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EFFECT OF SPACE FLIGHT ON SODIUM, COPPER, MANGANESE AND MAGNESIUM CONTENT IN THE SKELETAL BONES

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The problem of mineral metabolism in the organism under conditions of space flight continues to be the subject of intensive study. /66* The study of calcium metabolism in the skeleton [1-3] which is closely related to the metabolism of other macroelements (sodium, phosphorus and others) and microelements is especially interesting. It is interesting to study the sodium concentration as it is the basic cation in blood plasma and the extracellular tissue fluid and participates in the regulation of osmotic pressure in these fluids as well as the water balance and acid-base equilibrium of the organism. The spongy matter of the bony tissue is the major and relatively labile sodium depot in the organism and contains up to 30% of the total sodium concentration in the organism. The bony tissue reacts to sodium loading by the selective increase in the concentration of this ion in response to various stimulants; in acidosis and sodium deficiency in the organism a significant amount of sodium from the bony tissue may be mobilized. The sodium concentration in the bones is related to its diffusion in a hydrated layer and its metabolism at the surface of crystals since sodium is basically localized at the surface of crystals. The major type of sodium metabolism in the mineral phase of the bony tissue is metabolism in the surface layer of crystals of hydroxyapatite. With an excess of sodium in the hydrate layer of hydroxyapatite crystals, the concentration of phosphorus, as one of the basic

* Numbers in the margin indicate pagination in the foreign text.

components of the mineral phase of the bony tissue, is sharply reduced [5-8, 15, 17, 18].

The microelements also fulfil an important function in the physiology of the bony tissue by activating a series of biological catalysts and stimulating metabolic processes (enzymes, hormones, nucleic acids, etc.). Microelements, which are present in metallic enzymes, vitamins and other highly active biopolymers, play an important role in the regulation of metabolic processes in the bony tissue [4, 13]. For example, copper, magnesium and manganese actively participate in the restoration of the crystal lattice of hydroxyapatite in the bony tissue and are closely related to the metabolism of organic components in the bone, thus exerting an active effect on osteogenic cellular elements in the bony tissue. These microelements actively participate in the synthesis of mucopolysaccharides by means of intensive adsorption and in the formation of chelate complexes with mucoproteins. They also play an important role in the synthesis of collagen by the bony tissue and participate in the catalysis of enzyme reactions in the osteons, osteoblastic differentiation, etc. Microelements also play an important role in pathological changes in the bony tissue (resorption, osteoporosis, etc.) during the prolonged immobilization at the end, and are therefore used in the treatment of pathologies of the bone system [4, 9-13, 19]. With reference to the above, the study of several macro- and microelements in the bony tissue is of interest in deciphering the intimate mechanisms of the effect of factors arising during space flight.

Procedure. The task of the present investigation comprised the study of the concentrations of sodium, copper, manganese and magnesium in various bones in the skeleton: the calcaneus, the epiphysis and diaphysis of the femur, the vertebral body and the sternum (material came from the autopsies done on members of the space crew of the orbital station "Salyut-1"). The sodium concentration in the bony tissue was also studied in an experiment on manned-satellite "Kosmos-782" after a 22 day orbital flight. Sodium was located on flame spectrophotometer "Flafokol'" while copper, manganese and magnesium were determined on spectrograph ISP-28. Bony tissue from autopsy material taken from 3 men who died from acute trauma at ages 20-40 (without pathologic anatomically determined signs of illnesses of the internal organs or systems) was used as the control for purposes of comparative analysis. In all, 120 samples of bony tissue were examined and triple analyses were done on each. In order to obtain data with the previously set /67
(not less than 95%) degree of probability, the examinations were conducted using mathematical procedures [16] and the number of parallel tests, analyses and other conditions was determined.

Results and discussion. The sodium concentration in all of the bones in the test group was reliably lower than that in the control. Although deviations are low, considering the relatively low specific concentration of sodium in the bony tissue, these statistically reliable changes must be taken into account (Table 1). Completely different results were obtained from the experiments conducted on animals. One day after the completion of the space flight the sodium concentration in the bony tissue of rats increased on an average 63% over that in the synchronous and live controls. The sodium level in the bony

TABLE 1 THE SODIUM CONCENTRATION IN BONY TISSUE (IN % OF ASH, $M \pm m$)

Skeletal bone	Bony tissue		
	total	dense	spongy
Calcaneus			
norm	0,88±0,005	0,87±0,008	0,88±0,006
SF	0,80±0,007*	0,81±0,009*	0,79±0,009*
Epiphysis of femur			
norm	0,97±0,007	0,98±0,011	0,88±0,010
SF	0,80±0,011*	0,79±0,012*	0,91±0,011***
Diaphysis of femur			
norm	0,97±0,008	0,95±0,011	
SF	0,88±0,010*	0,90±0,015**	
Vertebral body			
norm	0,85±0,013	0,90±0,025	
SF	0,69±0,004*	0,70±0,001*	
Sternum			
norm	0,92±0,039	0,98±0,020	0,86±0,027
SF	0,82±0,014**	0,82±0,018*	0,84±0,024
Costal bone			
norm	0,93±0,013	0,95±0,015	0,89±0,026
SF	0,86±0,015*	0,85±0,017*	0,91±0,017

Note. Here and in Table 3: SF - space flight; one asterisk - $P<0,001$; two - $P<0,01$; three - $P<0,05$.

tissue is normalized 25 days after the termination of flight during the period of readaptation to terrestrial conditions (Table 2).

