatrial septum and anterior to the ostium of the coronary sinus and above the septal cusp of the tricuspid valve, while in rabbit (James, 1967) and guinea pig (Nabipour, 2004) the AV node is relatively small and displaced anteriorly and the entire region occupied by it is foreshortened. Since mentioned animals normally have a left cranial vena cava, the ostium of the coronary sinus (embryologically derived from the terminal portion of the left cranial vena cava in most mammals) is unusually large. The ostium of the coronary sinus drains not only cardiac veins but the normally present left cranial vena

cava. This effectively displaced the AV node and His bundle anteriorly toward the root of aorta. The AV node of the four-month ovine fetus is located near the root of aorta. Its shape is spherical (Nabipour and Shahabodini, 2007) (Fig. 1). The AV node has an ovoid shape in cattle (James 1965). It is an irregular elongated oval in shape in goat (Nabipour, 2002) and its shape is resembled to an irregular ellipse in camel (Ghazi and Tadjalli, 2002). It has an irregular elongated oval shape in cat (Nabipour et al., 1999). It is almost spherical in shape in guinea pig (Nabipour, 2004). Szabo et al. (1986) reported that there is not morphologically well-defined AV node in hens (*Gallus domesticus*, *Galliformes*), adult pigeons (*Columba livia*, *Columbiformes*) and young (4-6 month-old) quail (*Coturnix coturnix*, *Galliformes*). However, Lü et al., (1993) reported the AV node of chicken is just above tricuspid valve and anterior to the coronary sinus. Also, in fowl (Kim and Yasuda, 1979) and turkey (Nabipour and Safaei, 2008) the AV node is present and embedded in the connective tissue between the thin right arterial myocardium and the fibrous tissue of the right dorsal part of the right fibrous trigone on the caudodorsal part of the interventricular septum, a short distance to the

left and ventral to the opening of the cranial vena cava. It is elongated and elliptical in shape in fowl. In the heart of house sparrow (Yousuf, 1965) the AV node lies at the enlarged portion of the caudal end of the interatrial septum.

### Dimensions of the AV node

The dimensions of the AV node in human being (Titus et al., 1963), horse (Schummer et al., 1981), cattle (James, 1965), dog (James, 1964), rabbit (James, 1967), guinea pig (Nabipour, 2004), goat (Nabipour, 2002) and four month ovine fetus (Nabipour and Shahabodini, 2007) are shown in table 1. However, there is considerable variation in AV node size in human being (James, 1961)

### Histological structure of the AV node

Within the AV node there is a mass of twisting interlacing bundles, which are smaller and paler than ordinary myocardial fibers. They are interweaving with little amount of collagen fibers (Fig. 2). This characteristic is common in human being (Titus et al., 1963), dog (James, 1964), horse (Bishop and Calkins, 1967), cattle (James, 1965), camel (Ghazi and Tadjalli, 2002), goat (Nabipour, 2002), rabbit (Nabipour et al., 1999), guinea pig (Nabipour, 2004) and four-month ovine fetus (Nabipour and Shahabodini, 2007) but there is small amount of elastic fibers scattered within the AV node in human being (Titus et al., 1963), dog (James, 1964) and cat (Nabipour et al., 1999).

The AV node of guinea pig (Nabipour, 2004) and four-month ovine fetus is consisted of numerous of "P" (pacemaker) cells, while the number of "P" cells in other animals is very less. The differences between AV node fibers and atrial muscle fibers are not constant in human being and monkey heart. They are in sheep hearts. Similarly, the boundaries of the nodal region are not as easily recognized in the former as they are in the latter species (Copenhaver and Truex, 1952).

On electron microscopy study, the nodal

cells of the AV node of sheep are small in size and contained few nexuses with poor sarcoplasmic reticulum and myofibrillar development. The nodal cells are spindle-shaped and their ends often showed ramifications. In addition, the strands of nodal

cells in the central part of the AV node are considerably compact and connected with neighboring strands to form a complicated three dimensional architecture (Shimada et al., 1986).

Table 1: The dimensions of the AV node in human being and some other species

Species	Length (mm)	Width (mm)	Thickness (mm)
Human being	7.5	3.7	1
Horse	6-10	5-7	0.6-2.5
Cattle	13	6-8	
Dog	a little less than 2	a little more than 2	0.5-1
Rabbit	0.3-0.5	0.15-0.25	0.8-1
Camel	6.38 ± 1.41	4.08 ± 0.95	1.11 ± 0.51
Goat	4.23	2.13	0.61
Guinea pig	0.34	0.27	0.20
Four-month ovine fetus	0.13	0.09	0.23

