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The Identification and Surgical Significance of the Atrial Internodal Conduction Tracts

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THE EXACT configuration of the pathways for transmission of impulses from the sinoatrial to atrioventricular node has been controversial since Keith and Flack,[7] in 1907, described a muscular bundle directly connecting the sinoatrial (SA) node to the atrioventricular (AV) node. Two years later Thorel[9,10] demonstrated a direct path between the two nodes following the course of the crista terminalis and containing specialized fibers of the Purkinje type. In 1908, Wenckebach[13,14] found a second tract coursing along the limbus of the fossa ovalis and Bachmann,[1] in 1916, demonstrated a path from the sinus node to the left atrium.

In 1963, James[6] anatomically redescribed all of the previously discovered tracts, following their courses with sub-serial microscopic sections and electron micrographs. He found that Bachmann's bundle is a branch of one of the three major pathways connecting the SA node to the AV node. He believed that all three tracts contained fibers with the Purkinje characteristics of coarse myofibrils with a perinuclear clear zone and bulge. However, none of the tracts were composed exclusively of this type of fiber, nor were they continuous. He therefore considered each of these tracts as a potential pathway for rapid internodal conduction. The three atrial internodal bundles in the anatomic positions described by James are indicated in Figure 1.

We[5] developed an interest in the atrial conduction system when we noted that there were a significant number of older patients with atrial septal defects who had atrial arrhythmias both before and after surgical repair. In 1965, Bowman and Malm[2] found that with the use of the transeptal approach to mitral valve repair, temporary atrioventricular dissociation was a common complication. In a series of 38 patients two required temporary electrical pacing due to the slowness of the nodal pacemaker. The septal incision was then

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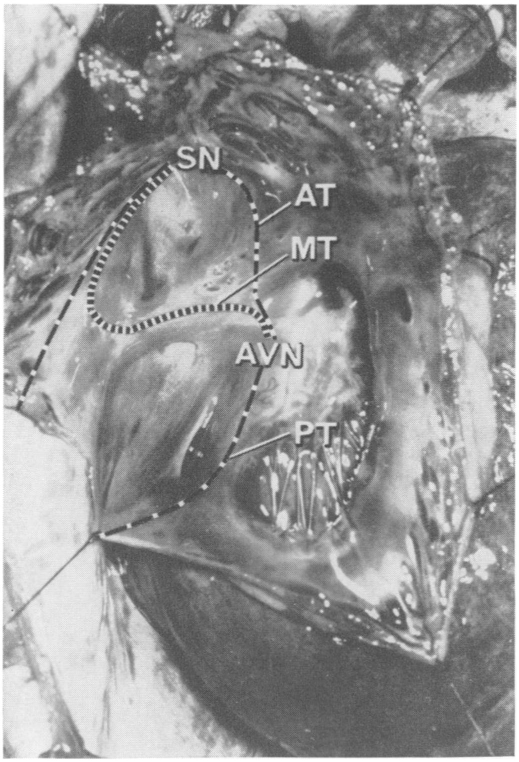

FIG. 1. Location of the internodal tracts in the right atrium and atrial septum. The right atrium of the dog heart has been opened along the atrioventricular groove. SN: sinus node. AVN: AV node. AT: anterior internodal tract. MT: middle internodal tract. PT: posterior internodal tract.

changed to one which did not divide all three tracts.

Our experiments using electrophysiologic technics were designed to locate the tracts and to determine the relationship of these pathways to the placement of atrial incisions and to the closure of atrial septal defects. With this information we could determine whether or not it would be possible to avoid these pathways for atrial conduction during surgical procedures on the atrium.

Methods and Results

1. Mapping of the Epicardial Surface of the Right Atrium: These experiments were designed to determine whether or not an incision in the right atrium parallel to the crista terminalis and the posterior tract coursing in it, or one transecting the tract, would produce a conduction disturbance.

In each of the following experiments adult mongrel dogs weighing 14 to 21 Kg. were utilized. Sodium pentabarbital was used for anesthesia and the right atrium exposed by a thoracotomy. In 10 experiments 19 points on the epicardial surface were arbitrarily selected to record myocardial excitation and its sequence. With the heart electrically paced from the sinus node at a rate fast enough to override the spontaneous pacemaker, the time which elapsed from the onset of the paced stimulus until electrical activity arrived at each of 19 points was measured.

