THE FORMS IN WHICH CERTAIN TRACE ELEMENTS ARE FOUND IN SKELETAL MUSCLE

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According to published reports [4], in muscles, some of the ions (predominantly ions and salts of Mg and Ca) are bound to protein, and some exist in the free form. The metabolism of the bound ions proceeds more slowly than that of the free ions.

The problem of the state in which the trace elements exist in muscle tissue has not been studied.

In the present work we have attempted to determine the forms in which manganese, silicon, aluminum, titanium, and copper exist in normal skeletal muscle, or in muscle after excitation by drugs, or after inhibition of the central nervous system.

EXPERIMENTAL METHOD

The experiments were carried out on dogs. Central nervous excitation was induced in 13 of the animals by injection of 50 mg/kg of the sodium benzoate salt of caffeine, and inhibition was induced in 25 animals by ether anesthesia. After 2 h excitation or anesthesia the animals were killed and the gastrocnemius muscle was removed for study. Muscles from 22 healthy dogs served as a control.

A portion of the muscle from 6 dogs of each group (control, excitation, and anesthesia groups) was homogenized in a phosphate buffer. The homogenate was transferred into collodion bags for ultrafiltration which was carried out in a special apparatus for 18-20 h under a pressure of up to 300 mm mercury. The trace element content of the muscle tissue was measured in the ultrafiltrate and in the residual fraction.

To compare the trace element content of muscle and blood, the level was determined in the blood plasma of 14 healthy dogs, and in the ultrafiltrate and residue of the plasma of seven healthy dogs. The samples of muscle and plasma, of ultrafiltrate, and residue were ashed in a muffel furnace at 400-450°.

The quantitative determination of manganese, silicon, aluminum, titanium, and copper was carried out spectrochemically. The results obtained were treated statistically.

EXPERIMENTAL RESULTS

From Table 1 it can be seen that in the muscles of normal animals most of the manganese, silicon, aluminum, titanium, and copper was contained in the residue remaining after ultrafiltration, i.e., it was in the bound condition combined with compounds of high molecular weight which were unable to pass through the semipermeable membrane.

In the plasma of healthy dogs (Table 2) manganese, silicon, and titanium were found chiefly in the ultrafiltrate, while copper and aluminum were in the residue. Therefore, the distribution of manganese, silicon, and titanium in muscle tissue differs from that in blood. In muscle the organic form of these trace elements predominates. This effect is probably brought about by the greater amount of anions of the proteins and of other components.

This result is in line with the conclusion drawn by A. P. Vinogradov [1], who maintains that the penetration of chemical elements in the form of soluble ionic compounds in the tissue and the formation of organo-metallic compounds are the chief means whereby these elements are involved in metabolic processes, and that it is through these

TABLE 1. Trace Element Content of Skeletal Muscles in the Ultrafiltrate and Residue and Muscle Tissue Normally, and After Excitation or Inhibition of the Central Nervous System (in mg% of Ash)

Element	Normal			Excitation			Ether anesthesia		
	Muscle tissue	Residue	Ultra-filtrate	Muscle tissue	Residue	Ultra-filtrate	Muscle tissue	Residue	Ultra-filtrate
	$M \pm m$								
Manganese	5,1±0,3	4,0±0,2	1,3±0,1	3,0±0,3	2,3±0,2	0,6±0,09	9,1±0,6	8,3±0,6	2,4±0,2
Silicon	229,4±12,3	159,9±11,6	56,9±5,6	122,6±19,7	107,3±7,8	20,8±5,4	369,0±29,2	234,5±14,6	112,7±14,8
Aluminum	90,5±4,7	71,3±8,2	14,4±1,2	51,3±7,3	46,8±1,6	5,6±1,0	149,5±3,8	111,9±5,2	49,1±5,5
Titanium	12,6±0,5	9,8±1,2	5,4±0,9	7,1±0,5	5,7±0,9	2,8±0,3	21,5±1,3	14,1±0,7	9,9±0,8
Copper	12,2±0,7	10,2±0,3	2,7±0,3	6,9±0,5	4,3±0,6	1,1±0,1	21,1±1,4	14,9±1,1	9,2±0,9

processes that the more specific functions of these or other organo-metallic compounds are mediated.

According to many authors [2, 5, 7] the biological activity of the trace elements is manifested in their combination with proteins, enzymes, respiratory pigments, vitamins, and hormones.

The condition of excitation induced by caffeine is associated with a highly significant reduction ($P < 0.02$) in the amount of manganese, silicon, aluminum, titanium, and copper in muscle tissue (see Table 1), chiefly due to a reduction in the amount of trace elements which readily pass into the ultrafiltrate. This effect is evidently due to the more ready mobilization of these free trace elements from the muscles after stimulation by caffeine and their subsequent passage into the blood is withdrawn [6].

Of all the trace elements studied in the residual fraction the greatest reduction was found in the silicon and aluminum. This circumstance is apparently evidence that in the residue silicon and aluminum form compounds which are less easily dissociated than are those of copper, manganese, and titanium.

With ether anesthesia there was a statistically significant accumulation ($P < 0.02$) of manganese, silicon, aluminum, titanium, and copper in skeletal muscle. The amount of copper, aluminum, silicon and titanium in muscle increased chiefly through an increase of the proportion in the ultrafiltrate, while in the case of manganese the increase was in the residue.

R. V. Zharova [3] also found an increase in the manganese content of rabbit muscle when she induced inhibition of the central nervous system by injection of sodium bromide.

The fact that various forms of trace elements accumulate in muscle during ether anesthesia agrees well with the results of our previous investigation [6] where we found that under this anesthetic muscles withdraw manganese, aluminum silicon, titanium, and copper from blood flowing through them.

The increase in the amount of trace elements in the residue of muscle tissue after ultrafiltration during inhibition of the central nervous system indicates that under these conditions there is a synthesis of organo-metallic compounds which proceeds at different rates for the different elements.

SUMMARY

Most of the manganese, silicon, aluminum, titanium and copper present in skeletal muscle tissue can be found in a nonfilterable form, i.e., bound to high-molecular components incapable of passing through semipermeable membranes. During excitation induced by caffeine, the decrease of the muscle trace element content was chiefly in the portion which formed the ultrafiltrate. During ether anesthesia both the ultrafilterable and nonfilterable forms of the trace elements under study accumulated in muscle tissue.

TABLE 2. Trace Element Content of Plasma in the Ultrafiltrate and Residue of Blood Plasma of Normal Dogs (in mg% of Ash)

Element	Blood plasma	Residue	Ultra-filtrate
	$M \pm m$		
Manganese	1,6±0,5	0,3±0,05	1,5±0,1
Silicon	44,3±2,2	9,0±0,9	32,4±2,3
Aluminum	31,1±1,6	26,4±1,9	6,9±1,0
Titanium	16,2±1,2	5,1±0,6	12,4±0,7
Copper	12,2±0,9	10,9±1,0	1,0±0,2

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.