Glycemic index of foods: a physiological basis for carbohydrate exchange[1-3]

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ABSTRACT To determine the effect of different foods on the blood glucose, 62 commonly eaten foods and sugars were fed individually to groups of 5 to 10 healthy fasting volunteers. Blood glucose levels were measured over 2 h, and expressed as a percentage of the area under the glucose response curve when the same amount of carbohydrate was taken as glucose. The largest rises were seen with vegetables (70 ± 5%), followed by breakfast cereals (65 ± 5%), cereals and biscuits (60 ± 3%), fruit (50 ± 5%), dairy products (35 ± 1%), and dried legumes (31 ± 3%). A significant negative relationship was seen between fat ($p < 0.01$) and protein ($p < 0.001$) and postprandial glucose rise but not with fiber or sugar content. *Am. J. Clin. Nutr.* 34: 362–366, 1981.

KEY WORDS Carbohydrate exchange, dietary carbohydrate, dietary fiber, blood glucose, diabetes

Introduction

Recent work has suggested that the carbohydrate exchange lists that have regulated the diets of many diabetics for over three decades may not reflect the physiological effect of foods. Such factors as food form (1), dietary fiber (2), and the nature of the carbohydrate (3) have been shown to have a marked influence on the postprandial glycemia and allowances cannot be made for these in lists which take into account only the available carbohydrate content of foods.

Currently, very good blood glucose control has been advocated for diabetics to reduce the incidence of long term complications (4). We have, therefore, fed a range of commonly eaten foods to healthy volunteers so that physiological data on the blood glucose response in man could be obtained to supplement tables based solely on chemical analysis.

Methods

Groups of 5 to 10 healthy nondiabetic volunteers drawn from a pool of 34 (21 male, 13 female; 29 ± 2 yr; 111 ± 3% ideal weight), took 62 foods and sugars in random order after overnight fasts. These were compared with an equivalent amount of carbohydrate taken as glucose. Fifty-six foods were given as 50-g carbohydrate portions calculated from food tables (5, 6). Due to the volume of the remaining six (Table 1), only 25-g portions were provided.

Dry grains, legumes, and vegetables were cooked by boiling in a minimum of water with 2 g salt. To increase palatability all meals included tea made with one tea bag and 50 ml milk so that the total volume of the meal was at least 600 ml. Breakfast cereals were taken with 300 ml milk. 120 g skinned, seedless tomato was added to the spaghetti, rice, bread, millet, buckwheat, and legumes.

Glucose tolerance tests (GTT) were taken over the same time as the respective meals in 550 ml tea with 50 ml milk (except for the cereal GTT where 250 ml tea and 350 ml milk was used). One hundred thirty-two 50 g GTT were performed and a further 23 were matched to test meals with lower carbohydrate content, making one GTT for every two to three foods.

In addition, further tests were performed using glu-

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cose, bread, and lentils to allow completion of dose response curves (Fig. 1).

Meals were eaten over 10 or 15 min at set times in the morning after standard activity and meals on the previous day. Finger prick samples were obtained with Autolet lancets (Owen Mumford Ltd., Woodstock, Oxon) at 0, 15, 30, 45, 60, 90, and 120 min from hands warmed between electric blankets to ensure good blood flow. Blood samples were collected into tubes containing 83 μg sodium fluoride and 250 μg potassium oxalate, and stored on crushed ice or frozen at −20°C before analysis for glucose by a glucose oxidase method (7) (Yellow Springs Instruments, 23AM Glucose Analyser).

Results are given as means ± SEM. The area under the 2-h glucose curve was expressed as a percentage of the appropriate mean GTT value. This value was defined as the "glycemic index". The significance of the percentage reduction in glucose area for each food was calculated using Student's *t* test.

Results

In general, the test meals were well received. Some subjects found the volume of garden peas, soya beans, apples, peanuts, and some of the root vegetables difficult to complete in the allotted time. The number of meals where subjects took longer or ate less than the prescribed amount was small (less than 3%).

The glycemic index for the foods is shown in **Table 1**. Great variation between different foods existed within most of the groups with the exception of dairy products. The group mean percentages in ascending order were: legumes 31 ± 3; dairy products 35 ± 1; fruit 50 ± 5; biscuits 60 ± 3; cereals 60 ± 3; breakfast cereals 65 ± 5; vegetables 65 ± 14; sugars 71 ± 20; root vegetables 72 ± 6.