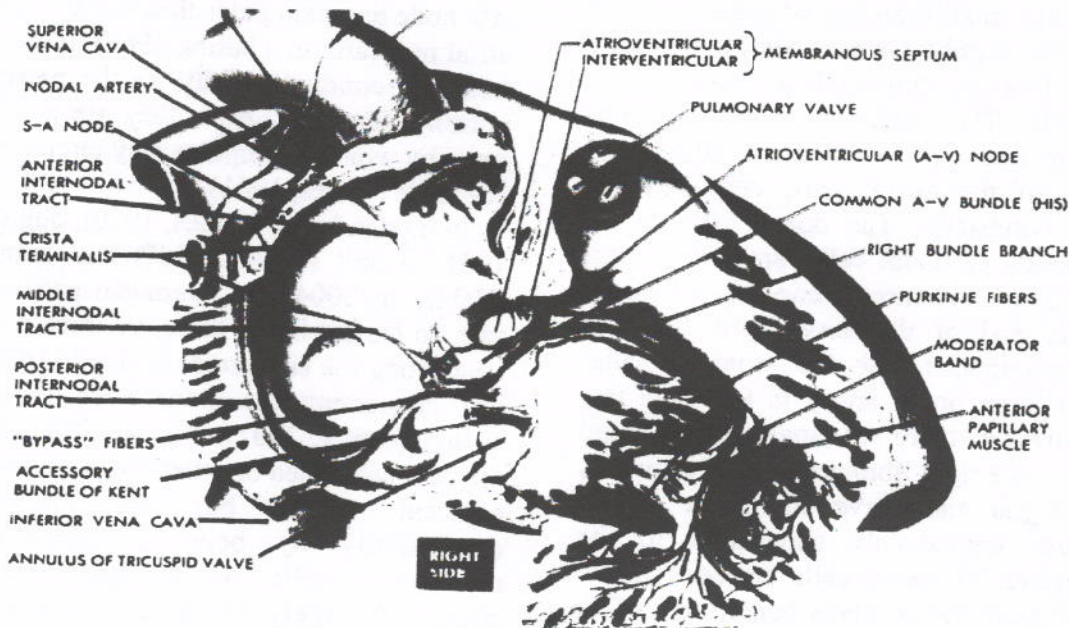


Figure. 4: Showing impulse generation and cardiac conduction system of the human being.

Glycogen was not observed in the AV node cells of goat (Nabipour, 2002), camel (Ghazi and Tadjalli, 2002) and guinea pig (Nabipour, 2002) however, the carbohydrates in of four-month ovine fetus (Nabipour and Shahabodini, 2007) is high. There is a small amount of nerve fibers within the AV node of human being (Titus et al., 1963), dog (James, 1964), cat (Nabipour et al., 1999), guinea pig

(Nabipour, 2004) and four-month ovine fetus (Nabipour and Shahabodini, 2007). In contrast, in cattle (James, 1965), horse (Meyling and Terborg, 1957) and goat (Nabipour, 2002) abundant nerve fibers are present in the node. In the heart of human being (Titus et al., 1963), dog (James, 1964), horse (Bishop and Cole, 1967), cattle (James, 1965), camel (Ghazi and Tadjalli, 2002), cat (Nabipour et

al., 1999), rabbit (James, 1967), goat (Nabipour, 2002) and four-month ovine fetus (Nabipour and Shahabodini, 2007) ganglia are present in the posterior part of the AV node and there are not seen ganglia in the node (Fig. 3). There are not ganglia either at the periphery or within the node in the guinea pig (Nabipour, 2004).

Within the center of the AV node of human being is usually a major artery, but this is less constant in either its presence or its central location than is the sinus-node artery (James, 1961). The cells of the AV node of rabbit organize into of smaller dimension and paler than those of ordinary atrial myocardium. However, the percentage of "P" cells is less in the AV node. The only arteries in the AV node of rabbit are small branches of a size suitable for nutrient supply (James, 1967). The AV node of fowl is consisted of two cellular components. The ventral part of the node consists of nodal cells which are larger than the cells of the dorsal part, and they are arranged compactly. The dorsal part of the node consists of nodal cells, smaller in size, multinucleated and more compactly arranged. The atrial end of the dorsal part becomes directly continuous with the atrial muscular cells. No large nodal artery is found in this node. However, there are small veins around the node in the right fibrous trigone. Numerous small ganglia and nerve fibers lie in the epicardium immediately superficial to the nodal region. No nerve cells are seen in the node, but many nerve fibers penetrate it (Kim and Yasuda, 1979). The AV node of lizard is a prominent, well defined and conspicuous spherical body situated ventral to the sinus node and very near to the right atrioventricular orifice. The fibers of the node are narrow, delicate, elongated and are interlaced with each other to form cells having deeply stained large oval nuclei. Some of the nuclei are very large and fill the entire cell; others have a surrounding clear zone of cytoplasm. Nerve fibers and an artery are also present in the region of this node (Prakash, 1960).

