SUGAR IN THE BLOOD OF PIGEONS

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A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE FACULTY OF PURE SCIENCE, COLUMBIA UNIVERSITY, NEW YORK CITY

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While it is a recognized fact that much of our experimental data in physiology must be obtained from animals other than man, there has been very little hesitation on the part of many experimenters in drawing conclusions concerning phenomena in man from data derived from other animals. In many cases the results have warranted the practice, in others disappointment has resulted. Actually the larger the number of experiments performed, and the greater the number of species from which the data have been derived, the more justification there is for a generalized statement, and for its application to species other than those upon which work has been done. With this idea in mind it was thought wise to make the determinations leading to the data published in the present paper, on an animal hitherto little used in metabolism work. A bird rather than a mammal was chosen largely because of the fact that in this form the red blood corpuscles are nucleated. That this makes a striking difference in the physiology of the blood is well illustrated by Warburg's (1) work on oxygen consumption in the drawn blood of birds as compared with that of mammals. The fact that the red corpuscles of birds are nucleated should prove of especial value in studies made on them with the idea of using the results as a means of giving a better understanding of the physiology of the cells of tissues other than blood. A considerable literature has developed upon the exchange of material between the red cells and the plasma. This is especially true of the chlorides and the sugars. The data upon which this literature is based have been obtained from studies on the blood of mammals. It seems probable that parallel studies on bird's blood with its nucleated cells should lead to a better understanding of this process.

The fact that the birds, characteristically, have a higher temperature than mammals is an additional reason why their metabolism should be studied for comparison with that of mammals. In fact, it has been suggested by Bierry (2) that this is the reason for the very high concentration of sugar found in their blood as compared with that found in the blood of mammals. That there is a correlation between body temperature and blood sugar concentration is shown by the work of Hollinger (3) and others.

Since most of these properties are of general interest the bird should be an instructive addition to our list of laboratory animals. Comparatively little has been done on the metabolism of birds aside from some work on polyneuritis. It is therefore advisable to extend our knowledge of this phase of their physiology.

From birds in general the pigeon was selected and it is thought that it should be a practical and convenient bird with which to work for the following reasons: *a*, it is of convenient size; *b*, it is comparatively easy to obtain; *c*, its first cost is not prohibitive; *d*, it is easily and economically kept; *e*, it is a seed eater and therefore herbivorous. Further, in the use of the carrier pigeon there is an opportunity for the study of fatigue. Mosso (4), in fact, has already made some use of it for this purpose. This phase of the work we hope to extend, and consequently further data on resting birds are necessary for comparison with those obtained from fatigued birds and from resting and fatigued mammals.

METHOD: *1. The care of the birds.* The pigeons were confined in the laboratory until they became accustomed to their surroundings. They were subjected to frequent handling in order to reduce their fear of the operator, and so to minimize as far as possible results which might arise from fright. In most cases the birds wholly ceased to resist handling when taken from the cage. During periods between experiments the pigeons were kept in a large enclosure giving them opportunity to fly about freely. The food consisted of a mixture of corn, oats, barley and some other grains, and a plentiful supply of fresh water. Access was given to both food and water at all times not otherwise noted.

2. Method of estimation of sugar. MacLean's (5) micro-method was used throughout the research. The macro-method had been successfully used in this laboratory for other blood sugar determinations. The micro-method possesses the obvious advantage of requiring only a small quantity of blood (0.2 cc.). It therefore may be used for animals having a comparatively small amount of blood, and it permits of drawing consecutive samples at relatively short intervals, without producing serious effects from hemorrhage. The extreme limits of error were found to be about 10 mgm. per 100 cc. of blood. Variations of this amount or less may, therefore, be disregarded.

3. Special technique. While the samples of blood were being drawn the birds were encased in a strong cloth jacket made especially for the purpose. This was done as a matter of convenience to the operator and of safety to the birds. The jacket laced across the ventral surface of the body in such a manner as to be adjustable to birds of varying size, and to secure the wings and legs.