A moveable bipolar silver wire recording probe was used as described by Stuckey.[8] Right atrial and right ventricular electrograms and esophageal EKG were monitored in all experiments. Following control mapping, either one of two incisions into the atrial chamber was made: (a) transverse to the crista terminalis and dividing it; or (b) parallel to the crista terminalis but not dividing it. After the atriotomy was closed, the surface of the right atrium was remapped. A control map of the right atrial surface is shown in Figure 2a. Lines have been drawn at timed intervals to show the approximate excitation wave front of a particular isochronous zone. The apex of each succeeding wave of excitation is the farthest distance traveled in a particular zone. This figure indicates that the rapid spread of the impulse occurs along the region which overlies the crista terminalis rather than in the immediately adjacent atrial tissue. In the experimental map (Fig. 2b) the course of activation proximal to the transverse incision is nearly identical to that of the control. However, distal to the incision, activation times are much delayed including those points overlying the crista terminalis.

The effect of an incision made parallel to the crista terminalis is shown in Figure 3. The control map (Fig. 3a) is nearly the

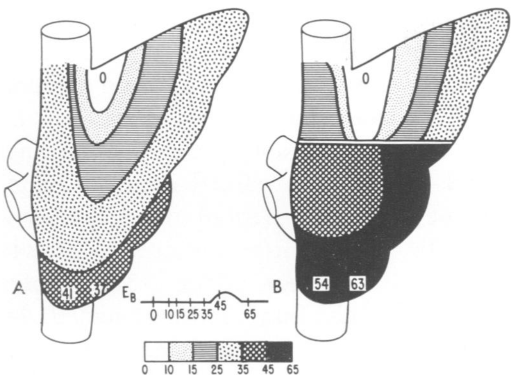

FIG. 2. Transverse atriotomy in the right atrium. A: control map. B: experimental map. E_B: esophageal electrocardiogram.

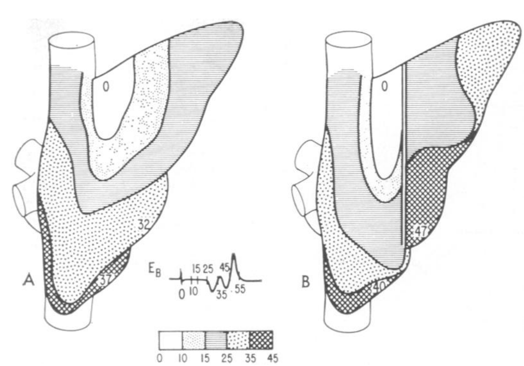

FIG. 3. Vertical atriotomy in the right atrium. A: control map. B: experimental map. E_B: esophageal electrocardiogram.

same as that seen in Figure 2a. In the experimental map (Fig. 3b) the course of activation posterior to the incision shows little change from the control including the areas overlying the crista terminalis. In the area anterior to the incision there is a minor prolongation at several distal points. Therefore, the sulcus terminalis with the underlying crista terminalis represents a landmark indicating one of the interatrial tracts. An incision parallel to the crista terminalis will thus preserve this tract. These data correspond well with the position of the posterior tract as described by James.[6]

2. Endocardial Time-Distance Relationship: This series of experiments was designed to determine the electrophysiologic difference between the atrial internodal tracts and the atrial muscle and in this manner to confirm the presence of specialized pathways. Three dogs were placed on cardiopulmonary bypass and the right atrium was opened parallel to the crista terminalis. With the heart artificially paced from the sinus node, activity was recorded from the middle and posterior internodal tracts utilizing a movable bipolar recording probe electrode. The distance from the sinus node was then plotted against the time necessary for the impulse to reach any particular point being recorded. The conduction velocity was calculated from the slope of the line. A representative time distance plot from one of these three studies is shown in Figure 4. In three dogs, the range of conduction velocity was 800–900 mm./sec., in the region of the crista terminalis and limbus of the fossa ovalis. The conduction velocity in the atrial muscle was 200–400 mm./sec. This indicates that there is specialized tissue both in the area of the crista terminalis and in the limbus of the fasso ovalis, resulting in rapid conduction in these two areas corresponding to the location of the posterior and middle internodal tracts.

