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THE GLYCEMIC RESPONSE TO ISOGLUCOGENIC QUANTITIES OF PROTEIN AND CARBOHYDRATE

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In past years several objections to the use of a diet high in protein for the diabetic patient have been forwarded. These have fallen into three main groups—first, that in some way protein exerted a specific action, the result of which was to interfere with the mechanism of sugar utilization (1, 2, 3, 4); secondly, that the specific dynamic effect of protein in increasing heat production was wasteful in terms of total energy expenditure and as such should be minimized (1, 4, 5, 6); and, thirdly, that protein constituted a large source of endogenous glucose and therefore should be carefully curtailed in the diabetic diet. The latter is the only one that has in any measure stood the test of time as far as practical diabetic management is concerned (7, 8, 9). It is our purpose to show that it is an advantage to the diabetic to derive a large part of his total metabolic glucose from protein foods.

It is a fact that during the metabolism of protein there occurs a yield of glucose which approximates 50 per cent of the weight of the ingested protein (10, 11, 12, 13, 14, 15). Janney (16) working with isolated proteins found that the glucose liberated varied from 48 per cent to 80 per cent. It is reasonable to state that 50 per cent represents a good average figure in calculating diets in which the total intake of protein is made up of a mixture of many single proteins.

Since protein in the diet represents a large source of glucose, it was decided to compare the blood sugar levels and glycosuria produced by ingestion of equivalent amounts of glucose derived on the one hand from protein and on the other from glucose and carbohydrate foods. The studies were made on fifteen diabetic patients and three normal fourth year medical students. Each subject was maintained aglycosuric for at least two weeks before the study was begun.

METHOD

The blood sugar level in the postabsorptive state was determined. At this time glucose was absent from all of the urine specimens. A breakfast consisting of 2 grams of protein per kilogram of body weight was given. The source of protein was lean beef from which all visible fat had been removed. This was ground and fried as hamburger steaks, using a minimum of butter in this process. The beef under these conditions contained 5 to 6 per cent of fat and 20 to 22 per cent of protein.

The time taken for ingestion of the meat varied from seven to twenty minutes. Blood and urine specimens were collected hourly for eight hours. Timing was begun immediately after the conclusion of breakfast.

Blood sugar was determined by the Benedict (17) method and blood urea nitrogen by the Van Slyke (18) urease method. Urinary sugar was determined by the Benedict (19) method and urinary nitrogen by the Kjeldahl method.

On another day a similar procedure was followed, but this time the breakfast consisted of one gram of carbohydrate per kilogram of body weight. This meal was given as glucose or as carbohydrate food calculated to yield this amount of glucose. When carbohydrate was used, specimens were collected for from three to four hours. In several subjects the response to various carbohydrate foods yielding equivalent amounts of glucose was compared with that obtained when the glucose was derived from protein. It is assumed that protein yields, during metabolism, glucose equal to 50 per cent of its weight.

RESULTS

Figures 1 and 2 represent the results obtained from the normal group, showing that the response to ingestion of glucose is the expected one with

