Observations on the Metabolism of Man during Starvation.

By D. Noël Paton, M.D., and Ralph Stockman, M.D.

(Read March 4, 1889.)

Although the metabolism during starvation has been investigated in the most elaborate and exhaustive manner in the lower animals by many different observers, as yet few observations have been accomplished in man.

In 1880 Tanner undertook a fast of forty days. We have been able to procure only a few fragmentary observations upon his case (*British Medical Journal*, vol. ii., 1880). At the commencement of his fast he weighed 71·600 kilos., and at the end of twenty-five days his weight had fallen to 60·000 kilos., indicating a loss of about 11·600 kilos., or ·162 kilos. per kilo. of his original weight.

During the first sixteen days he pretended to take no water, merely gargling his mouth with it. Under these conditions he became seriously ill, and lost weight with great rapidity. After the sixteenth day he took water *ad libitum*; and in the course of the next four days he gained 4½ lbs. After this he again commenced to lose weight.

On the 1st day of his fast he passed 29 grms. urea.
„ 5th „ „ 16 „
„ 18th „ „ 14 „

Throughout the period the weather was excessively warm. Tanner rarely walked, but daily drove for some time. He, however, spent much of his time receiving people and talking to them.

A more satisfactory series of observations was made upon an Italian named Cetti, who in 1887 commenced in Berlin a fast of thirty days. His parents interfered, and his fast was stopped on the tenth day.

A large number of the leading scientific men in Berlin interested themselves in the case, and together undertook a most careful and elaborate series of observations, which are recorded in the *Berliner klinische Wochenschrift* for 1887.

Cetti's age was 26. He was lean, and at the beginning of the fast weighed 57 kilos.; at the end, 50·650 kilos., so that in the

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ten days he lost 6350 grms., or ·111 kilos. per kilo. of his original weight. This loss was by no means regular, there being somewhat large variations. The whole fast might be divided into three periods:—1st period of five days, during which there was considerable waste, the loss amounting to 4400 grms., or 880 grms. per diem. In the 2nd period of two days the loss was very slight—only 250 grms., or 125 grms. per diem. During this period he drank more water than usual. During the last three days there was a nearly equal loss of from 500 to 600 grms. per diem—in all, 1700 grms.

The urea fell slowly and regularly from 29 grms. per diem to 20 grms. The chlorine of the urine fell from 5·5 grms. to 0·6 grms.; while sodium and potassium also diminished in amount and changed their relative proportions. The amount of urine passed fell gradually from the beginning, was always below the normal, and scanty in proportion to the fluid consumed.

It was always acid, and became more strongly so towards the end of the fast, being then passed thick and turbid, with large quantities of urate of ammonia crystals. Phosphoric acid and calcium were, although absolutely diminished, increased proportionately to the other urinary constituents, a result attributed by the observers to a waste of bony tissue.

Indican disappeared after the first day, showing a cessation of intestinal digestion, while acetone was present in very large amount. This is considered by Senator to be an inanition symptom, and its occurrence in diabetes and in some cases of cancer is by him supposed to be due to profound interference with the metabolic processes.

It may be mentioned that Cetti spent most of his time in a somewhat large and cold room.

The individual upon whom the following observations were made is a Frenchman named Alexandre Jacques, who in October 1888 voluntarily undertook, as a public performance, a fast of thirty days.

Considering the scantiness of our information in regard to the metabolism of man during starvation, we thought it advisable to make what use we could of the case.

On making inquiries we found that arrangements had been made with a number of medical students and others, who had constituted

themselves into a committee, taking watch in rotation, so that Jacques should never be left for a moment unattended by one of them. (*I may say that one or two members of my class acted upon this committee, and that I have not the slightest doubt that the surveillance was complete.*—D. N. P.)

We have to thank the gentlemen of this committee for much valuable assistance, without which our observations could not have been carried out. More especially are we indebted to Mr Griffiths for the endless trouble he took in preparing for us notes of weights, of amount of exercise taken, and of other points of interest.

Jacques is a somewhat slightly built individual, of 47 years of age. He is a block-printer, and was born at St Amant-les-Eaux, Nord. He has no great muscular development, nor has he any excess of subcutaneous fat. He has always enjoyed good health, and states that he has already successfully carried out five different fasts of varying duration.