The blood was drawn directly from the heart into a 0.2 cc. pipette by means of a long hypodermic needle. This needle was inserted at the end of the breast bone, going directly through the skin and body wall into the abdominal cavity. The tip of the needle followed the breast bone up to the region of the heart, and so avoided puncture of the liver and other viscera. When the heart could be felt at the tip of the needle the point was dropped slightly and plunged into the heart tissue. Following this procedure the needle struck the heart in such a way that arterial blood was drawn. Post-mortem examination showed that the needle usually entered the heart near the apex on the left side. Hypodermic needles, 20 gauge, and 3 inches long, were used most successfully. Since the distance from the tip of the breast bone to the heart is very nearly equal to the length of such a needle, it is obvious that this method of drawing blood would not be practicable for birds much larger than the pigeon. It is also probable, because of the lesser quantity of blood and the smaller and more delicate heart, that this method would not be applicable to species much smaller. All the experiments were performed during the fall and winter of 1920–21.

Study of the concentration of sugar in the blood of individual birds. It is a common practice in physiological laboratories to keep the experimental animals for only a short time. While there are probably many cases where repeated observations have been made on individuals, they have not been published with this point in view, and as a result it is difficult to find data showing whether or not the concentration of the sugar in the blood is approximately constant, or whether it is markedly variable from time to time in one animal, and from individual to individual.

In order to determine these points for the pigeons, two were set apart to be used exclusively for this study. They were kept in the laboratory throughout the period of observation and had access to food and water at all times. The observations were extended from

October 29, 1920 until the death of pigeon A on February 20, and until March 13, 1921 on pigeon B. The first six observations were made at intervals of one week. Following this the intervals were lengthened as indicated in table 1.

From this table it will appear that pigeon A, in all but four of the eleven determinations, had a sugar content of 175 mgm. or 180 mgm. per 100 cc. of blood; pigeon B, with four exceptions, 170 mgm. or 175 mgm. per 100 cc. These variations are well within the limits of error for the method, and so are to be considered constant.

TABLE 1

Blood sugar of normal birds

DATE	A		B	
	Weight	Glucose per 100 cc.	Weight	Glucose per 100 cc.
	grams	*mgm.*	*grams*	*mgm.*
October 29	317	200	368	140
November 5	325	175	372	170
November 13	327	175	375	170
November 20	330	180	380	175
December 5	330	150	377	215
December 11	335	180	375	175
December 18	335	175	370	170
January 8	337	180	375	170
January 15	340	175	377	175
February 6	337	185	375	165
February 20	342	195	377	190
March 13			375	175

Obviously, then, there is a concentration of sugar which is characteristic of the blood of a given bird. The fact, however, that the two birds which happened to be selected yielded characteristic values so close together, does not warrant the extension of this value to other birds, as will appear later. But while it is evident that there is a value which is characteristic of a given bird, it is also evident that this value will not necessarily be obtained at all times. The occasional striking variations shown in the table illustrate the fact that here we are dealing with an organism which is responsive to modified conditions, and one of its means of adjustment to its environment involves changes in the concentration of blood sugar. This offers experimental confirmation of the statement of Pike and Scott (6) that the concentration of sugar in the blood is one of those internal conditions existing in higher organisms which are generally constant, and which are regulated by the general nervous and physico-chemical mechanisms of the organism as a whole.

Three cases offered an opportunity for comparing the blood sugar concentration given by individuals at various times after a period of 48 hours' inanition. These data are given in table 2, from which it will be observed that each bird has a value which appears to be characteristic for it.

TABLE 2

Blood sugar of individuals after inanition

BIRD	DATE	BLOOD SUGAR PER 100 CC.	
		Normal	After inanition
		mgm.	*mgm.*
5	10–11	190	165
	12–17		175
9	10–22	185	165
	1– 7		185
20	11– 4	140	100
	12–18		135

TABLE 3

Blood sugar of normal dogs at different times

DOG	DATE	BLOOD SUGAR PER 100 CC.
		mgm.
A	11– 6	75
	1– 6	73
C	10–31	67
	11– 7	65
E	11–20	59
	1–16	63

These results are similar to those reported by Scott and Hastings (7) for dogs. Two determinations each were made on three different dogs, the greatest difference between consecutive determinations upon the same dog being 4 mgm., as shown in table 3.