The dose response curves for glucose, bread, and lentils are shown in **Figure 1**. Although there was a marked tendency for all the curves to flatten above 50 g carbohydrate, the differences in terms of glycemic

TABLE 1
Glycemic index: the area under the blood glucose response curve for each food expressed as a percentage of the area after taking the same amount of carbohydrate as glucose (result are means of 5 to 10 individuals)

Grain, cereal products			Vegetables			Fruit		
			Broad beans (25)¶	79 ± 16	(6)	Apples (golden delicious)	39 ± 3†	(6)
Buckwheat	51 ± 10*	(5)	Frozen peas	51 ± 6†	(6)			
Bread (white)	69 ± 5†	(10)				Banana	62 ± 9*	(6)
Bread (wholemeal)	72 ± 6†	(10)	Root Vegetables			Oranges	40 ± 3†	(6)
			Beetroot (25)¶	64 ± 16	(5)	Orange juice	46 ± 6†	(6)
Millet	71 ± 10‡	(5)	Carrots (25)¶	92 ± 20	(5)	Raisins	64 ± 11‡	(6)
Pastry	59 ± 6*	(5)	Parsnips (25)¶	97 ± 19	(5)			
Rice (brown)	66 ± 5†	(7)	Potato (instant)	80 ± 13	(8)	Sugars		
Rice (white)	72 ± 9§	(7)	Potato (new)	70 ± 8*	(8)	Fructose	20 ± 5†	(5)
Spaghetti (wholemeal)	42 ± 4†	(6)	Potato (sweet)	48 ± 6†	(5)	Glucose	100 ±	(35)
			Swede (25)¶	72 ± 8‡	(5)	Maltose	105 ± 12	(6)
Spaghetti (white)	50 ± 8|	(6)	Yam	51 ± 12§	(5)	Sucrose	59 ± 10§	(5)
Sponge cake	46 ± 6†	(5)	Dried legumes			Dairy products		
Sweetcorn	59 ± 11§	(5)	Beans (tinned, baked)	40 ± 3†	(7)	Ice cream	36 ± 8|	(5)
						Milk (skim)	32 ± 5†	(6)
Breakfast cereals			Beans (butter)	36 ± 4†	(6)	Milk (whole)	34 ± 6†	(6)
All-Bran	51 ± 5†	(6)	Beans (haricot)	31 ± 6†	(6)	Yoghurt	36 ± 4†	(5)
Cornflakes	80 ± 6‡	(6)	Beans (kidney)	29 ± 8†	(6)			
Meusli	66 ± 9§	(6)	Beans (soya)	15 ± 5†	(7)	Miscellaneous		
Porridge Oats	49 ± 8|	(6)	Beans (tinned, soya)	14 ± 2†	(7)	Fish fingers	38 ± 6†	(5)
Shredded Wheat	67 ± 10‡	(6)	Peas (blackeye)	33 ± 4†	(6)	Honey	87 ± 8	(6)
Wheatabix	75 ± 10‡	(6)	Peas (chick)	36 ± 5†	(6)	Lucozade	95 ± 10	(5)
			Peas (marrowfat)	47 ± 3†	(6)	Mars bar	68 ± 12‡	(6)
Biscuits			Lentils	29 ± 3†	(7)	Peanuts (25)¶	13 ± 6†	(5)
Digestives	59 ± 7*	(6)				Potato crisps	51 ± 7†	(6)
Oatmeal	54 ± 4†	(6)				Sausages	28 ± 6†	(5)
Rich Tea	55 ± 4†	(6)				Tomato soup	38 ± 9*	(5)
Ryvita	69 ± 10‡	(7)						
Water	63 ± 9*	(6)						

Significance of difference from equivalent glucose load: * = $p < 0.01$; † = $p < 0.001$; ‡ = $p < 0.05$; § = $p < 0.02$; | = $p < 0.002$; ¶ Only 25 g carbohydrate portion given.

