MORPHOMETRIC ANALYSIS OF CARDIAC CONDUCTION SYSTEM

N. U. BOZBUĞA, MD,
B. YAYMACI, MD,
V. ERENTUĞ, MD,
S. TAŞ, MD,
K. KIRALİ, MD,
E. KAYNAK, MD,
A. ÖZTÜRK*, MD,
Z. ARI*, MD,
E. AKINCI, MD,
K. ŞAHİNOĞLU *, MD,
C. YAKUT, MD

From: Koşuyolu Heart and Research Hospital,
* İstanbul Medical Faculty Department of Anatomy, İstanbul

Morphological features of the sinus node, interatrial conduction, atrioventricular junction (transitional cell zone, atrioventricular node, penetrating portion of bundle), the bifurcation of the bundle into the bundle branches were analysed by a detailed dissection of the anatomic structure of human conduction system complex of 18 adult hearts from fixed human cadavers (14 male and 4 female) at Department of Cardiovascular Surgery, Koşuyolu Heart and Research Hospital and Department of Anatomy, Faculty of Medicine of Istanbul University. After dissection of the vena cava superior, the thin walled part of the right atrium (sinus venorum) and right atrioventricular orifice, the heart material was prepared by fixation and stabilization technique which was adapted to the "Agduhr" block impregnation technique. The variations in the configuration of the conduction tissue and associated structures were examined for their importance in cardiac surgery.

The average dimension of sinus node was 15x5 mm and the average dimension of atrioventricular node was 8x3 mm with an oblonge shape. Persistent fetal dispersion of the AV node was observed in 1 case (5.6%). Neither discontinuity nor fragmentation of the conduction pathways was not observed in the series.

We believe that the morphometric analysis and knowledge of the variations are advantageous for preventing conduction system complications after cardiac operations.

Key words: Cardiac conduction system, morphometric, cardiac surgery

Specialized tissues of the heart (neuromyocardial cells) that initiate and conduct the cardiac impulse consist of three major parts (1-5):

• Sinus node (sinoatrial node, sino-atrial node, sinoauricular node, pacemaker of the heart, node of Keith-Flack) (6-8),

• Atrioventricular junctional area including the atrioventricular node (node Tawara, node of Aschoff-Tawara) (9-12),

• His bundle (penetrating bundle, AV-bundle), bundle branches and terminal Purkinje fibers (network of Purkinje, peripheral conduction system) (13-15).

The sinus node (SA-node) is located along the anterolateral aspect of the junction between the superior vena cava and right atrial appendage. In rare cases, it extends medially across the crest of the

Adress for reprints:
Dr. Nilgün U. Bozbuğa
Koşuyolu Heart and Research Hospital, İstanbul
Tel: + 90 216 325 54 57
Fax :+ 90 216 339 04 41
e-mail:
nbozbuga@kosuyolu.gov.tr

caval-atrial junction. The sinus node is superficial, lying on the epicardial surface in the sulcus terminalis.

The atrioventricular node (AV-node) is located at the apex of the triangle of Koch formed by the tricuspid annulus, the tendon of Todaro (the continuation of the eustachian dimentional valve that runs to the central fibrous body), and the coronary sinus ostium. The atrioventricular node lies directly on the atrial side of the central fibrous body (right trigone) in the muscular portion of the atrioventricular septum just anterosuperior to the coronary sinus.

The atrioventricular bundle (bundle of His) is a direct continuation of the atrioventricular node. The bundle passes through the right-ward part of the right trigone of the central fibrous body to reach the posteroinferior margin of the membranous ventricular septum. This area is just inferior to the commisure between the tricuspid valve's septal and anterior leaflets. The bundle courses along the posteroinferior border of the membranous septum and the crest of the muscular ventricular septum, giving off fibers that form the left bundle branch.

The left bundle branch occurs beneath the commissure between the right and noncoronary cusps in close proximity to the aortic valve.

The right bundle branch originates from the bundle of His in the region of the anteroinferior margin of the membranous septum and courses along the right ventricular septal surface, passing just below the septal papillary muscle and along the inferior margin of the septal band and the moderator band to the base of the anterior papillary muscle.

In this article, we revisit the anatomy of the specialized cardiac tissues, making special reference to the descriptions given at the time of their discovery. Our study was designed to examine the variations of in the configuration of the conduction tissue and associated structures and to establish their importance as cardiac surgery.