In a series of 22 blood sugar determinations made by Kramer and Coffin (8) on a quiet dog, the amount of glucose varies from 87 mgm. to 93 mgm. per 100 cc., the average being 89 mgm. per 100 cc.

Jones (9) states that in making repeated observations on individual rabbits the variations were within the experimental error, and so could be considered as constant. She frequently found, however, a considerable variation in passing from individual to individual.

In a recent paper Strouse (10) reported a series of observations on five normal persons covering a period of 8 months. In the series the variations for individuals range from 27 mgm. to 59 mgm. per 100 cc. of blood with an average variation of 41 mgm. per 100 cc. Thallinger (11) made repeated observations on a boy with furunculosis, whose blood sugar was abnormally high, varying from 145 mgm. to 155 mgm. per 100 cc. on a liberal diet which was low in carbohydrates.

Thus it will be seen that the pigeons agree with the rabbits and dogs in possessing a characteristic sugar value. Strouse's figures would

TABLE 4

Effect of excitement on blood sugar

BIRD	DATE	BLOOD SUGAR PER 100 CC.	REMARKS
		mgm.	
4	10– 9	185	
	1– 7	265	Excited by presence of several strangers
8	10–22	185	
	10–22	300	Excited by loud talking
10	11–19	175	
	11–20	250	Excited by escape from cage

indicate that the range may be greater in man, although it is not clear whether this greater range is due to a more ready response to changes in the environment than occurs in the other animals studied, or whether the sugar-controlling mechanism is not so perfectly developed, or whether possibly the conditions of living were not so carefully standardized

Effect of handling; emotional glycemia. As noted in the foregoing, noise, loud talking and the presence of strangers produce a rise in the blood sugar. Rough, sudden or uncertain handling also disturbs the pigeon and increases the blood sugar. In one instance the bird escaped from the cage just before a sample was drawn and some confusion attended its recapture. The amount of sugar in the sample of blood was high, as shown in no. 10, table 4.

From this table it will be seen that the bird offers no exception to the principle long ago pointed out by Boehm and Hoffman (12), Pavy (13) and others, and more recently by Cannon (14), Shaffer (15) and Scott (16), that to obtain blood sugar figures of value, samples of blood must be obtained without pain or other emotional disturbance of the subject. The fact, however, that birds which were known to be excited have such high figures as appear in table 4, indicates that the lower figure of about 185 mgm. per 100 cc. may be assumed to be normal. This was the value obtained by Scott and Honeywell (17) and though Fleming (18) found a much lower value for ducks, in fact a figure quite comparable with that characteristic of mammals, the normal value for the pigeon, at least, appears to be much higher and to agree well with the values published for other birds (cf. Scott and Honeywell).

Effect of inanition. For reasons which will be discussed later, the birds were subjected to a 48-hour period of inanition in determining the alimentary glycemia curve to be described in the following section. In all cases the concentration of sugar in the blood was determined soon after the arrival of the birds at the laboratory, and again at the close of the 48-hour fast and just before feeding the glucose. While the effect of this inanition was not the primary purpose of the experiment, this procedure offered opportunity for its study, provided that the initial values can be taken as normal values for birds on full feed. The propriety of this is in some doubt, as the birds had not yet become fully accustomed to their new environment and had not been subjected to standard conditions. This would probably result in rather wide variation from values characteristic for the individual with a general tendency to yield high values. It is felt, however, that the figures as they stand merit some attention.

As noted by Rogers (19), the general effect of inanition on the normal pigeon is to increase its natural restlessness. It becomes irritable and fights on the slightest provocation, such as a sudden noise. This might lead one to expect higher blood sugar values in birds subjected to inanition, and may explain those values which are even higher than normal that were occasionally found.

