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SIMPLE VERSUS COMPLEX CARBOHYDRATE USE IN THE DIABETIC DIET

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HISTORICAL PERSPECTIVE

Diet has been recognized as a cornerstone of therapy for diabetes mellitus since the disease was first described. Yet, as one looks at the therapeutic dietary efforts from the early historical accounts to the present, one sees wide swings between different approaches (1). Before the insulin era, diet therapy usually consisted of low calories, but the carbohydrate content was either high or low (Table 1). After the discovery of insulin, controversy continued as to whether the carbohydrate content should be relatively high or low, but carbohydrate-restricted diets seemed to prevail and low-carbohydrate diets were widely used

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in this country for many years. In the early 1970s, the trend reversed, and the American Diabetes Association recommended that the carbohydrate content of the diabetic diet be liberalized (2). This position was supported by observations that high carbohydrate intakes led to improvement in glucose tolerance and insulin sensitivity (3, 4) and was motivated by a desire to reduce total and saturated fat to levels felt to be associated with decreased risk of atherosclerotic heart disease. This position is also supported by data indicating that a change in the percentage of energy supplied as carbohydrate (45 vs 65%) in the diet of normal individuals does not significantly influence the 24-hour integrated concentration of either glucose or insulin (5). However, in this later study, the source of the carbohydrate energy (sucrose vs corn syrup) did have an effect; sucrose-containing diets required lower insulin concentrations to maintain euglycemia than did the corn-syrup-containing diets. Nevertheless, the issue of how much carbohydrate should be in the diabetic diet remains controversial (6, 7).

Currently, most experts suggest that carbohydrate should comprise 50–60% of total calories; however, the more important issue may relate to the type of carbohydrate used. Recommendations about the type of carbohydrate in the diabetic diet have remained somewhat more stable and subject to less controversy through the years. According to traditional thought, simple sugars were to be limited and dietary carbohydrate intake was to come primarily from complex carbohydrates or starches. The assumption was that complex carbohydrates are more slowly digested and absorbed than are simple sugars and that

Table 1 History of dietary composition (relative proportion of carbohydrate and fat calories) used in management of diabetes mellitus[a]

Date	Source	Carbohydrate	Fat
1550 BC (approx.)	Ebergs papyrus (Egypt)	High	
0001	Aretaeus (Asia Minor)	High	
1675	Willis	High	
1797	Rollo	Very low	High
1860–1880	Bouchardat	Low	High
1900–1920	Naunyn; Allen	Low (+ fasting)	Low
1900–1920	von Noorden	High	
1923	Geyelin	High	
1929	Sansum	Normal	Normal
1931	Rabinowitch	Moderate	Low
1935	Himsworth	High	
1940–1960	Kempner; Ernest	High	Low
1940–1970	ADA[b] (US)	Limited	Moderate
1971 to date	ADA (US)	Increased	Reduced

[a]Taken from Bierman, E. L. (1).
[b]ADA = American Diabetes Association.

they therefore cause a flattened blood glucose rise (Figure 1). All complex carbohydrates were considered to have similar effects on blood glucose and insulin responses. However, recent studies, discussed below, demonstrated that there are significantly different blood glucose and insulin responses to different types of simple and complex carbohydrate. As happens in many areas of science, ideas leading to investigation of the physiologic responses to foods were not new. Others had considered and tested these concepts (8, 9), but for some reason the significance of this early research was not realized or accepted and the papers seemed to get lost in the literature. For example, Moskowitz concluded in a 1937 paper (8) that the analyzed carbohydrate content of a food did not correspond with subsequent blood sugar responses, and advised that dietary advice be based on biologic responses to foods rather than on their chemical content. Nonetheless, it is only with the advent of more recent studies, that the old beliefs have begun to crumble.

