XV. EFFECT OF SEVERE MUSCULAR WORK ON COMPOSITION OF THE URINE.

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A FAIRLY complete series of observations was undertaken to determine the effect of severe muscular work on the composition of the urine, using recent standard methods. These observations form part of a research connected with industrial fatigue, the subject being employed at the same time for observations on respiratory exchange.

In a previous paper [1921] we recorded the results of observations on day and night urine under various routines—five days' complete rest, five days' ordinary laboratory work, and five days' light muscular work, 67,500 kilogram-meters (kgm.) per day. In the present paper we give results obtained from the same subject, under similar conditions as regards diet, time of meals, etc., during five days' severe muscular work. The diet was controlled as regards quality. About $\frac{1}{2}$ litre more fluid per diem was swallowed during the severe muscular work than during the other routines.

Our subject was accustomed to do 13,500 kgm. per hour, on a bicycle ergometer, working three hours before dinner—10 a.m. to 1 p.m.—and two hours in the afternoon—2 p.m. to 4 p.m.—the total, 67,500 kgm. producing only a slight degree of fatigue. For severe muscular work he attempted to do 100,000 kgm. per day at the rate of 20,000 kgm. per hour with the same interval for dinner. 100,000 kgm. represents a full day's work for a vigorous labourer, and, as might be expected, our subject—a laboratory assistant—found this amount of work a severe task. Table I shows the details of the work actually performed. On the first day the subject had to give up the attempt at the end of the third hour, the first hour's work of 20,000 kgm. affecting him very much. On the second day he was able to do more and on the third, fourth and fifth days he completed the full amount in the five hours. It was obvious from the subjective and objective symptoms that the experiment produced severe strain. The average composition of the 24 hours' urine for the five days is shown in Table II; the significance of any of the five days' results was similar. For comparison we have given the figures for the 24 hours' urine obtained in our previous research [1921]. It will be observed that the undetermined nitrogen, creatinine, neutral

sulphur—and, therefore, the total sulphur—and lactic acid were distinctly increased during the severe muscular work. Acetone bodies were present during the third and fourth days and the third night, probably indicating complete consumption of available carbohydrate. Purine nitrogen was also increased, but we had not complete figures for comparison. Other observers have obtained somewhat similar results. Cathcart [1921] reviews the most important of the recent and older researches in his monograph on protein metabolism.

Table I.

Date	Work done in kgm.	Working period in hours	Remarks
10. x. 21	44,482	3	Felt very hot, perspired freely; very much fatigued; severe headache; sore all over
11. x. 21	72,440	5	Felt very hot, perspired freely; very much fatigued; felt stiff all over
12. x. 21	104,760	5	Felt very hot, perspired freely; very much fatigued; felt stiff all over; acetone bodies in urine
13. x. 21	100,000	5	Not so hot; not so fatigued; not so stiff as on previous days; acetone bodies in urine
14. x. 21	100,000	5	Not so hot; not so fatigued; not so stiff as on previous days

Osterberg and Wolf [1907] showed that the undetermined nitrogen was increased during activity. Shaffer [1908] found that muscular activity—walking ten miles—did not increase the excretion of creatinine. Pekelharing and Harkink [1911] obtained a similar result, but observed that after prolonged tonic contraction the output rose. Our subject exhibited muscular stiffness and this may have been a cause for the increased excretion of creatinine. Hoogenhuyze and Verploegh [1908] found that in fevers and other pathological conditions in which there is an increased breaking down of tissue, the creatinine excretion is increased. In our subject there was the possibility that some muscle fibres were injured. The brain contains a fair proportion of creatine [Janney and Blatherwick, 1915], and was a possible seat of production of creatinine during the severe fatigue produced. Weinberg [1921] considers that an important influence on the excretion of creatinine in the urine should be assigned to the mind, high excretion being connected with emotion. Scott and Hastings [1920], Garrat [1898] and others noted that there is a rise in output of inorganic sulphate during activity. Although we observed a similar increase of sulphate during the light muscular work it was the neutral sulphur that was most increased during the severe work. This may have been due to the want of oxygen, so that the sulphur was not so completely oxidised during the severe work. With regard to lactic acid, many observers have found that this acid is increased by severe muscular exercise. Fletcher and Hopkins [1907] clearly demonstrated that lactic acid is produced in excised muscle only when the muscular contraction occurs in a deficiency of O_2 . When it occurs in an adequate supply of O_2 , CO_2 instead of lactic acid is produced. Hill and Flack [1909] showed that in the fatigue of athletes oxygen inhalation increases the lasting power and decreases fatigue, probably

by maintaining or restoring the vigour of the heart. This leads to the question whether creatinine, neutral sulphur and undetermined nitrogen were increased because of insufficient oxidation. This was a possibility, but in one respect these substances differed greatly from lactic acid; lactic acid was excreted in much greater amount during the day (Table II) than at night, whereas creatinine, neutral sulphur and undetermined nitrogen were more evenly distributed between day and night. With regard to the latter substances we did not notice in our previous researches [1921] that there was any parallelism in these excretions; but, nevertheless, there may be the same explanation for

Table II.

