THE CAPILLARY CIRCULATION OF SKELETAL MUSCLES DURING HYPOKINESIA

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Recent investigations have shown that limitation of motor activity (hypokinesia) of animals and man inevitably leads to atrophy of the limb muscles and to a reduction in their blood supply, which is manifested morphologically as emptying of some of the capillaries and an increase in the number of arteriovenous anastomoses [1, 2, 5, 8, 9]. However, it should be pointed out that muscles whose fibers differ in their function and composition respond differently to hypokinesia. For instance, unlike most of the hind-limb muscles, not only atrophic changes are observed in the antigravity soleus muscle of rats, but also severe dystrophic changes [3, 6, 7, 10]. The reasons for differences in the response of muscles to hypokinesia are not clear, and it can only be suggested that they are connected with differences in blood supply to the muscles.

This paper describes the results of a quantitative histological study of the microcirculation of the hind-limb muscles of rats during hypokinesia.

EXPERIMENTAL METHOD

Experiments were carried out on 20 albino rats weighing 240 g, 10 of which were kept for 20 days in individual restriction cages, severely restricting the animals' movements, while 10 rats were kept under normal animal house conditions. Immediately after the end of the experiment, the experimental and control animals were weighed and decapitated. The soleus, gastrocnemius, and tibialis anterior muscles and also the biceps femoris muscle were fixed in 10% neutral formalin and embedded in paraffin wax. (All muscles except the biceps femoris were weighed before fixation in formalin.) Dewaxed sections through the muscles, 6 μ thick, cut perpendicularly to the long axis of the muscles, were stained with hematoxylin-eosin, with azan by Heidenhain's method, and with iron-hematoxylin by a modification of the method suggested previously [4], selectively revealing functioning (containing erythrocytes) capillaries. The number of functioning capillaries was counted under the light microscope with a magnification of 450×; the number of capillaries in 500 muscle fibers was counted. In the gastrocnemius muscle, besides counting the total number of functioning capillaries, the number of functioning capillaries in the white (consisting mainly of white muscle fibers) and "red" (consisting of white, red, and intermediate muscle fibers) parts of the muscle was determined. The results were subjected to statistical analysis, differences between mean values for which $P < 0.05$ being taken as significant.

EXPERIMENTAL RESULTS

Hypokinesia for 20 days led to loss of body weight by the animals and a decrease in the weight of the hind-limb muscles (Table 1). Besides atrophy in the gastrocnemius, tibialis anterior, and biceps femoris muscles, the number of functioning capillaries decreased by 19, 30, and 30%, respectively (Table 2). The decrease in the number of functioning capillaries in the gastrocnemius muscle took place mainly on account of a decrease in the number of capillaries in its "red" part (the number of functioning capillaries diminished by 24%), whereas in the "white" part of the gastrocnemius muscle the number of functioning capillaries decreased by only 9% (not statistically significant).

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TABLE 1. Body Weight and Weight of Hind-Limb Muscles of Rats under Normal Conditions and after Hypokinesia (M ± m)

Character of experiment	Weight of rats, g	Weight of muscles, mg		
		gastrocnemius	soleus	tibialis anterior
Control	300±9	1683±75	130±4	557±20
Hypokinesia for 20 days	228±7*	1360±36*	115±6*	428±16*

Legend. Here and in Table 2, asterisk indicates statistically significant differences between control and experiment.