Perhaps it is the unexpected variability of blood glucose response to different kinds of carbohydrate that accounts for the different opinions on the total amount of carbohydrate allowable in the diabetic diet. It is possible that a variety of different levels of total carbohydrate are consistent with good diabetic control, provided that the types of carbohydrate used are those with less of a glycemic impact. It should be recognized that the amount and type of carbohydrate in the diabetic diet is only one aspect of dietary management. Consistency of diet, activity, and insulin therapy in the person with insulin-

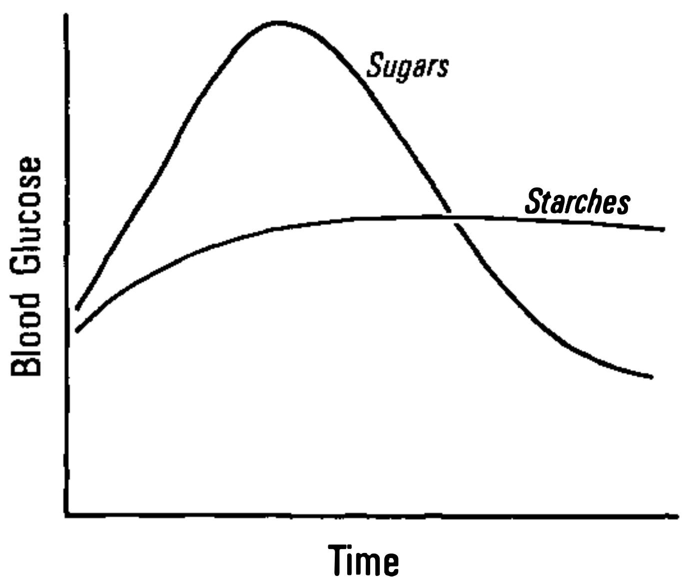

Figure 1 Assumption of complex and simple carbohydrates behaving in predictable ways.

dependent or insulin-treated diabetes, and caloric control in the person with non-insulin-dependent diabetes, are of primary importance.

CARBOHYDRATE IN FOODS—DEFINITIONS, OCCURRENCE, AND USAGE

Digestible Carbohydrate

COMPLEX CARBOHYDRATES The terms complex carbohydrate, polysaccharide, and starch all refer to carbohydrates comprised of a large number of monosaccharide molecules. In general terms, these molecules are either digestible or indigestible (fiber). Complex carbohydrates occur naturally in foods, or are added to foods during production to bring about desired physical characteristics. They play important roles in the structures of plant and animal tissues and the changes that these tissues undergo during cooking. The monosaccharides can be linked together in straight chains (amylose) or in branched chains (amylopectin). Starch is the major constitutent of cereals; of the cereals, wheat, rice, and corn (maize) are used in the greatest quantities (10). Potatoes, taro root, and legumes (including a wide variety of beans and peas) are also rich in starch.

Total carbohydrate content of the diet in the United States has declined during this century. Nearly 500 g of carbohydrate per person per day were available in the early part of the century as compared to 380 g in 1970. Decreased consumption of flour and cereal products was largely responsible for this decline. The decline in total starch over the years is twice as great as the decline in total carbohydrate on a percentage basis because of the increased use of total sugars and, in particular, refined sugars (11).

SIMPLE CARBOHYDRATES Chemically, simple carbohydrates are defined as either monosaccharides or relatively low-molecular-weight polymers (oligosaccharides) of the monosaccharides, and are also referred to as sugars. Sugars occur naturally in foods or are intentionally added to foods during processing or preparation.

Naturally occurring sugars The monosaccharides glucose, fructose, galactose, mannose, and certain pentoses such as xylose, arabinose, and ribose are found in foods, but only glucose and fructose occur in abundance. Those oligosaccharides that occur naturally are usually polymers of glucose, fructose, and galactose in different combinations. While many oligosaccharides are known to occur naturally, only sucrose, lactose, maltose, raffinose, and stachyose occur in abundance. Glucose, sucrose, and fructose occur widely in fruits and vegetables. Lactose is the sugar of mammalian milk. Stachyose occurs in certain foods, such as legumes, that also contain raffinose and sucrose. Stachyose and raffinose are generally believed to be metabolically inert, although there may be some fermentation of these sugars in the lower digestive tract, and they may be a component of the flatus elicited by leguminous foods (10).

Sugars added to foods The sugars that are added to foods are essentially those that already occur naturally in foods. They include crystalline sucrose, fructose, or glucose, as well as sugar syrups prepared by hydrolysis of starch or sucrose (invert) or through the isomerization of glucose syrups (often referred to as high-fructose corn syrups).