Four or five years ago he fasted in private for one week. A month later he fasted for fourteen days. In 1886 he fasted in London for twenty-one days, being watched during the period. We have ascertained that the surveillance was by no means so thorough as could be desired.

In the spring of 1887 he fasted in private for thirty days, and in the spring of 1888 he underwent in private a fast of forty days.

During all these fasts he believes that he has been sustained by taking in very small quantities a mixture of certain herbs, which he in his first three experiments used in the form of a decoction, but in all subsequent experiments as a powder.

The composition of this preparation he keeps a profound secret. But before commencing the present fast, he made a sworn declaration that it was entirely composed of herbs growing in Kent. Of this powder he took only the smallest quantities, a mere pinch, generally once, more rarely twice daily. On several days he did not take any.

During the course of his fast he rubbed into his thighs and trunk small quantities of camphorated olive oil. But in the course of the thirty days, only 306 grms. were so rubbed in. He also used small quantities of a lotion which he applied to the head, as he said, because it refreshed him greatly. On examination this was found

to be composed of water with a little alcohol, and a small quantity of carbonate of ammonia.

On the third day of his fast he developed the habit of drinking his urine in quantities of from 2 to 9 oz. This he did daily, usually on rising in the morning. The disturbing influence of this upon the metabolism is practically *nil*, since all the urinary constituents are simply excreted unchanged. This somewhat disgusting habit is by no means unknown, as Jacques himself informed us that it has long been the custom among French miners to drink their urine when deprived of food, owing to mining accidents. Certain savage peoples, such as the Patagonians, also do so during starvation.

He was permitted to drink ærated mineral waters *ad libitum*, a careful note being always made of the amount consumed. He smoked a good many cigarettes daily, and occupied himself in reading newspapers, in playing cards, in talking, and in resting on the sofa. He almost daily took a walk, sometimes during the earlier part of his fast two. The time occupied in this way was noted.

During the whole period of the fast his health was never much disturbed. He was usually cheerful, though rather irritable. During the first few days his tongue became somewhat coated, and his breath very offensive. On the third and fourth day he complained of dull epigastric pain, which he said was relieved by taking a pinch of his powder. His bowels were not moved during the whole period of his fast, except on the first day, when a few scybalous masses were passed, but were not kept. A few hours after his first meal on the completion of his fast, he had a copious formed evacuation, which was, however, unfortunately lost.

During the whole period, but more especially towards the latter part, he was very sensitive to cold and draughts, and, although he kept his room at a temperature usually of 75° F., his temperature was invariably subnormal, ranging from 96° to 93°·4 F. His pulse averaged between 50 and 60. His respirations were usually from 23 to 30. His skin felt moist and warm during the whole period. His expression, naturally somewhat anxious, became rather haggard towards the end.

On the 9th of November he complained of pain and tenderness in the ball of the great toe, which was observed to be red and

inflamed. His pulse was 84 at 12 noon, the only occasion on which it rose so high; but his temperature was only 96°·8–97°·8 F. Since a few days after the completion of his fast he had a well-marked attack of gout, it is fair to conclude that this also was a slight attack of the same disease.

One very important point, upon which we hoped to gain valuable information, was the influence of exercise on the metabolism during starvation. Unfortunately, it was not possible to get results at all satisfactory. In the first place, the amount of exercise taken was exceedingly small; in the second place, it was not easy to estimate the precise amount of exercise taken daily. Inasmuch as during the hours spent indoors practically no exercise was indulged in, we came to the conclusion that the most satisfactory results might be arrived at by taking, as a measure of the muscular exercise, the duration of his daily walks.

It is to be regretted that the conditions of the fast and the pressure of other work rendered it impossible for us to undertake anything like the complete series of observations carried out in Cetti's case.

The following observations only could be accomplished:—

The weight was daily taken before Jacques had dressed. The amount of fluid consumed was carefully measured. The urine passed was all collected and measured. Its reaction was taken, and the amount of urea estimated by the hypobromite method—Dupré's apparatus, previously tested on standard solutions of urea, being used. A record of the pulse, temperature, and general condition was also kept.

From the urea the daily waste of flesh was calculated. By this term is, of course, meant not merely the muscle substance, but all the various tissues of the body containing nitrogen in the proportion in which this occurs in muscle.