From table 5, which contains the data for the blood sugar of pigeons after inanition, it appears that in 36 experiments 19 pigeons show a lower blood sugar after inanition than before. The results vary from 3.1 per cent to 70 per cent below the initial value. Fifteen pigeons exhibited an increase in blood sugar ranging from 5 per cent to 100 per cent. Two pigeons showed no change whatever. The entire series

TABLE 5

Effect of inanition

BIRDS	DATE	PERIOD OF INANITION	WEIGHT			BLOOD SUGAR PER 100 CC.		
			Before inanition	After inanition	Per cent of loss	Before inanition	After inanition	Per cent of difference
		hours	*grams*	*grams*		*mgm.*	*mgm.*	
10	November 17 to 19	48	280	250	10.7	200	175	− 8.00
11	November 17 to 19	48	350	320	8.5	175	120	−31.0
12	November 17 to 19	48	300	240	20.0	155	150	− 3.1
13	December 15 to 17	48	300	280	6.6	160	100	−37.6
14	December 15 to 17	48	310	275	11.3	105	90	−14.2
5	December 15 to 17	48	340	325	4.4	190	175	− 7.8
9	January 5 to 7	48	280	272	2.8	140	185	32.0
17	January 5 to 7	48	325	312	4.0	185	265	43.0
18	January 5 to 7	48	300	290	3.3	175	310	77.0
19	January 5 to 7	48	350	330	5.6	150	290	93.0
20	November 2 to 4	48	280	248	11.4	140	100	−28.0
21	November 2 to 4	48	310	280	9.65	120	105	−12.5
22	December 8 to 10	48	330	305	7.6	200	170	−15.0
23	November 10 to 12	48	340	310	8.8	155	155	0.0
14	November 10 to 12	48	330	315	4.5	105	210	100.0
25	November 10 to 12	48	230	215	6.5	105	170	62.0
26	November 10 to 12	48	290	250	13.8	255	155	−39.0
27	December 2 to 5	48	345	340	1.4	120	150	25.0
28	December 2 to 5	48	330	305	7.6	150	140	− 6.6
29	December 8 to 10	48	365	340	6.8	120	175	46.0
8	December 16 to 18	48	330	300	9.1	185	55	−70.0
9	December 16 to 18	48	300	262	12.6	140	135	− 3.5
4	December 16 to 18	48	300	290	3.3	185	100	−46.9
33	December 20 to 22	48	340	330	2.9	160	175	9.4
12	December 20 to 22	48	330	317	3.9	155	155	0.0
11	December 20 to 22	48	300	285	5.0	175	150	−14.2
36	December 19 to 21	48	300	280	6.7	185	110	−40.6
37	December 19 to 21	48	300	285	5.0	190	160	−15.8
38	December 19 to 21	48	380	340	10.5	185	115	−37.9
9	December 19 to 21	48	350	340	2.8	140	180	28.6
2	September 11 to 14	48	220	195	11.3	290	300	3.4
3	September 11 to 14	48	216	200	7.4	190	200	5.2
8	October 20 to 22	48	356	300	15.7	185	200	8.1
9	October 20 to 22	48	360	280	22.2	187	165	−11.7
51	October 20 to 22	48	330	272	17.6	195	205	5.1
52	November 2 to 4	48	340	320	5.9	140	160	14.3
Average......						166	165	− 0.6

gave an average decrease in blood sugar of 0.6 per cent. It may, therefore, be that 48 hours inanition has practically no effect on the blood sugar of the pigeon. As pointed out above, the evident irritability of the birds subjected to inanition with its possible effect upon the concentration of sugar in the blood should be borne in mind.

Effect of ingestion of glucose: *1. Special technique and discussion.* As noted in the previous section, the sugar was determined upon the arrival of the birds in the laboratory. Also as described above, after the birds had become accustomed to the laboratory, they were subjected to a fast of 48 hours and the sugar in the blood again determined. The results of these two determinations were given in table 5. In addition to the reasons usually assigned for a preliminary period of inanition, this somewhat prolonged period seemed to be necessary to empty the crop and so to insure a rapid passage of the sugar to the region of the alimentary tract where absorption might be expected to take place. It will be readily appreciated that this is even more essential in the case of such birds as the pigeon, which are provided with crop and gizzard, neither of which is presumably a region of absorption, than it is with the mammals, and possibly than it would be with other birds. The alimentary canal was empty in all birds examined, so this period of inanition may be considered as sufficient to fulfill its purpose.