CONSUMPTION PATTERNS During this century there has been an almost fivefold increase in world sugar production while there has been only a doubling of the world population (12). However, the sugar consumption patterns of individuals and countries varies considerably, with a high per capita consumption figure of 150 g per day in Iceland and a low of 48 g per day in Romania, Albania, and Greece, according to official statistics (11). When there is an increase in sugar consumption patterns, there is usually a simultaneous increase in fat content. So, in general, the higher the sugar consumption, the higher the fat consumption and the lower the polysaccharide or starch content. Thus, these changes usually result in a decreased content of essential nutrients through the reduced consumption of foods that contain important nutrients as well as energy.

In the United States the total sugar content of the diet increased 25% during this century; the increased use of refined sugar (as distinguished from those sugars occurring naturally in foods) may be responsible for this. An increasingly larger proportion of refined sugar is being used in prepared foods and beverages, with the largest increase in use coming from the sugars used in soft drinks. The per capita consumption of refined sugar in the early 1970s was 102 kg per year or about 130 g per day (11). Of the total sugar content of the diet, over two thirds comes from sugar or syrups; the remainder comes from dairy products and fruits.

Indigestible Carbohydrate

Dietary fiber refers to all components of food (plant polysaccharides and lignin) that are resistant to hydrolysis by the endogenous secretions of the human digestive tract. Each of these components has a complex chemical structure. The water-insoluble fibers, such as cellulose, lignin, and most hemicelluloses, appear to have a major impact on gastrointestinal transit times and fecal bulk, but less impact on plasma glucose and insulin levels or cholesterol metabolism. In contrast, the water-soluble fibers (pectins, gums, storage polysaccharides, and a few hemicelluloses) have little effect on fecal bulk but may influence glucose and insulin levels by as yet not completely understood mechanisms (13–16). The need to separate dietary fiber into its individual components and to evaluate their individual effects is recognized, and as data on the precise fiber composition of foods accumulates, this will be easier to accomplish. In addition, dietary fiber needs to be evaluated on the basis of the mixture of different fibers or "biologic units" that exist within foods (13). Until these are evaluated, some confusion about the effects of dietary fiber on various parameters of health will continue. Nevertheless, associations between certain health factors and total dietary fiber and the food sources of that fiber are still worthwhile (17).

Calculations from average food intakes and from typical meal patterns indicate that the average intake of dietary fiber in the United States is in the range of 20 g per day. However, when the amount of dietary fiber that is available for consumption in the American diet is evaluated, the mean value is in the range of 25–30 g per day (17). Diets that include significant amounts of wheat cereals may contain about 35 g of dietary fiber per day. For comparison, the plantain banana diet typical of Uganda provides about 100 g of dietary fiber per day, and comparative studies report ranges in dietary fiber from 22.8 g per day in Australia to 93.6 g per day in Mexico (17). Many of the modern methods of food processing remove fiber from natural foodstuffs, and it has been suggested (18) that the fiber-depleted starchy food is a diabetogenic factor for susceptible individuals.

METABOLISM OF CARBOHYDRATE

Glycemic Responses to Different Foods

A great deal of interest in the glycemic response to different starches was sparked several years ago. Initial studies at that time with just four different foods (baked potato, boiled white rice, kernel corn, and white bread) found that the particular rice used (a converted rice) had the expected flattened glycemic response pattern, but that potato elicited a blood glucose response not significantly different from that of an equivalent amount of glucose (19). The differences in glycemic response to rice versus potato were even greater when diabetics or patients with impaired glucose tolerance were studied (20, 21). (Mean peak plasma glucose differences between potato and rice were 16, 43, and 48 mg/100 ml in controls, patients with impaired glucose tolerance, and diabetic subjects, respectively). Studies of different simple carbohydrates also demonstrate widespread variations in blood glucose response. Fructose ingestion resulted in a markedly flattened glycemic response compared to glucose or sucrose, both when given alone and when given in test meals to normals, subjects with impaired glucose tolerance, or diabetic individuals (22–25). As with the complex carbohydrates, the difference in glycemic response between the sugars was greater in subjects with diabetes or impaired glucose tolerance (22). Fructose ingestion always led to the least glycemic response, but that response was increased the more glucose intolerant the subject (22). When sucrose and fructose were incorporated into cakes and ice creams, the fructose products elicited lower glycemic responses than did the sucrose products, although, surprisingly, both ice creams elicited attenuated glycemic responses in comparison to the cakes (26). Subsequent studies found that the blood glucose responses to different complex and simple carbohydrate foods vary so greatly that the two groups cannot in general be distinguished on the basis of post-ingestion glycemic excursion (27–30).

