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Effects of Adrenaline, Acetylcholine, Ca^{++} and K^{+} on the Conduction through the SA Node in the Rabbit[1]

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= Abstract =Although many studies have been performed on the electrical properties of the SA node, there are few studies on the conduction time through the SA node. The reason for that lies mainly on the intrinsic characteristics of the SA node and problems in the applied methods.

In order to investigate the effects of neurotransmitters and ions on the intranodal conduction, the conduction time in various regions was studied in the SA node of the rabbit. A small strip of 1 mm X 10 mm in parallel with crista terminalis was made, and two microelectrodes were inserted in different locations. After having recorded the conduction time under normal Tyrode solution, neurotransmitters (adrenaline, acetylcholine) or ions (Ca^{++}, K^{+}) were applied, and their effects on the conduction time were observed.

The results obtained were as follows: in the presence of adrenaline, the conduction time through the SA node was shortened and the pacemaker site was shifted downward. In the presence of acetylcholine or 1 mM Ca^{++}, the conduction time was prolonged and the pacemaker site was shifted downward. At under 8 mM Ca^{++}, the conduction time was shortened and the pacemaker site was not shifted. The conduction time and the pacemaker site were not affected under 1.5 mM K^{+}.

Key words: ***SA node, Conduction time, Pacemaker shift***

INTRODUCTION

The automaticity of the heart arises from changes in the electrophysiological properties of the sinoatrial(SA) node. Lewis *et al.* (1910) first found the area of primary negativity in the small part of the SA node, but they could not determine the exact site initiating pacemaker activity. After West (1955) described the first microelectrode study of the SA node, many investigators were concerned with SA node function, and it was revealed that only a small part of the SA node, consisting of thousands of cells, functioned as the pacemaker. Most other part of it functioned as a conduction system (West 1955; Sano and Yamagishi 1965). Thereafter, conduction of action potential through the SA node has been investigated intensively.

Two methods have been used in studying the conduction through the SA node. The first method was to make an activation map of the whole SA node area (Bouman *et al.* 1978; Steinbeck *et al.* 1978; Masson-Pevet 1982), which directly revealed the spread of an impulse through the SA node. It was technically difficult and impossible to compare the differences in conduction time between the changed environments directly. The second method was to investigate the conduction of a premature beat that originated from an external stimulus. It provided a way of direct measurement of the conduction time but was applicable only to the fixed area of SA node.

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Two considerations about conduction through the SA node have been addressed-the conduction time itself and the pacemaker shift. Many studies have been done on the pacemaker shift-the change in the site of pacemaker according to the pharmacological and/or ionic environmental changes (West 1955; Bouman *et al.* 1968; Toda and Shimamoto 1968; Lu 1970; Spear *et al.* 1979). Studies on the conduction time has been rarely performed due to the technical limitations. One of the major problems lies on the pacemaker shift. Another is the fact that action potential does not propagate through the shortest path between two points (Noble 1979).

The present investigation deals with the conduction time using the method that could remove most of the problems. In order to prevent the conduction from straying, we made a small strip of the SA node. The location of microelectrodes were determined considering the pacemaker shift. Then, conduction time through the SA node under various environmental changes was compared.

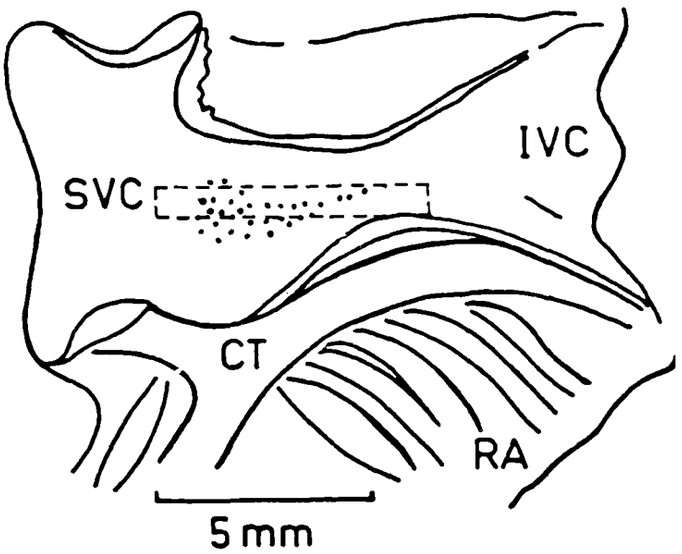

Fig. 1. A diagram of the rabbit SA node. Small dots indicate the compact area where the typical nodal cells are found (Bleeker *et al.* 1980). Preparations were made from the area marked by rectangle. CT: crista terminalis, IVC: inferior vena cava, RA: right atrium, SVC: superior vena cava.

MATERIALS AND METHODS

Preparation of the SA node

Rabbits of either sex weighing about 1 kg were used. Animals were killed by a blow on the hind neck and exsanguinated. The chest was opened, and the heart was removed quickly and transferred into a dissection chamber containing oxygenated Tyrode solution. Atria were separated from the rest of the heart and cut open through the superior vena cava (SVC) and inferior vena cava (IVC) to expose the SA node (Fig. 1). After a recovery period of one hour, the isolated SA node was cut parallel to the crista terminalis into 2 or 3 strips of 0.5-1 mm in width and 0.8-1 cm in length with a fine razor blade. After soaking in normal Tyrode solution with 10 mM Ca^{++} for 1-2 minutes, preparations were placed in normal Tyrode solution of 2 mM Ca^{++} for one hour. This preparation was placed in an experimental chamber which was being perfused with oxygenated Tyrode solution and was held by fine entomological pins.

Solutions

Normal Tyrode solution contains NaCl 140 mM, KCl 3 mM, $CaCl_2$ 2 mM, $MgCl_2$ 1 mM, glucose 5 mM. With 5 mM Tris-HCl, pH was adjusted to 7.4 at 37C. In order to change Ca^{++} concentration, Ca^{++} was simply removed from or added to normal Tyrode solution. In case of K^+, the same method was applied. Drugs or chemicals used in this experiment were adrenaline and acetylcholine.

Experimental setup

For recording the membrane potential, a glass microelectrode with tip diameter of 1 μm and resistance of 30 MΩ were used. Action potential through the SA node was recorded by an oscilloscope (Gould) and a physiograph (Devices) passing through the preamplifier that was connected with the microelectrode.

By using hydrostatic pressure, solutions were flowed into a water jacketed tissue bath of which temperature was maintained with constant temperature circulator (Haake FE).

The protocol of the experiment was as follows: at first, the exact site of pacemaker was determined in the SA node by utilizing the two microelectrodes. One microelectrode was inserted in the region slightly above the pacemaker and another in the region near SVC. After having recorded the time interval between two action potentials in normal Tyrode solution, the intervals in either adrenaline, acetylcholine, Ca^{++} or K^+-containing solution were recorded. The differences between them were compared.

