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EFFECT OF GEOMAGNETIC STORMS ON THE STATE OF THE MYOCARDIAL MITOCHONDRIA AND THEIR ROLE IN ENERGY SUPPLY FOR CARDIAC CONTRACTIONS

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KEY WORDS: scanning electron microscopy; mitochondria; magnetic storm.

Helio-geomagnetic disturbances have a significant influence both on biological rhythms [2] and on the course of some pathological processes, including the development of myocardial infarction and its complications, among them sudden death [1, 4, 8]. However, the subcellular and molecular mechanisms of this effect have not been adequately studied.

The aim of this investigation was to study the state of ultrastructures of the intact heart (with the aid of scanning electron microscopy) and to assess its contractility under conditions of geomagnetic storms.

EXPERIMENTAL METHODS

Experiments were carried out on 120 mature male Chinchilla rabbits weighing 2.5-3.5 kg. For 3 days (from midnight on September 20, 1984, to 9 p.m. on September 23, 1984) every 3 h the highest value of the intraventricular pressure attained (IVP_{max}) in the left ventricle, determined during occlusion of the ascending aorta for 5 sec, was recorded electromanometrically in five rabbits in the acute experimental group under superficial hexobarbital anesthesia. Pieces of papillary muscles from the left ventricle were then rinsed in Hanks' solution, frozen in liquid nitrogen, sheared, and placed in 2% glutaraldehyde solution. The material was then dehydrated in acetone, dried by taking through the critical point from liquid carbon dioxide (Balzers Union, Liechtenstein), and sputtered with gold-palladium alloy by means of ionic bombardment, using a cold "Sputter" apparatus (Poliron, England). The IsI-60 scanning electron microscope used had a resolving power of 6 nm (magnification 1000-20,000). The volume of the mitochondria (MC) was calculated on electron micrographs by appropriate equations for similar geometric shapes. Simultaneously with the study of cardiac function, the concentration of free fatty acids (FFA) in the arterial blood of the experimental animals was determined spectrophotometrically. The intensity of geomagnetic activity was characterized by the Ap and Cp indices, values of which were obtained at the International Data Center (IDC-2, Moscow). During statistical analysis of the results, besides calculating the mean values of the parameters studied and determining the significance of the difference between the means by Student's test, correlation analysis for the presence or absence of correlation between values recorded during the experiment was undertaken on the "Iskra-1256" minicomputer (correlation was considered to be strong when $r \geqslant 0.7$, moderately strong when $r = 0.3$—0.69, and as weak when $r \leqslant 0.29$).

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TABLE 1. Some Characteristics of Geomagnetic Activity on September 21-23, 1984

Index	Sep 21	Sep 22	Sep 23
Ap	10	22	112
Cp	0,6	1,1	1,9

TABLE 2. Circadian Rhythm of Volume of MC (in μ^3) of Left Ventricle and IVP_{max} (in mm Hg) in Left Ventricle of a Rabbit on Magnetically Quiet Day (September 21), on Day of Approaching Storm (September 22), and on Day of Geomagnetic Storm (September 23)

Time of determination of parameter	Parameter	Time of determination of parameter, h								Mean value for 24-h period
		midnight	3	6	9	noon	15	18	9 p.m.	
Sep 21	Vol. MC	0,38±0,1	0,017±0,002	1,35±0,1	1,39±0,06	1,13±0,12	1,18±0,07	1,06±0,11	1,39±0,08	0,99±0,19
	IVP_{max}	209±10	177±18	191±8	224±9	223±4	236±9	220±15	234±10	214±8
Sep 22	Vol. MC	1,08±0,05	1,26±0,1	1,86±0,09	1,82±0,04	1,19±0,03	2,06±0,06	0,53±0,02	2,04±0,08	1,48±0,2
	IVP_{max}	209±12	226±36	209±11	204±10	218±45	206±9	222±13	187±11	210±5
Sep 23	Vol. MC	0,86±0,08	1,42±0,04	0,76±0,04	1,09±0,05	1,3±0,07	1,27±0,07	1,84±0,06	1,62±0,05	1,27±0,14
	IVP_{max}	177±9	207±8	207±8	217±14	198±9	207±9	201±8	202±6	202±4

RESULTS

The indices of geomagnetic activity (Table 1) indicate that on September 23 there was a violent magnetic storm, accompanied by sharp fluctuations of the earth's magnetic field.

We could thus compare the morphological and functional state of the heart on a magnetically quiet day (September 21), on a day of approaching magnetic storm (September 22), and on the day the storm broke (September 23). The state of MC of the left ventricle on September 21 did not differ in principle from that during other seasons [7]. The presence of a very large number of small MC at 3 a.m. will be noted. Focal concentrations of MC also were observed at 9 a.m. and 3 p.m. Marked signs of degradation of MC, mainly by desquamation of their outer membranes, were visible at 6 and 9 a.m. and 9 p.m. (Fig. 1a).