TABLE 2. Number of Functioning Capillaries in Different Hind-Limb Muscles of Rats under Normal Conditions and after Hypokinesia (M ± m)

Character of experiment	Number of functioning capillaries per 500 muscle fibers					
	soleus	tibialis anterior	biceps femoris	gastrocnemius	"white" part of gastrocnemius	"red" part of gastrocnemius
Control	657±31	425±28	696±53	437±18	277±15	597±26
Hypokinesia for 20 days	654±34	296±14	492±20	356±12	254±12	458±19

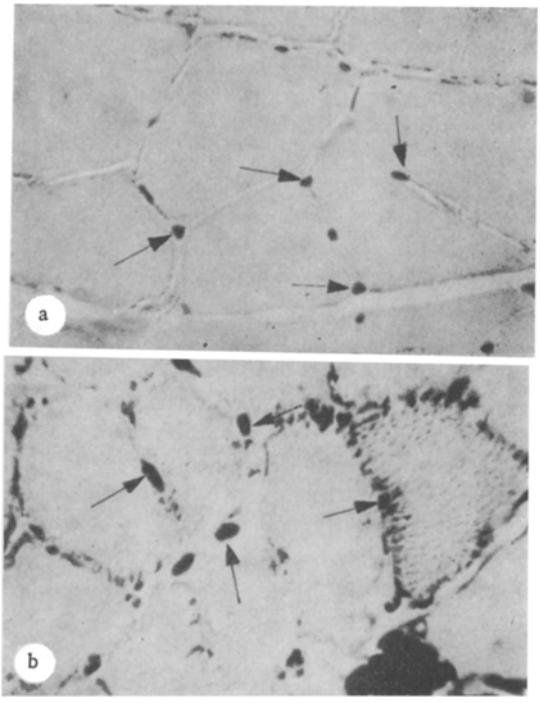

Fig. 1. Transverse section through soleus muscle: a) control rat (arrows indicate functioning capillaries containing erythrocytes); b) rats kept for 20 days under conditions of hypokinesia, capillaries and small veins are dilated and congested. Stained with iron-hematoxylin, 450×.

The results are further evidence in support of a direct relationship between the functional load on muscles and the level of their blood supply. The fact that the decrease in the number of functioning capillaries was greater in the "red" part of the gastrocnemius muscle can evidently be explained on the grounds that red fibers, with their oxidative type of metabolism, require more oxygen during active work of the muscle, and this is supplied to them by the numerous capillaries which run toward them, whereas at rest (during hypokinesia) the oxygen consumption of the red muscle fibers falls sharply and some of the capillaries supplying

them cease to function. In other words, the level of the blood supply to the red muscle fibers during active work and at rest varies over a much wider range than the level of the blood supply to the white fibers with a glycolytic type of metabolism.

By contrast with the hind-limb muscles mentioned above, the number of functioning capillaries in the soleus muscle was not reduced after hypokinesia for 20 days (Table 2). Moreover, the study of the microcirculation of the soleus muscle of rats kept under conditions of hypokinesia showed signs of congestive stasis, reflected in the large number of dilated capillaries and small veins, congested with blood (Fig. 1). The congestion of the veins and capillaries of the soleus muscle was evidently connected with the fact that the function of the "muscular pump" is disturbed during hypokinesia and, as a result, the blood flow along the thin-walled intramuscular veins, incapable of contracting by themselves, is slowed. Slowing of the blood flow is invariably accompanied by the development of tissue hypoxia, and this most probably is the direct cause of the development of dystrophic changes in the muscles.

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INDUCTION BY THYROXINE OF STRUCTURAL CHANGES IN SARCOPLASMIC RETICULUM MEMBRANES OF RABBIT SKELETAL MUSCLES

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Previously, the writers reported a fall in the level of functional parameters of fragments of the sarcoplasmic reticulum (FSR) of skeletal muscles of rabbits with thyrotoxicosis. In particular, a decrease in the efficiency of accumulation of Ca^{++} ions from the medium by FSR preparations was observed against the background of a decrease in Ca-dependent ATPase activity. The effects observed may be caused by various factors: a change in lipid composition occurring during thyrotoxicosis; disturbance of the stoichiometry of FSR proteins responsible for Ca^{++} transport and utilization; a change in the character of protein–lipid interactions in the membrane complex. In fact, if the energy barrier to passive outflow of Ca^{++} ions from the vesicles is lowered because of structural changes in the protein–lipid complex of FSR membranes, this must cause both

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