SURVIVAL OF THE HEART AS A HETEROGENEOUS EXCITABLE MUSCLE SYSTEM DURING HYPOTHERMIA

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It was shown early in this century that specific musculature has the power of automatic contraction [4, 12]. The important hypothesis was put forward [6, 8] that a functional "synapse" may develop between the specific muscle and the myocardium at the site of the boundary substance.

Smirnov [2, 3] concluded from his own observations and data in the literature that a functional synapse exists between the specific muscle and the myocardium, and is sensitive to the effects of humoral factors and extracardiac nervous influences. The results obtained by Arutyunova [1], working under A. I. Smirnov's direction, confirmed the hypothesis of the existence of a functional synapse between the two structures of the heart.

Despite the fact that cooling of the heart during operations is now regarded as a method almost free from risk, the physiology and pathophysiology of the cooled heart have been inadequately studied.

The object of this investigation was to study the effect of cooling on the functional properties of the specific muscle and the myocardium, and their ability to survive in hypothermic conditions.

EXPERIMENTAL METHOD

Experiments were carried out on the isolated heart of rabbits and dogs. The heart was taken from rabbits anesthetized with urethane and from dogs anesthetized with morphine and urethane.

The isolated heart was placed temporarily in a jar with Ringer–Locke solution at 38°. A cannula was introduced into the aorta above the aortic valves, and through it Ringer–Locke solution at the same temperature, but saturated with oxygen, was injected under a pressure of 150 mm.

The cardiac contractions were determined from the electrocardiogram (ECG) and visually. The contractions of the specific muscle and also of the myocardium were observed in a binocular loop with a magnification of 12-15 times through an incision in the wall of the myocardium of the left ventricle above the ventricular septum by Smirnov's method [3]. Observations were made on the isolated heart for 2-3 h every day (from 2 to 9 days). After each observation the heart was immersed in cold Ringer–Locke solution (temperature from 0 to 4°) and kept in a refrigerator for 20-24 h, after which it was warmed to 38-39°.

Altogether, 35 experiments were carried out (22 on rabbits and 13 on dogs).

EXPERIMENTAL RESULTS

During daily warming of the heart with Ringer–Locke solution saturated with oxygen at 25-30°, temporary fibrillation of the specific muscle fibers was often observed, changing at 35-38° into rhythmic contractions with a frequency of 22-140 per minute. In the isolated rabbit's heart the contractions of the specific muscle were recorded in every case on the 2nd-3rd day and in one case they persisted until the 4th day; contractions of the myocardium were observed in only two cases on the 2nd day and in one case on the 3rd day of survival of the heart.

As an example, an extract from the record of an experiment on a rabbit on June 20, 1966 may be consulted (Fig. 1).

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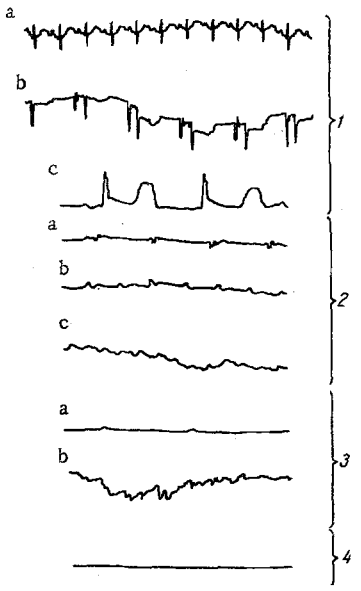

Fig. 1. ECG of a rabbit. Experiment on June 20, 1966. 1) First day of observations; ECG of heart before isolation (a), of isolated heart before (b) and after (c) the beginning of hypothermic perfusion (temperature of the heart 25°); 2) 2nd day of observations; a-c) ECG from ventricles; 3) 3rd day of observations; a,b) ECG of ventricles; 4) 4th day of observations. Explanation in text.