On 22 September a decrease in the total number of MC and considerable swelling of most of these organelles were observed. At all times of the investigation degradation of MC was well marked; by contrast with previous times, this took place not through desquamation of the outer membranes, but as a result of the appearance of breaks in the outer membranes of the swollen MC (Fig. 1b), followed by deformation and shrinking of the organelles (Fig. 1c).

The number of MC in the cardiomyocytes on September 23 was sharply reduced and most of them were in a state of marked destruction (especially at 3 a.m., noon, and 6 p.m.). A characteristic feature was deformation of the outer mitochondrial membranes (Fig. 1d). The volume of MC was less than on September 22 but greater than on September 21. Many tiny amorphous and thread-like conglomerates of low electron density were observed in the cytoplasm.

The results of quantitative analysis of the electron micrographs and also the results of evaluation of the contractile force of the left ventricle are given in Table 2. They show that the volume of MC and the parameter reflecting the contractility of the heart exhibit a clearly defined circadian rhythm; MC, moreover, have a marked tendency to swell on the 2nd day, and IVP_{max} a definite tendency to decrease during development of the geomagnetic storm. Correlation analysis showed that strong positive correlation ($r = +0.76$; $P < 0.05$) was present on September 21 between the volume of MC and IVP_{max}, it was parabolic in character (Fig. 2), and was described by the equation $y = bx^m$, where $b = 218.4$ and $m = 0.05$. On the day of the magnetic storm, correlation between these parameters disappeared. These results showed that the magnetic storm disturbs the energy supply for the contractile act by the mitochondrial apparatus, characteristic of the intact heart. This may be connected with the marked swelling of MC, leading to spatial discontinuity of the energy-forming complexes located on the mitochondrial membranes, and a decrease in the output of energy [5]. In addition, increasing destruction of MC, noted on the day the magnetic storm was approaching and on the day it burst, may also lead to a similar effect. Yet another factor likewise cannot be ruled out. According to the results of correlation analysis, strong and significant positive correlation ($r = +0.998$; $P < 0.01$) exists between the volume of MC and the blood FFA level (according to the mean values for the 24-h period, the blood FFA concentration was 34.5 ± 15 nmoles/ml on