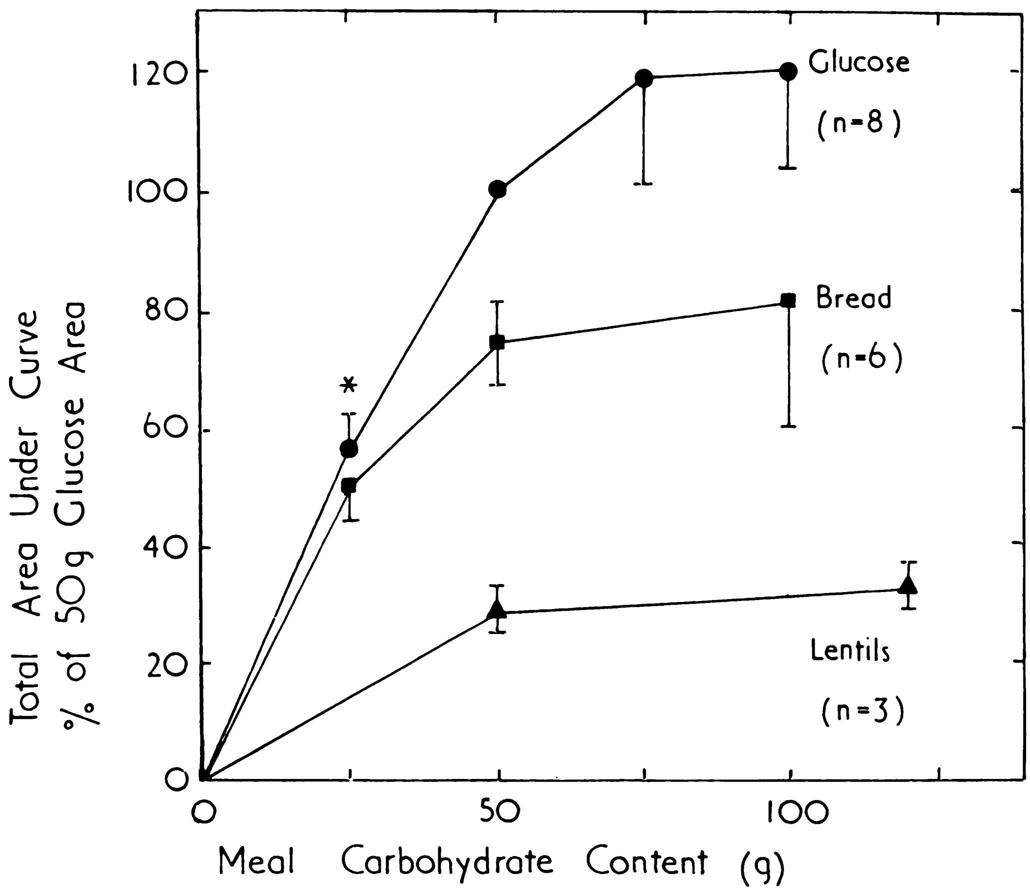

FIG. 1. Dose response curve to glucose, wholemeal bread, and lentils in healthy volunteers. * represents 11 subjects.

index were greater rather than smaller. On the other hand, at 25 g no significant difference was seen between bread and glucose. Thus, the glycemic index of those foods where only 25 g was taken (i.e., broad beans, beetroot, carrots, parsnips and swede) may be artificially high by comparison with 50-g portions.

A significant negative relationship was seen between fat ($r = -0.386$, $p < 0.01$) and protein ($r = -0.523$, $p < 0.001$) content of the foods and the glycemic index (**Fig. 2**). There was, however, no relationship between glycemic index and dietary fiber or sugar content.

Discussion

The results demonstrate great inequality in the extent to which different carbohydrate sources raise the blood glucose and indicate that simple carbohydrate exchanges based on chemical analysis do not predict the physiological response. Great differences were seen not only between but also within most of the food groups, e.g., among cereals the glycemic index for wholemeal bread was 72% while for wholemeal spaghetti it was 42%, and amongst the root vegetables, parsnips were 97% compared with 48% for sweet potatoes.

One striking feature was that the high carbohydrate foods with the lowest glycemic index were those eaten commonly by the poor in Western countries or the inhabitants of large parts of Africa and Asia. They included oatmeal porridge, spaghetti, buckwheat, yam, sweet potato, and dried leguminous seeds.

It is tempting to speculate that positive selection may be operating to eliminate carbohydrate-rich, low glycemic index foods