3. Sequential Division of the Atrial Internodal Tracts: In order to determine the functional significance of these tracts and to relate them to their possible interruption during atrial surgery, 10 dogs were used in a separate experiment in which each of the atrial internodal tracts were divided in sequence. The anterior tract was sectioned as it coursed through the anterior interatrial septum, the middle tract where it passes through the limbus, and the posterior at a point distal to the limbus. The heart was artificially paced from the sinus node and the change in the PR interval following sectioning of the tracts was recorded (Fig. 5). In the first series of 5 dogs when the posterior tract was divided first there was no change in the PR interval. Next, division of the middle tract failed to

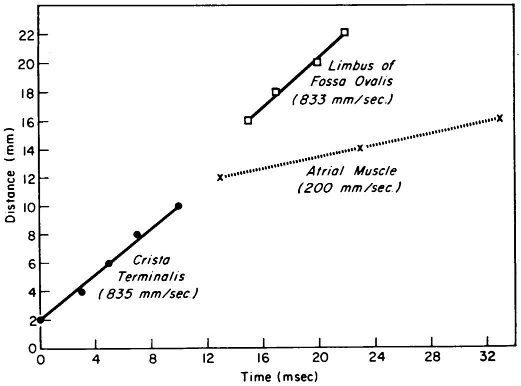

FIG. 4. Time distance plot showing conduction velocity in the middle and posterior tracts and atrial muscle.

produce a delay. However, division of the anterior tract, now the only one intact, produced a delay of 25–30 msec. In the second series of 5 animals when the middle tract was divided first there was no delay. However, if the anterior tract was divided next, there was still a 25–30 msec. delay in conduction time. Finally when the posterior tract was divided there was an additional 15–25 msec. delay. This represented a 30–50% increase above the normal interval of 65–70 msec. Consequently, it would appear that the anterior tract is usually the preferential pathway for internodal conduction. The posterior tract would appear to be the longest and least likely to carry the conduction from the SA node to the AV node; though it will do so when other two are injured.

It was also found in 7 of 10 dogs with all three tracts divided, that an AV nodal rhythm resulted when the heart was allowed to beat with a spontaneous rhythm. Figure 6 shows tracings obtained before and after dividing all three tracts. It may be seen that a regular rhythm occurred either spontaneously or by electrical pacing from the sinus node prior to cutting of any of the tracts. Following division of all three tracts, a spontaneous nodal rhythm occurred with the P wave following the QRS complex and atrial activation occurring after ventricular activation. With pacing from the sinus node following division of all three tracts, a regular paced rhythm was produced. However, there was a delay in atrial to ventricular conduction time, which could be accounted for by conduction occurring by way of the left atrium through Bachmann's interatrial bundle which had not been divided. Since fibers of Bachmann's bundle were joined by fibers of the middle internodal tract near the AV node it may be possible for the impulse to arrive at the AV node in this manner.[6]

4. Atrial Septal Mapping and Potassium Infusion: Pilot studies have been carried out in which the extracellular potassium concentration was increased to levels great enough to block contraction of atrial muscle, yet preserving excitability of the nodal tissue; as suggested by Hoffman and his associates.[3, 4, 11, 12] These observers found that the specialized fibers of the sinus and AV nodes were less sensitive to excess potassium than were the atrial muscle fibers. Excitability of these fibers was maintained at potassium concentrations which rendered the remainder of the atrium inexcitable. In explaining this phenomenon it may be postulated that there is a difference in permeability of either potassium or chloride ions between atrial muscle and tissue specialized for conduc-

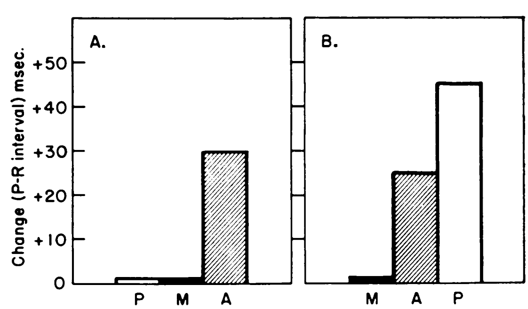

FIG. 5. Functional importance of internodal tracts showing the change in PR interval following sequential division of the three tracts. A: anterior internodal tract. M: middle internodal tract. P: posterior internodal tract.