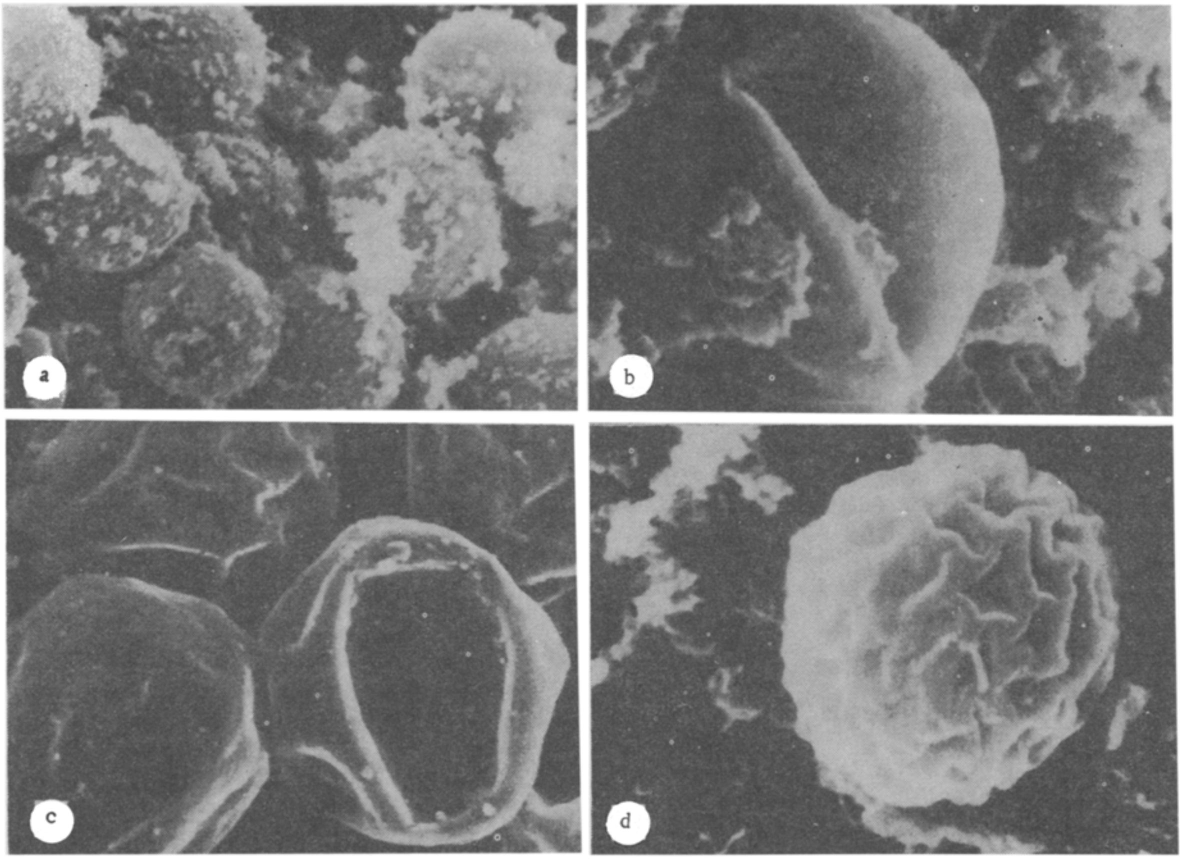

Fig. 1. State of MC of left ventricle on magnetically quiet day (a), on day of an approaching storm (b, c) and on the day of the storm (d). a) Desquamation of outer mitochondrial membranes; scanning electron micrograph, 5000×. b) Rupture of outer mitochondrial membrane; scanning electron micrograph, 10,000×. c) Shrinking of MC; scanning electron micrograph, 10,000×. d) Deformation of outer membrane of MC; scanning electron micrograph, 10,000×.

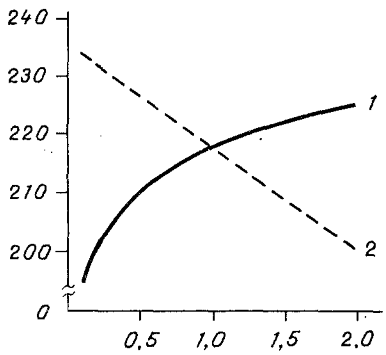

Fig. 2. Correlation between volume of MC and contractile function of left ventricle on magnetically quiet day (1) and on day of an approaching magnetic storm (2). Abscissa, volume of MC (in μ^3); ordinate, IVP_{max} of left ventricle (in mm Hg).

September 21, 253 ± 95 nmoles/ml on September 22, and 140 ± 41 nmoles/ml on September 23. We know [7] that FFA depress the energy-forming function of MC and cause them to swell, and this ultimately reduces the energy supplied to the myocardium. The direct harmful effect of a magnetic storm on mitochondrial membranes also is possible, because we know [3] that magnetic fields disturb transmembrane transport of water and ions.

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MAINTENANCE OF HYPERTENSION DURING AVERSIVE EMOTIOGENIC INFLUENCES AS A FUNCTION OF THE BARORECEPTOR REFLEX

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KEY WORDS: arterial pressure; emotiogenic influences; baroreceptor reflex.

It was shown previously [2, 4] that under conditions of emotional stress due to aversive influences and accompanied by a raised arterial pressure (BP) the baroreceptor reflex is depressed. Meanwhile the positive emotional state induced by intracerebral self-stimulation does not change the baroreceptor reflex, although it also is accompanied by hypertension [1]. A direct connection has been noted in cats between depression of baroreceptor reflexes and the conditions of emotional strain and the absence of hypertensive responses to emotiogenic stimulation in animals with deafferentation of the carotid sinus and aortic reflexogenic zone [2, 4].

The object of this investigation was to discover whether the baroreceptor reflex is necessary to maintain the hypertensive response to emotiogenic stimulation of varied genesis in laboratory rats.

EXPERIMENTAL METHODS

Experiments were carried out on 12 conscious rats (180-250 g) into whose aorta (through the carotid artery) and external jugular vein catheters had been introduced 1-5 days before the experiment, under anesthesia (pentobarbital sodium, 45 mg/kg), to record the systemic BP and the period of the cardiac contractions, and to inject phenylephrine (0.01-0.1 mg/kg) intravenously. At the same time, the sinus, aortic, and superior laryngeal nerves and the cervical sympathetic trunks were divided in most of the animals, to completely denervate the mechanoreceptor zone of the aortic arch and carotid sinuses. In three rats the mechanoreceptor zones were denervated after experiments to study changes in the hemodynamics during aversive and positive emotiogenic stimulation. A negative emotional state was induced in the animals by a loud acoustic stimulus (the ringing of a bell) for 15 sec, which was combined during the period of conditioning with nociceptive stimulation of the base of the tail (30 stimuli/sec; 1 msec; 2-3.5 mA; 10 sec). To simulate a positive emotional state the method of electrical stimulation of the lateral hypothalamic region (diameter of electrode 150 μ), with parameters of 100 stimuli/sec, 1 msec, 10-250 mA, was used. The positive-reinforcing properties of self-stimulation were studied by the technique of pedal self-stimulation under two conditions: with no limitation of the time for closing the electrical circuit (free conditions), or under conditions of a burst of stimuli with fixed duration of 0.5 sec (fixed conditions).

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