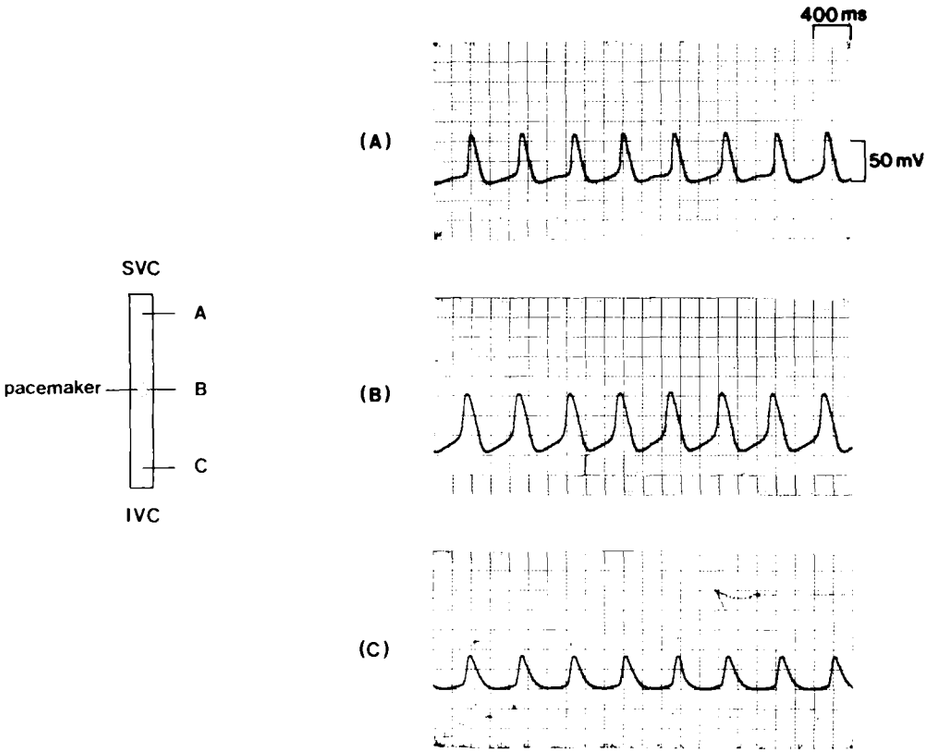

Fig. 2. Typical action potential recorded from various areas within the SA node. (B) was recorded from the central compact area and (A) and (C) were recorded from the peripheral area. The record from the central area showed a smooth transition from pacemaker depolarization to rapid upstroke.

Next, the microelectrode placed slightly above pacemaker was left in place, but the other microelectrode was placed in the region near the IVC. Differences in time intervals were observed under various conditions. Studies were done also with one microelectrode inserted in the region slightly below the pacemaker and another in the region near SVC or IVC.

RESULTS

Action potential recorded in the SA node

Action potentials showed the regional differences within the SA node. The action potential recorded from the pacemaker site is shown in (B) of Fig 2, from the region near the SVC in (A), and from the region near the IVC in (C).

The pacemaker action potential was identified by the smooth transition from pacemaker depolarization to rapid upstroke and the earliest occurrence than other regions. Away from the pacemaker, the transition from pacemaker depolarization to rapid upstroke became abrupt and the action potential was generated at later period than in the pacemaker site. The site of impulse formation was dependent on the criterion used to delineate the earliest discharging group of cells, but the peak of action potential was used as the criterion in this experiment.

Effects of adrenaline on conduction

One electrode was inserted in the region slightly above the pacemaker and another in the region near the SVC. The conduction velocity of action potential was estimated by observing the difference in time intervals between action potentials. The left panel of Fig. 3(A) shows the results recorded in normal Tyrode solution and the right panel in 10^{-7}M adrenaline. The difference of time intervals between action potentials decreased. Next, while the electrode placed above pacemaker was left in place, the other electrode was inserted in the region near the IVC (Fig. 3(B)). In this case, the difference also decreased. Therefore, in the presence of adrenaline, the conduction was enhanced.

In the other preparation, one electrode was inserted in the region slightly below pacemaker. When another electrode was inserted in the region near the SVC, the difference in time interval increased (Fig. 4(A)). When another electrode was inserted in the region near the IVC, the dif-

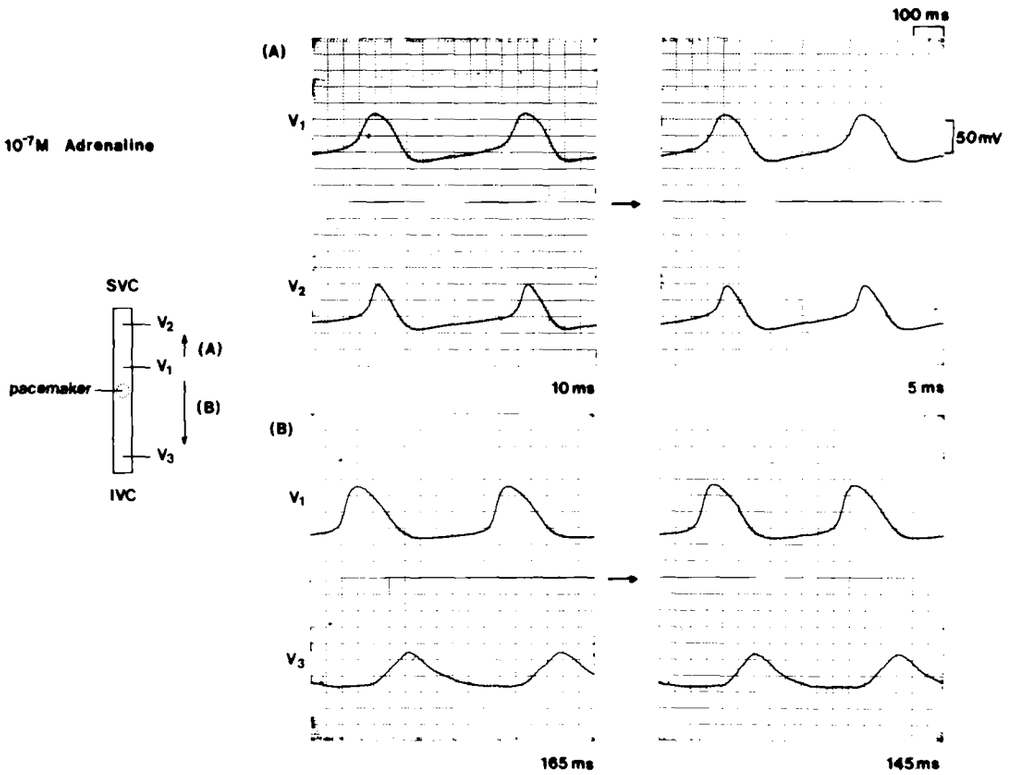

Fig. 3. Effect of adrenaline (10^{-7}M) on the conduction time. Microelectrodes were impaled at V_1, V_2, V_3 and the conduction time was recorded. The conduction time was measured by the differences between the action potential peaks. (A) shows that the upward conduction time was shortened from 10 ms to 5 ms. (B) shows that the downward conduction time was shortened from 165 ms to 145 ms.