Based on these results, it has again been suggested that dietary recommendations concerning blood glucose control be based on the measured physiologic response to food. As one method to accomplish this, Jenkins and his colleagues suggest the use of a glycemic index to classify carbohydrate-containing foods (27). This approach compares the area under the blood glucose response curve for a test food to that of a standard food (Tables 2 and 3) and is expressed as a percentage of the standard food. Many interesting comparisons can be seen in these data. For example, ice cream ingestion results in a glycemic response that is 30–39% that of glucose ingestion (Table 2) whereas ingestion of an equivalent amount of carbohydrate in carrots results in a blood glucose response that is 80–90% that of glucose. As can be seen, a Mars® candy bar has a lower glycemic index than cornflakes or bread in this same table. A subsequent study evaluating the use of ice cream in well and poorly controlled diabetic individuals confirmed again the relatively modest rise in blood glucose levels after ice cream ingestion (31).

Our present knowledge of the glycemic response to different carbohydrates under physiologic conditions is inadequate to predict consistently and accurately the glycemic response to a particular food. Investigators are beginning to examine the mechanisms underlying the differences in postprandial glucose response to different foods. Clearly, the processes of digestion, absorption, and subsequent metabolic responses are more complicated than perhaps previously appreciated. Indeed, recent studies have begun to elucidate which factors are most critical in determining the glycemic response to ingested food.

Factors Affecting Glycemic Response

FOOD FORM The importance of food form to glycemic response is noted in a number of recent research studies. Evaluation of brown and white rice, for example, demonstrated that there is no significant difference in glycemic response between whole white and brown rice; both elicit a flattened glycemic curve (32). However, when the rices were ground into flours, the glycemic responses were both dramatically higher than those caused by the whole rices. Thus, the form of the food markedly changed the glycemic response. (Interestingly, the fiber content did not change). Similar results are seen with whole and ground lentils (33). When orange juice (devoid of most of the orange's fiber) is ingested and the glycemic response to it is compared to that of a whole orange, peak glucose responses are not significantly different. However, later glycemic values (130–180 min) are significantly lower to the juice and are associated with subsequent feelings of more hunger (34).

There is also no significant difference in glycemic response between whole-meal bread (high fiber) and white bread (low fiber) (35) or between white or

Table 2 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[a]

100%	50–59%	40–49%
Glucose	Buckwheat	Spaghetti (whole-meal)
	Spaghetti (white)	Porridge oats
80–90%	Sweet corn	Potatoes (sweet)
Cornflakes	All-bran	Beans (canned navy)
Carrots	Digestive biscuits	Peas (dried)
Parsnips	Oatmeal biscuits	Oranges
Potatoes (instant mashed)	"Rich Tea" biscuits	Orange juice
Maltose	Peas (frozen)	
Honey	Yams	30–39%
	Sucrose	Butter beans
70–79%	Potato	Haricot beans
Bread (whole-meal)		Blackeye peas
Millet		Chick peas
Rice (white)		Apples (golden delicious)
Weetabix		Ice cream
Broad beans (fresh)		Milk (skim)
Potatoes (new)		Milk (whole)
Swede		Yogurt
		Tomato soup
60–69%		
Bread (white)		20–29%
Rice (brown)		Kidney beans
Muesli		Lentils
Shredded Wheat		Fructose
"Ryvita"		
Water biscuits		10–19%
Beetroot		Soya beans
Bananas		Soya beans (canned)
Raisins		Peanuts
Mars Bar		

[a]Data from normal individuals (Ref. 27).

