

GENERAL PATHOLOGY AND PATHOLOGICAL PHYSIOLOGY

Morphological and Functional State of the Heart during Magnetic Storm

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Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 132, No. 12, pp. 627-630, December, 2001
Original article submitted June 22, 2001

Magnetic storm modulates morphological and functional state of the heart and the related systems. Changes in cardiomyocyte ultrastructure induced by changes in geomagnetic activity were studied in experiments on rabbits. We describe a possible mechanism underlying changes in cardiac activity in intact animals induced by geomagnetic perturbations. The most pronounced alterations of cardiomyocyte ultrastructure were observed during the major phase of magnetic storm.

Key Words: *cardiomyocyte; ultrastructure; magnetic storm; lysosomes*

Considerable attention is now focused on the effect of geomagnetic fluctuations on biological objects. Most works describe clinical and statistical data on the effect of geomagnetic fluctuations on humans. There is evidence that the incidence of cardiovascular events increases during geomagnetic storms [1,5-8,10]. Our aim was to study the morphological and functional changes in rabbit heart during magnetic storm.

MATERIALS AND METHODS

Experiments were performed on 120 male Chinchilla rabbits weighing 2.6-3.5 kg. The animals were kept in a vivarium on a standard ration. The experiments were performed during abatement of a moderate geomagnetic storm C1, initial phase of the subsequent strong storm A2, the major phase B2, and the first hours of C2 phase corresponding to abatement of a large-scale planetary storm. An increase in the parameters of geomagnetic field during A2 phase was recorded at 20:00 in a day after the start of experiment. The active per-

iod and the peak of major phase B2 of this strong storm occurred on the next day at 13:00 and 17:00, correspondingly. The data on the state of geomagnetic field were obtained in Magnetic Observatory of Russian Academy of Sciences (IZMIRAN). The specimens (5 animals per experimental point) were taken during 3 days with 3-h intervals. Cardiomyocytes from left (LV) and right (RV) ventricles were examined by transmission electron microscopy (TEM) at $\times 6000$ and in a JEM-100C microscope at $\times 20,000$. Quantitative analysis of TEM data was performed as described elsewhere [2]. The following parameters were determined: mitochondrion energetic efficiency coefficient ($MEEC_X$); TEM-determined mitochondrion energetic efficiency coefficient ($MEEC_{TEM}$); lysosomal membrane permeability coefficient (LMPC); peak systolic intraventricular pressures in unclamped LV and RV; peak systolic pressure in LV and RV after 5-sec aorta and pulmonary artery occlusion, respectively (near-isometric contraction of heart chambers). Serum content of free fatty acids was measured as described previously [9] with modifications [3].

RESULTS

Enhanced geomagnetic activity induced pronounced alterations in cardiomyocyte ultrastructure. During

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phase C1, ultrastructure of mitochondria did not significantly differ from that under normal conditions. The mitochondria were equally distributed in cells, sometimes they concentrated in the perinuclear zone. Polymorphism and swelling of organelles and clear-cut duplication of the outer mitochondrial membrane were seen. Some mitochondria demonstrated thickening of the outer membrane with ruptured fragments. Cristae were dense and partially fragmented. Matrix in most mitochondria was dense, although some mitochondria were clarified. Mathematical analysis revealed a significant ($p<0.05$) positive correlation between contractile force developed by LV and RV and mitochondrial volume ($r=0.76$ and $r=0.81$, correspondingly), which was described by the following formula:

$$y=b+x^m,$$

where $b=218$ and $m=0.05$ for LV and $b=24.6$ and $m=9.55$ for RV.

Phase A2 was characterized by pronounced changes in myocardial ultrastructure. The cardiomyocytes membrane was loosened, and the integrity of its outer leaflet was disturbed. Arcades filled with mitochondria and pronounced intercellular edema were seen. The cytoplasm demonstrated individual striated lipid deposits. In most cases, the nuclear membrane was invaginated. Sometimes chromatin margination and its focal washout were noted. The capillary walls were thickened and sometimes surrounded with a collagen sheath. The number of lysosomes increased compared to the previous day. The myofibrils had pronounced homogenization foci. The intercalated disks were thickened and their boundaries were blurred. Myofibrils were edematous and fibrous. Focal lysis, breaks of myofibrils, and invaginations of the nuclear membrane were characteristic of phase A2. Most mitochondria were markedly swollen; the structure of their outer membrane leaflet was disturbed. Some mitochondria had vacuolated matrix. Many mitochondria were destructed and degraded. The cristae were strongly fragmented; the number of cristae in a representative mitochondrion or their total number in a representative TEM image was 2-fold lower than during phase C1. MEEC decreased 2-fold (from 3.9 ± 0.8 to 1.9 ± 0.2). Swelling of mitochondria, fragmentation of cristae, decrease of their number, vacuolation of the matrix, destruction and degradation of mitochondria were characteristic of phase A2. The volume of mitochondria markedly increased compared to phase C1, and the correlation between mitochondrion volume and contractile forces of LV and RV became negative ($r=-0.73$ and $r=-0.81$, correspondingly, both remained significant), which attested to further increase in the volume of organelles and the drop in contractile force of the heart.