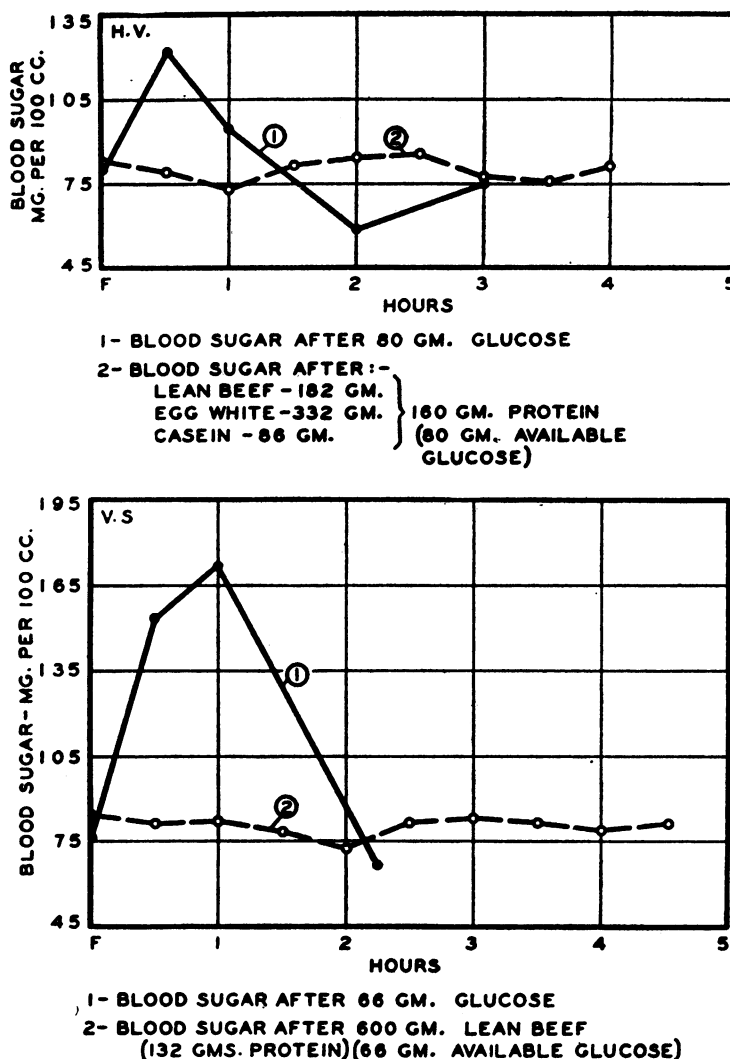


FIG. 1. BLOOD SUGAR CURVES IN NORMAL SUBJECTS, V. S. AND H. V.

the usual variation. When an equivalent amount of glucose is derived from protein, however, the blood sugar curve remains flat. The rising blood urea nitrogen in Figure 2 indicates that protein is being metabolized. During the same period the blood sugar does not rise significantly.

Figures 3 and 4 show the results obtained in two diabetic subjects. A diabetic response to the ingestion of glucose is obtained. The curves after protein ingestion, however, remain essentially flat for an 8 hour period. Again, the rising blood urea nitrogen indicates protein utilization. The other curves show the values obtained after ingestion of equivalent amounts of glucose de-

rived from various carbohydrate foods. These curves resemble to a large degree those obtained after glucose ingestion.

This confirms the recent observations of Wishnofsky and Kane (20) on the effect of equivalent amounts of dextrose and starch on glycemia and glycosuria. A marked glycosuria was found, in our studies, after ingestion of glucose or carbohydrate, while there was none after the protein meal.

Table I presents in quantitative terms the glycosuria found during the experimental period illustrated by Figure 4. When glucose or soluble starch was fed, approximately one-third of the

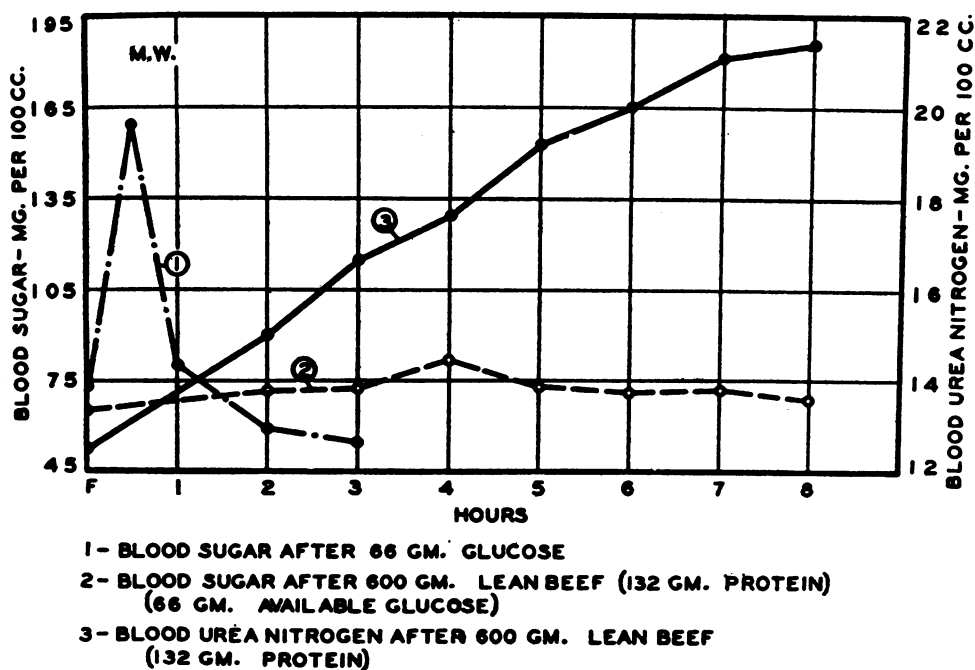


FIG. 2. BLOOD SUGAR AND BLOOD UREA NITROGEN IN NORMAL SUBJECT M. W.