MATERIAL AND METHOD

We have studied the conduction system of 18 hearts from noncardiac death cases. 18 human hearts were obtained from fixed human cadavers (14 male and 4 female). The human hearts were dissected to elucidate the clinical anatomy of these purportedly anatomosurgical segments of conduction system. A revised technique is used in which the SA-node, the AV-node and the distal part of the His bundle of the cardiac conduction system are demonstrated with fine dissection.

Dissection Technique

After dissection of vena cava superior, the thin walled part of the right atrium (sinus venosum) and the right atrioventricular orifice, the heart material was prepared by fixation and stabilization technique which was adapted to the "Agduhr" block impregnation technique. The heart material was reserved in neutral formal (1/1) for 7 days. Then it was reserved in pyridin (4/40) and 40% NaOH (1/40) solution in water for 5 days. Formalin-fixed material was dissected by removing the epicardial or endocardial tissue covering the fibers of conduction system. Conduction tissue fibers showed up dark shadows (Figure 1).

All measurements were done with a digital compass.

Figure 1. Conduction system dissection.

RESULTS

The average dimension of the SA-node was 15x5 mm and the average dimension of the AV-node was 8x3 mm with an oblonge shape. The long axis of SA-node averaged between 11.5 and 25 mm with a mean of 15.1±2.2 and the short axis SA-node averaged between 2.5 and 6.5 mm with a mean of 5.1±0.6 (Figure 2). The long axis of AV-node averaged between 3.5 and 16 mm with a mean of 8.4±2.3 and the short axis AV-node averaged between 2.5 and 6.5 mm with a mean of 3.5±0.8 (Figure 3).
Persistent fetal dispersion of the AV node was observed in 1 case (5.6%) (Figure 4).
There was no accessory bundle. Fragmentation of the His bundle was not observed in the series. Discontinuity of the conduction pathways was not recorded.
Persistent fetal dispersion of the AV node can be a normal variation present during many years in life and must not be considered the anatomic substrate for arrhythmias.

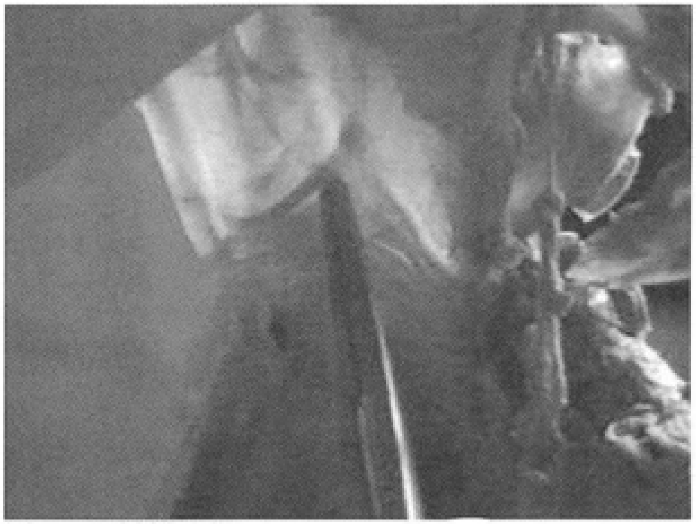

Figure 2. SA-node

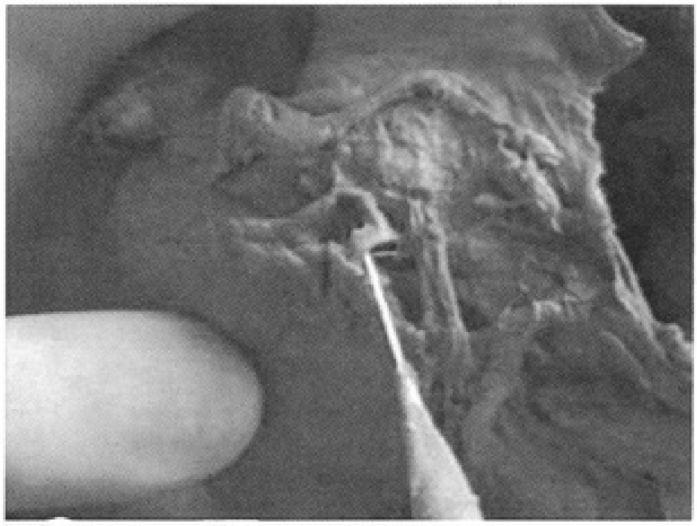

Figure 3. AV-node

Figure 4. Persistent fetal dispersion of the AV node

DISCUSSION

Concomitant with the development of catheter ablation techniques for the treatment of atrial arrhythmias, there is renewed interest in the morphologic arrangement of the cardiac conduction system. Cadaveric studies are the basis for surgical anatomy and new surgical methods before they are applied in patients (16).
The heterogeneous tissues of the pacemaking and conduction system comprise the "electricle components" of the heart, responsible for setting, maintaining, and coordinating the rhythmic pumping of cardiac muscle (17, 18). New information has been collected about the genetic and phenotypic characteristics during cardiac morphogenesis. In particular, there is evidence that extracardiac populations of cells migrating into the tubular heart have important morphogenetic roles in the inductive patterning and functional integration of the developing conduction system (19). The development of the cardiac conduction system begins in human embryos ranging in age from