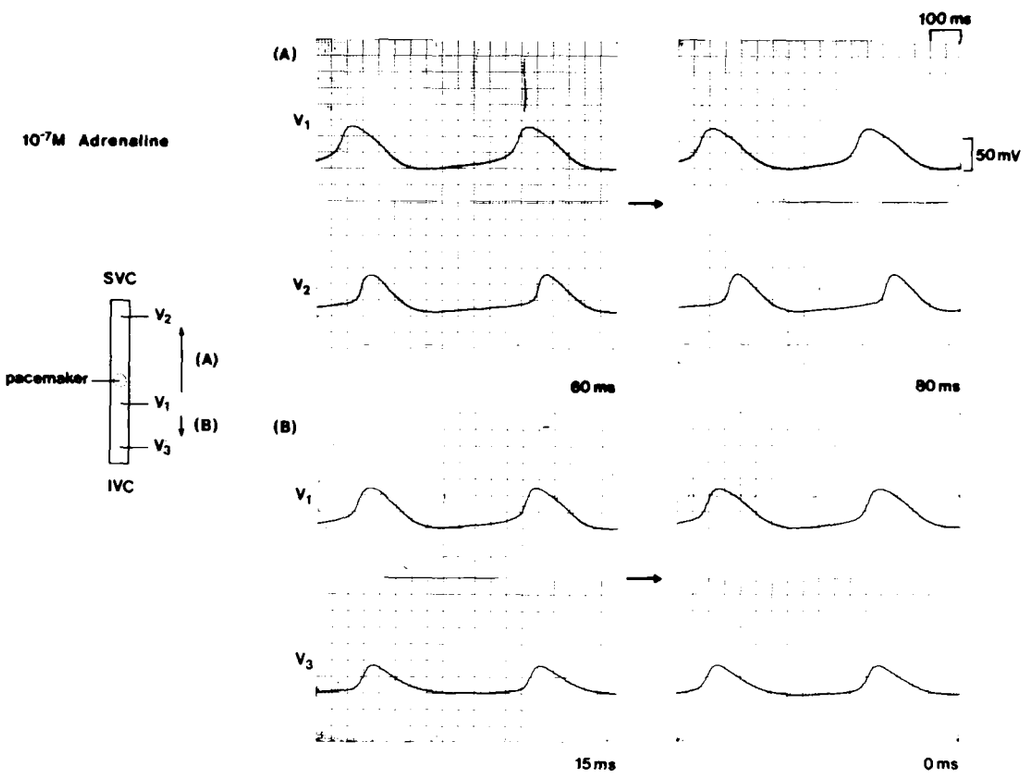

Fig. 4. Effect of adrenaline (10^{-7}M) on the conduction time. Microelectrodes were impaled at V_1, V_2, V_3 and the conduction time was recorded. The conduction time was measured by the differences between the action potential peaks. (A) shows that the upward conduction time was prolonged from 60 ms to 80 ms. (B) shows that the downward conduction time was shortened from 15 ms to 0 ms.

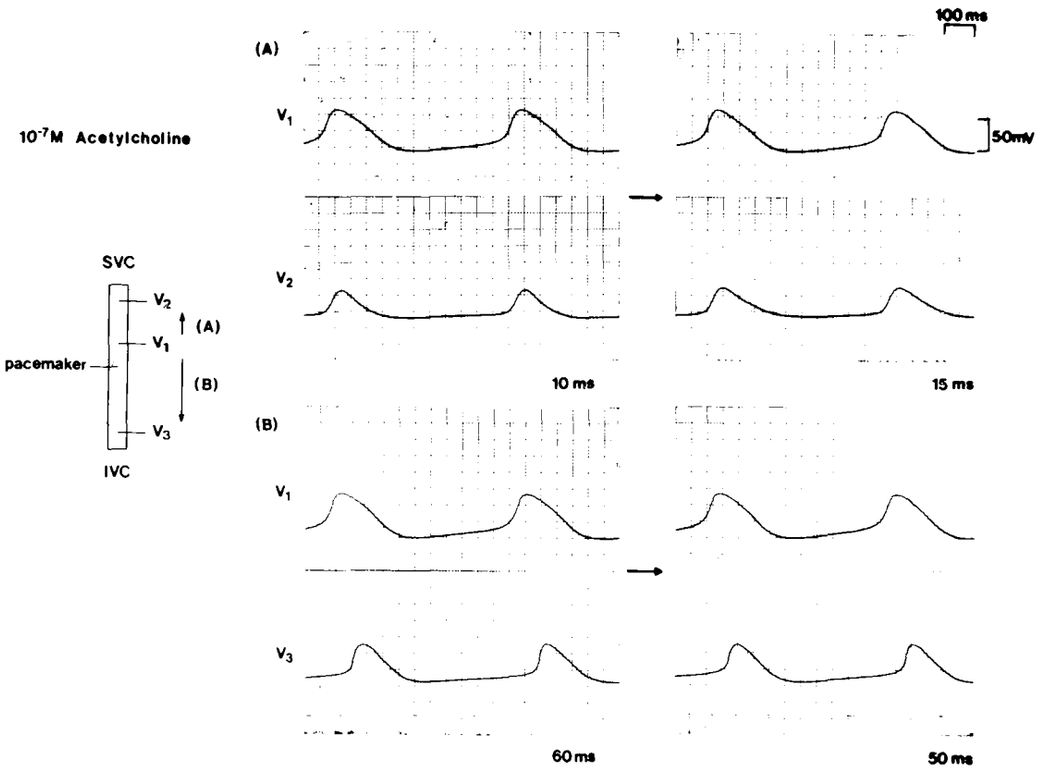

Fig. 5. Effect of acetylcholine (10^{-7}M) on the conduction time. Microelectrodes were impaled at V_1, V_2, V_3 and the conduction time was recorded. The conduction time was measured by the differences between the action potential peaks. (A) shows that the upward conduction time was prolonged from 10 ms to 15 ms. (B) shows that the downward conduction time was shortened from 60 ms to 50 ms.

ference decreased (Fig. 4(B)). In this case, the impediment of upward conduction was due to the downward pacemaker shift by adrenaline. In most preparations, heart rate increased during adrenaline application, and we could obtain nearly the same results in the range of 10^{-8}M to 10^{-6}M adrenaline.

Effects of acetylcholine on conduction

With the same method, 10^{-7}M acetylcholine was applied. When one electrode was inserted in the region slightly above pacemaker and another in the region near the SVC, acetylcholine prolonged the conduction time. When one in the region slightly above pacemaker and another in the region near the IVC, acetylcholine shortened the conduction time (Fig. 5).

Next, one electrode was inserted in the region slightly below the pacemaker. The conduction time was prolonged when the other electrode was placed in the region near the SVC. On the other hand, the conduction time was not changed when the other electrode was placed in the region near the IVC (Fig. 6).

In addition, acetylcholine decreased the heart rate and had similar effects in the range of 10^{-8} M to 10^{-6}M.

From the above results, it was known that acetylcholine prolonged the conduction time. The shortening of conduction time when electrodes were in the site above the pacemaker and in the site near IVC was probably due to downward pacemaker shift by acetylcholine.

Effects of Ca^{++} on conduction

1) Effects of low Ca^{++} concentration

Normal Tyrode solution containing 1 mM Ca^{++} was used. When electrodes were placed in the area slightly above pacemaker and in the area near the SVC, the conduction time was prolonged. But when the position of one electrode was changed from the SVC to the IVC, the conduction time was shortened (Fig. 7).

In another preparation, one electrode was placed in the area slightly below the pacemaker. When another electrode was near the SVC, the conduction time was prolonged. In contrast, when another electrode was near the IVC, the conduction time was not changed (Fig. 8).

