Conduction of Excitation from the Sinus Node to the Atrioventricular Node

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The presence or absence of the specialized conduction pathway between the sinus and atrioventricular (A-V) node has been a matter of considerable debate ever since the two nodes were discovered. A number of investigators, notably Thorel and Wenckebach, were actively engaged in studies of this problem. The general consensus of the opinions has been up to present, against the presence of such pathway. The present speaker postulated the presence of specialized conduction pathways between the sinus and A-V node some 20 years ago and undertook a series of studies, which culminated, in 1953, in the discovery, by Oosawa, of 3 such pathways and a specialized muscle bundle running from the sinus node to the left atrium, demonstrated with serial sections of dog’s heart. These pathways are shown, schematically, in slide on the left. The same slide shown, on the right, a schematic sketch of pathways found by T. N. James, of Detroit, in 1963 as a result of serial section of the atrium of human heart. The two sketches appear, at the first glance, to be different, because the way the sketches were made is different; however, a closer inspection will reveal that the two are very close to each other. Thus, the anterior internodal tract of James, running from the sinus node to Bachmann’s bundle, perfectly corresponds to systema septoangularis anterior described by Oosawa. The middle tract and posterior tract, of James, differ only slightly from Systema septoang. post. and Systema dextroatri caudalis described by Oosawa.

This paper is intended to describe a study made with optical and electron microscope on the heart of a species of monkey, Macaca irus, together with physiological investigations made with microelectrodes.

I. Studies on the Heart of Monkey, Macaca irus

1. Materials and methods

The species of monkey used was Macaca irus; this species of monkey was used because it was close to Homo sapiens and has a relatively small body size, permitting the use of microelectrodes; moreover, it had, in 12 of 23 cases, one or more muscle fascicles simulating a false tendon just in the area of the atrium where the specialized conduction pathway is likely to lie (Fig. 1). This muscle fascicle constituted a part of the conduction pathways in this species of animal, this area was explored with microelectrodes. Next slide shows that this false tendon differed from ordinary heart muscles in that its action potential was preceded by a slow depolarization. The left side of the slide concerns with the anteriorly located false tendon, and the right side concerns with the posteriorly located false tendon. Serial sections were made, centering would this spot and in 2 directions, and the sections were studied with Van Gieson, Malory Asan, PAS, and Haematoxylin eosin stains. Connection of this muscle fascicle, proximally, with the sinus node, and distally, with the A-V node was also studied.

The same false tendon, obtained from other animals, was subjected to electron microscope study, with fixing by glutaraldehyde and then osmic acid and embedding in epoxy resin. The ultra-thin sections were studied with lead hydroxide stains.

2. Results
Next slide (Fig. 2) shows the histology of the false tendon, for the anteriorly located are on the left (Fig. 2) and the posteriorly located one on the right. There are muscle bundle which are surrounded by connective tissues and which consist of cells that are smaller than ordinary atrial muscle cells, irregular in arrangement.

Next slide shows an electron micrograph of atrial muscle cells in the appendage, as a control; these atrial cells are smaller than muscle cells of the ventricle but they are essentially the same. In slide (Fig. 3) it is shown that the muscle cells found in the false tendon in question are different in shape from ordinary atrial
muscle cells and that, with the cells in the false tendon, adjacent cells do not necessarily form end-to-end junction but form, frequently, side-to-side junctions; also branched intercarated disks are seen. Other characteristic features include random direction of the course of myofibrils and abundant glycogen granules.

As shows in next slide (Fig. 4) these muscle cells are rich in glycogen granules but have slender and sparsely distributed myofibrils; a few of these cells, resumable on smooth muscle cells in appearance and are surrounded by connective tissues. As shown in next slide, there are occasional aggregates of electron-dense filaments of unknown nature. At higher magnification, these aggregates reveal a lattice-like structure with disorderly arrangement.