The number of vessels surrounded by collagen sheaths increased during phase B2 (Fig. 1). Cell nuclei with chromatin margination and partial matrix washout were noted. During the daytime, the number of primary and secondary lysosomes and glycogen content in cardiomyocytes increased (Fig. 2). A characteristic feature of this phase was widening of the sarcoplasmic reticulum. MEEC_{TEM} remained at initial level. Mitochondrion volume decreased in comparison with the initial phase of magnetic storm, but was higher than during the abatement phase. No correlation was revealed between mitochondrion volume and contractile force of the heart, the latter gradually decreased.

Correlation analysis revealed a strong and significant positive correlation between mitochondrion volume and serum content of free fatty acids ($r=0.998$, $p<0.01$). Taking into consideration that the correlation coefficient between the content of free fatty acids and the number of cristae in an average TEM pattern was $r=-0.988$, and that the number of cristae closely correlates with mitochondrion volume ($r=-0.95$), one can conclude that free fatty acids suppress energy production in mitochondria by inducing their swelling and spatial separation of their cristae. This inference is also corroborated by correlation between mitochondrion volume and MEEC_{TEM} ($r=-0.92$).

The unidirectional character of changes in living organisms induced by magnetic storm is confirmed by a significant correlation between myocardial MEEC and LMPC of hepatocytes ($r=0.977$). Taking into consideration the reaction of lysosomal apparatus of cardiomyocytes and cardiac contractile function to geomagnetic storm, one can conclude that decrease in LMPC attesting to condensation of lysosomal membranes, cut down participation of these organelles in the processes of intracellular regeneration. Stabilization of lysosomal membrane impedes the effect of lysosomal hydrolases, which among other functions initiate the release of mitochondrial DNA and promote reproduction of mitochondria [4].

It is noteworthy that in nocturnal and morning hours during phase C2, the increase in the content of free fatty acids disturbed permeability of lysosomal membranes (correlation coefficient between the content of free fatty acids and LMPC is 0.949). During phase B2, the sign of correlation changes ($r=-0.929$), which means that lysosomal membranes are stabilized by free fatty acids. In the periods when free fatty acids produce this effect, the number of mitochondria drastically decreased, and most of them degraded. MEEC and MEEC_{TEM} decreased more than 2-fold: from 3.9 ± 0.8 to 1.3 ± 0.4 and from 19.3 ± 4.9 to 8.7 ± 2.1 , correspondingly.

