VIA MEDICA

ORIGINAL ARTICLE

Vol. 60, No. 1, pp. 27–31

ISSN 0015–5659
www.fm.viamedica.pl

Development of the atrioventricular junctional area in the human heart

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[Received 20 December 2000; Accepted 12 January 2001]

The structure of the heart has been the subject of many observations since the beginnings of medical research. The first information regarding the existence of the conduction system of the heart was described by Purkinje and regarding the a-v node by Tawara. From the history regarding this structure it seems that this special system, so relevant to today's invasive cardiologist, is not understood in full. With regards to the interventional electrophysiology on the basis of histological study we decided to evaluate in detail the morphology and the topography of the various portions of the a-v junction. In order to confirm this hypothesis we made observations on the autopsy material of 100 normal human hearts, both sexes from 16 weeks of foetal life to 105 years of age, in which no pathological changes or inborn faults were found. Sections were done containing the heart's septum, stained using Masson's method with Goldner's modification. This research proves that the atrioventricular junction is a stable structure occurring in all hearts, undergoing involutionary changes with age, in which two main parts can be differentiated: the node and the bundle. The morphology of the node is very complex, because it is composed of three zones: the prenodal, the perinodal and the main, differing in cell structure and position. The topography of the node is generally stable, as it lies in the interatrial septum and always above the septal leaflet of the tricuspid valve. The structure of the bundle, in contrast to the node, is more stable and consists of the following parts: the penetrating, the non-branching and the branching. Its topography is also stable, as it lies in the membranous septum, mainly below the septal cusp of the tricuspid valve.

key words: a-v node, a-v bundle, morphology and topography, ontogenesis

INTRODUCTION

The heart has been the subject of much research, and observations regarding its structure reach back to the beginnings of medical research. The first information regarding the existence of special neuromuscular fibres was described by Purkinje [11]. He differentiated strands of cells within the ventricles, which now carry his name, he described them as nerve cell cardiac fibres — he was not however, aware of their connection to the conductive system of the heart. Most publications which determined the structure of the atrioventricular part of the conduction system were written by Tawara [13]. He described the a-v node in great detail and showed its connection to the bundle of His and Purkinje fibres. Also Bharati et al. [5] and Truex et al. [14] described the microscopic anatomy of the a-v node and bundle with connection to the cause of death. The system-

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atising information began with the "Anderson model" of the a-v junction, which is still recognised today. Anderson et al., evaluating on the basis of histological examination, morphology and topography of various types of cells, differentiated four zones: the transitional cell zone, the compact node zone, the penetrating bundle zone and finally branching bundle zone [2,3]. In contrast, Hecht et al. [7], on the basis of the joint anatomical and electrophysiological study, did not include the last mentioned zone in the a-v part of the conduction system. In the "Becker model" the authors focused their attention on the initial portion of the a-v node and determined that the so-called posterior extension does not occur in all hearts [8]. Furthermore clinical research entailed electrophysiological evaluation of the node and bundle with regards to arrhythmias without any reference to anatomical research. From the presented research history regarding the clinical anatomy of the atrioventricular conduction system, it seems that this structure, so relevant to today's invasive cardiologist, is not understood in full. With regards to the above, on the basis of histological study we decided to evaluate in detail the morphology and the topography of the various portions of the a-v junction with respect to ontogenesis.

MATERIAL AND METHODS

Research was conducted on material consisting of 100 human hearts of both sexes (42 females, 58 males) from the age of 16 Hbd to 105 years of age, fixed in a formalin-ethanol solution, in which no pathological changes or inborn faults were found (Table 1). Sections were done containing the heart's septum, stained using Masson's method with Goldner's modification [9]. In the microscopic examination we concentrated on searching for and determining the localisation of the elements of the conduction system of the heart forming the a-v part named, according to the most recent literature, the atrioventricular junctional area. Multivariate analysis was conducted using the F-Snedecor regressive model of proportional risk and t-Student tests for odd number data. In situations where the distribution was not normal, the differential significance between the arithmetic means of two groups was tested using Mann-Whitney-Wilcoxon test. As statistically significant, $p < 0.05$ was considered to be the level of significance.