In most preparations, the heart rate decreased

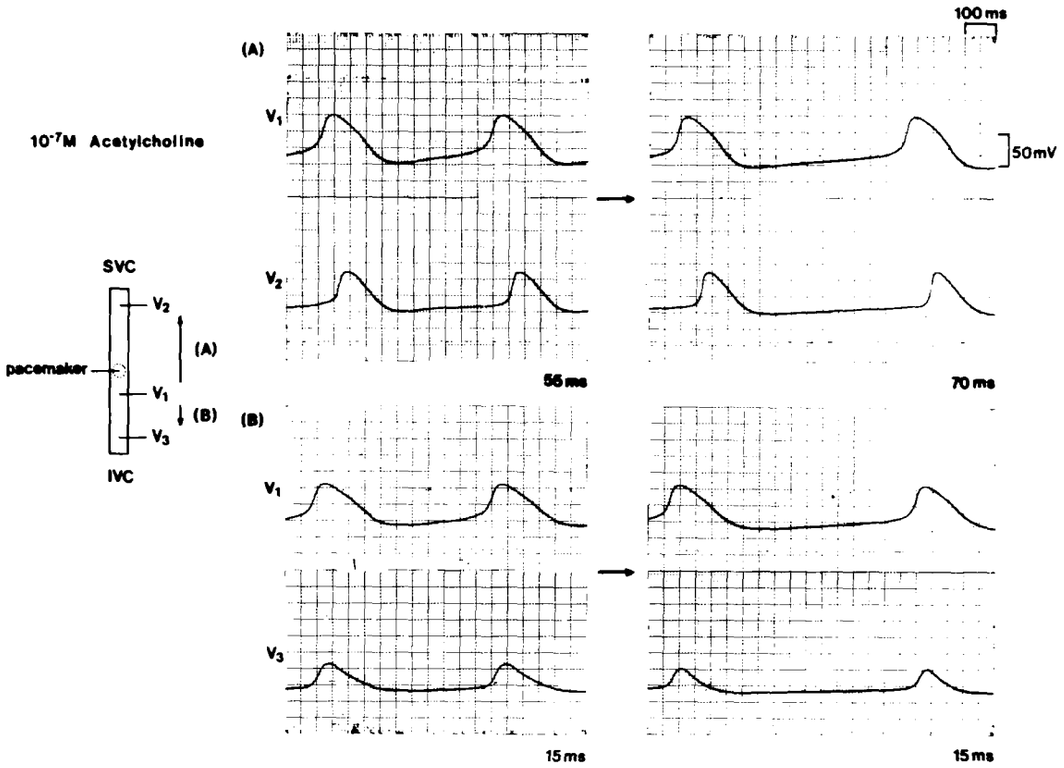

Fig. 6. Effect of acetylcholine (10^{-7}M) on the conduction time. Microelectrodes were impaled at V_1, V_2, V_3 and the conduction time was recorded. The conduction time was measured by the differences between the action potential peaks. (A) shows that the upward conduction time was prolonged from 55 ms to 70 ms. (B) shows that the downward conduction time was not changed from 15 ms.

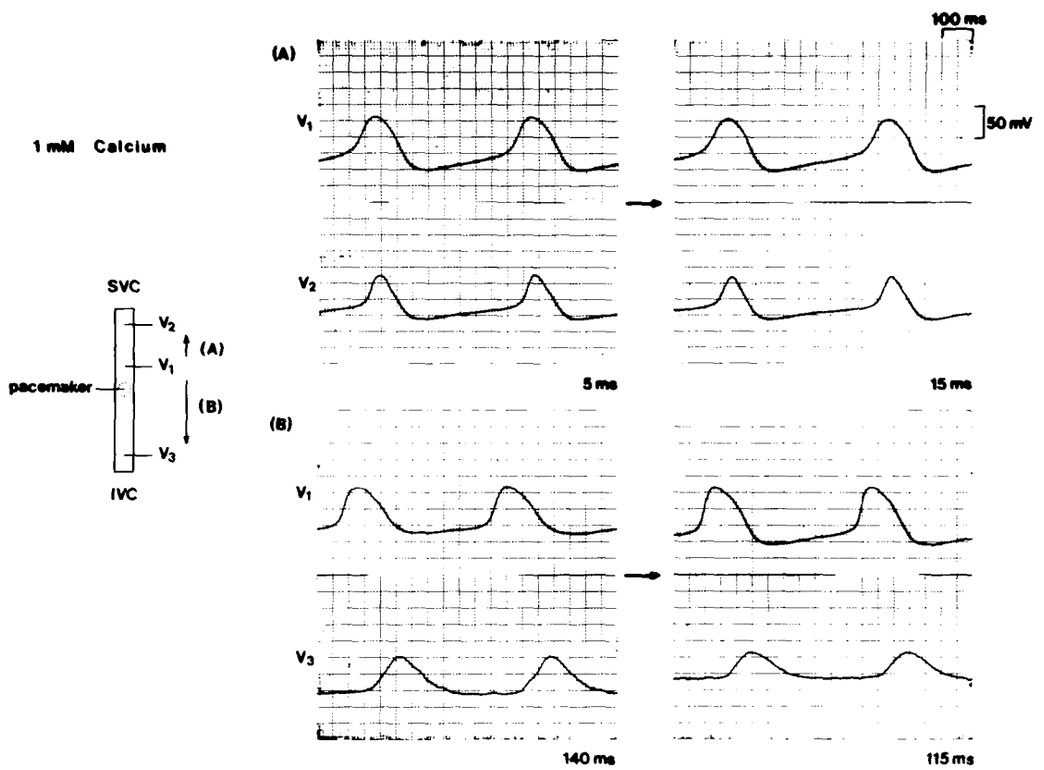

Fig. 7. Effect of 1 mM Ca^{++} on the conduction time. Microelectrodes were impaled at V_1, V_2, V_3 and the conduction time was recorded. The conduction time was measured by the differences between the action potential peaks. (A) shows that the upward conduction time was prolonged from 5 ms to 15 ms. (B) shows that the downward conduction time was shortened from 140 ms to 115 ms.

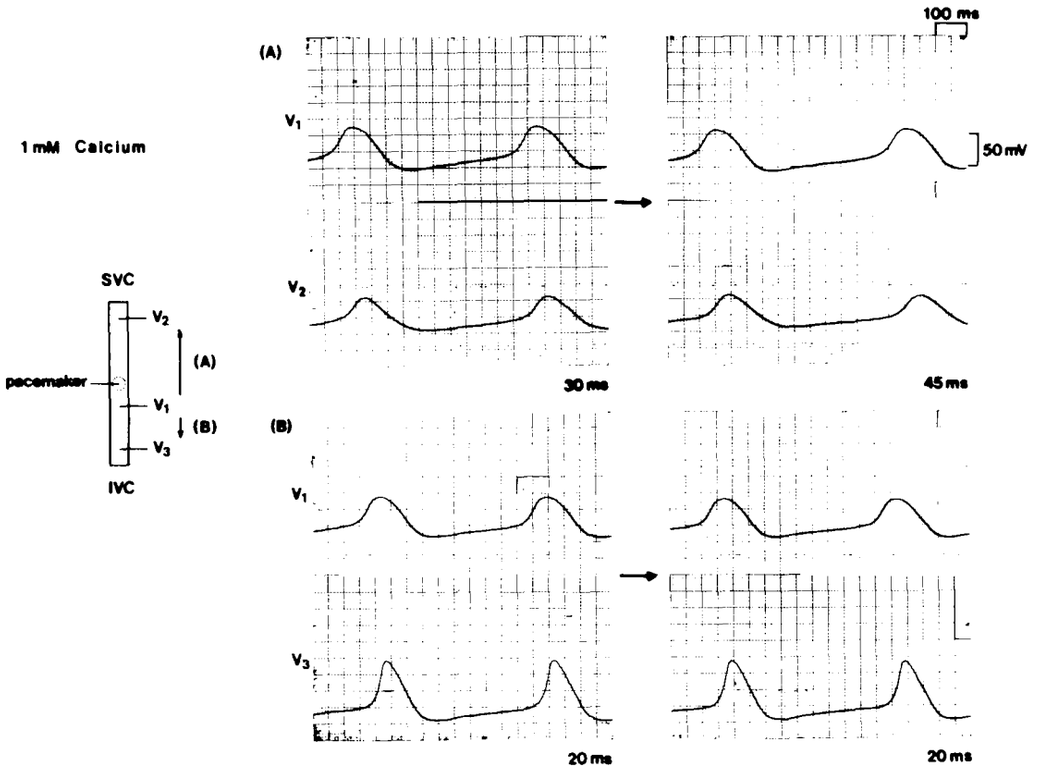

Fig. 8. Effect of 1 mM Ca^{++} on the conduction time. Microelectrodes were impaled at V_1, V_2, V_3 and the conduction time was recorded. The conduction time was measured by the differences between the action potential peaks. (A) shows that the upward conduction time was prolonged from 30 ms to 45 ms. (B) shows that the downward conduction time was not changed from 20 ms.

and nearly the same effects were observed in 0.5 mM Ca^{++}.