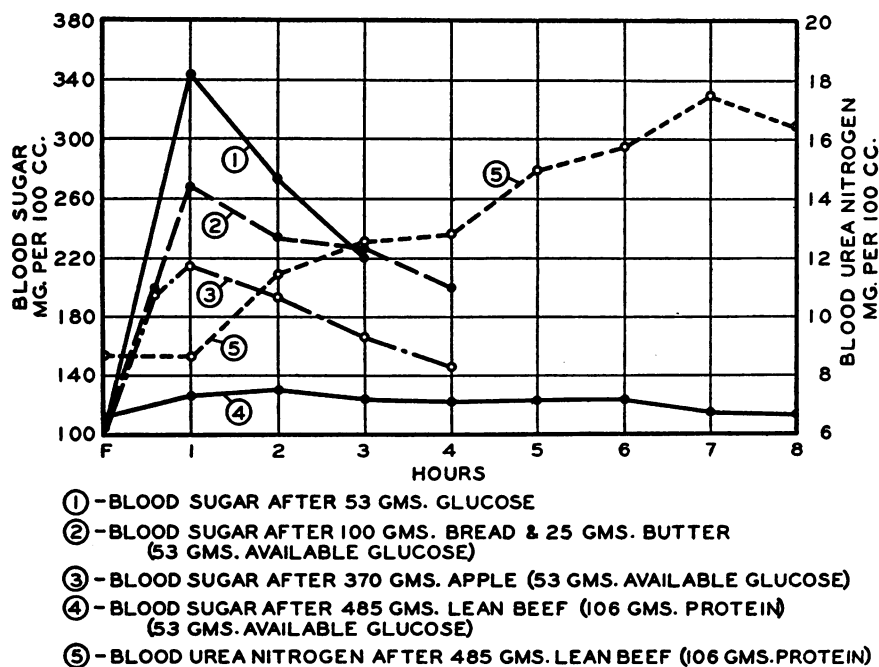


FIG. 3. BLOOD SUGAR AND BLOOD UREA NITROGEN IN CASE II

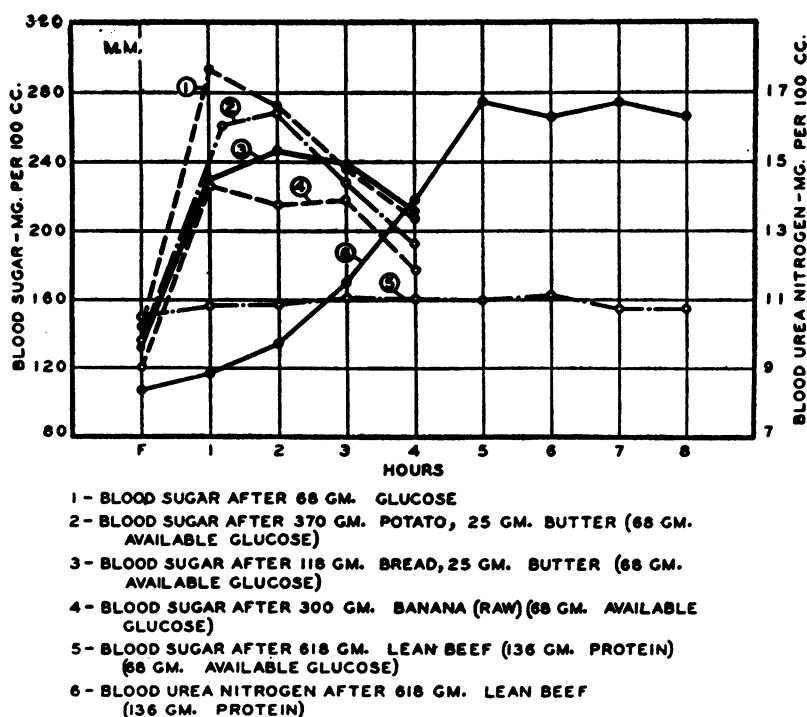


FIG. 4. BLOOD SUGAR AND BLOOD UREA NITROGEN IN CASE I

ingested glucose appeared in the urine in 4 hours. In the case of raw starch (raw fruits) a lesser amount of glycosuria appeared in the four hour period. During the entire 8 hour period following ingestion of 617 grams of lean beef, however, there was no glycosuria.

Detailed data of these and the other subjects studied are seen in Table II. The average maximal increase in blood sugar above the fasting level after ingestion of carbohydrate was 160

mgm. per 100 cc. of blood and was invariably attended by glycosuria. When an equivalent amount of glucose was derived from protein the average maximal increase was 37 mgm. per 100 cc., and little or no glycosuria resulted. It is noteworthy, too, that the small increase in blood sugar after protein feeding appears to parallel the severity of the disease much more closely than does the rise after the ingestion of glucose.