Table 1. Break down of the researched material

Material (hearts)	Age	Number of hearts
Foetal	16–42 Hbd	31
Newborn	5 minutes–1 month	11
Infant	2–11 months	9
Children	2.5–16 years	16
Younger adult	19–46 years	21
Older adult	50–105 years	12
Total	**16 Hbd–105 years**	**100**

RESULTS

Evaluating on the basis of histological examination the morphology and the relative position of various types of cells, we could further differentiate six zones: atrioventricular nodal area (the prenodal zone, the perinodal zone, the compact zone) and the atrioventricular bundlar area (the penetrating zone, the non-branching zone, the branching zone). Within the prenodal zone we differentiated two bundles: a superior and inferior. The superior ran around the edge of the oval fossa, and we observed the inferior between the ostium of the coronary sinus and the inferior vena cava. The a-v perinodal zone consists of various well-known types of cells (typical muscle cells, typically conductive cells, and untypical intermediate cells — so-called transitional cells), which as a whole unit formed a tight coat around the deeper lying compact zone of the a-v nodal area. In the area of transitional cells, due to their topography, we could differentiate two main groups: posterior and anterior, and also in each of these a superficial and deep layer. Posterior transitional cells have their origin in the area of the coronary sinus: the subostial area (the venous-coronary area) and also in the anteostial area (the coronary-septal area) (Fig. 1).

The compact zone was composed of three main parts: the initial,the main and the terminal part. The initial part is composed of a group of cells which can form two or three groups around the a-v nodal artery (three-parts in foetuses, newborns and infants; two-parts in adult hearts). The main part is made up of two clearly visible layers: an external and internal. The cells of this zone are smaller than the cells of the working myocardium and their structure is more star-shaped in contrast to the oval shape of the transitional cells. The morphology of this part was convex in foetuses and infants; less convex in children and young adults and very flat in older adults. The terminal part of the compact zone was visible in all examined hearts as a group of cells which extended beyond the fibrous annulus and entered the right fibrous triangle. Within the cells of compact zone, fibrous tissue made 2 (young hearts)

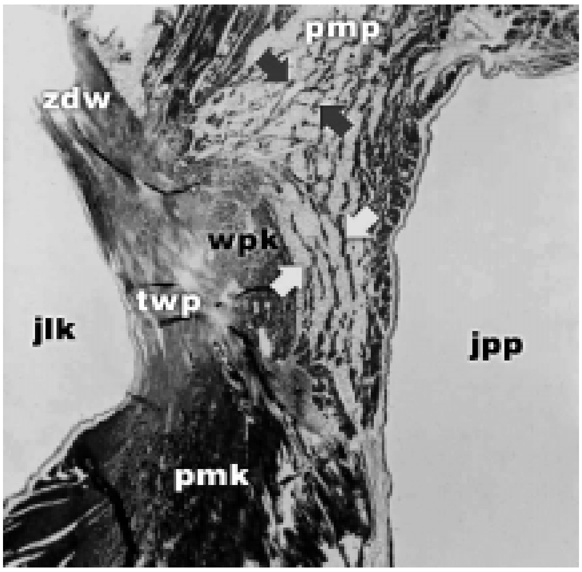

Figure 1. Photomicrograph showing the perinodal zone of the conduction atrioventricular junctional aea. Arrows: superficial and deep parts of the transitional cells. wpk — atrioventricular node; twp — right fibrous triangle; pmp — interatrial septum; pmk — interventricular septum; zdw — base of anterior leaflet of the mitral valve; jlk — left ventricle; jpp — right atrium (F, 66-years-old, Masson-Goldner, × 45).

