ENERGY CONVERSIONS IN RATS DEVELOPING DURING EXPOSURE TO VARIOUS SKELETAL MUSCULAR LOADS: A PHYSIOLOGICAL AND BIOCHEMICAL INVESTIGATION

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In rats developing from the age of 1 month during exposure to various skeletal muscular loads the oxygen consumption, respiration rate, and heart rate at rest were lower than in control animals. These findings coincided with an increase in the concentrations of ATP, creatine phosphate, glycogen, and pyruvate and a decrease in the concentration of lactic acid in the muscles. These changes varied depending on the type of load to which the experimental animals were exposed in their development, and the differences were reflected particularly in the animals' working capacity.

The role of skeletal muscles as an essential factor in determining the animal's pattern of development has been demonstrated by laboratory investigations. This pattern of development is expressed as the creation of a certain energy level and a certain level of activity of the various autonomic systems of organs (the respiratory, cardiovascular, and blood systems) in the resting state. The pattern thus revealed has been described as the "energy rule of the skeletal muscles" [1-3].

In connection with results obtained in the writers' laboratory, it became necessary to investigate the forms of skeletal muscular loads to which the body is exposed during its development and to determine the state which is most economical with regard to energy and most efficient as shown by its working capacity. Besides physiological characteristics, biochemical tests also were used to evaluate conversions in the skeletal muscle itself.

EXPERIMENTAL METHOD

Experiments were carried out on male albino rats, divided into four groups (10 rats in each group), beginning at the age of 30 days (weight 48-50 g). The experiments lasted 6 months. Three types of skeletal muscular loads were used and were applied on alternate days: in group 1 the rats had to swim for 5-20 min, in group 2 a static load was applied (hanging on a support) for 5-10 min, and in group 3 running on a treadmill for 20-120 min. Control rats developed while kept in cages under ordinary conditions (group 4). The oxygen consumption was determined by the chamber method, modified in the writers' laboratory [4]. The temperature in the chamber was 22-23°C. After their stabilized level of oxygen consumption in the resting state had been determined, the animals were decapitated, and one hind limb was simultaneously amputated and fixed immediately in liquid nitrogen. The concentrations of the following substances were determined in the limb muscles: ATP (by the method of Meshkova and Severin), creatine phosphate (by Alekseeva's method), inorganic phosphorus (Lowry), creatine (Jaffe), pyruvic acid and lactic acid (Meshkova and Severin), glycogen (by the anthrone method), and myoglobin (by De Duve's method). To assess the potential energy capacity of the animal as a whole, not only concentration characteristics (the intensity factor) but

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TABLE 1. Physiological and Biochemical Indices of Control and Experimental Rats at the Age of Seven Months

Parameter studied	Control rats	Experimental rats		
		swimming	static loading	running
O_2 consumption (ml/kg/min)	29,4±1,24	21,1±0,31	27,2±0,50	18,5±0,65
Respiration rate per minute	72±2,5	63±1,48	66±2,0	61±3,0
Heart rate per minute	356±3,8	309±4,8	329±5,9	300±6,2
Concn. in muscle (mg %)				
ATP	32,7±2,6	56,3±3,7	47,0±2,4	62,1±1,31
Creatine phosphate	210±4,1	378±8,1	469±9,1	365±3,45
Creatine	509±10,6	424±9,5	447±31,4	390±15,6
Inorganic phosphorus	31,2±0,97	26,9±0,87	28,6±0,64	21,9±0,82
Lactate	42,7±1,33	27,5±2,50	30,1±3,18	26,5±1,82
Pyruvate	7,7±0,39	12,7±1,5	12,7±0,89	14,2±0,79
Glycogen	454±38	1005±42	859±33	1150±70
Myoglobin (g)	0,72±0,03	1,46±0,04	1,21±0,02	—
	0,68±0,02	1,25±0,04	0,79±0,03	—
Lactate/pyruvate ratio	5,54	2,16	2,3	1,9
Glycogen concn. in liver (mg %)	2572±192	4385±370	4947±882	5250±218

TABLE 2. Gravimetric Characteristics (in absolute and relative terms) and Indices of Working Capacity of Control and Experimental Rats at the Age of Seven Months