From these results, in low concentration of extracellular Ca^{++}, the conduction time was prolonged and pacemaker was shifted downward.

2) Effects of high Ca^{++} concentration

The effects in high Ca^{++} concentration were different from those in low Ca^{++} concentration.

In Tyrode solution containing 4 mM Ca^{++}, changes in the conduction time were variable. While one preparation showed prolongation of the conduction time (Fig. 9(A)), other preparations showed shortening of the conduction time (Fig. 9(B)). These results were consistent within one preparation, regardless of position of electrodes.

In Tyrode solution containing 8 mM Ca^{++}, the results were comparatively consistent. The conduction time was shortened when one electrode was placed in the site near the pacemaker and the other was in the site near the SVC. The conduction time was not changed when one was in the site near the pacemaker and another was in the site near the IVC (Fig. 10). The results were almost the same whether the electrode was in the site above the pacemaker or below the pacemaker. Heart rates increased in most preparations. Therefore, in 8 mM Ca^{++} solution, the conduction time was prolonged and the pacemaker shift did not occur.

Effects of K^+ on conduction

1) Effects of low K^+ concentration

In Tyrode solution containing 1.5 mM K^+, regardless of position of electrodes, conduction time was not changed and heart rate decreased (Fig. 11).

From these results, it is known that conduction time and the position of pacemaker did not vary with 1.5 mM K^+.

2) Effects of high K^+ concentration

In Tyrode solution containing 6 mM K^+, the results were variable. One consistent finding was that the conduction time was shortened when heart rate increased, and the conduction time was lengthened when heart rate decreased. In Fig. 12, where the direction of conduction was upward, increased heart rate and shortened conduction time were observed in (A), and decreased heart rate and prolonged conduction time were observed in (B). The conduction

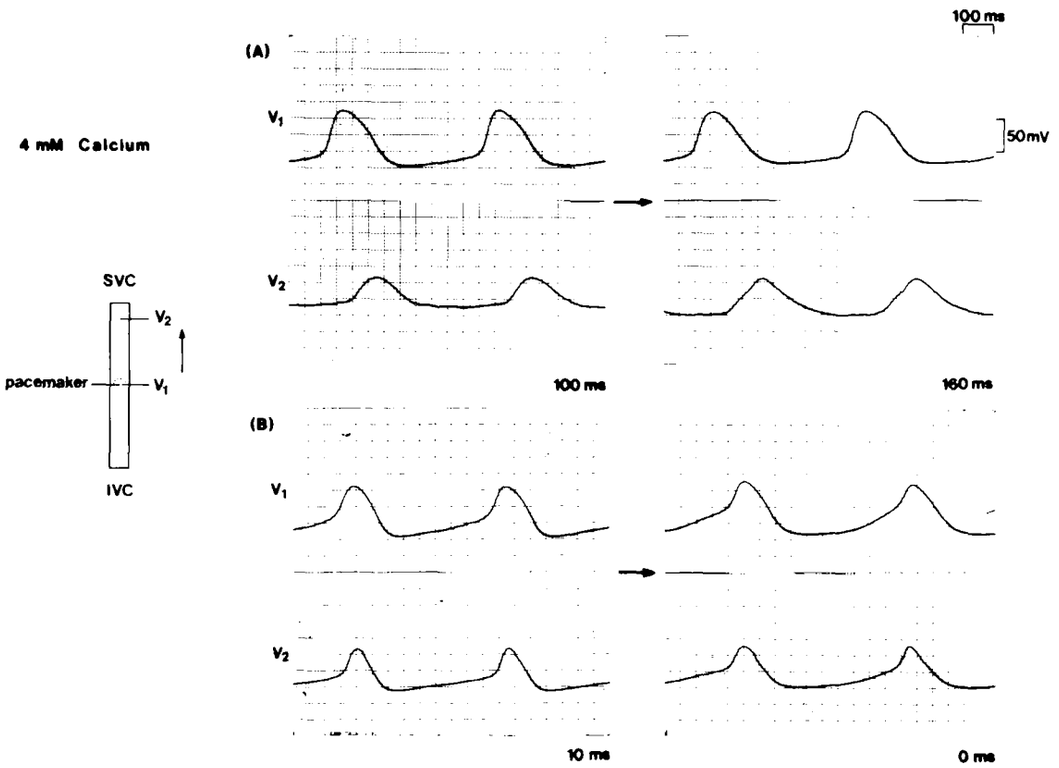

Fig. 9. Effect of 4 mM Ca^{++} on the conduction time. Microelectrodes were impaled at V_1, V_2 and the conduction time was recorded. The conduction time was measured by the differences between the action potential peaks. (A) shows that the upward conduction time was prolonged from 100 ms to 160 rns. (B) shows that in another preparation, the conduction time was shortened from 10 ms to 0 ms.

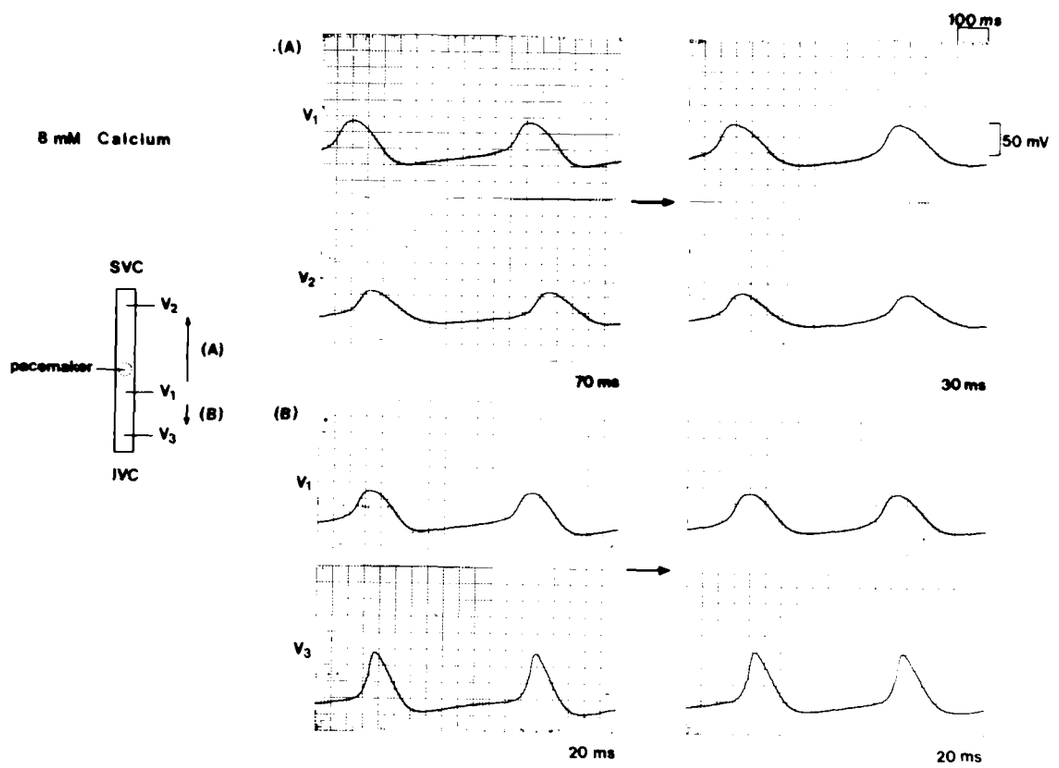

Fig. 10. Effect of 8 mM Ca^{++} on the conduction time. Microelectrodes were impaled at V_1, V_2, V_3 and the conduction time was recorded. The conduction time was meaured by the differences between the action potential peaks. (A) shows that the upward conduction time was shortened from 70 ms to 30 ms. (B) shows that the downward conduction time was not changed from 20 ms.