After the second sugar determination, the appropriate amount of glucose was administered. To facilitate the feeding, the glucose was made into tablets and a weighed amount, 1, 2 or 3 grams, according to the series, was given to each bird. In feeding the sugar, the beak was opened and the tablets were dropped well back into the mouth. If the pellets were not readily swallowed, a little water was given through a dropper. Sometimes gentle stroking of the throat seemed to aid when swallowing was especially slow.

Three series of experiments were carried out. In series I, each pigeon was fed 1 gram of glucose; in series II, 2 grams; and in series III, 3 grams. In terms of grams per kilogram of body weight, the average amount of glucose fed was 4 grams, 7 grams, and 10 grams in the respective series.

The ordinary clinical test for carbohydrate tolerance is 100 grams or about 1.4 grams per kilogram of body weight, if the average weight for man is taken to be 70 kilograms. This amount was fed by Cummings and Piness (20), Hiller and Mosenthal (21), Jacobsen (22), Tachau (23) and Strouse, who has also fed 2 grams and 2.8 grams per kilo to normal men. Jones gave rabbits an average dose of 7.87 grams per kilogram.

From the foregoing it will be seen that the amounts given to the pigeon exceed those usually given man in similar experiments. In spite of this, the smallest dose used in the present experiments which is equivalent to one of 1.75 grams for a man weighing 70 kilograms, had very little effect on the concentration of sugar in the blood of the pigeon. In a man such an amount would in all probability raise the concentration of blood sugar to 200 mgm., and probably induce glycosuria.

2. Time of the maximum. Since it was desired to determine the principal points in the entire curve, that is, to follow the curve to its return to the initial value, and since the number of samples of blood which could be drawn safely in any one experiment was limited because of the injury to the heart which would result from repeated

TABLE 6

Time of maximum of alimentary glycemia

BIRD	GLUCOSE FED	BLOOD SUGAR AFTER INANITION	BLOOD SUGAR PER 100 CC. AFTER FEEDING GLUCOSE				
			1 hour	2 hours	3 hours	4 hours	5 hours
	grams		*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
61	3	160	155	240	400	335	320
62	3	180	185	235	305	210	215
64	2	210	205	245	315	275	260
65	2	185	200	215	240	250	205
66	1	170	190	200	215	240	200
67	1	165	170	185	205	225	190

punctures at short intervals, it was necessary to determine the time elapsing between the administration of the glucose and the maximum sugar concentration in the blood. For this purpose, as indicated in table 6, hourly determinations were made after the sugar was fed. It will be seen from the results given in this table that the maximum may be assumed to occur between the third and fourth hours. This last interval was therefore allowed to elapse after feeding and before drawing the first sample, and the sugar level at this time may be assumed very nearly to represent the maximum attained.

When 3 grams of glucose were fed the maximum occurred at or about the third hour. When 2 grams of glucose were fed the maximum occurred in one case at the third hour and in the other case at the fourth hour. After the feeding of 1 gram of glucose, the maximum occurred at about the fourth hour. From these results, given in table 6, it will appear that the greater the amount of glucose fed the earlier the maximum will be reached.

In this connection it is interesting to note, as Strouse has pointed out, that a heavy dosage often has the effect in man of delaying the onset of the maximum rather than accelerating it as in the pigeon. There must be, then, some fundamental difference between the carbohydrate economy of the pigeon and that of man.