Table 3 Glycemic index for individual foods in diabetic patients (From Ref. 28)

Meal	Number of Patients	Glycemic index[a]
Whole-meal bread	6	102 ± 6
Whole-meal bread and cottage cheese	9	100
Whole-meal bread and milk	6	108 ± 5
White bread	6	102 ± 5
Half whole-meal bread and half cottage cheese	5	58 ± 4
Whole-meal bread, butter, and marmalade	5	88 ± 4
White rice	6	80 ± 5
White spaghetti	6	60 ± 9
"All bran"	6	72 ± 5
"Cornflakes"	7	123 ± 5
Porridge oats	6	98 ± 9
Digestive biscuit	6	79 ± 9
Banana	6	83 ± 7
New potato	6	77 ± 11
Kidney beans	7	66 ± 7
Romano beans	6	65 ± 7
Red lentils	7	44 ± 7
Blackeye peas	6	71 ± 5
Chick peas	7	47 ± 9

[a]Results expressed as mean ± SEM.

brown spaghetti (36). But when white flour is given in the form of spaghetti, blood glucose levels rise much less than when the same amount of white flour is given in the form of bread, which again suggests that food form is important in determining glycemic response (37). In the case of whole and ground rices it may be that the low ratio of surface area to starch limits access to intestinal hydrolytic enzymes. Likewise, the greater glycemic response seen following ingestion of wheat bread as compared to wheat pasta, both similar in starch/protein ratios, may be due to food form. It has been suggested that the compact nature of the starch in pasta (a "hard" wheat) reduces accessibility of the starch to digestive enzymes (36). Other possibilities that come to mind are the chain length of the individual starches or the amount of amylose versus amylopectin components of a starch. At issue would be whether a longer starch chain or a branched- versus straight-chained starch would be more or less rapidly digested and absorbed. One study of the effect of saccharide chain length on glucose absorption and metabolic response found that the chain length did not have an effect (37), and suggested that the dietary form of the starch was the critical element. A study comparing rices with high and low amylose content, however, found that ingestion of rice with high amylose content resulted in lower and flatter glycemic response patterns than rice with no amylose (38). The authors suggested differential enzymatic hydrolysis of the high-amylose rice or some other factor such as lipid/starch complexes as being responsible for a delay in digestion and absorption.

The physical form of food appears to be a major determinant of the rate at which the starch is hydrolyzed. The fiber in some foods may affect hydrolysis rate by forming a physical barrier to hydrolytic enzymes, but the fiber must be in its natural form in order to be effective.

RATE OF MEAL INGESTION When high-glycemic, carbohydrate-containing foods are ingested slowly, the postprandial glucose excursion is blunted, mimicking the pattern seen when low-glycemic carbohydrate is given. Thus, bread fed continuously at an even rate (small divided portions given over four hours) results in a blood glucose pattern similar to that of lentils fed in a 15–20-minute period of time (39). Similar effects are seen when glucose is sipped over a 4-hour period as when the glucose is given in a short period of time along with guar (40). When the glucose load during an oral glucose tolerance test is given quickly (1 min) or slowly (10 min) the more rapid ingestion results in an earlier rise in blood glucose, insulin, and C-peptide levels (41). Later (90–135 min) the blood glucose concentrations are higher after the slow intake. Thus, rate of intake of a meal may in part control subsequent metabolic responses.

COOKING Cooking alone can alter the glycemic response to a food. Studies indicate that ingestion of raw starches such as purified amylopectin or corn starch causes much flatter glycemic and insulinogenic responses as compared to cooked forms of these starches (42, 43). Cooking of milk has also been reported to increase the blood glucose response to its ingestion (44). Increasing the percentage of raw food in the diet was proposed in the past as an aid to the control of blood glucose and a means of reducing insulin requirements (45). It is possible that the cellulose cell walls of raw foods are not completely disrupted in chewing, impairing access of digestive enzymes to the starch within the cell. Cooking swells the starch within the cell, bursting the cell wall, and potentially makes the starch more available for digestion. Alternatively, some foods contain natural amylase inhibitors that may be inactivated by cooking or other aspects of food processing or preparation (46).