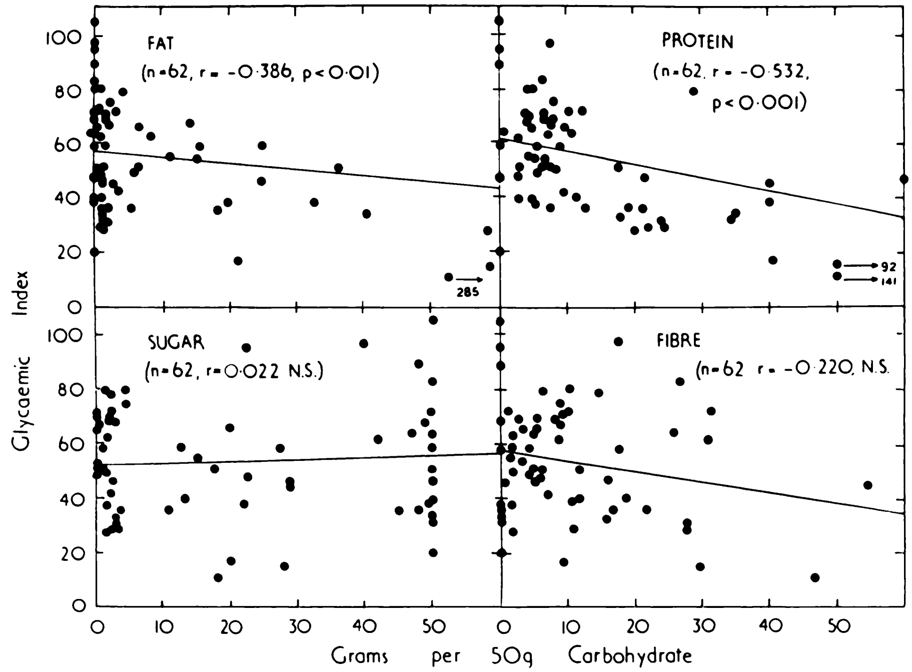

FIG. 2. Relationship of fat, protein, sugars, and fiber content of 62 foods to the glycemic index of 50-g carbohydrate portions.

from affluent Western nutrition. At the same time, certain foods that cause relatively large rises in blood glucose such as rice, millet, and bananas are nevertheless preserved in diets of less developed communities.

Surprisingly, no significant relationship was seen between glycemic index and dietary fiber. This may have been due to the fact that many of the high fiber foods were wheat products and wheat fiber has little effect on blood glucose (2). Indeed, there was little difference between the high fiber wholemeal bread (8), spaghetti and brown rice and their low fiber white counterparts.

The other major high fiber group was the legumes and by comparison with the cereals, they were remarkable in how little they raised the blood glucose. The mean glycemic index for cooked whole grains, breads, spaghetti and porridge was 59% compared with 31% for the legumes ($p < 0.001$). In this context, it is of interest that the dietary fibers, guar and tragacanth, from leguminous plants, are known to flatten the blood glucose rise after 50 g glucose more markedly than other forms of dietary fiber and fiber analogues (2).

Sugar content was not related to blood glucose response even though absorption may have been more rapid. This is presumably due to the very small rise (20%) produced by fructose (9) and reflected in the response to sucrose. On the other hand, both fat ($p < 0.01$) and protein ($p < 0.001$) showed a significant negative correlation with glycemic index. Fat is known to delay gastric emptying (10) and protein stimulates insulin secretion (11). However, it is not clear whether these actions or a direct effect of fat and protein in reducing the digestibility of food were responsible for the negative correlation. The similarity seen here between the blood glucose response to whole and skimmed milk suggests that the action of fat may not be simple. Furthermore the action of protein is not readily explained since addition of cottage cheese to wholemeal bread had little effect on the blood glucose response (D.J.A. Jenkins, T.M.S. Wolever, R.H. Taylor, and A.C. Bowling, unpublished observations).

There are very few studies comparing the effects of different foods on blood glucose. A comparison of glucose, potato, bread, rice, and corn (3) showed that the nature of the starch itself may be of major importance in determining the glucose and insulin response and may be part of the reason for differences seen here between cereals and legumes. Apart from variations amongst individuals taking part in the tests, small differences in the nature of the food or its preparation may also have a great influence on the glycemic response. Nevertheless, in the only trial (12) where a sufficient number of foods (12) was tested to allow comparison, the results correlated significantly with our own for the 10 items common to both studies (glucose, sucrose, fructose, bread, porridge, rice, potato, orange, apple, dried pea: $r = 0.823$, $p < 0.001$). However, the greatest similarities were between the sugars for which, unlike foods, no differences in composition or preparation would exist.

The dose response curves for glucose, bread, and lentils demonstrated that when more than 50 g carbohydrate from any source was taken, the increase in glycemic index was smaller than expected. However, the relative differences between the three carbohydrate sources was, if anything, accentuated indicating that simple increases in meal size would not invalidate tables based on 50-g carbohydrate portions.

We believe, therefore, that classification of foods according to their effects on blood glucose is useful due to the differences in response which exist. The ability to prescribe for diabetics a varied diet of low glycemic index foods is especially appropriate at a time when more emphasis is being placed on "tight" blood glucose control (4) in order to avoid long-term complications. The same range of foods may be useful, both for post-gastric surgery patients who suffer from hypoglycemia after large rises in blood glucose and insulin after meals, and also for patients with carbohydrate-induced hyperlipidemia. On the other hand, patients with reduced absorptive capacity or diabetics on the brink of insulin-induced hypoglycemia may benefit from foods with a higher glycemic index.

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