Next slide (Fig. 5) is from the posteriorly located false tendon and reveals essentially the same histological features as for the anteriorly located false tendon. There are small cells with irregular arrangement. Mitochondrial granules are seen, the myofibrils are not clearly discernible and this also applies to Z-band; possibly because the preparation from which this section was taken has been bathed for prolonged periods of time in Tyrode solution for the purpose of recording action potentials by means of microelectrodes. Next slide (Fig. 6) shows unmyelinated nerve fibers found in the false tendon, coursing through between muscle cells, the one on the left being taken from the anteriorly located false tendon and the other, on the right, from the posteriorly located false tendon. Next slide (Fig. 7) shows the histology of the anteriorly located false tendon at the point of its proximal insertion, on the left; on the right, it is shown, with higher magnification, that there are muscle bundles that are surrounded by connective tissues. Tracing its course proximally, it is found, as shown in next slide, that the bulge penetrates into the wall of the atrial septum and spreads out flat just beneath the endocardium. Its connection towards the
left is visible in the picture shows on the right of the same slide. This system runs from the right towards the left subendocardially, in next slide, and reaches the sinus node, shows on the left of the slide.

Next slide shows, on the left, the false tendon at the point of its distal insertion, studied with Malory stain. On the right a section is shown that was cut at the right angle, with subendocardial bulge of muscle bundles. This system spreads out flat subendocardially, as shown on the left side of next slide (Fig. 8), and makes a contact with heart muscle fibers. Finally, this system makes a contact with A–V node, as shown on the right side of the slide.

Next slide concerns itself with the posteriorly located false tendon, studied at the point of its proximal insertion, on the left; on the right, it is seen to traverse towards Crista terminalis. In next slide, it is seen to traverse still proximally, making connection with muscle layers of the septum. With the posteriorly located false tendon, it was not possible to establish its connection with the sinus or A–V node as clearly as with the anteriorly located false tendon.

II. PHYSIOLOGICAL STUDIES WITH MICROELECTRODES ON RABBIT’S HEART

The present speaker reported at the Congress last year that the addition, in amount of $10^{-5}$ to $10^{-6}$g/ml, of acetylcholine to the Tyrode solution bathing rabbit’s atrial preparation, with recording of action potentials from the vicinity of the sinus node and A–V node with microelectrodes, resulted in a dissociation between the sinus and A–V node, and that, under this circumstance, the action potentials recorded from the A–V node exhibited a small hump in response to the impulse of sinus origin, this hump triggering ventricular capture occasionally. When a cut is placed in systema septoangul. ant. this hump of sinus-impulse origin disappeared, the activity recorded from the A–V node becoming that of simple A–V nodal rhythm.

This communication describes an experiment in which a study was made on the pace-maker shift induced by the application of acetylcholine on the head of the sinus node with emphasis on the effect on systema septoangul. post.

1. Methods

Action potentials were recorded from the sinus node and A–V node of 62 rabbit’s hearts bathed in oxygen-saturated Tyrode solution of 32°C, by means of microelectrodes filled with 3 MKCl mixed with cobalt chloride in a concentration of 0.5%. Upon the application of acetylcholine, in concentrations ranging between $10^{-6}$ and $10^{-7}$g/ml, on the head of the sinus node, there occurred a shift of pace-maker. A study was made on the effect, on action potentials, of the section of systema septoangul. post. in 29 cases.

The location of the tip of the microelectrode was verified by effecting a migration of cobalt chloride electrophoretically, the tissue being fixed and studied with the method of Okamoto and Sonoda.

2. Results

As Tateishi reported yesterday in the scien-
tific session, this procedure produced on internodal block in most cases, although a delayed conduction between the sinus node and A-V node was found occasionally, next slide shows, on the left (Fig. 9), recordings from the site of the pace-maker (a), and, action potentials of the A-V node (b). A shows a normal conduction and B, after the application of acetylcholine. After the application of acetylcholine the electrical activity recorded from site (a) showed a rate of slow diastolic depolarization with slowed rhythm, suggesting that pace-maker has probably shifted distally. Apparently, site (b) and (a) were responding to the stimulus. As shown in column C, A-V node (b) became out of rhythm with sinus node (a) after placing a section in systema septoanuul. post.

As shown by a slide on the right side (Fig. 10), in the middle column labelled B, the application of acetylcholine, caused a shift of pace-maker from sinus node, where slow diastolic depolarization virtually disappeared; recording from the A-V node, (b), indicate 2:1 block. With the section of syst. septoanugul. post., there occurred a complete dissociation, as shown in the lower column, C.