3. Course of alimentary hyperglycemia. In each case samples of blood were drawn just before the administration of the glucose and again after the lapse of 4, 6 and 24 hours. The results are collected in

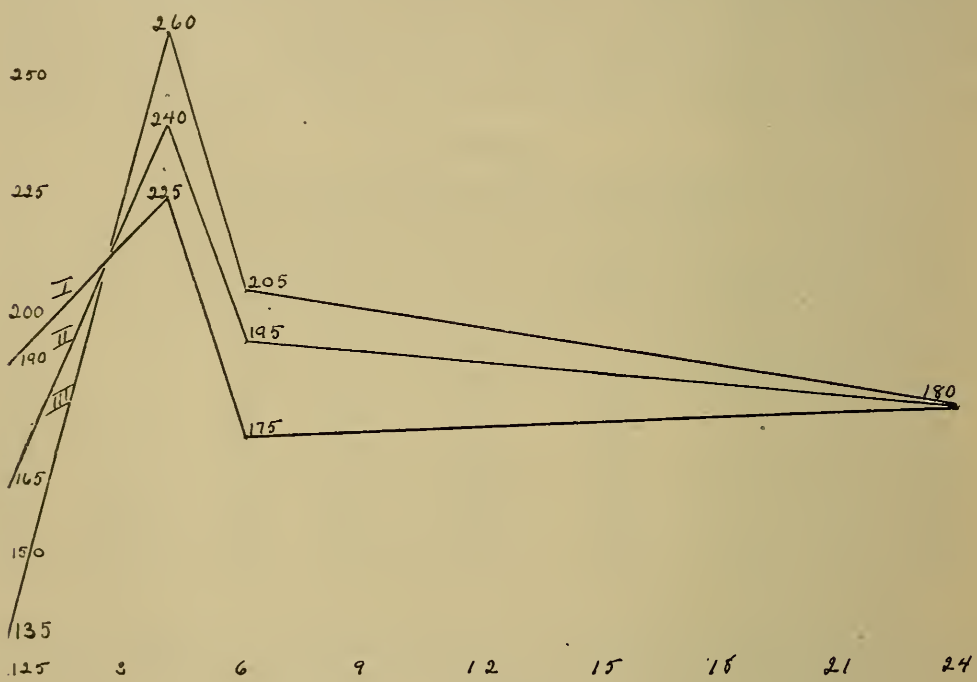

Fig. 1

tables 7, 8 and 9 and summarized in the accompanying curves (fig. 1). In the first series one gram of glucose was given each bird. As noted before, this is about double the ratio of the test meal usually given man for diagnostic purposes. From table 7 it will appear that there is no change or as occurs more frequently, only a slight rise at the end of the first period. The average for the series gives a rise of 18 per cent at this time.

In the second and third series there is a different manifestation. In the second series 2 grams, and in the third 3 grams were given each bird. The average rise at the end of 4 hours in the second series was 45 per cent, and in the third, 93 per cent. From table 8 it will be seen that in the second series only five birds had returned to their previous level at the end of 24 hours; and in the third series, table 9, one alone had returned in that interval to the level which existed before the ingestion of the glucose.

While the average at the end of the inanition period may vary somewhat for the different groups, the average at the end of 24 hours after feeding the glucose is approximately that of the normal birds. Because of the relatively low initial values found in the second and the third series, the final values found for these series are distinctly higher

TABLE 7

Effect of ingestion of glucose upon the sugar in the blood

Series I

BIRD	DATE	WEIGHT	GLUCOSE FED PER KILO	BLOOD SUGAR PER 100 CC. AFTER FEEDING GLUCOSE				PER CENT OF INCREASE	REMARKS
				Inanition	4 hours	6 hours	24 hours		
		grams	*grams*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
10	November 19	250	4.0	175	100	110	250	−37.0	Bird excited by
11	November 19	320	3.1	120	150	150	125	25.0	escape from
12	November 19	240	4.2	155	150	160	150	3.2	cage before
13	December 17	280	3.5	100	275	245	195	175.0	drawing of 24
14	December 17	275	3.6	90	210	300	270	233.0	hour sample
5	December 17	325	3.1	175	170	160	230	− 2.8	
9	January 7	272	3.7	185	270	175	265	46.0	
17	January 7	312	3.2	265	280	275	275	5.7	
18	January 7	290	3.4	310	350	300	250	1.3	
19	January 7	330	3.0	290	295	260	155	1.7	
Average		259	3.9	190	225	175	180	18.0	

than the initial values. Whether or not this is significant we are not prepared to state definitely, although it would seem to be accidental.

