ELECTROLYTES AND SPONTANEOUS RHYTHMICITY OF VENTRICULAR MUSCLE

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Summary : The effect of electrolytes (Ca,K and Na) on idioventricular rhythm (IVR) produced by the second Stannius ligature in frog's heart has been studied. IVR appearance time decreased and rate and force of contraction increased with increasing concentration of Ca in the perfusing fluid, while a decreasing concentration showed the opposite effects. High as well as low concetration of K in the perfusing fluid produced a delayed appearance of rhythm and decreased the rate and force of IVR. The IVR did not appear in the absence of Ca, and when K concentration in the perfusion fluid was increased to 4 times the normal.

IVR contractions became more vigorous with a 50% reduction in the Na content but with no change in the rate and appearance of IVR. With complete absence of Na, IVR appearance time was increased, rate became irregular and force of contraction was decreased.

Key Words : idioventricular rhythm effect af Na, K, and Ca on heart

The property of the heart to continue beating rhythmically after complete denervation has aroused considerable interest from the earliest times (1, 12). The exact mechanism governing the spontaneous rhythm of the myocardium, however, has remained obscure. More intriguing is the fact that the myocardial cells can generate rhythmic impulses even when the pacemaker and A.V. node fail to do so. This has come to be regarded as idio-ventricular rhythm (IVR). One possible approach for investigating the mechanism underlying the appearance of spontaneous myocardial rhythm could be to study the influencc of electrolytes on the IVR. In this paper the effects of changing the electrolyte composition on the IVR of perfused frog's heart are described.

MATERIALS AND METHODS

The excised frog heart was prepared according to Straub's method as described by Gaddum (4). The perfusion cannula, however, was the one described by Krayer et al (9). The surrounding glass chamber was modified to facilitate the application of 2nd Stannius ligature by making two holes. Through each hole the ends of the loose thread for the ligature were taken out and left to be pulled when the production of IVR was required. The perfusion fluid had the following composition in mMol/liter:

NaCl—110, KCl—19., $CaCl_2$—1.05, $NaHCO_3$—2.38, NaH_2PO_4—.09 and Dextrose 5.5.

The constancy of perfusion pressure was maintained by adjusting the level of the perfusing fluid which was always kept at a constant mark in the Krayer's cannula.

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After producing complete heart block by applying the 2nd Stannius ligature in t normally beating heart, following values were obtained :

1. The time of appearance of IVR.
2. The rate of IVR.
3. The force of contraction of IVR.

The time of appearance and rate of IVR was measured from the continuously monitore E.C.G. record. The force of contraction was calculated from the height of kymographicall recorded contraction. The height of normal heart beat before the application of ligature wa taken as 100% with which the IVR height was compared to calculate the percentage increas or decrease. In the series in which electrolyte composition of the perfusing fluid was change the 2nd Stannius ligature was applied only after the particular concentration of electrolyte ha shown its effect on the normal heart tracings.

RESULTS

(a) Effect on appearance time of IVR: The results of the effect of change in Ca, K and Na concentrations on the appearance of IVR are tabulated in Table I.

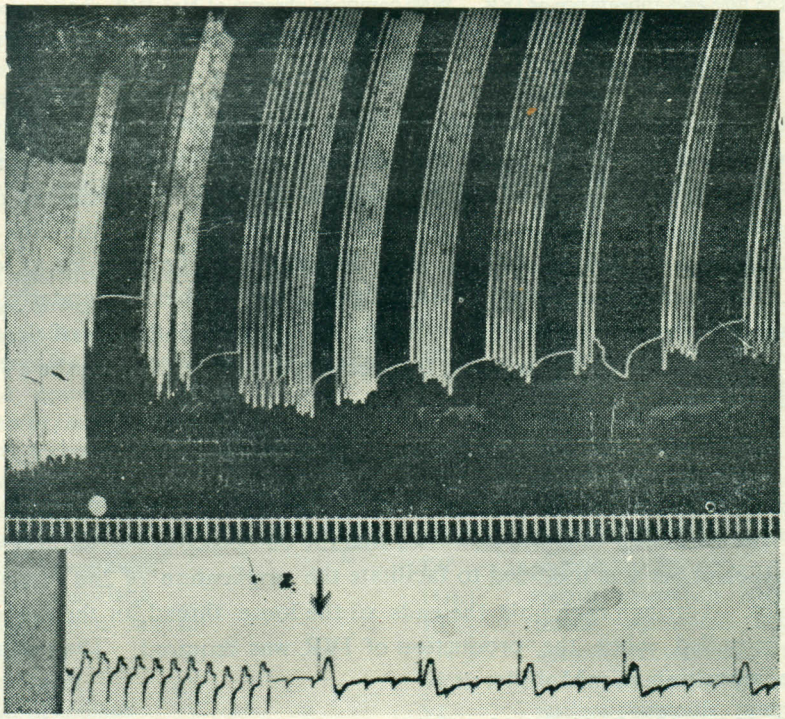

Fig. 1 : Frog's heart perfused with Ringer solution containing 4.20m mol Ca/litre. Upper tracing : Kymographic record of the contractions. 2nd Stannius ligature tied at the dot under the tracing. Note that IVR appears in less than 20 seconds. Time tracing T every 5 seconds.