Parameter studied	Control rats	Experimental rats		
		swimming	static loading	running
Body wt. (g)	260±8,6	265±5,3	294±9,9	335±3,3
Wt. of heart in mg	980±49,2	1000±22,3	996±41,3	1110±47,0
in % of body wt.	0,35±0,008	0,37±0,005	0,33±0,004	0,33±0,001
Wt. of lungs in mg	1530±84,1	1835±35,7	1825±39,0	1408±43
in % of body wt.	0,55±0,020	0,68±0,008	0,62±0,016	0,43±0,01
Wt. of liver in mg	921±45	807±172	951±125	1035±305
in % of body wt.	3,53±0,14	3,29±0,15	3,22±0,18	3,09±0,14
Wt. of kidneys in mg	1820±44,5	1830±27,5	1935±23,1	1937±103
in % of body wt.	0,68±0,02	0,69±0,02	0,66±0,04	0,59±0,01
Wt. of adrenals				
in mg	60,7±3,06	61,8±2,11	60,1±2,00	56,9±4,9
in % of body wt.	0,02±0,0001	0,02±0,001	0,02±0,0005	0,01±0,002
Wt. of thyroid gland				
in mg	22,8±0,86	20,8±0,87	19,4±0,81	17,1±0,5
in % of body wt.	0,009±0,0002	0,007±0,00005	0,007±0,0003	0,005±0,0001
Wt. of muscle mass				
in g	106,9	119,7	140,4	162,8
in % of body wt.	41,1±0,37	44,1±0,34	47,0±58	48,6±0,6
Duration (in min):				
of swimming	138±4,6	304±14,2	95±4,5	180±15.4
of running	32,2±5,4	—	—	430±20,6

also capacity characteristics (the extensiveness factor) were estimated, as is usual in thermodynamics. In this connection not only the body weight, but also the absolute and relative weights of the muscle mass were determined. This enabled the content of the test substances in the muscle mass as a whole to be obtained. In laboratory investigations the role of various components of the pattern of development of the skeletal muscles as a factor in the functional transformation of the autonomic systems of organs was established. In this connection several internal organs were weighed. The working capacity of the control and experimental rats was assessed 5-6 months after the beginning of the experiment by measuring the maximal duration of swimming and, in the rats of group 3 (and in the appropriate control) by determining the maximal duration of running and of swimming.

EXPERIMENTAL RESULTS

Figures for the oxygen consumption in a resting state and functional and biochemical indices (concentration characteristics) of the skeletal muscles of the control and experimental animals are given in Table 1.

The body weight of the animals and the weights of the organs investigated are given in Table 2. It will first be noted that the weight of the experimental animals was greater (except group 1) than that of the controls, mainly on account of an increase in the muscle mass (Table 2). In all the experimental animals a more economical utilization of oxygen in the resting state was combined with a lower heart and respiration rate and an increase in the energy reserves in the muscles and liver. For instance, the glycogen content in the whole liver in the control and experimental animals in the four groups respectively was 236.8, 353, 470.5, and 543.4 mg. The glycogen content, calculated for the whole muscle mass, was 485.3, 1,203.0, 1,206.0, and 1,872 mg, respectively. The total glycogen content in the muscles and liver was 722.1, 1556.9, 1676.5, and 2415 mg, respectively. The total content of glycogen in the muscles and liver of the experimental rats was increased by 2.2 times in group 1, 2.4 times in group 2, and 3.3 times in group 3 compared with the control. The creatine phosphate and ATP content in the muscles was increased. The ATP content, calculated for the whole muscle mass, was 34.95, 67.39, 65.99, and 101.1 mg for the control and experimental rats, respectively. The ATP content in groups 1 and 2 was increased by 1.9 times and in group 3 by 2.9 times compared with the control. Breakdown products in the muscles (lactic acid, inorganic phosphorus, creatine) were present in much smaller quantities in the experimental rats than in the control. The working capacity of the animals of group 1 and the glycogen content in the muscles and liver of these animals were 2.2 times higher than in the control. These results suggest that the glycogen reserves in these organs are directly dependent on the working capacity of the animals during the performance of their specific work for which they were trained. The animals of group 3, when performing their specific work (running on the treadmill), increased their working capacity by 13 times while when performing nonspecific work (swimming) the increase was only 30%. The working capacity during performance of specific work, i.e., static work, was not determined in the animals of group 2. However, static loads after training for 5 months were 3 times greater than after training for 1 month. During the performance of nonspecific work (swimming) the working capacity of the rats of this group was lower than the control by 30%. Consequently, static exercises do not lead to an increase in dynamic working capacity (swimming). Of all the experimental groups, group 3 stood out sharply. Compared with the rats of groups 1 and 2, the animals of this group were heavier, and they had a much greater total muscle mass, expressed both in absolute and in relative terms. They had a larger reserve of energy materials, a more economical energy metabolism in the resting state, and a slower respiration and heart rate. The skeletal muscles of the rats of this group showed the lowest lactic acid and creatine content and the highest pyruvate content.

The decrease in the relative weight of the thyroid gland in the experimental rats coincided with a lower oxygen consumption. The absolute weight of the heart in the experimental rats was greater than in the controls. The heart was relatively larger in the rats of group 1 and smaller in the animals of groups 2 and 3 than in the control. The adrenals were the same size in absolute terms in the experimental animals as in the control. The decrease in the relative weight of the lungs and kidneys in the rats of group 3 is particularly interesting. It is worth noting that the weight of the lungs in the rats of group 3 correlates with the lowest specific value of the oxygen consumption and the lowest respiration rate. The relative weight of the liver in all the experimental rats showed a tendency to decrease compared with the controls. This change in the experimental rats was evidently compensated by the fact that the liver function (glycogen reserves) was taken over to some extent by the muscles in which the glycogen content, both in total mass and in concentration, was considerably increased.

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