EFFECT OF DEVELOPMENT UNDER CONDITIONS OF SKELETAL MUSCLE LOADING AND OF HYPODYNAMIA ON ENERGY METABOLISM IN RATS

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In rats developing from the age of 1 month during exposure to skeletal muscle loading the reduced general level of oxygen consumption in a state of rest is combined with an increase in the concentrations of ATP, creatine phosphate, and glycogen in the muscles and also with an increase in the pyruvate concentration and a decrease in the lactic acid concentration in them. In rats developing under hypodynamic conditions the increase in the total oxygen consumption in a state of rest is combined with intensification of energy metabolism in the skeletal muscles.

Investigations in the author's laboratory have shown that in developing mammals of different species the level of energy metabolism and of activity of the respiratory and cardiovascular systems, together with characteristics of the red blood cells at different age periods are determined by differences in the pattern of function of the skeletal muscle [1-9]. This general pattern has been described as the energy rule of skeletal muscles. It has also been shown that the established level of energy metabolism and of activity of the various systems and organs differs depending on the character of motor activity taking place while the animal develops.

In view of the importance of the problem, it was decided to investigate the character of energy metabolism, based on the oxygen consumption and certain biochemical indices, in developing rats during exposure to skeletal muscle loading (running on a treadmill) and of hypodynamia.

EXPERIMENTAL METHOD

Experiments were carried out on noninbred male albino rats aged 30 days and over (weight 48-50 g), subdivided into 3 groups with 9 animals in each group. Observations continued for 2 months. Group 1 consisted of control rats developing under ordinary conditions of life in cages; group 2 consisted of experimental rats subsequently described as "muscular," made to run on a treadmill (after 1 day) during development. At the beginning of the observations the animal ran on the treadmill for 20 min, after 1 month the period of running was 60 min, and after 2 months 120 min; group 3 consisted of experimental rats subsequently described as "hypodynamic," kept in solitary conditions in small chambers greatly restricting motor activity. To estimate the oxygen consumption, which reflected the level of energy consumption in the resting state (in the rats of group 2 after the end of the recovery period following muscular exertion), the chamber method [6] slightly modified in the writer's laboratory was used. The temperature in the chamber was 22-23°C. All the animals, after their resting level of oxygen consumption had become stabilized and had been recorded, were sacrificed by decapitation, and a hind limb was amputated at the same time and fixed instantly in liquid nitrogen. The concentration of ATP (by the method of Meshkova and Severin), of creatine phosphate (by Alekseeva's method), inorganic phosphorus (by Lowry's method), creatine (by Yaffe's reaction), lactic and pyruvic acids (by the method of Meshkova and Severin), and glycogen (by the anthrone

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TABLE 1. Energy Indices in Control and Experimental Rats at the Age of 3 Months (M ± m)

Index studied	Group of rats		
	control	"muscular"	"hypo-dynamic"
Oxygen consumption (in ml/kg/min)	22,6±0,8	18,8±0,6	36,4±1,9
ATP (in mg %)	34,3±3,8	45,0±1,9	31,2±5,3*
Creatine phosphate (in mg %)	198±13,4	276±16,9	216,4±16,1*
Inorganic phosphorus (in mg %)	37,3±3,43	25,2±1,99	31,9±2,29*
Creatine (in mg %)	549±25,4	400±17,1	389±49
Glycogen in muscles (in mg %)	497±69,1	679±33,0	416±47*
Lactic acid (in mg %)	56,6±17,9	36,4±2,44	121,7±5,8
Pyruvate (in mg %)	7,7±0,73	9,05±0,76*	7,2±0,53*
Lactate/pyruvate	7,48±0,50	4,08±0,29	17,2±1,08
Liver glycogen	2403±385	3730±240	2926±431*

*Difference between indices in control and experimental rats not significant.