Lower tracing : ECG reord. IVR appears at the arrow. Rhythmic potentials before that are those of sinus venosus.

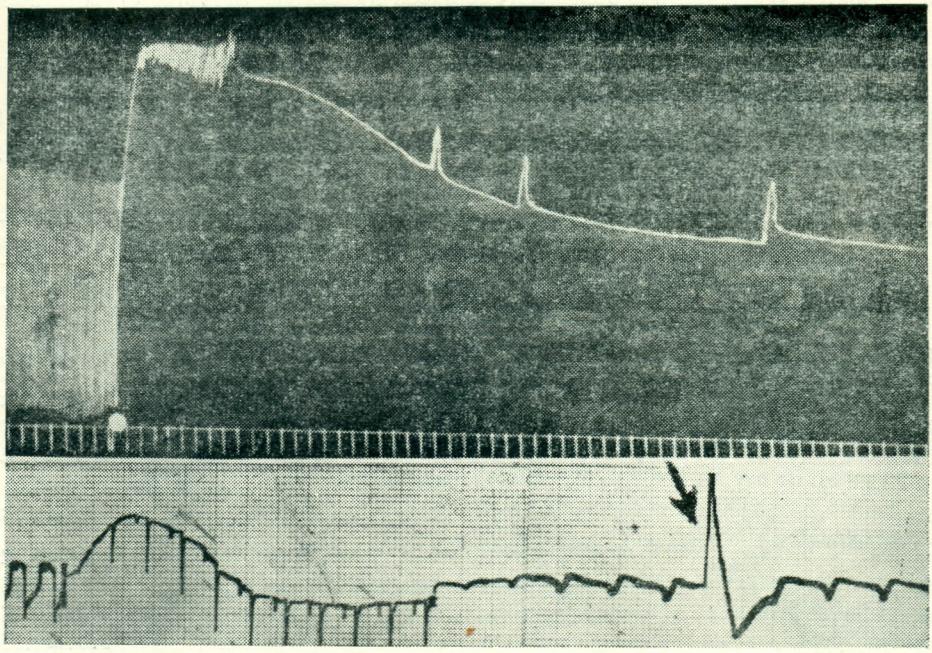

Fig. 2: Frog's heart perfused with isosmotic Ringer solution without Na. 2nd Stannius ligature tied at the dot. The IVR appearance time is about 2 minutes. Note that the IVR is rather slow and diminutive. Time tracing T every 5 seconds.

Lower tracing : ECG record. IVR appears at the arrow smaller potentials before and after the idioventricular beat belong to the sinus venosus.

Increasing concentrations of Ca in the perfusion fluid led to a progressive decrease, and decreasing concentrations produced an increase in the appearance time of IVR. Fig. 1 depicts a record in which 2nd Stannius ligature was tied in a heart perfused by a fluid with the Ca concentration of 4.20 m Mol/litre. The IVR appeared after an interval of 0.3 min, the range of the control hearts being 1.68—1.94 min. Both decrease and increase in K concentrations produced an increase in the appearance time of IVR. When K concentration was increased to 7.6 m Mol/litre, the IVR did not appear at all. The decrease in Na concentration upto half the normal did not affect the appearance time but complete absence of Na while the perfusion fluid was kept isosmotic with the addition of sucrose significantly increased the appearance time (Fig. 2)

(b) Effect on rate and force of IVR : The effects of change in electrolyte concentrations on rate and force of IVR are given in Table II.

Both the rate and force of IVR were significantly raised with increased concentration of Ca and considerably decreased with reduced concentration of Ca. With high as well as low concentrations of K, the rate and force of IVR showed a significant decrease. There was no significant change in rate of IVR with Na concentration reduced to half but force of contraction

increased markedly. When Na was completely replaced by sucrose, the force of contraction was much decreased, rhythm was quite irregular and lasted for only few beats.