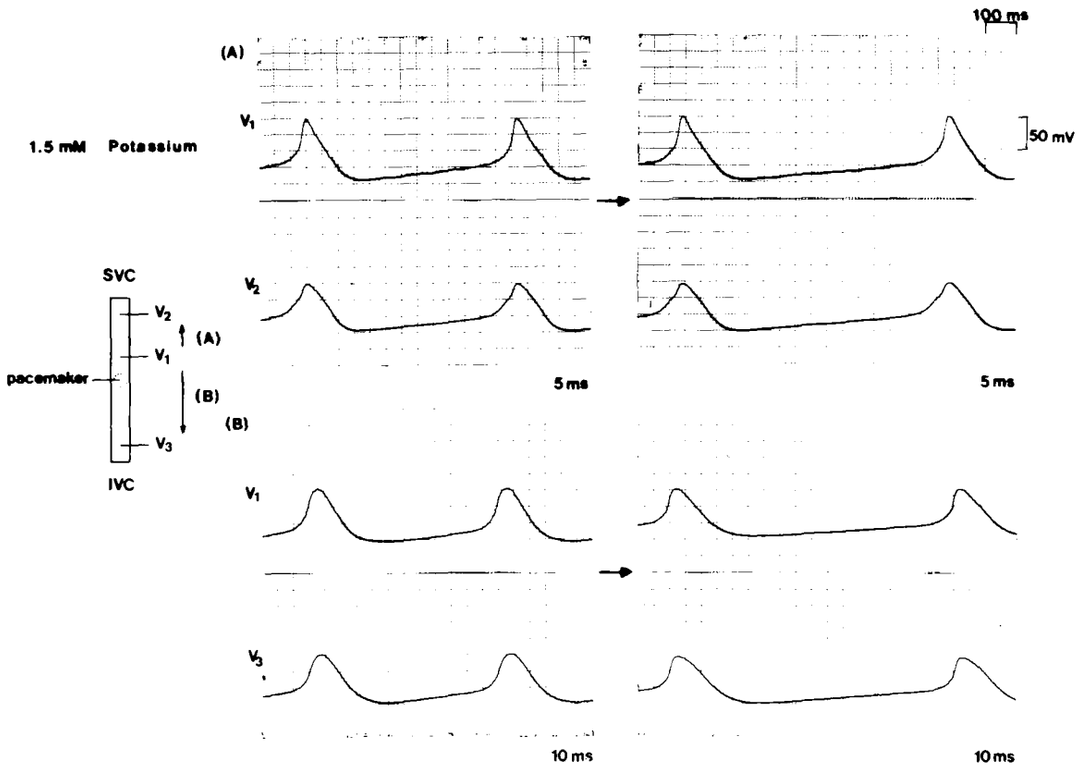

Fig. 11. Effect of 1.5 mM K^+ on the conduction time. Microelectrodes were impaled at V_1, V_2, V_3 and the conduction time was recorded. the conduction time was measured by the differences between the action potential peaks. (A) shows that the upward conduction and downward conduction times were not affected in 1.5 mM K^+.

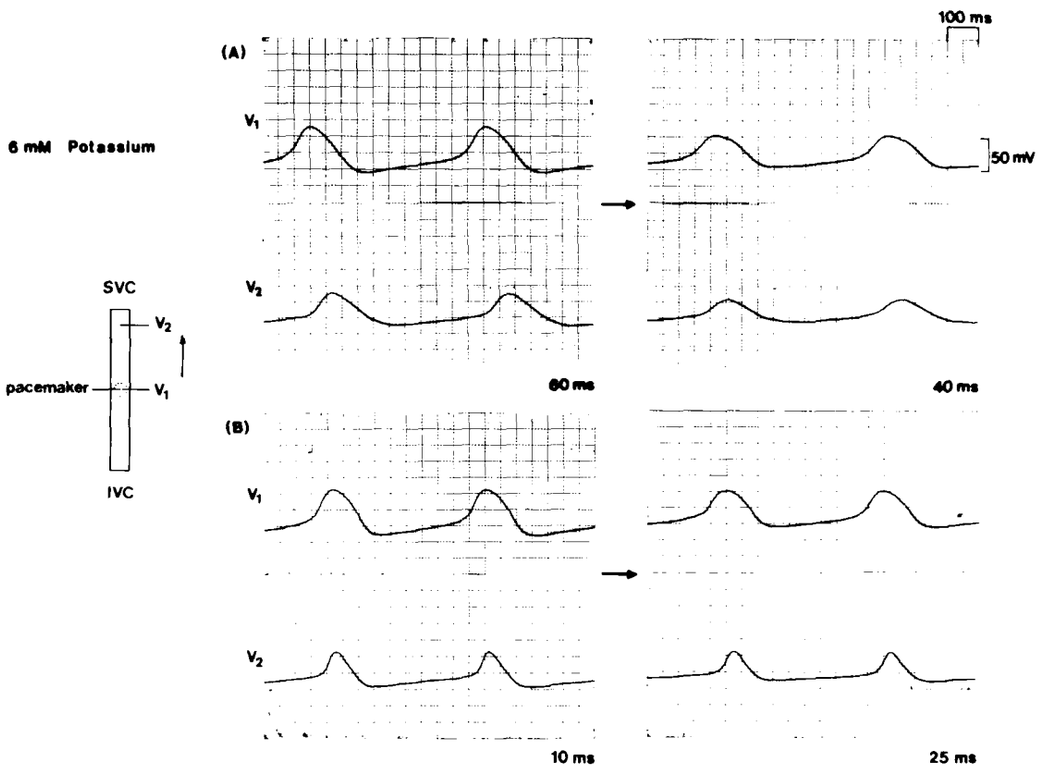

Fig. 12. Effect of 6 mM K^+ on the conduction time. Microelectrodes were impaled at V_1, V_2 and the conduction time was recorded. The conduction time was measured by the differences between the action potential peaks. (A) shows that the upward conduction time was shortened from 60 ms to 40 ms. (B) shows that in another preparation, the conduction time was prolonged from 10 ms to 25 ms.