TABLE 2. Weight Characteristics of Control and Experimental Rats (M ± m)

Weight of rats and their organs	Group of rats		
	control	"muscular"	"Hypody-namic"
Weight (in g)	329±10,1	377±12,0	271±6,08
Muscle mass (in percent of total body weight)	40,10±0,53	46,8±0,70	37,7±0,24
Heart:			
mg	1023±27	1219±55	851±44
% of total weight	0,30±0,003	0,33±0,06*	0,28±0,13*
Liver:			
g	12,500±0,290	12,5±0,53*	10,6±0,38*
% of total weight	3,86±0,32	3,31±0,32*	3,81±0,41*
Kidneys (mg)	2610±60	2930±149*	2580±80*
% of total weight	0,79±0,10	0,78±0,09*	0,95±0,18*
Spleen:			
mg	1300±90	1575±88	820±190
% of total weight	0,40±0,16	0,42±0,15*	0,30±0,07*

*Difference between indices of control and experimental rats not significant.

method) were determined in the previously weighed limb muscles. The body weight of the animals, the absolute and relative weight of the muscle mass, and the weight of the heart, liver, kidneys, and spleen also were determined.

EXPERIMENTAL RESULTS

The results showing the specific values of oxygen consumption in a state of stabilized rest and the results of the biochemical tests on the skeletal muscles of the control and experimental animals are given in Table 1. The weight of the rats and the weight of the organs tested are given in Table 2. To begin with it will be noted that the weight of the "muscular" rats was significantly higher, while that of the "hypodynamic" rats was lower than in the controls. This occurred mainly as the result of an increase in the relative value of the total muscle mass in the former and its decrease in the latter. In the form in which it was used in this case, skeletal muscle loading had both dynamic and static components (as well as running, the resistance exerted by the moving belt of the treadmill). Investigations in the writer's laboratory have shown that the increase in mass of the skeletal muscles takes place mainly on account of the increase in the static components of the load [10]. The well-marked economy of energy expenditure, as reflected in the level of oxygen consumption in the resting state, will be noted in the "muscular" rats (17% lower than in the controls), and the high energy expenditure in the "hypodynamic" animals (62% higher than in the controls). Economy of energy expenditure in the resting state in the "muscular" rats was combined with a high concentration of ATP, creatine phosphate, and glycogen in the muscles when determined in a resting state (the state after completion of the recovery period following skeletal-muscle loading). In these animals a high glycogen concentration was found in the liver. Parallel with this finding, there was an increase in the pyruvate concentration and a decrease in the lactate concentration in the muscles of the "muscular" rats compared with the controls. The marked decrease in the lactate pyruvate ratio (by 1.9 times) compared with the control is

evidence of the predominance of respiratory phosphorylation over glycolytic in the "muscular" rats. Further evidence of this is given by the higher ATP concentration in their muscles compared with the control. The lower concentrations of inorganic phosphorus and creatine in their muscles (compared with the control rats) is evidence of a more intensive utilization of these substances for creatine phosphate formation.

The figure given in Table 1 for the "hypodynamic" rats are evidence that high specific values of oxygen consumption were combined in these animals with high energy metabolism in the skeletal muscles. As investigations carried out in the writer's laboratory but not yet published (É. Z. Rabinovich) show, notwithstanding the fact that in the "hypodynamic" rats there was no dynamic load on their skeletal muscles, their high energy metabolism was connected with the thermoregulatory function of the muscles, necessary to maintain a state of homothermia under the external environmental conditions used (20-22°C). The thermoregulatory function of the skeletal muscles of the "hypodynamic" rats was intensified, in particular, by the fact that their relative total muscle mass was reduced. The sharp increase in the lactate pyruvate ratio in the "hypodynamic" rats compared with the controls indicates that in these animals there was a considerable element of glycolytic phosphorylation as well as respiratory. It is important to note the decrease in the relative size of the liver in the "muscular" rats compared with the controls. The sharp decrease in relative size of the spleen in the "hypodynamic" rats was associated with their lowered reactivity. The greater relative weight of the kidneys of the "hypodynamic" rats by comparison with the control and "muscular" groups must also be noted.

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