The difference between this and the total loss of weight gave the loss of non-nitrogenous substances. These non-nitrogenous wasting substances are the fats and carbohydrates; but inasmuch as the latter occur only in small quantities, and are rapidly used up, they may be neglected, and we may consider these non-nitrogenous matters as practically entirely composed of fat.

Of course, the possibility of variations in the percentage amount of water in the body had to be considered, and in all probability this

played a certain part in the variations of loss of weight from day to day. But its influence over longer periods need not be considered, as is clearly indicated by some recent observations of L. Hermann (Pflüger's *Arch.*, Bd. xliii. p. 239).

The first table gives the results of our daily observations.

TABLE I.—*Alexandre Jacques. Thirty Days Fast.*

	Date.	Weight in grms.	Fluid taken. cub. cms.	Urine passed. cub. cms.	Difference between Fluid taken and Urine passed.	Urea in grms.	Loss of Weight in grms.	Loss of Flesh in grms.	Exercise in Minutes (Walking).
	1888.								
I.	Oct. 25,	62,008	566?	...	...	...	1333	...	0
	,, 26,	60,675	850?	...	...	...	935	...	105
	,, 27,	59,740	1672	917	755	21·37	510	292·77	120
	,, 28,	59,230	1672	1037	635	29·70	+7	406·89	90
	,, 29,	59,237	1501	1073	428	21·40	262	293·18	45
II.	,, 30,	58,975	2124	986	1138	13·60	623	186·32	45
	,, 31,	58,352	1388	1230	158	9·40	+198	128·78	75
	Nov. 1,	58,550	1275	1145	130	13·70	1870	187·69	90
	,, 2,	56,680	1218	1030	188	12·40	454	169·88	30
	,, 3,	56,226	1417	893	524	11·10	0	152·07	105
III.	,, 4	56,226	594	1040	+446	13·50	425	182·95	0
	,, 5,	55,801	779	765	14	12·60	198	172·62	60
	,, 6,	55,603	1317	486	831	5·67	936	77·68	60
	,, 7,	54,667	1374	1100	274	16·67	0	228·38	20
	,, 8,	54,667	1118	683	435	6·10	+369	83·57	10
IV.	,, 9,	55,036	1246	770	476	12·32	57	168·51	20
	,, 10,	54,979	1133	628	505	7·89	+ 85	117·09	25
	,, 11,	55,064	990	725	265	5·30	255	72·61	0
	,, 12,	54,809	1331	778	553	11·00	878	150·70	0
	,, 13,	53,931	1331	873	458	10·00	0	137·00	0
V.	,, 14,	53,931	1473	812	661	10·52	114	143·85	20
	,, 15,	53,817	842	835	7	9·87	455	135·22	20
	,, 16,	53,362	850	575	275	2·78	367	38·08	20
	,, 17,	52,995	1183	515	668	8·55	255	117·13	0
	,, 18,	52,740	1162	892	270	14·30	284	195·91	0
VI.	,, 19,	52,456	609	529	80	4·20	57	57·54	0
	,, 20,	52,399	1020	560	460	8·12	509	111·24	0
	,, 21,	51,890	921	585	336	8·93	+339	112·34	drive.
	,, 22,	52,229	991	450	541	6·55	367	89·73	0
	,, 23,	51,862	878	440	438	8·80	170	120·56	20
	,, 24,	51,692	...	...	...	...	...	...	...
	Totals, .	...	33,409	22,052	11,357	316	8813	4330	...

It will be observed that on some occasions the loss of flesh, as calculated from the urea, is greater than the total loss of weight. This is to be explained by the fact that Jacques was by no means regular in the hours at which he emptied his bladder, so that the weighing of one day is with a full bladder, on another with the viscus empty.

During the thirty days he lost 10·316 grms. or ·166 kilos. per kilo. of his original weight; in all about $\frac{1}{6}$ of his original weight. On an average he lost ·34 kilos. per diem.

During the first five days of the fast the urea excretion was high and irregular—a fact which has been so frequently observed in starving animals, but which was not manifested in Cetti's case.

Dividing the fast up into six periods of five days, we see the gradual fall in the daily excretion of urea till the very low figure of 7·3 grms. per diem is reached.