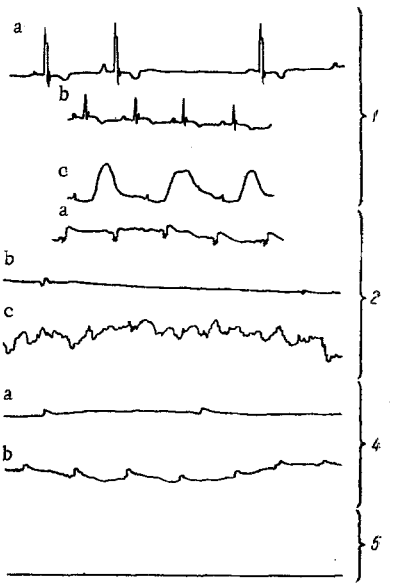

Fig. 2. ECG of a dog's heart. Experiment on May 31, 1966. 1) First day of observations: ECG of heart before isolation (a), of isolated heart before (b) and after (c) the beginning of hypothermic perfusion (temperature of heart 25°); 2) 2nd day of observations; a-c) ECG from ventricles; 4) 4th day of observations; a,b) ECG from ventricles; 5) 5th day of observations. Explanation in text.

Observations on the contractions of the specific muscle and the myocardium on the first day showed that they were synchronized.

Observations on the second day showed that at 38-39° the rhythmic contractions of the whole heart were at the rate of 120-240 per minute (see Fig. 1a, b). Subsequently the rhythmic contractions changed into fibrillation of the whole heart (Fig. 1c). During observations on the third day low-amplitude waves were recorded on the ECG at the rate of 120-180 per minute (Fig. 1a) and weak contractions of the myocardium were seen visually. After 1 h, ventricular fibrillation with high-amplitude waves appeared on the ECG (Fig. 1b). Observations on the fourth day showed that the contractions of the specific muscle of the ventricle were at the rate of 80-90 per minute. In the observations on the fifth day no contractions of the specific muscle could be seen.

In the experiments on dogs, contractions of the specific muscle of the isolated heart on the 2nd-4th day were observed in every case, on the 5th day in 3 cases, on the 6th in 2, on the 7th in 3, on the 8th in 2, and on the 9th in one case. Contractions of the myocardium on the 2nd-3rd day were found in all experiments, on the 4th day in 3, and on the 5th in 1 experiment.

As an illustration an extract from the record of an experiment on the isolated dog's heart on May 31, 1966 is shown in Fig. 2.

Observations on the contractions of the specific muscle and of the myocardium on the 1st day showed that at 19° myocardial fibrillation began. The specific muscle contracted at the rate of 36 per minute. Observations on the 2nd day showed that the rate of cardiac contractions was 120 per minute (Fig. 2a). After perfusion had been stopped, atrial arrest developed. The ECG showed waves with a frequency of 25 per minute, corresponding to the rhythm of contractions of the left ventricle (Fig. 2b). After repeated perfusion, the myocardial contractions changed into high-amplitude fibrillation (Fig. 2c); the specific muscle contracted at the rate of 84 per minute. During observations on the 4th day, contractions of the left ventricle were seen at the rate of 40 per minute, visually and also on the ECG (see Fig. 2a). No atrial contractions were observed. After injection of caffeine, the rhythm of the ventricular contractions increased

to 120-130 per minute (Fig. 2b). Observations on the 5th and 6th days revealed contractions of the specific muscle only, at the rate of 40-60 and 30-45 per minute. Observations on the 7th day revealed no contractions of the specific muscle.

The results showed that the heart of higher animals possesses considerable reserve powers of survival in unfavorable conditions during hypothermia to 0-4°, and these properties are characteristic, especially of the specific muscle, the unique "trigger mechanism" in the working heart.

Considerable importance must be attached at the present time not merely to the biopotentials of the specific muscle, but also to its active contractions which, in the authors' opinion, participate in the genesis of the myocardial contractions of the ventricles through the intervention of a functional synapse. This synapse is extremely sensitive to the influence of unfavorable external and internal environmental factors.

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