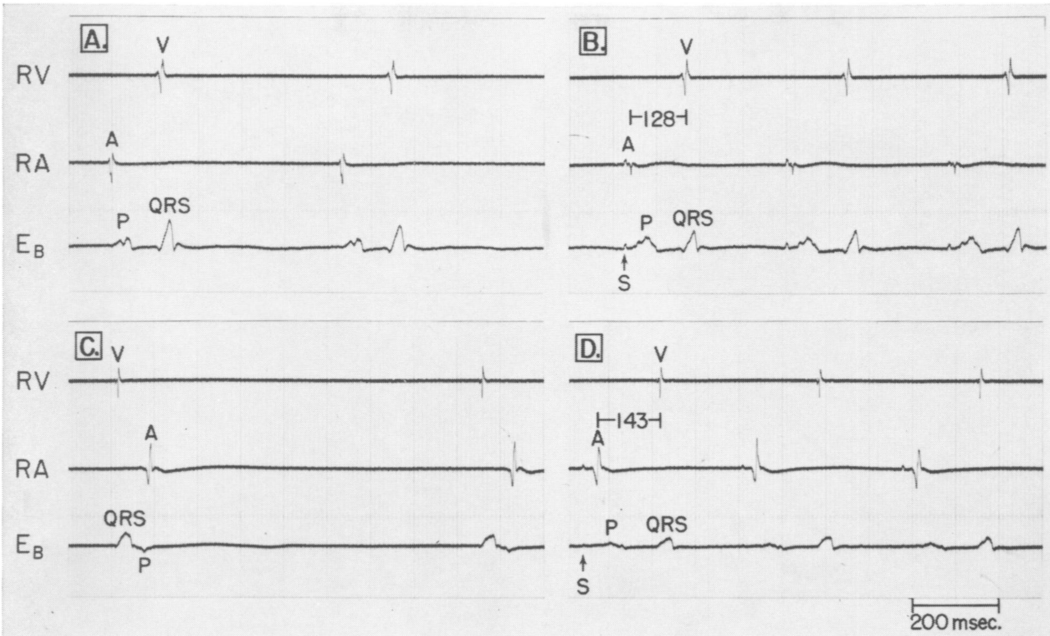

FIG. 6. Nodal rhythm after division of the internodal tracts. Panel A: normal sinus rhythm. Panel B: regular paced rhythm. Panel C: nodal rhythm following division of all three tracts without pacing. Panel D: regular paced rhythm following division of all three tracts. RA: right atrial electrogram. RV: right ventricular electrogram. E_B: esophageal electrocardiogram. S: stimulus application at sinus node.

tion. In these studies a modified cross-circulation experiment was used making it possible to inject graduated quantities of 10% potassium solution into the coronary circulation so that atrial muscle ceased to contract but atrial conduction still occurred. In these experiments two dogs were utilized; one as the experimental and the other as a support animal, the cross-circulation technic supporting the experimental heart. In these studies the same bipolar movable probe electrode was used for mapping. Reference for timing once again was made to the onset of the electrically induced stimulus at the sinus node.

An atrial septal map was first made prior to potassium infusion to serve as a control (Fig. 7). At this time an electrogram was recorded from each of the 64 arbitrarily selected points on the septal surface. The zones of activation were developed in a manner similar to that used with the right atrial maps. After the control map was made, KCl was infused into the experimental heart by way of the coronary arteries. Once the atrial electrogram and the P wave had disappeared, a second map (Fig. 8) was made. Electrograms were recorded only where plus signs appear on the diagram. As can be seen these seem to correspond with the position of the atrial internodal bundles. There was no activation of the surrounding atrial muscle. One interesting note is that in four of the five dogs that comprised this pilot study, once potassium infusion was adequate, there was no contraction of the atrial muscle fibers but the bundles comprising the internodal tracts continued to contract.

Discussion

Further evidence for the presence of three specialized internodal pathways in the right atrium and septum for conduction between the SA nodes and the AV node is shown by these studies. Time distance plots