Unfortunately there is very little data available which permits of a comparison of the course of the alimentary hyperglycemia of different species. In fact, only three species seem to have been studied from this point of view. In her recent paper, Jones has made determinations on the blood of rabbits only at a single period after the ingestion of the glucose. From the work of Bang (24), the 1-hour period which she chose would presumably give figures at or near the maximum attained. Her results do not, however, permit one to follow the course of the curve. Bang reported a short series of experiments on rabbits which had been fed from 5 to 20 grams of glucose. After a 5-day period of inanition he found that the maximum was reached in $1\frac{1}{2}$ to $2\frac{1}{2}$ hours, and that in general the sugar level had returned to normal in 6 hours. The amount of sugar did not seem materially to modify the time relations of the curve. The same may be said of a similar but even shorter series, in which sugar was given without a previous period of inanition.

Fisher and Wishart (25) in experimenting with dogs weighing 8 to 9 kilograms, fed approximately 6 grams of glucose per kilogram, and found that the maximum blood sugar occurred one hour after the ingestion of the glucose.

TABLE 8

Series II

BIRD	DATE	WEIGHT	GLUCOSE FED PER KILO	BLOOD SUGAR PER 100 CC. AFTER FEEDING GLUCOSE				PER CENT OF INCREASE
				Inanition	4 hours	6 hours	24 hours	
		grams	*grams*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
20	November 4	248	8.4	100	150	125	295	50.0
21	November 4	280	7.1	105	300	250	180	185.0
22	December 10	305	6.5	170	290	280	260	70.0
23	November 12	310	6.4	155	440	140	145	184.0
14	November 12	315	6.3	210	210	250	240	19.0
25	November 12	215	9.3	170	200	190	120	17.0
26	November 12	250	8.0	155	250	210	160	61.0
27	December 4	340	5.9	150	280	100	130	87.0
28	December 4	305	6.5	140	200	285	175	103.0
29	December 10	340	5.9	175	270	160	110	54.0
Average		290	6.9	165	240	195	180	45.0

The work of many investigators, notably Cummings and Piness, Hiller and Mosenthal, Hamman and Hirschman (26), Jacobsen and Strouse, indicates that after the ingestion of 100 grams of glucose the maximum concentration of sugar in the blood of man occurs normally in about 30 minutes and that it has returned approximately to its previous level by the end of the second hour. Jacobsen and Strouse point out that occasionally the maximum is attained only after a longer period, and that when this is true the level is apt to be higher than usual, and the return to the previous value is usually slower.

Strouse particularly calls attention to the fact that in diabetes and other conditions which may be presumed to alter the carbohydrate metabolism, such curves are common but that such individuals may be induced to give the "normal" or usual curve if given less sugar. On the other hand normal individuals will give the "diabetic" curve if the dose be doubled or tripled.

A study of the curves obtained from pigeons shows that the maximum occurs from the third to the sixth hour after feeding, and when amounts were fed which essentially altered the sugar level, the curve did not return to normal for a much longer period, in some cases exceeding 24 hours. Thus they resemble more closely the delayed curves obtained from men rather than the usual or normal one, and, at first thought, the obvious reason is the very heavy dose of glucose given to the birds.

TABLE 9

Series III

BIRD	DATE	WEIGHT	GLUCOSE FED PER KILO	BLOOD SUGAR PER 100 CC. AFTER FEEDING GLUCOSE				PER CENT OF INCREASE	REMARKS
				Inanition	4 hours	6 hours	24 hours		
		grams	*grams*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
8	December 18	300	10.0	55	215	200	205	291.0	
20	December 18	262	11.4	135	320	150	160	137.0	Excited by presence of strangers when third sample was shown.
4	December 18	290	10.3	100	160	300	220	200.0	
33	December 20	330	9.0	175	335	200	110	91.5	
12	December 20	317	9.4	155	240	210	225	55.0	
11	December 20	285	10.5	150	320	195	175	113.0	Struggled and died during drawing of last sample.
36	December 21	280	10.7	110	225	205	260	104.5	
37	December 21	285	10.5	160	200	265	180	65.5	
38	December 21	340	8.8	115	265	110	195	130.4	
9	December 21	340	8.8	180	330	220	210	84.0	
Average		303	9.8	135	260	205	180	93.0	