TABLE Ia.—*Urea Excretion in Grms., Average per Diem during Six Periods of Five Days.*

I. 25·7	IV. 9·3
II. 11·6	V. 9·2
III. 10·9	VI. 7·3

On account of his irregular habits in regard to the emptying of his bladder, whereby the night urine is sometimes counted with the past day, sometimes with the succeeding day, the urea excretion manifests on one or two occasions somewhat large variations.

Table II. gives a general summary of the results worked out for six periods of five days each.

The results for Period I. are not given, because our observations during this period were incomplete.

It will be observed that in Periods II., III., IV., V., and VI. there is a slow and steady fall in the flesh waste. On the other hand, the loss of non-nitrogenous matter is by no means so constant, its relationship to the flesh waste being in Periods III., IV., and VI. as about ·6 to 1, while in Periods II. and V. the proportion is very much raised. That this is not due to a retention of water during the former three periods is indicated by column 8 of the table. Period III. may, perhaps, be accounted for by this, but in the other periods the proportion between the fluid taken and the fluid excreted by the urine remains constant. Of course, it is

possible that a diminished loss of water from the skin and air passages may have occurred during these periods. On this subject we have no evidence. We do not consider that the variations in the exercise taken during these different periods will account for these variations in the non-nitrogenous waste, although it is highly probable that the large non-nitrogenous waste during the second period was associated with the large amount of exercise taken. We are entirely at a loss to explain the rise in the non-nitrogenous waste during Period V.

TABLE II.

Period.	Loss in Grms.	Total in Period.	Per Diem.	Per Kilo. of Body Weight per Diem.	Proportion of Flesh to Fat.	Average Exercise in Min. per Diem.	Relationship of Water not excreted by Kidneys to Water so excreted.
II.	Total,	2749	549	9·4	...	...	...
30th to 3rd,	*Flesh,*	*825*	*165*	*2·8*	*1 : 2·3*	*69*	*1 : 1*
inclusive, 5 days.	Non-nitrogenous,	1924	384	6·6	...	...	...
III.	Total,	1190	233	4·3	...	...	...
4th to 8th,	Flesh,	745	149	2·7	1 : 0·6	30	1 : 3·6
inclusive, 5 days.	Non-nitrogenous,	445	89	1·6	...	...	...
IV.	Total,	1105	221	4·0	...	...	...
9th to 13th,	Flesh,	646	129	2·3	1 : 0·7	9	1 : 1·8
inclusive, 5 days.	Non-nitrogenous,	559	112	2·7	...	...	...
V.	Total,	1475	295	5·5	...	...	...
14th to 18th,	Flesh,	630	126	2·3	1 : 1·3	12	1 : 1·9
inclusive, 5 days.	Non-nitrogenous,	845	169	3·2	...	...	...
VI.	Total,	764	152	2·9	...	...	...
19th to 23rd,	Flesh,	491	98	1·8	1 : 0·5	4	1 : 1·6
inclusive, 5 days.	Non-nitrogenous,	273	54	1·1	...	...	...

But we may analyse still further these results.

During the twenty-eight days on which Jacques was under observation, he passed 316 grms. of urea, corresponding to about 147 grms. of nitrogen. This represented a waste of flesh amounting to 4330 grms., which would contain 500 grms. of carbon. Of this, 63 grms. were excreted as urea. The remaining 437 must have been passed out as carbonic acid.

But in addition to this, 4046 grms. of non-proteid matter were used up. Now this, as already indicated, we may practically regard as fat, since the cabohydrates need not be considered. Now fat contains 30 per cent. of water, and hence this amount would represent 2832 grms. of solid fat, and in this would be contained about 2174 grms. of carbon.

Thus we see that in all 2230 grms. of carbon were lost from the body in twenty-eight days; that is, during the fast there was an average daily excretion of 77·6 grms. of carbon. Now in a man on ordinary diet and work about 280 grms. of carbon are daily excreted, so that the carbon excretion fell to about $\frac{1}{3}$ of its normal amount.

On the other hand, 147 grms. nitrogen being excreted in these twenty-eight days, we have a daily excretion of 5·2 grms. instead of the normal 15 or 16 grms., so that the nitrogenous excretion also fell to about $\frac{1}{3}$ of its normal amount.

In this case, then, apparently the proportion of the proteid to the non-proteid waste was undisturbed during starvation.