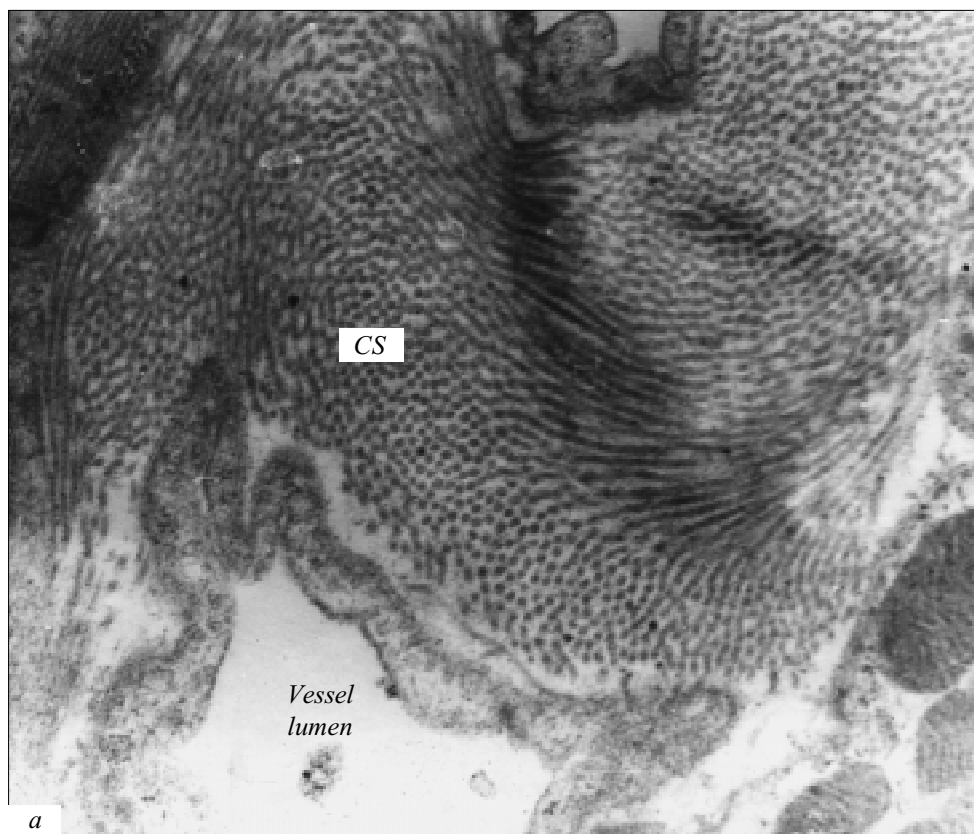


Fig. 1. Transmission electron microscopy of left ventricle myocardium of intact rabbit during phase B2 of geomagnetic storm. $\times 20,000$. The number of vessels surrounded by collagen sheath (CS) markedly increased.

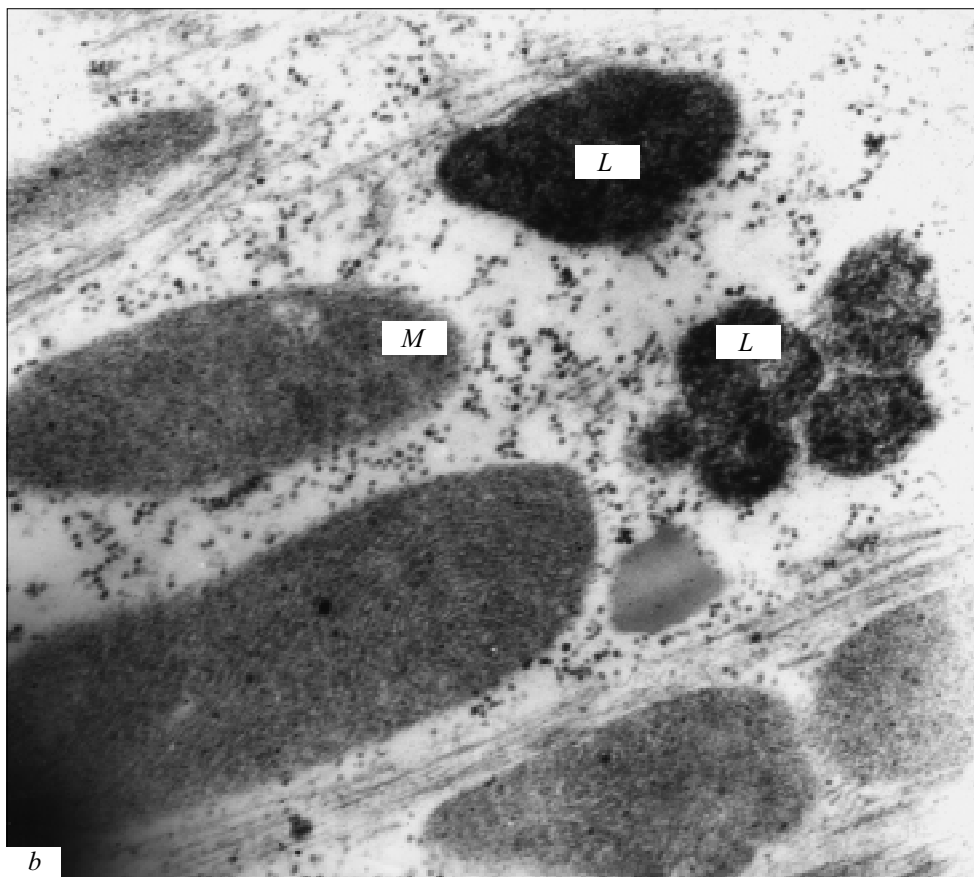


Fig. 2. Transmission electron microscopy of left ventricular myocardium of intact rabbit during phase B2 of geomagnetic storm. $\times 20,000$. Accumulation of secondary lysosomes (L). M: mitochondrion.

Therefore, one of the effects of magnetic storm on living organisms is stabilization of lysosomal membrane. This conclusion is supported by the existence of a strong negative correlation between C_p index of geomagnetic activity and LMPC ($r=-0.977$). Analysis of correlation between C_p and LMPC carried out during a period of one year revealed a non-linear interdependence of these indices described by a power function:

$$y=bx^m,$$

where $b=31.5$ and $m=-0.268$. Hence, enhancement of geomagnetic perturbations is accompanied by a decrease in lysosomal membrane permeability, which is especially pronounced during strong geomagnetic fluctuations. Free fatty acids belong to the main intermediaries in the membranotropic effects of electromagnetic radiation, and their influence undoubtedly depends on the phase of intrinsic physiological rhythms of entire organism and its target organs.

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