TABLE 2 THE SODIUM CONCENTRATION IN RAT FEMURS AFTER SPACE FLIGHT (IN % OF ASH, $M \pm m$)

Group of animals	Time of examination after end of flight	
	4-8 hours	25 days
1-st - under conditions of space flight	0,57±0,023	0,27±0,015
2-nd - synchronous control	0,37±0,007	0,30±0,009
	$P_{1-2}<0,001$	$P_{1-2}<0,05$
3-rd - live control	0,33±0,006	0,24±0,009
	$P_{1-3}<0,001$	$P_{1-3}<0,001$
	$P_{2-3}<0,001$	$P_{2-3}<0,05$

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The copper concentration in the bony tissue of the test group changed ambiguously in various sections of the skeleton: it increased in the epiphysis of the femur by 81-159% and it decreased in the vertebral body by 36% and in the sternum by 58% in comparison with the control. No statistically reliable changes in the copper concentration were observed in the costal bone, calcaneus or epiphysis of the femur (Table 3).

The manganese concentration in the bones of people in the test group rose basically 26-187% over the concentration in the control: the most clearly expressed increase occurred in the diaphysis (38%) and the epiphysis (64-187%) of the femur. No statistically reliable changes in the manganese concentration were observed in the dense layer of the calcaneus or the spongy part of the diaphysis of the femur in comparison with the control (see Table 3).

The magnesium concentration dropped in the dense layer of the epiphysis and diaphysis of the femurs, vertebral body and sternum by 12-32% in comparison with the control; these deviations appear with a sufficiently high degree of reliability. No substantial changes were noted in the calcaneus, while in the costal bone a tendency to an increased magnesium concentration was noted (see Table 3).

Investigations have shown that changes in the concentrations of /68
sodium and the microelements studied in bony tissue after space flight conform to general regularities which have been determined but show some peculiarities. The directions of changes in the concentrations of sodium and the microelements differ. The concentration of sodium,

TABLE 3 COPPER, MANGANESE AND MAGNESIUM CONCENTRATIONS IN BONY TISSUE (IN % OF ASH; $M \pm m$)

Skeletal bone	Copper		Manganese		Magnesium	
	bony tissue					
	dense	spongy	dense	spongy	dense	spongy
Calcaneus						
norm	0,00082±0,00003	0,00120±0,00006	0,00033±0,000049	0,00042±0,000039	0,435±0,020	0,395±0,014
SF	0,00089±0,00009	0,00129±0,00030	0,00029±0,000032	0,00092±0,000290	0,440±0,020	0,466±0,026***
Epiphysis of femur						
norm	0,00085±0,00003	0,00105±0,00002	0,00014±0,000052	0,00015±0,000007	0,503±0,032	0,410±0,017
SF	0,00220±0,00052**	0,00190±0,00014*	0,00023±0,000028**	0,00043±0,000110***	0,360±0,045**	0,480±0,036
Diaphysis of femur						
norm						
SF						
Vertebral body						
norm	0,00088±0,00015	0,00085±0,00005	0,00013±0,000006	0,00016±0,000009	0,368±0,014	0,430±0,024
SF	0,00110±0,00023	0,00081±0,00006	0,00018±0,000005*	0,00015±0,000006	0,250±0,030**	0,302±0,02**
Sternum						
norm	0,00250±0,00030		0,00036±0,000130		0,424±0,020	
SF	0,00160±0,00006**		0,00048±0,000001		0,375±0,001***	
Costal bone						
norm	0,00300±0,0		0,00026±		0,550±0,009	
SF	0,00125±0,00019*		0,00036±0,000056		0,430±0,030**	
	0,00073±0,00007		0,00019±0,000009		0,460±0,020	
	0,00087±0,00005		0,00024±0,00001**		0,540±0,033	

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copper and manganese is basically increased while that of magnesium is reduced. In isolated skeletal bones no changes in the concentrations of microelements were observed.

It is interesting to compare results for the concentrations of sodium in human and animal bones. While in the first case the sodium concentration in the bones was reduced, in the second case (in animals), the level was much higher than in the control.

On the basis of the existing data it is still difficult to explain the results obtained. We suppose that an increase in excretion of sodium from the organism is related to active muscular work. On board the "Salyut-1" space station the cosmonauts performed a complex of physical excercies which were aimed at eliminating the undesirable effects of weightlessness and hypokinesis [1]. It is possible that as a consequence of the muscular load the increased excretion of sodium caused its mobilization from the skeletal bones. At the same time, although animals on board the satellite retained relative motor activity, they were deprived of active physical loads. This might have led to the retention of sodium in the organism and its fixation in the skeletal bones. In addition, a deviation appears towards an increase in the phosphorus concentration in human skeletal bones after prolonged space flight [1]. In these investigations we may see the reverse of the well known dependence of changes in the sodium-phosphorus balance in the bony tissue: a decrease in the sodium concentration in the surface layer of hydroxyapatite crystals is accompanied by an increase in the phosphorus concentration.

In animals after space flight no substantial changes were observed in the phosphorus concentration in the bones [3]. It is possible that the activation of the mineral corticoid function in the adrenal glands (in a stress reaction) under conditions of animal space flight plays a decisive role in the mechanism of retaining sodium in the skeletal bones under these conditions. We must also not exclude the possibility of so-called dry retention of sodium in the bony depot [14, 18].

On the basis of the data obtained there is no basis for considering the changes in the concentrations of sodium and the microelements (copper, manganese and magnesium) in the skeletal bones under the effect of factors operating in space flight to be pathological manifestations. Further study of this problem is necessary. However, while in previous investigations it was not possible to detect substantial changes in the concentrations of the basic components of bony tissue, /70
calcium and phosphorus [1], in the present investigation deviations from the norm were detected in the concentrations of sodium and such precise indicators as microelements which react sensitively to the effect of various extreme factors [4]. For this reason it is necessary to conduct further investigations of the intimate mechanisms of reactions of the bony tissue to the effect of factors operating in space flight.

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