Is it possible, from these observations, to come to any general conclusions in regard to the probable composition of the body at the end of the fasting period as compared with the beginning? Taking as our basis the composition of the body of a man aged 33 years, as given by Bischoff (*Zitsch. f. rat. Med.*, 3d Reihe, Bd. xx. p. 75), we may conclude that at the beginning of the fast Jacques' body had something of the following composition :—

Total weight on 26th October, . .	60,675 grms.
"Flesh," *i.e.*, muscle, liver, lung, &c., .	35,550 ,,
Fat, ...	10,834 ,,

His condition at the end of the experiment may be calculated by subtracting from these figures the loss in total weight, in flesh, and in other substances, or fat :—

	Loss.	Wt. at end of Fast.
Total, ...	8813	51·862
Flesh, ...	4330	31·220
Other substances—Fat, . .	4046	6·788

The oil rubbed in amounted to only 306 grms., an amount which need not be considered. Hence we see that even at the end of a fast of thirty days, there still was a very considerable quantity of fat in the body.

Hofmann (*Ztsch. f. Biolgie*, Bd. viii. p. 153) found that dogs had to be starved for a period of about thirty days before all the fat had disappeared from the body, and that the final disappearance of fat was indicated by a sudden rise in the excretion of nitrogen, after which the dogs, unless fed, rapidly died. This did not occur in Jacques' case, and we should consider the appearance of such a rise in the urea excretion as the important indication for instantly stopping any voluntary fast.

From the accompanying table it will be seen that the metabolism in the present case was much slower than in either Tanner's or Cetti's. Nor was there any evidence of the same profound disturbance in the metabolism which was indicated in Cetti's case by the appearance of acetone in large quantities in the urine. At one period Jacques' urine was observed to have a peculiar smell, suggestive of liquorice, but not in the least resembling acetone. Some of this urine was distilled, but the distillate was free of any unusual smell.

Altogether the metabolism here is much more like that observed by Voit in old fat dogs, while Cetti's case rather resembles the processes as seen in young lean animals.

Comparison of Tanner, Cetti, and Jacques.

	Tanner.	Cetti.	Jacques.
		Weights.	
1st Day.	71·600	57·000	62·008
10th Day.	...	50·650	56·226
25th Day.	60·000	...	52·740
30th Day.	...	...	51·692
Loss of Weight per Kilo.		*Original Body Weight, in Kilos.*	
10th Day.	...	·111	·093
25th Day.	·162	...	·149
30th Day.	...	...	·166
Loss of Flesh per Diem (in Jacques' Case, in Average of 3 Days).			
5th Day.	219	315	295
10th Day.	...	270	168
18th Day.	192	...	113
28th Day.	...	...	107

While Cetti spent most of his time in a large somewhat cold room, Jacques, on the contrary, inhabited a small highly-heated chamber.

In every way the conditions of his case were peculiarly favourable to the maintenance of life with the smallest possible metabolism. Exercise was only taken in most moderate amount, while the katabolic changes necessary to maintain the temperature of the body were reduced to a minimum by the high temperature at which his room was constantly kept.

Whether his powder had any influence in diminishing metabolism we are unable to say. But even without it we see no reason why a man should not undergo with impunity such a period of starvation under like favourable circumstances.

A Method of Demonstrating the Presence of Uric Acid in the Contractile Vacuoles of some Lower Organisms.

By **Dr A. B. Griffiths**, F.R.S. (Edin.), F.C.S. (Lond. and Paris), *Member of the Physico-Chemical Society of St Petersburg, &c.*

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After some years of patient observation and research, I have found, from direct experiment, that at certain times the contractile or pulsating vacuole of the Protozoa performs the function of a true kidney, or, in other words, its secretion is capable of yielding microscopic crystals of uric acid.

Three organisms were used in these experiments, namely:—Amœba, Vorticella, and Paramœcium.

I. Amœba.

We will consider, in the first place, the small Protozoon which Haeckel called *Amœba sphærococcus*. By observing a number of these organisms under the high powers of the microscope, there is seen, within the structure of each, a small cavity or vacuole filled at certain times with a transparent fluid. There is little doubt that the fluid which gathers in the vacuole is drawn from the surrounding protoplasmic substance, and is returned to it, or forced out to the exterior on the contraction of the walls of the vacuole.

I have shown in my paper, "Further Researches on the Physio-