	Average 24 hours results				Average hourly day and night results during severe muscular work	
	Complete rest	Laboratory work	Light muscular work (67,500 kgm. in five hours)	Severe muscular work (100,000 kgm. in five hours)	Day	Night
Amount cc.	1112	1116	971	686	32.4	25.9
Acidity %	49.5	53.7	58.0	65.0	60.0	70.0
Titrateable acidity (Folin) cc. N/10	309	312	332	342	14.0	14.4
Total acidity cc. N/10	703	673	723	722	29.0	30.7
Total N g.	8.010 (100)*	9.015 (100)	9.465 (100)	10.250 (100)	.446 (100)*	.414 (100)*
Urea N g.	5.990 (74.80)	7.131 (79.10)	7.647 (80.80)	7.680 (74.93)	.336 (75.3)	.308 (74.5)
Ammonia N (A) g.	.439 (5.48)	.385 (4.27)	.442 (4.67)	.412 (4.02)	.015 (3.4)	.019 (4.6)
Ammonia N (B) g.	.548	.505	.552	.533	.021	.023
Amino-acid N g.	.109 (1.36)	.120 (1.33)	.110 (1.16)	.121 (1.18)	.006 (1.4)	.004 (1.0)
Creatinine N g.	.741 (9.25)	.736 (8.17)	.695 (7.34)	.925 (9.02)	.036 (8.2)	.040 (9.6)
Uric acid N g.	.154 (1.92)	.141 (1.56)	.133 (1.40)	.134 (1.31)	.006 (1.4)	.005 (1.2)
Undetermined N g.	.578 (7.19)	.502 (5.57)	.438 (4.63)	.978 (9.54)	.047 (10.3)	.038 (9.1)
Chloride (NaCl) g.	9.410	7.207	8.801	6.736	.394	.200
Phosphate (P ₂ O ₅) g.	1.550	1.703	1.711	1.811	.070	.080
Total S (SO ₃) g.	1.594 (100)	1.749 (100)	1.770 (100)	2.069 (100)	.084 (100)	.087 (100)
Inorganic S (SO ₃) g.	1.148 (72.0)	1.400 (80.0)	1.432 (80.9)	1.422 (68.7)	.057 (67.9)	.061 (70.1)
Ethereal S (SO ₃) g.	.212 (13.3)	.132 (7.5)	.140 (7.9)	.209 (10.1)	.007 (8.3)	.009 (10.4)
Neutral S (SO ₃) g.	.234 (14.7)	.227 (12.5)	.198 (11.2)	.438 (21.2)	.020 (23.8)	.017 (19.5)
Lactic acid g.	trace	trace	trace	.061	.0040	.0014
Calcium (CaO) g.	—	.281	.252	—	—	—
Magnesium (MgO) g.	—	.173	.156	—	—	—
Purine N g.	.035	—	—	.058	.0023	.0025

(A) Van Slyke's method.

(B) Malfatti's method.

* Figures in brackets are percentages. Total acidity is Ammonia (B) + titrateable acidity.

the increase of each during severe work. It is well known that creatinine and neutral sulphur resemble one another in that they are of endogenous origin, and that they are practically constant in amount for each individual, being evidently connected with the mass of active living protoplasm. In our subject both creatinine and neutral sulphur were higher on the first day than on the succeeding days of severe work. We consider that the probable explanation of the increased excretion of creatinine, neutral sulphur and undetermined nitrogen was damage to protoplasm both nervous and muscular by the excessive fatigue and strain.

Cathcart [1921] states that no one has been able to demonstrate clearly that muscular work affects greatly the total nitrogen excretion, provided the

supply of food, particularly of carbohydrate and of oxygen be sufficient. Under our conditions of experiment we found a slight and steady increase in total nitrogen from complete rest to severe work (Table II). We also found that during the five days' severe work the total nitrogen rose from 8 g. on the first day to 10 g. on the second day, to 12 g. on the third day and fell to 10 g. for the fourth and fifth days, whereas the increments in undetermined nitrogen, neutral sulphur, creatinine were marked from and including the first day. Garratt [1898] found that a rise of sulphate preceded a rise in total nitrogen as a result of exercise. Whilst the figures for total nitrogen are of interest and of some significance and show that the excretion of total nitrogen was increased, we cannot conclude that there was an increased katabolism of nitrogen in our subject as the result of exercise, since we did not estimate the total nitrogen in the food and in the faeces. Under ordinary conditions our subject's total nitrogen averaged only 9 g. per diem during six months and was never as high as 12 g. The large amount of nitrogen, 12 g. on the third day of severe work, was probably due to lack of carbohydrate as indicated by the presence of acetone bodies on that day. Many observers have found an increase of nitrogen when there is an inadequate supply of nitrogen-free food available.

Because it was necessary to increase greatly the amount of work for our subject before any definite change in composition of urine was detected we consider that under equally good dietary and atmospheric conditions a healthy industrial worker would not show any such change in urinary composition unless undertaking work far more severe than his customary daily task. We have done a few experiments with some subjects sitting at rest under hot (36° C.) and close atmospheric conditions and found that the day urine showed higher figures for titratable acidity and ammonia than when under comfortable atmospheric conditions. We hope to extend these observations. One of us [J. A. C.] has noted high excretion of ammonia in a hot climate [1919, 1920].

Table II also gives the average hourly day and night results during the five days' severe work. As in our previous research [1921] we found that the acidity, ammonia and phosphate were higher at night than during the day; also that the sulphur was evenly distributed between day and night, whilst the total nitrogen was higher during the day than at night. We consider that during the night there is an excretion of fixed acids which have been formed in the cells during the day and that these fixed acids are concerned in the production of fatigue and sleep. For all routines examined we observed that the differences between day and night urine were most marked during rest in bed and less marked as the activity increased, activity probably hastening the processes concerned.

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SUMMARY.

A healthy subject, who was accustomed to do 67,500 kgm. of work, on a bicycle ergometer, in five hours, developed symptoms of muscular strain on attempting to do 100,000 kgm. of work in five hours and showed pathological changes in urinary composition. Creatinine, undetermined nitrogen, neutral sulphur and lactic acid were much increased, whilst acetone bodies were present during part of the experiment.

Our previous results regarding composition of day and night urine were confirmed.

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