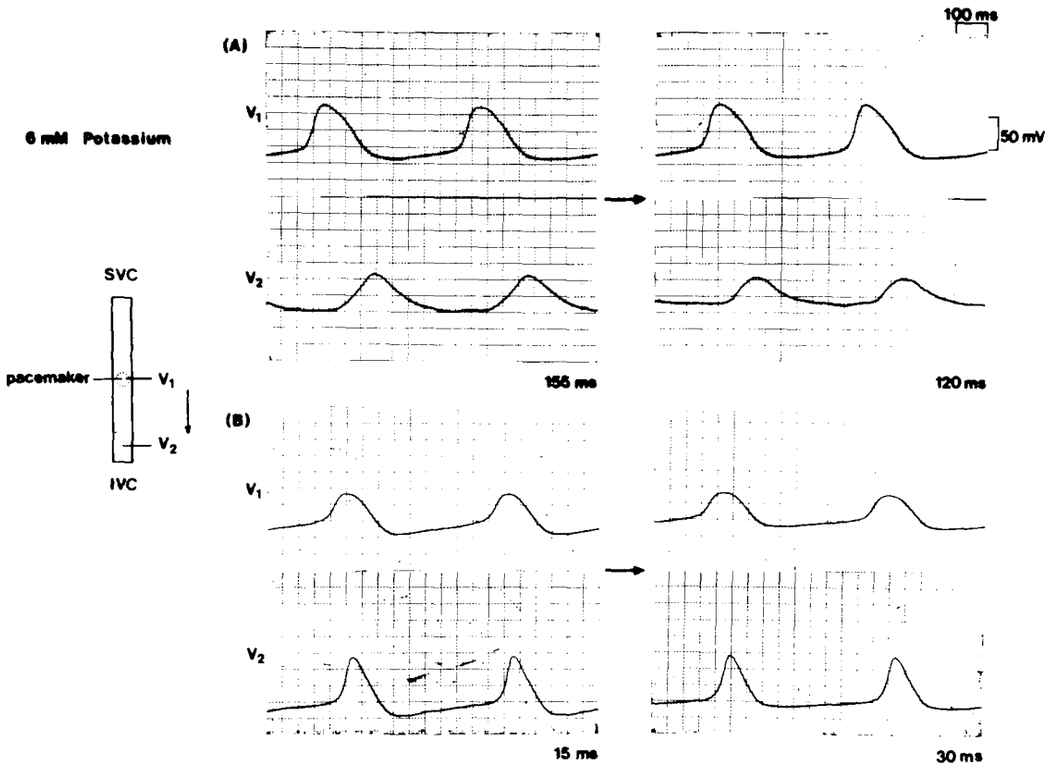

Fig. 13. Effect of 6 mM K^+ on the conduction time. Microelectrodes were impaled at V_1, V_2 and the conduction time was recorded. The conduction time was measured by the differences between the action potential peaks. (A) shows that the upward conduction time was shortened from 155 ms to 120 ms. (B) shows that in another preparation, the conduction time was prolonged from 15 ms to 30 ms.

Table 1. Effects of adrenaline, acetylcholine, Ca^{++} and K^+ on the conduction time through the SA node in the rabbit

	Changes in conduction time	
	pacemaker →SVC	pacemaker →IVC
Adrenaline	shortened (prolonged)	shortened (shortened)
Acetylcholine	prolonged (prolonged)	shortened (none)
Calcium 1 mM	prolonged (prolonged)	shortened (none)
4 mM	variable	variable
8 mM	shortened (shortened)	none (none)
Potassium 1.5 mM	none	none
6 mM	variable	variable

*Results shown above were obtained from preparations in which microelectrodes were inserted at the point slightly above the original pacemaker site. While the results in the parenthesis were obtained from preparations in which microelectrodes were inserted at the site slightly below the pacemaker.

toward the IVC showed similar findings (Fig. 13). The possibility of pacemaker shift could not be excluded in this experiment.

In Tyrode solution containing 9 mM K^+, similar results were obtained.

The results of this experiment are summarized in Table 1.

DISCUSSION

Pacemaker shift

It is well known that the SA nodal region of the heart is composed of a large number of cells which posess various degrees of automaticity. Of these cells only a few at a time can be the pacemaker which sets the rhythm for the heart. It has been noticed that the dominant pacemaker site is not fixed but shifts under certain circumstances. In spite of the technical limitations, Meek and Eyster (1914) were able to detect a shift of the pacemaker site as the K^+ concentration in blood was raised. West (1955, 1956) was the first to demonstrate the occurrence of the pacemaker shift at cellular level by applying acetylcholine. Thereafter, it had been reported that the pacemaker site was shifted under the stimulation of vagus nerve (Toda and West 1965; Bouman *et al.* 1968), the stimulation of sympathetic nerves (Toda and Shimamoto 1968), high K^+ concentration (Lu 1970), low Ca^{++} concentration and low temperature (Bouman *et al.* 1978; Mackaay *et al.* 1980). The pacemaker site was shifted downward in most preparations.

These results are determined by the electrical connections between the SA nodal cells. The shift could be the result of either a suppression of the true pacemaker cells, an acceleration of the latent pacemaker cells, or both. Generally there are three hypotheses accounting the pacemaker shift. First, shifts are the consequence of differences in sensitivity of the pacemaker fibers in different parts of the node to the shift-inducing agents. Second, in the case of nerve stimulation, an uneven distribution of nerve endings may also play a role (Brooks and Lu 1972). The third hypothesis is the "two fiber model". The SA nodal cells are histologically similar but functionally or electrically different. Bouman *et al.* (1978) explained the pacemaker shift on the basis of the assumption that the SA node was composed of head fibers and tail fibers.

In this experiment, we determined the position of electrodes and analyzed the obtained results in consideration of the pacemaker shift. From these experimental results, we confirmed indirectly the presence and the direction of the pacemaker shift.

Effects of environmental changes on the conduction

1) Effects of adrenaline

It is difficult to interprete the fact that the conduction time was prolonged when electrodes were placed in the region slightly below the pacemaker and in the region near the SVC. This can be explained by the fact that adrenaline shifts the pacemaker site downward. Both because the pacemaker is located between electrodes and because the action potential spread in two opposite directions, the difference in time intervals between action potentials acted as if it were traveling a shorter distance. Adrenaline shifted the pacemaker site downward, and two electrodes were positioned above the pacemaker, so the effect of adrenaline on the conduction was counteracted and the conduction time seemed to be prolonged consequently.

In consideration of these facts, the site in which pacemaker did not move between two microelectrodes best showed the effect of adrenaline on the conduction time. This was the site where the elctrodes were in the region slightly above the pacemaker and near the SVC.

Therefore, in the presence of adrenaline, the conduction through the SA node was enhanced and there was indirect evidence of downward pacemaker shift.

2) Effects of acetylcholine

It is well known that acetylcholine shifts the pacemaker site downward (Goldberg 1975; Mackaay *et al.* 1982). Like adrenaline, when the electrodes are in the region slightly above the pacemaker and near the SVC, one could best show the effect of acetylcholine. The conduction through the SA node was inhibited in the presence of acetylcholine. In consideration of four experimental models, there was indirect evidence of downward pacemaker shift.

These results are consistent with those of Bonke *et al.* (1982).

3) Effects of low Ca^{++} concentration

It is known that the pacemaker site is shifted downward under the condition of a low concentration of extracellular Ca^{++} (Bouman *et al.* 1978). With this fact, it is also known that conduction through the SA node is inhibited in low Ca^{++} concentration.

The action potential in the SA node is caused by Ca^{++} and the conduction velocity is mainly

dependent on $(dV/dt)_{max}$. Therefore, under low Ca^{++} concentration, the decreased slow inward current would slow down the conduction velocity.

4) Effects of high Ca^{++} concentration

In Tyrode solution containing 4 mM Ca^{++}, the results were variable among preparations. There are a few possible explanations. In high concentrations of extracellular Ca^{++}, slow inward current decreases, but the stability of cell membranes increase (Hille 1984). The dominant effect will determine the conduction velocity. Another possibility is the effects of Ca^{++} varying in relationship to the size of preparations of the SA node (Ho *et al.* 1987). We made efforts in making the preparations to be same size, but because of the different sizes of the hearts, it was difficult to make the same sized preparations.