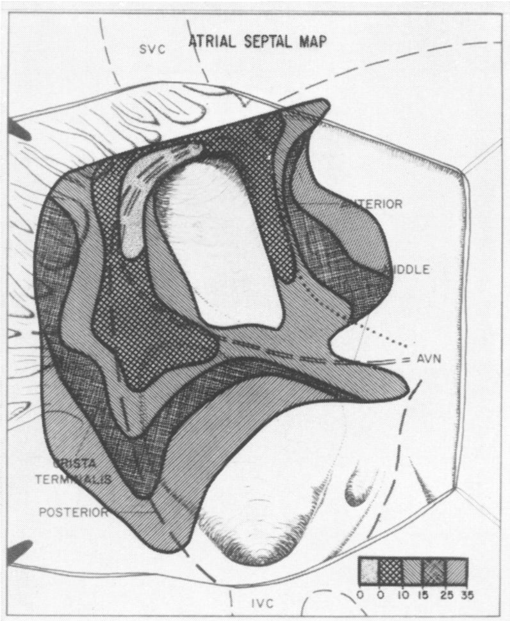

FIG. 7. Atrial septal map. Right atrium open along atrioventricular groove. SN: sinus node. AVN: AV node. Anterior: anterior internodal tract. Middle: middle internodal tract. Posterior: posterior internodal tract. SVC: superior vena cava. IVC: inferior vena cava.

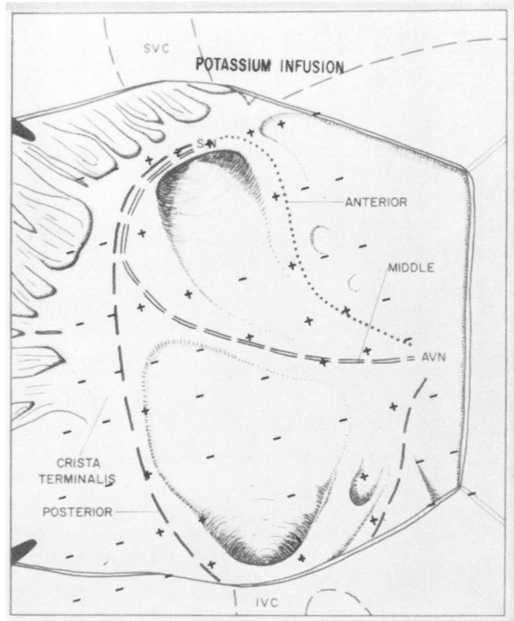

FIG. 8. Potassium infusion study. SN: sinus node. AVN: AV node. Anterior: anterior internodal tract. Middle: middle internodal tract. Posterior: posterior internodal tract. SVC: superior vena cava. IVC: inferior vena cava. +: points where electrical activation was recorded following potassium infusion. −: points where electrical activation was recorded prior to potassium infusion but not after potassium infusion.

have shown that the conduction velocity in the tracts is 2 to 3 times greater than that observed in atrial muscle. Maps of the atrial septum further confirm that the impulse arriving from the sinus node may reach the AV node much more rapidly than might be expected if the impulses were to reach the AV node through atrial muscle. This indicates that the sinus node impulse reaches the AV node over specialized pathways rather than through atrial muscle acting as a physiologic syncytium. Potassium infusion experiments give an additional confirmation of their anatomic locations.

From the studies where the tracts were selectively divided, it is evident that the anterior tract is the preferential route for the propagation of the impulse from the sinus node to the AV node in the dog. Division of all three tracts was frequently associated with nodal escape rhythm. However it was noted that once all three pathways were sectioned, electrical pacing of the heart from the sinus node regions was still possible. This is interpreted to mean that the impulse was conducted to the left atrium by way of the specialized interatrial pathway, Bachmann's Bundle, and then from the left atrium to the middle internodal tract and finally to the AV node. The failure to produce nodal escape rhythm in all dogs can be explained by the presence in some dogs of well developed specialized tissue in the region of the coronary sinus left from the embryologic sinus venosus. This may serve as the atrial pacemaker.

The location of the three internodal tracts is such that they are all vulnerable to injury during operation, not only from the atrial incision but from the closure of atrial defects as well. Attenuation of the tracts either by enlargement of the atrium or by turbulent flow may be expected, although this has not been proven and malposition as a part of the anomaly may occur as well.

Summary

The position of the anterior, middle and posterior internodal tracts in the atrium, the pathways of conduction from SA to AV node, was determined by electrically mapping the external surface of the right atrium and the atrial septum.

Sequential division of the tracts revealed that an impulse traveled most rapidly by the anterior internodal tract. Division of all three resulted in nodal rhythm in 7 of 10 dogs.

The possibility that three tracts may be divided or injured during operation is clearly shown. A longitudinal incision anterior to the crista terminalis will preserve one tract even if the remaining two tracts are compromised by repair of the atrial defect.

The importance of preserving one tract during operation is stressed. This can be accomplished by placing the atrial incision parallel to the crista terminalis. The latter is the location of the posterior internodal tract.

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