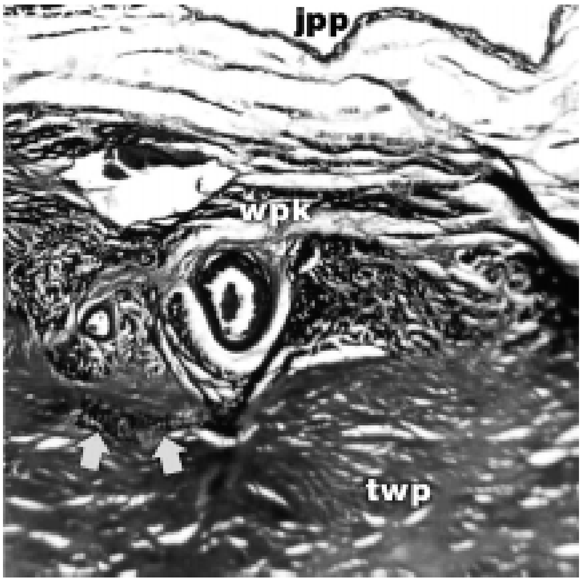

Figure 2. The compact zone of the atrioventricular node. Arrows: islet in the form of the "tongue". wpk — atrioventricular node; twp — right fibrous triangle; jpp — right atrium as Fig. 1 (F, 47-years-old, Masson-Goldner, × 250).

up till 6 (older hearts) compartments of nodal tissue and their cells pass over the right fibrous trigone form in 70% islets ("tongue" like — 80%, "loop" like — 20%), especially in the very young (foetal) and old (older adults) hearts (Fig. 2).

The penetrating bundle is built of typical, well-known small cells, forming the muscle tissue of the conductive system of the heart. This is a homogeneous structure and completely bounded by a sheath of connective tissue. With regards to topography, it is located in the membranous septum, and more precisely in the a-v part of the septum. Within the penetrating zone, fibrous tissue made 2–5 (only older hearts) compartments of tissue and their distal cells could form in 5% of examined hearts islet ("tongue" like only — 100%), especially in the very young (foetal) and old (older adults) hearts. The non-branching bundle does not differ practically from the penetrating with regards to morphology but the difference was in its topography. However, it is not a stable structure, as it occurred in only 10% of examined hearts, and only in hearts above 50 years of age (Fig. 3). The branching bundle did not differ with regards to histological structure from the previously mentioned parts, but the main difference was that within it the right and left branches were starting to form. As the origin of the branching bundle we accepted the exit of the left branch, as it first emerged from the bundle. In 87% of hearts it is placed very superficially and completely subendocardially, but only at the level of the smooth muscle part of the interventricular septum (Fig. 4). However, most often, in 98%, the right

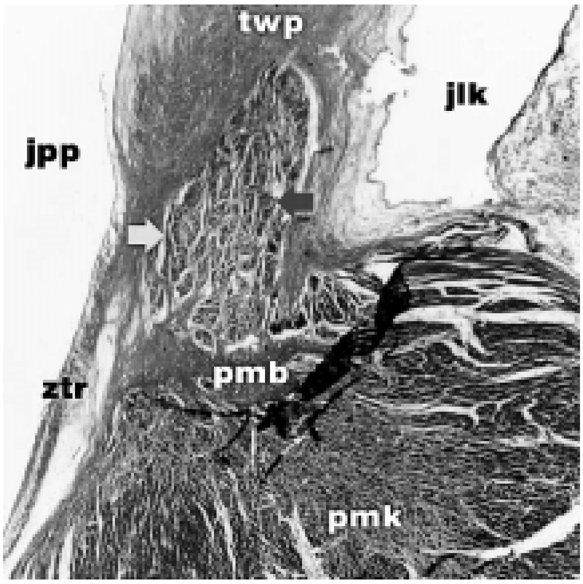

Figure 3. Non branching bundle with two compartments. Arrows: left and right parts of the bundle. twp — right fibrous triangle; pmb — interventricular septum, membranous part; pmk — interventricular septum, muscular part; ztr — base of septal leaflet of the tricuspid valve; jlk — left ventricle; jpp — right atrium (F, 52-years-old, Masson-Goldner, × 125).

