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STUDIES IN CONGESTIVE HEART FAILURE

VII. The Effect of Overwork on the Potassium Content of Skeletal Muscle[1]

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In preceding studies it has been shown that the skeletal and cardiac muscles of patients dying of congestive heart failure were abnormally low in potassium (Harrison, Pilcher and Ewing, 1930). The loss of potassium from the skeletal muscle was apparently due to edema (Pilcher, Calhoun, Cullen and Harrison, 1930). The loss of potassium from the cardiac muscle was not due to edema but appeared to be related to over-work (Calhoun, Cullen, Clarke and Harrison, 1930). This conclusion was based on the observation that in a given patient the ventricle which had presumably been most overworked showed the greatest diminution in potassium content. In patients, however, complicating factors are often present and, before regarding these conclusions as established, it seemed wise to test them by animal experiments. The first series of observations were made on skeletal muscle. This is more suitable than cardiac muscle for the purpose because the muscles of one extremity can be overworked while those of the opposite limb are used as controls.

METHOD

Dogs were used. They received 0.3 gram of barbital per kilogram of body weight, one or two hours before the experiment was begun. The two sciatic nerves were exposed in the thigh, and one of them was stimulated rhythmically by means of electrodes connected with an induction coil and dry cell batteries. The muscles were made to

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contract against a weight of several hundred grams. The strength of the current and the number of stimuli were varied in the different experiments in such a way as to keep the contractions as rapid as possible without the development of local tetany. When local tetany did supervene stimulation was stopped for a few minutes and then was begun again at a slower rate. The number of twitches per minute varied between thirty and two hundred.

After this stimulation had gone on for several hours the animal was killed and samples were taken from the two gastrocnemius muscles. Determinations of potassium content were carried out according to the technique which has already been described (Harrison, Pilcher and Ewing).

RESULTS

In six of the ten experiments the muscle from the stimulated leg contained somewhat less solids than did that from the normal leg. In one instance the reverse was true. In the remaining three experiments, the water contents of the two legs were practically the same. Average values of water content were 25.1 per cent in the normal muscle and 24.3 per cent in the stimulated muscle. The difference is too small to be significant. In this connection it is of interest to note that Barcroft and Kato (1915) found increased rate of passage of water into actively contracting muscles.

The duration of stimulation was eight hours or less in four experiments. In one of these the potassium content of the dry tissue from the stimulated leg was slightly greater than that from the normal leg. In another, the values were practically the same. In the remaining two instances the dried tissues from the stimulated leg contained less potassium than those from the normal extremities.

The duration of stimulation was eleven hours or more in the other six experiments and in all of these the dried muscle of the stimulated leg was poorer in potassium, the average diminution as compared with the control specimen from the same animal being approximately 20 per cent. Average values for the entire series of experiments were 1.46 per cent for the normal legs and 1.25 per cent for the stimulated legs. The potassium content of the wet muscle from the stimulated leg was higher than that of the control leg in one instance and lower in

nine instances. The single exception occurred in one of the experiments of short duration. Average values for all the experiments were 0.362 per cent potassium for the normal legs and 0.304 per cent for the stimulated legs. If only the six experiments of longer duration be considered the differences are somewhat greater, the averages being 0.371 per cent and 0.289 per cent.

TABLE 1

The effect of stimulation of the sciatic nerve on the solids and potassium content of the gastrocnemius muscle

Experiment number	Duration of stimulation	Solids		Potassium content of dry muscle		Potassium content of wet muscle	
		Normal leg	Stimulated leg	Normal leg	Stimulated leg	Normal leg	Stimulated leg
	hours	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
P_1	6	24.5	21.6	1.60	1.60	0.391	0.345
P_3	8	23.7	22.7	1.38	1.26	0.327	0.284
P_4	6	26.6	27.8	1.29	1.37	0.343	0.381
P_7	5	26.7	25.7	1.33	1.14	0.354	0.292
P_5	12	24.2	24.0	1.52	1.29	0.369	0.310
P_9	11	26.2	25.2	1.38	1.16	0.362	0.293
P_{11}	12	23.8	22.6	1.64	1.33	0.390	0.300
P_{13}	13	25.2	25.3	1.48	1.15	0.372	0.291
P_{15}	12	25.5	25.7	1.45	1.17	0.370	0.301
P_{16}	13	24.4	22.4	1.50	1.08	0.365	0.242
Average		25.1	24.3	1.46	1.25	0.362	0.304

DISCUSSION

These experiments seem to show clearly that overwork of a skeletal muscle, if of sufficient degree and duration, is likely to be followed by a decrease in its potassium content. The loss of potassium is probably to be ascribed to an increase in the hydrion concentration since Höber (1929) observed in vitro that increase in hydrion concentration increased the diffusion of potassium from the muscle, and Hawk and Bergheim (1926) state that acidosis causes increased excretion of potassium.

There is indirect evidence (Harrison, and Pilcher (1930)) that edema may cause tissue oxygen lack. It is well known that lack of oxygen tends to cause local acidosis. It has been shown that edematous

muscles often lose potassium (Pilcher, Calhoun, Cullen and Harrison). It seems likely, therefore, that tissue acidosis is at least one factor in the cause of the loss of potassium in edematous muscles.

The loss of base would, other things being equal, tend to predispose the muscle to fatigue (Hill, Long and Lupton (1923)). However, the specific influence of loss of potassium might tend to have the opposite effect. In any case the observations on skeletal muscle of the dog reported in this paper seem to confirm the conclusion drawn from our previous investigations of human cardiac muscle that increased work may cause loss of potassium from muscle.

SUMMARY

Overwork of the muscles of one leg of dogs, produced by stimulation of the sciatic nerve, usually leads to a diminished content of potassium in these muscles as compared with those of the opposite unstimulated leg.

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