In Tyrode solution containing 8 mM Ca^{++}, the upward conduction was enhanced but the downward conduction was not changed. There are reports that the pacemaker site does not shift under high concentrations of extracellular Ca^{++} (Bouman *et al.* 1978). The results in this study can be interpreted as demonstrating the different response of the head fibers and tail fibers to high Ca^{++} concentration. The diastolic depolarization rate of the head fibers increases, but that of the tail fibers decreases under high Ca^{++} concentration.

5) Effects of low K^+ concentration

In the presence of 1.5 mM K^+, the conduction time was not changed, and the pacemaker site was not shifted. The decrease in the slope of diastolic depolarization results in the decreased heart rate. Maximum diastolic potential or threshold potential is not affected.

6) Effects of high K^+ concentration

In the presence of 6 mM K^+, the results were variable. The effect of high K^+ concentration has two facet. One is decrease in the diastolic depolarization rate, and the other is decrease in the maximum diastolic potential with consequent decrease in the threshold level. Therefore, the results are variable dependent on which action has more influence.

REFERENCES

Bleeker WK, Mackaay AJC, Masson-Pevet M, Bouman LN, Bleeker AE. Functional and morphological organization of the rabbit sinus node. Circ. Res. 1980, 46:11-22

Bonke FIM. Electrotonic spread in the sinoatrial node of the rabbit heart. Pflügers Arch. 1973, 339:17-23

Bonke FIM, Allessie MA, Slenter VAJ, Kengen R. Conduction in the sinus node and its modification by autonomic drugs. In Bouman LN and Jongsma HJ (Ed) Cardiac rate and rhythm. Nijhoff, Hague, 1982: pp. 525-542

Bouman LN, Gerlings ED, Biersteker PA, Bonke FIM. Pacemaker shift in the sino-atrial node during vagal stimulations. Pflügers Arch. 1968, 302:255

Bouman LN, Mackaay AJC, Bleeker WK, Becker AE. Pacemaker shifts in the sinus node:effects of vagal stimulation, temperature and reduction of extracellular calcium. In Bonke FIM(Ed) The sinus node. Nijhoff, Hague, 1978: pp. 245-257

Brooks CMC, Lu HH. The sinoatrial pacemaker of the heart. *Springfield, Illinois*, 1972

Goldberg JM. Intra-SA-nodal pacemaker shifts induced by autonomic nerve stimulation in the dog. Am J Physiol. 1975, 229:1116-1123

Hille B. Ionic channels of excitable membranes. *Sinauer, Massachusetts*, 1984

Ho WK, Kim KW, Hwang SI. Temperature-dependency of calcium effect on the electrical activity of rabbit SA node. Kor J Physiol. 1987, 21(1):1-12

Lewis TH, Oppenheimer BS, Oppenheimer A. The site of origin of the mammalian heart beat; the pacemaker in the dog. Heart. 1910, 2:147-167

Lu HH. Shifts in pacemaker dominance within the sinoatrial region of cat and rabbit hearts resulting from increase of extracellular potassium. Circ Res. 1970, 26:339-346

Mackaay AJC, Bleeker WK, Op't Hof T, Bouman LN. Temperature dependence of the chronotropic actions of calcium: fuctional inhomogeneity of the rabbit sinus node. J Mol Cell Cardiol. 1980, 12:433-443

Mackaay AJC, Op't Hof T, Bleeker WK, Jongsma HJ, Bouman LN. Interaction of adrenaline and acetylcholine on sinus node function. In Bourman LN and Jongsma HJ (Ed) Cardiac rate and rhythm. Nijhoff, Hague, 1982: pp. 507-523

Masson-Pevet M, Bleeker WK, Besselsen E, Mackaay AJC, Jongsma HJ, Bouman LN. On the ultrastructural identification of pacemaker cell types within the sinus node. In Bouman LN and Jongsma HJ(Ed) Cardiac rate and rhythm. Nijhoff, Hague. 1982: pp. 507-523

Meek WJ, Eyster JAE. The effect of vagal stimulation and of cooling on the location of the pacemaker within the sino-auricular node. Am J Physiol. 1914, 34:368-383

Noble D. Initiation of the heart beat. Oxford University, Oxford. 1979

Sano T, Yamagishi S. Spread of excitation from the sinus node. Circ Res. 1965, 16:423-430

Spear JF, Kronhaus KD, Moore EN, Kline RP. The effect of brief vagal stimulation on the isolated rabbit sinus node. Circ Res. 1979, 44:75-88

Steinbeck G, Allessie MA, Bonke FIM, Lammers WJEP. Sinus node response to premature atrial stimulation in the rabbit studied with multiple microelectrode impalements. Circ Res. 1978, 43:-695-704

Steinbeck G, Bonke FIM, Allessie MA. Cardiac glycosides and pacemaker activity of the sinus node-a microelectrode study on the isolated right atrium of the rabbit. In Bonke FIM (Ed) The sinus node. Nijhoff, Hague, 1978: 258-269

Toda N, Shimamoto K. The influence of sympathetic stimulation on transmembrane potentials in the SA node. J Pharmacol Exp Ther. 1968, 159:298-305

Toda N, West TC. Changes in sinoatrial node transmembrane potentials on vagal stimulation of the isolated rabbit atrium. Nature. 1965, 205:808-809

West TC. Ultramicroelectrode recording from the cardiac pacemaker. J Pharmacol Exp Ther. 1955, 115:283-290

West TC, Falk G, Cervoni P. Drug alteration of transmembrane potentials in atrial pacemaker cells. J Pharmacol Exp Ther. 1956, 117:245-252

= 국문초록 =

동방결절내에서의 흥분전도에 미치는 Adrenaline, Acetylcholine, Ca^{++} 및 K^{+}의 영향

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동방결절은 심장의 자동능의 근원으로서 여러가지 각도에서 연구가 진행되어왔다. 그 중 동방결절 내에서의 전도 시간에 관한 연구는 여러가지 장애요인과 방법상의 문제점 등으로 어려움이 많았다. 본 연구에서는 이러한 문제점들을 고려하여, 약물 및 이온들에 의한 동방결절 내의 전도 시간의 변화를 서로 비교해 보고자 하였다.

토끼의 심장에서 상대정맥-하대정맥 방향으로 동방결절의 strip을 만들었다. 여기에 두 개의 유리 미세전극을 여러가지 위치에 설치하여 adrenaline, acetylcholine, Ca^{++}, K^{+}등에 의한 시간차의 변화를 비교하여 다음과 같은 결과를 얻었다.

1. Adrenaline은 전도시간을 단축시켰으며 아래쪽으로의 pacemaker shift를 일으켰다.
2. Acetylcholine은 전도시간을 연장시켰으며 아래쪽으로의 pacemaker shift를 일으켰다.
3. 1 mM의 Ca^{++}은 전도시간을 연장시켰으며 아래쪽으로의 pacemaker shift를 일으켰다.
4. 8 mM의 Ca^{++}은 전도시간을 단축시켰으며 pacemaker shift는 일으키지 않았다.
5. 1.5 mM의 K^{+}은 전도시간과 pacemaker shift에 영향을 미치지 않았다.

이상의 사실에서 Adrenaline과 8 mM의 Ca^{++}은 동방결절 내의 전도를 촉진하고, acetylcholine과 1 mM의 Ca^{++}은 동방결절 내의 전도를 억제하며, 1.5 mM의 K^{+}은 전도 속도에서 아무런 영향도 미치지 않는 것으로 결론 지을수 있겠다.