### The internodal pathways (tracts)

In the normal human heart, the internodal pathways may be divided into two general groups of atrial fibers, those entering the crest of the AV node and those bypassing the bulk of the node to enter it along its convex surface. The later were referred to as "bypass tracts" since they were in proper anatomic position to bypass the conventionally described atrionodal junction, which is considered the point of maximal electrophysiologic delay in AV conduction (James and Spence, 1966). In the dog, many of the bypass fibers have purkinje characteristics, which are also true in human heart (James, 1964). The minimum thickness of the bypass tracts of rabbit is 50 to 150 $\mu$ . The cells in the tracts are larger than those of the AV node but stain paler than those of ordinary atrial myocardium (James, 1967). If the bypass tracts do conduct rapidly, as the presence of purkinje fibers suggests, they are an obvious route by which an impulse may circumvent the AV node (James, 1961).

In human being (James, 1970), dog (James, 1964), rabbit (James, 1967) and guinea pig (Nabipour, 2004) the internodal pathways are exit. In human being there are three pathways connecting the sinus node to the AV node, and one connecting the sinus node to the left atrium (Netter, 1981) (Fig. 4). The pathways are not ensheathed or otherwise separated from adjacent tissue, but are distinguished anatomically by being a continuum of myocardial cells in a region otherwise composed largely of fat and collagen. The cells of these pathways are a mixture of Purkinje cells and cells resembling ordinary working myocardium. The anterior internodal pathway corresponds to Bachmann's bundle, and the posterior internodal pathway corresponds to the crista terminalis and Eustachian ridge; both of these pathways are easily visualized grossly and are better developed than middle internodal pathway. Since the anterior and middle internodal pathways merge in the interatrial septum within the torus Loweri, and because the

foramen ovale does not normally close until a short period after birth, it is probable that the septal course of the internodal pathways becomes fully defined only during postnatal period. When there is abnormal development of the atrial septum or primitive venous valves, it may be anticipated that the pathways for internodal connection will be altered. Conduction speed in the internodal pathways is distinctly more rapid than in working myocardium (James, 1970).

There are muscular pathways between the sinus node and AV node in the horse as has been reported in man, the course of these large atrial purkinje-like fibers does not coincide with them. Their course from the crista terminalis over the pectinate muscles suggests that they may function to spread the excitation impulse rapidly and evenly over the atrium. The nodal fibers are not connecting directly with the large atrial purkinje-like fibers. This suggests that both ordinary atrial fibers and specialized purkinje-like fibers are active in conducting the impulse from the sinus node to the atrium and AV node (Bishop and Cole, 1967).

There is no direct connection between the sinus node and the AV node in fowl (Kim and Yasuda, 1979).

### **Blood supply of the AV node**

In human being, the AV node is regularly supplied by the AV node branch arising from the coronary artery crossing the crux of the heart, this being the right coronary artery in 90% of human hearts. Posterior infarction caused by an occlusion proximal to the origin of the AV artery results in AV node ischemia and often heart block. The degree of block may vary from slight P-R interval prolongation through the various forms of second-degree to complete heart block. 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 (Frink and James, 1973). The arterial supply of the AV node of the dog is

dual, with a significant portion (perhaps half) coming from the left circumflex artery when it crosses the crux of the heart, and the rest from terminal branches of the septal artery, which penetrates inward from the left anterior descending ramus. There are two important differences in the arterial supply of the AV node between human being and dog. 1- The primary arterial supply of the human AV node is single and in 90% of instances originates from the right coronary artery. 2- The primary arterial supply of the canine AV node is dual (from both the front and the back) and both branches virtually always originate from the left coronary artery (James, 1964).

Within the AV node of dog there are numerous venous lacunae and small veins which communicate with each other. The nodal veins drain predominantly into the right atrium through thebesian ostia, although a few drain posteriorly into the coronary sinus before it enters the right atrium (James, 1964).

In the sheep heart, the crux of the heart, and subsequently the AV node, is always supplied by the circumflex artery. Intercoronary anastomoses are present in the majority of hearts, particularly in the upper ventricular septum (Frink and Merrick, 1974). For the AV node of rabbit, the only arterial circulation available is that from the septal artery (a branch of left coronary artery). At their origin, branches from the septal are perpendicular to its long axis and ascend across the right ventricular septal endocardium to reach then the AV node. This sequence of arterial penetration is opposite to that in man, in whom the blood supply of this region enters from the posterior margin of the AV node after originating at the crux. To understand this particular void in arterial distribution to the region of the crux of the heart of the rabbit, it should be kept in mind that a left cranial vena cava is normally present, the coronary sinus consequently very large, and most atrial septal structures (including the AV node) displaced anteriorly away from the epicardium of the crux (James, 1967).



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