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The Starvation Ketosis of a Monkey.

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In sharp contrast to human beings, most animals (dog, cat, pig, steer, goat, guinea pig, rat, rabbit, etc.) appear to develop only slight ketosis when starved. In man, on the other hand, starvation ketosis is a regular phenomenon, and is apparently a necessary consequence of the failure to metabolize a sufficient amount of carbohydrate. And conversely it is believed that the metabolism of carbohydrate is essential for the normal complete combustion of the precursors of the acetone bodies. This seems applicable only to man. The ability to avoid ketosis without the direct intervention of metabolizing glucose appears to be possessed by most animals. Man is the exception. That animals have high tolerance for the acetone bodies is indicated by the results of acetoacetic acid injection (dog[1], mouse[2], cat[3]). This ability of animals to burn acetone bodies (apparently without the antiketogenic action of carbohydrate) would seem to be not an acquired property, but rather a function normal to all animals with the exception of man in whom it appears to have been lost. A parallel case is perhaps the ability to further metabolize uric acid to allantoin, possessed in general by mammalia, but lacked by man and the chimpanzee.

The following observation has been made on a fasting monkey, which developed a ketosis quite comparable to that of man which was promptly abolished by glucose and food. Whether the results are representative of the behavior of the species or of primates generally can be determined only after observations on other individuals, though the writer sees no reason to suppose that the behavior of this monkey is exceptional.

The subject was an adult male brown capuchin monkey, whose probable normal weight was 1.3 to 1.4 kilos. He was sent to the laboratory suffering with "cage paralysis."[4]

The animal was placed in a small metabolism cage in a room kept at a temperature of about 30°C. The animal always sat at one end of the cage and, except for motions of the head, was very quiet. The absence of activity permits an approximate estimate of the total metabolism. The starvation was continued through the third day during which urine was collected in short periods without catheterization.

At the end of three days glucose and food was given. *The ketosis disappeared almost immediately.* An increase in weight from 830 grams to 1,020 grams occurred in less than 24 hours after consumption of food.

That the ketosis is comparable to that of man is shown in Table I. When compared on the basis of body weight the ketosis of the monkey per kilo is more than three times as great as that of man. A more logical basis of comparison is on the basis of surface area

TABLE 1.
Comparison of Maximum Fasting Ketosis of Man and Monkey.

	Normal weight kilos	Estimated Total Metabolism* calories	Total Acetone Bodies Excreted		
			In 24 hours Total mMols.	Per kilo body wgt. mMols.	Per 100 Cal. heat output mMols.
Old-world monkey(?) (Baer)†	6.65		4.6	.7	
Capuchin monkey (Friedemann)	1.4	160	14.7	10.5	9.2
Subject "L" (Benedict)	61	1260	101	1.7	8.0
Fasting woman "M. K.",catatonic stupor (Grafe)	52	1325	167	3.2	12.6
Fasting obese woman (Means, Folin and Denis)		2039 1st fast	237		11.6
		1796 2nd fast	166		9.2
		1759 3rd fast	193		11.0

*Some of the estimates are cited by Shaffer, *J. Biol. Chem.*, 1922, liv, 399.
†Baer, J., *Arch. Exp. Path. u. Pharm.*, 1906, liv, 153.

or of total metabolism. The surface area was determined after death by two methods which agreed within 6 per cent. Measurements on various parts of the body and calculation of the surface area yielded a value of .143 sq. meter. The skin when stretched out on paper covered an area of .152 sq. meter. The calculations of the total metabolism were based on the following assumptions:

Surface area	.152	sq. meter
Basal metabolism per sq. meter	40	Cal.
Allowance for activity	10	per cent

This gives 160 Cal. per 24 hours. As is shown by the last column of Table I, the acetone body excretion per 100 Cal. heat output is of the same order of magnitude as that of man.

It is of interest to attempt an evaluation of the acetone body excretion on the basis of the ketogenic versus anti-ketogenic factors used by Shaffer.[5] The results of such calculations are shown in Table II. The expected or estimated excretion agrees remarkably

TABLE II.
Protocol of Experiment.

Period of Urine Collection.	Calculated to 24 hours.						
	Urine volume	Aceto-acetic acid + acetone	B-oxy-butyric acid	*B-oxy*:acetone etc.	Total urinary nitrogen	Calculated total acetone bodies (Shaffer)	Total acetone bodies excreted.
	cc.	mMols.	mMols	Ratio	grams	mMols. in 24 hrs	mMols. in 24 hrs
Food eaten on Friday morning. Was brought to the laboratory Saturday and immediately placed in small metabolism cage.							
Saturday 12 M. to 5:30 P. M.	148	.07	.10	1.43	.742		
Sat. Sun. 5:30 P. M. to 7:30 A. M.	45	2.01	2.83	1.41	.308*		
Sun. Sun. 7:30 A. M. to 6:00 P. M.	325	5.46	6.05	1.11	.849	13.5	11.5
Sun. Mon. 6:00 P. M. to 9:30 A. M.	101	4.18	7.02	1.68	.785*	15.6	11.2
Mon. Mon. 9:30 A. M. to 2.30 P. M.	226	5.49	9.18	1.67	.820	15.0	14.7
At 2:30 P. M. drank about 25 cc. of 50 per cent glucose but vomited after 5 minutes. Urine specimen containing glucose was discarded at 5:00 P. M.							
At 5:00 P. M. injected 7-8 cc. of 25 per cent glucose subcutaneously. Immediately ate one-fourth of banana. During the night ate 2 bananas and about 100 cc. milk.							
Mon. Tues. 5:00 P. M. to 9:00 A. M.	30	.04	.16	4.00	.291		

*Vomited. Total nitrogen determination was made on $CuSO_4$ and $Ca(OH)_2$ filtrate, which was also used for B-oxybutyric acid determination.

well with the values found by analysis. This close agreement is consistent with the view that the marked ketosis in this animal was the consequence of the same factors which determine human ketosis.

[1] Wilder, R. M., *J. Biol. Chem.*, 1917, xxxi, 59. Friedemann, T. E., Somogyi, M., and Webb, P. K., *J. Biol. Chem.*, 1926, lxvii. (Proc.) 44.

[2] Robertson, T. B., *Med. J. Australia*, 1923, ii, 191.

[3] Burn, J. H., *J. Physiol.*, 1925, lx, 16.

[4] Fox, H., "Disease in Captive Wild Mammals and Birds." Lippincott, 1923.

[5] Shaffer, P. A., *J. Biol. Chem.*, 1922, liv, 399.