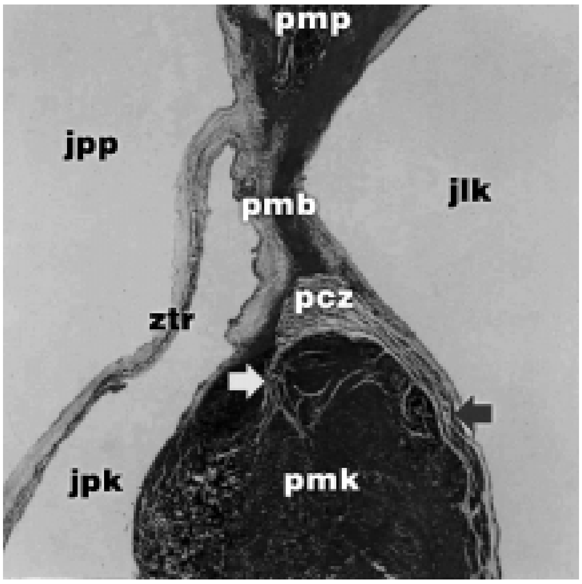

Figure 4. Branching bundle with branches. Arrows: right and left branches. pmb — interventricular septum, membranous part; pmk — interventricular septum, muscular part; ztr — base of septal leaflet of the tricuspid valve; jlk — left ventricle; jpp — right atrium; jpk — right ventricle; pcz — His bundle (F, 33-years-old, Masson-Goldner, ×125).

branch was the direct prolongation of the a-v bundle axis and its initial part was a homogeneous structure, and afterwards directed itself downwards and penetrated the middle part of the septum.

DISCUSSION

The atrioventricular junctional area, due to its clinical significance, was the subject of interest for many researchers. Some were only interested in its anatomy, others took their observations from a clinical standpoint (invasive electrophysiology). Anderson et al. [2,3] differentiated four parts of the a-v junctional area, based however on the examination of adult human hearts only. Based on the relative position of various types of cells, we could differentiate an additional two zones: prenodal zone (occurred in all hearts) and non-branching bundle zone (occurring in 10% of examined hearts). This difference comes from the various group of examined hearts (35 *vs* 100 hearts). Inoue and Becker [8] determined that the initial portion of the a-v node in the form of posterior extensions does not occur in all hearts. They examined 21 hearts only and did not give details regarding the age of the histologically proved hearts. In our study, in contrast to the above — mentioned authors, we observed the presence of the initial a-v node's part in all groups of hearts, which is consistent with our previous results [9]. This part was composed of cells which can form three groups around the a-v nodal artery. The prenodal zone, running into the consistency of the so-called internodal zone, directly joining both nodes, the sinoatrial and the atrioventricular, has been and still is a place of much controversy. Hypothetically, within the right atrium three internodal tracts are differentiated: the anterior (Bachmann's bundle), the middle (Wenckebach's bundle) and the posterior (Thorel's bundle). Their placement in the prenodal zone was similar to the course of the atrial muscle tissue forming the terminal bundles [6]. Hecht et al. [7], based on electrophysiological properties within the a-v part of the conduction system, differentiated two main zones: junctional tissues and subjunctional tissues. We stated that within the prenodal zone two bundles were visible: superior and inferior only. Both of them consisted of typical muscle working atrial cells. However this does not exclude any incremental conduction from the clinical point of view, as observed by McGuire et al. [10]. Within the cells of the compact zone we stated fibrous tissue made 2 up to 6 compartments of nodal tissue and their cells pass over the right fibrous trigone form in 70% islets ("tongue" like — 80%, "loop" like — 20%), especially in the very young (foetal) and old (older adults) hearts. Additionally within the penetrating zone fibrous tissue made 2–5 compartments of tissue and their distal cells could form in 5% of examined hearts islet ("tongue" like only — 100%). In the literature we found information regarding this from the clinical point of view only. Rossi et al. [12] and Batsford et al. [4] stated that in the presence of cardiac sudden death such islets may play a role in the creation of the impuls and its circulation, leading to death. We did not think in such a way, because islets (loops or tongues) could be stated in approximately 70% of hearts, which belongs to normal anatomical structure.

This research proves that the atrioventricular junction is a stable structure occurring in all hearts, undergoing involutionary changes with age, in which two main parts can be differentiated: the node and the bundle. The morphology of the node is very complex, because it is composed of three zones: the prenodal, the perinodal and the main, differing in cell structure and position. The topography of the node is generally stable, as it lies in the interatrial septum and always above the septal leaflet of the tricuspid valve. The structure of the bundle in contrast to the node is more stable and consists of the following parts: the penetrating, the non-branching and the branching. Its topography is also stable, as it lies in the membranous septum, mainly below the septal cusp of the tricuspid valve.

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