DISCUSSION

Surawicz et al (18) observed that a decrease in Ca concentration decreased the force of contraction progressively until no contraction could be recorded in the isolated rabbit heart.

TABLE I: Effect of Ca, K, and Na on the appearance time of IVR

Concentration of Electrolyte in m Mol/liter	*Number of experiments*	*Appearance time (min)*
		Means ± S.D.
Control.		
(Normal Frog's Ringer)	15	1.84±0.13
Calcium concentration.		
0	5	No rhythm
0.52	5	2.00±0.27
2.10	5	1.33±0.22
3.15	5	1.00±0.27
4.20	5	0.36±0.08
Potassium concentration		
0.00	5	4.28±0.32
0.95	5	2.84±0.34
3.80	5	2.66±0.28
5.70	5	3.04±0.36
7.60	5	No rhythm
Sodium concentration		
0.00	5	2.90±0.41
55.00	5	1.86±0.35

TABLE II: Effect of Ca, K and Na on force and rate of IVR contractions

Concentration of electrolyte in mmol/liter	*Number of experiments*	*%change in force of contraction Mean ± S.D.*	*Time to complete one beat (min) Mean ± S.D.*
Control (Normal Frog's Ringer)	15	*26.50±4.20	0.33±0.05
Calcium concentration			
0.00	5	No rhythm	No rhythm
0.52	5	*74.42±5.46	0.87±0.08
2.10	5	†19.00±2.24	Rhythm appeared in groups of rapid successive beats
3.15	5	†25.62±3.62	,, ,, ,,
4.20	5	†35.62±3.24	,, ,, ,,
Potassium concentration			
0.00	5	*45.22±2.62	1.80±0.82
0.95	5	*29.24±3.40	0.45±0.52
3.80	5	*30.62±3.82	1.12±0.14
5.70	5	*48.24±4.50	1.00±0.15
7.60	5	No rhythm	No rhythm
Sodium concentration			
0.00	5	*79.82±4.56	1.00±0.35
55.00	5	†14.24±3.88	0.30±0.34

†Increase in force of contraction
*Decrease in force of contraction

Siefen et al (17) observed a progressive increase in rate and force of contraction in the isolated dog heart with increase in Ca concentrations. They attributed it to the effect of Ca on the diastolic depolarization of the S.A. node. Reiter (15) and Feinberg et al (3) considered the Ca effects to be due to the release of cardiac catecholamines or of small amounts of acetylcholine. In this study in which the pacemaker was disconnected, early appearance of the IVR could be due to the speeding up of diastolic depolarization of ventricular musculature by increased Ca concentration. With decrease in Ca concentration to half, the time of appearance of IVR was increased while its rate and force was markedly decreased. In complete absence of Ca the rhythm failed to appear. The inotropic effect of increased Ca concentrations is also supported by Niedergerke (14) who observed that force of contraction is proportional to the extracellular Ca concentration.

Increase as well as decrease in K concentration led to a progressive delay of IVR appearance, and decrease in rate and force of contraction. Garb (5) attributed the effect of increased K concentration to its direct depressant action on contractile mechanism of the perfused hearts for K reduced the resting membrane potential. The reduction was linearly proportional to the log of extracellular K concentration. Lowering of serum K leads to a transitory hyperpolarization of the cell membrane followed by a gradual decrease in resting potential (12). A reduction in contractility by change in K concentration was also observed by Salter (16).

A 50% reduction in the Na content of the perfusion fluid significantly increased the force of contraction of the isolated ventricle. but had little effect on the time of appearance of IVR. In complete absence of Na, however, IVR appearance time was much delayed. It appears, therefore, that a minimal amount of Na is necessary for the appearance of ventricular rhythmicity. Hoffman and Cranefield (6) have demonstrated that continued exposure to very low concentration of Na (1/10 normal or below) suppressed the pacemaker activity completely. But beyond this, variation in the Na concentration did not have much bearing on the rate and rhythm. However, reduction in Na content of the perfusion fluid can also increase the force of contraction. This has been documented earlier also (7,11), where the authors suggested that lowering the Na content of the extracellular fluid might diminish the work of the Na pump thus sparing some more energy for the performance of mechanical work by the heart muscle resulting in greater contraction. On the other hand Luttgau and Niedergerke (10) have stated that Ca and Na ions compete at the cell membrane, for some negatively charged receptor surface (R), forming either CaR which activates contraction or NaR which is inert. From this point of view, a reduction in extracellular Na would produce a preponderance of CaR leading to more vigorous contraction. The delayed onset of rhythm, decreased force of contraction and its irregularity as a result of complete absence of Na suggest the possibility of some damage to the contractile element (8, 11).

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