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Next slide (Fig. 11) with the application of acetylcholine, recordings from the A–V node, (b), are only small humps (waves) and showed no burst (no firing). When a cut was placed in sistema septoan. post. recording from A–V node became that of an arrest, followed, as shown on C, by automaticity of lower centers.

As shown in next slide on the left side, (Fig. 12), the application of acetylcholine caused the slow diastolic depolarization of sinus node to diminish (middle column, B) and recordings from A–V node became that of a fusion of (1) humps, synchronized, probably, with the pacemaker impulse and (2) action potentials of presumably lower-nodal rhythm. When a cut is placed in sistema septoan. post., there occurred a disappearance of humps which used to originate, presumably, from impulses coming down from above.

As shown on a slide on the right side, after the application of acetylcholine there occurred a shift of the pace-maker and recordings from the A–V node showed (1) small waves, originating in impulses coming down from above, and (2) action potentials of lower automaticity. After a cut was placed in sistema septoan. post. small waves disappeared, leaving behind automaticity of A–V nodal rhythm.

Next slide shows the histological picture of the site of the microelectrode impalement, i.e., head of the sinus node as verified by electrophoretic migration of CoCl₂. On the right side a picture of the tail of the sinus node is shown, into which a shift of pacemaker occurred. The location of the tip of microelectrodes is indicated by a orange spot of cobalt-stained tissue.

III. DISCUSSION

As to the false-tendon-like structure found in the atrium of the monkey, Macaca irus, it resembles, in some cases, Chiarri net of man in location and appearance; although it may or may not be a residuum of a structure that formed during fetal development of the heart, it has the following morphological and physiological characteristics; that is (1) it contains a muscle bundle in its center and this muscle bundle shows histological features considerably different from those of ordinary atrial muscles and rather close to those of the nodal tissues, (2) physiologically, it generates action potentials preceded by a slow diastolic depolarization, (3) it occurs at a special geographical location. From these characteristics, it appears that this structure might form a part of the specialized pathway connecting sinus and A–V node. Investigation of serial sections made towards both direction, i.e., upward and downward, from this structure, gave evidences, shown earlier in this report, suggesting, partially, that this structure was in continuity with both sinus and A–V node. Since it was not possible, in this study, to trace the whole course of the pathway down to the A–V node, a definite conclusion can not be drawn from this study.

Investigation on rabbit’s heart by means of microelectrodes showed that (1) the application of acetylcholine caused, delayed conduction of impulses between the sinus and A–V node, and (2) section of sistema septoan. ant., after the application of acetylcholine, made this conduction delay even more pronounced, and (3) when a shift of pacemaker from the head to the tail, of the sinus node, has been previously produced by the application of acetylcholine, the section of sistema post, not anterior, caused the conduction of impulse between the sinus and A–V node to be blocked. These observations become easily understandable, when one recalls the fact that a short-cut pathway to A–V node is provided by sistema anterior for those impulses originating in the head of the sinus node and by sistema post for those impulses originating in the tail of the sinus node. In this sense, the above experimental observations constitute evidences suggesting that specialized conduction pathways exist between the sinus node and A–V node.

IV. SUMMARY

1. A structure (muscle fascicle) resembling a false-tendon was occasionally found (in 12 of 23 animals) in the right atrium of the monkey, Macaca irus, at a geographical location corresponding to the usual site of the specialized conduction system of the atrium, a subject that has long been studied by this author. This structure generated action potentials preceded by a slow diastolic depolarizations. The cells

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constituting this structure differed, both optically-microscopically and electron microscopically, from ordinary atrium muscle cells in that the cells were small in size, irregular in arrangement and with in nuclei, a histological feature that makes this structure appear more or less like nodal tissues.

2. Investigation of serial sections made towards too directions, that is, upward to the sinus node and downward to the A-V node from this structure, showed that this structure was in continuity with muscle bundles of similar nature towards both directions.

3. Investigation on the hearts of 62 rabbits by means of microelectrodes showed that, when a shift of pacemaker from the head to the tail of the sinus node has been previously produced by the application of acetylcholine to the sinus node, section of the systema septoangularis post. resulted in a complete dissociation between sinus node and A-V node.

4. The location of the tip of microelectrode was verified my effecting electrophoretic migration of cobalt hydrochloride solution, both for the head of the sinus node (usual site of the pacemaker) and for the tail of the sinus node (site of a pacemaker after the application of acetylcholine).

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