42 to 54 days of gestation. The muscle cells forming the myocardium are both derived from the visceral mesoderm. All cardiomyocytes display autorhythmicity, intercellular conduction via gap junctions, and contraction, irrespective of whether they are derived from atrium, ventricle, node, or bundles. It is the anatomical arrangement of the distinct components that is responsible for the coordinate contraction wave over the heart (17, 19).

The penetrating bundle of His and the ventricular bundle branches are the tracts of specialized cells encased by insulating sheaths of fibrous tissue. In contrast, the sinus and AV nodes are recognized histologically but are not insulated from the working atrial myocardium. At its distal extent, the AV node is distinguished from the penetrating bundle not so much by cellular characteristics, but by the presence of a fibrous collar that surrounds the specialized cells. At the atrial part, a zone of histologically transitional cells interposes between the compact node and the working atrial myocardium. Transitional cells enter the triangle of Koch to join the compact node from superiorly, inferiorly, posteriorly, and from the left. Transitional cells of the sinus node, in contrast, are limited to short tongues that interdigitate with musculature of the terminal crest. Apart from a variable extension of its tail, there are no prominent histologically discrete extensions from the sinus node into the working atrial musculature. The internodal myocardium does not contain discrete conducting tracts comparable with the ventricular bundle branches. Preferential conduction more likely reflects the arrangement of the working internodal cells and their related cellular properties (5).

The cardiac conduction system may be involved by various congenital or acquired heart diseases and systemic hereditary diseases (20-22). But the cause of severe cardiac conduction disturbances is often uncertain. Abnormalities of the conduction system are associated with certain congenital cardiac malformations which are determined primarily by the alignment between atrial and ventricular septal structures and the pattern of ventricular architecture (20). Patients with coronary artery disease and severe conduction disturbances that require implantation of permanent pacemakers are more likely to have a specific pathological coronary anatomy that combines a compromised blood flow to the septal branches of the left anterior descending artery with right coronary artery lesions (28). The location of lesions in the coronary tree rather than severe diffuse atherosclerosis appears to be responsible for the conduction disturbances (21).

The study of the sinus node and the specialized atrioventricular junction by serial sections in cardiac transplantation revealed that acute rejection involving the conduction system was equally severe as the working myocardium, with the exception of the His bundle. During acute rejection, the sudden appearance of a first-degree atrioventricular block may suggest severe involvement of the conduction system with impending cardiac arrest (23).

A high resolution, three dimensional, computer model of the cardiac conduction system has been developed. Cardiac geometry was modeled and reconstructed as a matrix of cells that fill its anatomical structure. Mathematical simulations and experimental findings document the relationships between cardiac electrophysiology and fiber structure. The pattern of the excitation sequence propagation as well as potentials on the body surface points were computed on a single processor. The working memory and the time for computation of the algorithms were minimized using efficient data structures. The time to compute an excitation sequence over one cardiac cycle was 4 hours (22, 24, 25). Due to the complex architecture of the fibers, many different pathways are available to an excitation wavefront as it spreads from a pacing site: the straight line; the multiple, bent pathways resulting from the epi-endocardial rotation of fiber direction; the coiling intramural pathways and the pathways involving the Purkinje fibers. To compute the potential distributions and ECG waveforms generated by a spreading excitation wave we must know the successive shapes and positions of the wavefront, the architecture of the fibers through which it propagates and the spatial distribution of their anisotropic electrical properties (18, 26, 27).

Our revised technique for demonstrating the SA-node, the AV-node and the distal part of the His bundle of the cardiac conduction system is easy and informative. We believe that the morphometric analysis and knowledge of the variations are advantageous for preventing conduction system complications after cardiac operations. In conclusion, the examination of the cardiac conduction system is necessary to concentrate on conduction system complications and makes the routine cardiac surgical procedures more secure.

We are grateful to Prof. Dr. Türkan Erbengi for her excellent guidence and help in providing the histological studying techniques.