In order to determine this point, that is, whether the pigeons would respond to a smaller dose and whether or not a maximum occurring during the first hour had been overlooked, four birds were fed 0.4 gram of glucose each, after an inanition period of 48 hours. This is the amount of glucose which, for the weight of the bird, approximates the usual test dose for man. Blood sugar determinations were made 30 minutes, 1 hour and $1\frac{1}{2}$ hours after the ingestion of the glucose. The results are shown in table 10. Since the variations were all within the limits of experimental error, it may be concluded that the pigeon does not respond to as small a dose as does man and that there is a fundamental reason for the difference in the alimentary glycemia curves shown by the two species.

In his series on normal men Strouse obtained an average increase of 42 per cent after an ingestion of 100 grams of glucose, or 1.4 grams per kilogram. The pigeons show an average increase of only 18 per cent after the ingestion of 1 gram or about 3.5 grams per kilogram, and it was not until they had been given 2 grams or 7 grams per kilogram that they approached the percentage increase reported by Strouse for men.

In addition it should, perhaps, be pointed out that the resemblance is more apparent than real for, as mentioned above, the effect of the size of the dose upon the time elapsing between the administration of the dose and the occurrence of the maximum is in the opposite sense in the pigeon and in man. It would thus seem that the mechanism of storage of sugar is somewhat different in the two groups.

Post-mortem examinations of two pigeons which were killed after inanition and before feeding showed that the crop and gizzard were

TABLE 10

Effect of varying amounts of glucose on time of maximum

BIRDS	WEIGHT	AMOUNT OF GLUCOSE FED PER KILO	BLOOD SUGAR IN MGM. PER 100 CC. AFTER FEEDING GLUCOSE			
			Inanition	½ hour	1 hour	1½ hours
	grams	*grams*				
1	250	1.6	180	165	180	175
2	370	1.1	220	225	230	225
3	280	1.4	195	200	190	205
4	350	1.1	185	175	180	175

empty, while the intestine contained only a small amount of fluid. Conditions were the same in pigeons which were examined at the end of the fourth and sixth hour after feeding. The contents of the alimentary tract were not tested for the presence of sugar. Consequently, while the indications as they stand are that the delay in reaching the maximum is not due to delay in absorption, but rather to some peculiarity in the mechanism of storage, one is not justified in definitely drawing such a conclusion until a study of the contents of the alimentary canal has been made in parallel with blood sugar determinations.

Since concentration of the sugar in the bird is normally so high as compared with mammals, in this particular resembling the diabetic, and since the curve obtained from birds somewhat resembles that obtained from diabetic man, there may possibly be some relationship between the absolute initial height of the sugar concentration and the form of the curve of alimentary hyperglycemia. However, as noted above, it would seem more probable that in the birds the storage mechanism is somewhat different from that common in mammals and that further work must be done before a satisfactory correlation is possible.

SUMMARY

1. Each bird has a characteristic sugar level about which it varies from day to day. In this it resembles the rabbit and dog.

2. These individual variations are caused by variations in the external and internal environment of the bird.

3. A series of inanition values for blood sugar is given and compared with the values found on full diet. From these figures it is concluded that 48 hours' inanition has practically no effect on the blood sugar of the pigeon.

4. It has been found that, in general, when from 1 to 3 grams of glucose are fed to the pigeon the maximum rise in the blood sugar occurs in 3 to 4 hours.

5. It is indicated that the greater the amount of glucose given the earlier will the maximum be reached.

6. When 1 gram of glucose or less is fed to pigeons there is very little modification of the sugar in the blood. When 2 or 3 grams are fed there is a manifest rise in the blood sugar which gradually approaches its former level.

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