DISCUSSION

These studies demonstrate that ingested protein causes a very much smaller increase in the blood sugar than results from an equivalent amount of glucose or carbohydrate food. We believe that the explanation involves a principle which has received very little attention.

We are accustomed to measure the capacity of a diabetic to dispose of glucose in terms of the total number of grams of glucose released from his diet in 24 hours. The number of grams of glucose that just fails to produce glycosuria is taken to be a measure of the largest amount of glucose that the patient can utilize in a 24 hour period. This conception takes no account of the

TABLE I
Glycosuria of various foods in diet of Case I (M. M.)

Food ingested	Amount	Available glucose grams	Urinary glucose (first 4 hours)	
	grams		grams	per cent of ingested glucose
Lean beef	617	68	0*	0*
Orange juice	200	68	23.0	33.8
Dextrose	47			
Potato (steamed)	370	68	22.5	33.0
Butter	25			
Bread	118	68	23.3	34.2
Butter	25			
Banana, raw	300	68	11.2	16.4

* No urinary glucose during entire 8 hour experimental period.

rate at which the total amount of glucose produced in 24 hours enters the blood stream. Since maximal tolerance without glycosuria depends upon the *rate* at which the body is able to remove glucose from the blood stream by oxidation, deposition as glycogen, and transformation to fat, the time element assumes an importance at least equal to that of total yield of glucose in grams.

Doyon and Dufourt (21) in 1901 first noted that the rate of injection of glucose into the blood stream was a very important factor in the production of glycosuria. They found that a much

greater quantity of glucose could be given per unit of time without causing glycosuria if the rate of injection was slow. Blumenthal (22) in 1905 did an interesting experiment bearing on the influence of the time element upon the production of glycosuria. He ascertained the dose of glucose that could be given intravenously every fifteen minutes without producing glycosuria. A dose slightly in excess of this always produced glycosuria. After having found the maximal dose that failed to produce glycosuria when given every fifteen minutes, he then gave one of

TABLE II
Data from all of the subjects studied

Case number	Weight	Age	Tolerance* (available glucose)	Food ingested				Blood sugar		Glycosuria †		Maxi- mal in- crease in blood urea nitro- gen	Urinary nitrogen (8 hour period)	
				Type	Amount	Pro- tein	Avail- able glucose	Fasting	Maxi- mal in- crease				Fast- ing	During test
	kgm.	years	grams		grams	grams	grams	mgm. per 100 cc.	mgm. per 100 cc.		grams	mgm. per 100 cc.	grams	grams
DIABETICS														
I M.M.	68	21	110	Lean beef Dextrose Bread Butter Potato Butter Banana	618 68 118 25 370 25 300	136	68 68 68 68 68 68	149 144 132 135 120	11 148 114 133 106	0 ++++ ++++ ++++ ++++	23.0 23.3 22.5 11.2	8.4	0.8	5.7
II	53	23	125	Lean beef Dextrose Bread Butter Apple (raw)	485 53 100 25 370	106	53 53 53 53	112 105 108 109	16 240 159 104	0 ++++ ++++ ++	7.8	8.8	1.7	4.4
III	46	16	50	Lean beef Lean beef Dextrose	418 418 46	92 92	46 46 46	87 100 168	33 51 156	0 0 ++++	7.0 10.7	1.4 2.9	7.5 8.7	
IV	60	52	95	Lean beef Dextrose	430 47	94	47 47	89 104	43 132	0 ++++	12.2	6.4		
V	51	47	65	Lean beef Dextrose	480 51	102	51 51	111 132	46 158	0 ++++		8.3		
VI	65	20	50	Lean beef Dextrose	590 65	130	65 65	65 60	57 192	0 +++				
VII	38.2	14	80	Lean beef Dextrose	347 38.2	76.4	38.2 38.2	136 106	26 142	0 +++	4.8	10.5	2.2	6.5
VIII	69	46	300	Lean beef Dextrose Bread Butter	627 69 135 25	138	69 69 69	98 104 102	6 84 41	0 +++ 0		9.8	1.7	5.2
IX	55	17	80	Lean beef Dextrose Bread Butter	500 55 118 25	110	55 55 55	110 79 94	69 151 169	+ ++++ ++++	0.3 9.1 5.4	5.9	3.1	11.8

* Tolerance here is meant to represent the maximal number of grams of available glucose that the diabetic can utilize without glycosuria in a 24 hour period without the aid of exogenous insulin when he is given the usual three diabetic meals a day. (The usual diabetic diet contains about two-thirds of a gram of protein per kilo per day). This implies the absence of infection or other complication known to lower tolerance.