REFERENCES

1. Moore KL, Dalley AF. Clinically oriented anatomy. Fourth edition, Lippincott Williams&Wilkins, 1999.
2. Gabella G. cardiovascular system. Gray's Anatomy - The anatomical Basis of Medicine and Surgery. Williams PL (editor), 38. edition, Churchill Livingstone, London, 1995.
3. Wilcox BR, Anderson RH: Surgical Anatomy of the Heart, Gower Medical Publishing, London 1992.
4. Dean JW, Ho SY, Rowland E, Mann J, Anderson RH. Clinical anatomy of the atrioventricular junctions. J Am Coll Cardiol 1994;24:1725-32.
5. Anderson RH, Ho SY. The architecture of the sinus node, the atrioventricular conduction axis, and the internodal atrial myocardium. J Cardiovasc Electrophysiol 1998;9:1233-48.
6. Keith A, Flack M. The form and nature of the muscular connections between the primary division of the vertebrate heart. J Anat Physiol 1907;41:172-82.
7. James TN. Anatomy of the human sinus node. Anat Rec 1961;141:109-39.
8. Anderson KR, Ho SY, Anderson RH. The location and vascular supply of the sinus node in the human heart. Br HeartJ 1979;41:28-32.
9. James TN. The connecting pathways between the sinus node and the A-V node and between the right atrium and left atrium in the human hearts. Am Heart J 1963;66:498-508.
10. Anderson RH, Becker AE, Brechenmacher C, Davies MJ, Rossi L. The human atrioventricular junctional area. A morphological study of the AV node and bundle. Eur J Cardiol 1975;3:11-25.
11. James TN, Sherf L. Specialized tissue and preferential conduction in the atria of the heart. Am J Cardiol 1971;28:414-27.
12. Janse MJ, Anderson RH. Specialized internodalatrial pathways-fact or fiction. Eur J Cardiol 1974;2:117-36.
13. Mahaim I. Kent's fiber in the AV paraspecific conduction throug the upper connection of the bundle of His-Tawara. Am Heart J 1947;33:651-3.
14. Massing GK, James TN. Anatomical configuration of the His bundle and bundle branches in the human heart. Circulation 1976;53:609-21.
15. Mahaim I. Kent's fiber in the A-V paraspecific conduction through the upper connection of the bundle of His-Tawara. Am Heart J 1941;33:615-58.
16. Anderson RH, Wilcox BR. Understanding cardiac anatomy: the prerequisite for optimal cardiac surgery. Ann Thorac Surg 1995;59:1366.
17. Moorman AF, de Jong F, Lamers WH. Development of the conduction system of the heart. Pacing Clin Electrophysiol 1997;20(8 Pt 2):2087-92.
18. Taccardi B, Lux RL, Ershler PR, MacLeod R, Dustman TJ, Ingebrigtsen N. Anatomical architecture and electrical activity of the heart. Acta Cardiol 1997;52:91-105.
19. Gourdie RG, Kubalak S, Mikawa T. Conducting the embryonic heart: orchestrating development of specialized cardiac tissues. Trends Cardiovasc Med 1999;9:18-26.
20. Lev M. The conduction system in congenital heart disease. Am J Cardiol 1968;21:619-23.

21. Hansson A, Holm M, Blomström P, Johansson R, Lührs C, Brandt J, Olsson SB. Right atrial free wall conduction velocity and degree of anisotropy in patients with stable sinus rhythm studied during open heart surgery. Eur Heart J 1998;19:293-300.
22. Kohl P, Day K, Noble D. Cellular mechanisms of cardiac mechano-electric feedback in a mathematical model. Can J Cardiol 1998;14:111-9.
23. Calzolari V, Angelini A, Basso C, Livi U, Rossi L, Thiene G. Histologic findings in the conduction system after cardiac transplantation and correlation with electrocardiographic findings. Am J Cardiol 1999;84:756-9.
24. Balasubramaniam C, Gopakumaran B, Jagadeesh JM. Simulation of cardiac conduction system in distributed computer environment. Biomed Sci Instrum 1997;33:13-8.
25. Lab MJ. Mechanosensitivity as an integrative system in heart: an audit. Prog Biophys Mol Biol 1999;71:7-27.
26. Fast VG, Kleber AG. Cardiac tissue geometry as a determinant of unidirectional conduction block: assessment of microscopic excitation spread by optical mapping in patterned cell cultures and in a computer model. Cardiovasc Res 1995;29:697-707.
27. Maglaveras N, Van Capelle FJ, De Bakker JM. Wave propagation simulation in normal and infarcted myocardium: computational and modelling issues. Med Inform 1998;23:105-18.