† During the protein test the presence or absence of glycosuria was followed for the entire 8 hour experimental period. After glucose or carbohydrate foods this was followed for only four hours and many subjects continued to have marked glycosuria after four hours.

TABLE II—*Continued*

Case number	Weight	Age	Tolerance* (available glucose)	Food ingested				Blood sugar		Glycosuria †		Maxi- mal in- crease in blood urea nitro- gen	Urinary nitrogen (8 hour period)	
				Type	Amount	Pro- tein	Avail- able glucose	Fasting	Maxi- mal in- crease				Fast- ing	During test
	kgm.	years	grams		grams	grams	grams	mgm. per 100 cc.	mgm. per 100 cc.		grams	mgm. per 100 cc.	grams	grams
X	72	47	80	Lean beef Dextrose Bread Butter	654 72 124 125	144	72 72 72	90 89 66	64 208 211	++ ++++ ++++	4.1 20.0 10.8	9.3	2.7	11.4
XI	66	32	80	Lean beef Dextrose	610 66	132	66 66	101 115	75 163	+ ++++		7.5		
XII	72	29	0 (Total diabetic)	Lean beef Dextrose	615 67	135	67.5 67	125 166	170 174	++++ ++++		11.3	3.4	7.3
XIII	62	49	?	Lean beef Dextrose	560 62	124	62 62	128 142	34 138	0 ++++	9.4		3.2	5.9
XIV	28	10	65	Lean beef Dextrose	254	56 not done	28	120	56	Tr.	0.4	9.3	2.5	5.8
XV	56	16	?	Lean beef Dextrose	509 56	112	56 56	128 81	9 141	0 ++++	4.8		4.1	8.6
NORMALS														
H.V.	73	23	Normal	Lean beef Egg white Casein Dextrose	182 332 86 80	160	80 80	83 80	2 42	0 0				
V.S.	75	24	Normal	Lean beef Dextrose	600 66	132	66 66	84 76	-1 97	0 +				
M.W.	71	24	Normal	Lean beef Dextrose	600 66	132	66 66	66 74	16 82	0 +	8.9			

the series of injections 10 minutes after the preceding one. This provoked glycosuria. The next injection at the regular time in the series failed to produce glycosuria. The crest of the glycemie wave produced by the irregular injection was higher than those which followed the regularly timed injections (every 15 minutes). The renal threshold was thus exceeded even though the total amount of glucose for the whole period was the same. Woodyatt et al. (23) in 1915 made the incisive statement, "Tolerance must be regarded as a velocity, not as a weight. It must be measured and expressed in grams of glucose per kilogram of body weight per hour of time or in other convenient units of weight and time."

It is not surprising, then, that the diabetic, whose capacity to utilize glucose is already damaged, when given his total 24 hour quantity of glucose in the form of three meals over a 10 hour period, has excessive hyperglycemia and glycosuria. Yet his true capacity for disposing of glucose in 24 hours may not have been exceeded. In 1922

Gray (24) reported better results in diabetics when the total quantity of food was divided into six meals than when three meals were given. This could easily be explained on the time factor alone.

In the process of protein metabolism, the complex protein molecule is split in the intestinal tract to amino-acids. These are absorbed into the blood stream and transported to the liver where oxidative deamination occurs. Here the glyco-genic amino-acids are split to form urea and glucose. That this process is a slow one is shown in the charts by the slowly rising blood urea nitrogen. Glucose is, therefore, liberated into the blood stream in this process at a slow and even rate over a prolonged period of time. Under these conditions the diabetic is able to utilize a greater total amount of glucose without glycosuria in the eight hour period. Therefore, the inability of a diabetic to dispose of large quantities of glucose is partially compensated if the glucose is presented for utilization slowly and evenly. There appears,

then, to be some advantage to the diabetic of this slow liberation of glucose from protein foods.¹

CONCLUSIONS

(1) A comparison was made between the glyce-mic and glycosuric responses after ingestion of equivalent amounts of glucose derived from glucose per se, protein and carbohydrate foods in normals and in diabetics.

(2) Within the limits of these studies there is a decided advantage to the diabetic of deriving glucose from protein.

(3) The slow rate of liberation of glucose into the blood stream during protein metabolism is the explanation of the results obtained.

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¹ Studies are now being conducted with prolonged feeding of high protein diets to diabetics to determine the therapeutic significance of these observations.