In vitro studies of starch hydrolysis rates indeed indicate that uncooked carbohydrates are not as readily digestible as are their cooked counterparts. Thus, for example, cooked rolled oats were approximately 69% hydrolyzed after 30 minutes while raw rolled oats were only 19% hydrolyzed by that time (46). Likewise, stone-ground whole-meal flour is hydrolyzed more slowly than roller-milled white flour, perhaps because of the heat that develops during milling. In feeding studies, legumes that are boiled, blended, and dried for 12 hours produce larger increases in blood glucose than do legumes that are only boiled for 20 minutes, boiled 20 minutes and blended, or boiled for one hour (47). Thus, if maximal benefit (lowest blood glucose level) is to be realized from low-glycemic foods, attention must be paid to the amount of heat, and particularly in the case of lentils, to the amount of dry heat used in their preparation. However, at least one study points out that cooking does not always increase digestibility, as the postprandial glycemic responses after ingestion of raw and cooked carrots were not significantly different, in contrast to the responses to raw and cooked potato (48).

Although more definitive studies are needed, recommendations regarding cooking methods may prove useful in controlling blood glucose.

THE EFFECT OF ONE MEAL UPON SUBSEQUENT MEALS When carbohydrates are given in a slowly digestible form, not only are glucose responses reduced following the meal during which the carbohydrate is ingested, but carbohydrate tolerance to subsequent standard meals is also improved (39, 40). Thus, breakfasts containing lentils (associated with flattened glycemic and insulin responses) are followed by significantly flatter glycemic responses to a standard lunch as compared to breakfasts containing identical amounts of carbohydrate in the form of bread (39). A similar effect was reported using the dietary fiber guar (40). When guar is added to an initial glucose load, it improves the tolerance to a subsequent guar-free glucose load (taken four hours later).

ANTI-NUTRIENTS Comprehensive analysis of the anti-nutritive constituents of foods, such as natural enzyme inhibitors, lectins, phytates, tannins, starch/protein and starch/lipid interactions, is lacking. However, leguminous seeds, which elicit a very low glycemic response, are also one of the richest sources of such anti-nutrients. Some of the anti-nutrients reduce the rate of carbohydrate digestion and absorption (49, 50). While it is assumed that most starches are completely absorbed in health, and many studies confirm that assumption, at least one study suggests that nearly all normal subjects fail to absorb an appreciable portion of white, all-purpose, wheat flour, possibly because of starch/protein interactions (51). In this regard, it was shown that removal of wheat protein from bread and pasta increases carbohydrate digestibility. Thus, starch/protein interactions appear critical. Studies of legumes indicate that the malabsorption that occurs after their ingestion is only minor, not great enough to account for their markedly flattened blood glucose responses (52, 53). A range of enzyme inhibitors occur naturally in foods and to some degree their activity may survive processing and cooking. This indicates once again why chemical analysis, even when available, does not predict the physiologic response to a food.

OTHER FACTORS Several other factors affecting the metabolic response to foods can also be postulated and have been suggested. For example, ingestion of a sugar in the liquid part of a meal results in a different metabolic response than when it is ingested in the solid part of a meal (54). This may be because when liquids are ingested along with solid foods they empty more rapidly from the stomach into the small intestine. The presence of fat and protein in a food or meal may also affect glycemic response. While fat is associated with decreased gastric emptying times, addition of fat to a carbohydrate load does not necessarily alter its glycemic effect (55). The issues are not simple. Some studies suggest that fat has no impact on blood glucose responses; others (56, 57) show a reduction in postprandial blood glucose responses when saturated fat (butter) is ingested with carbohydrate, without a corresponding decrease in insulin response. Addition of protein to a carbohydrate load can decrease its glycemic effect (55). Addition of both fat and protein to test carbohydrates resulted in decreased glycemic responses and increased insulin responses, but these effects may have been entirely due to the addition of the protein (22, 42). However, the effect of adding protein and fat to isolated sources of carbohydrate (generally given in liquid form) may be quite different from the interactions of protein, fat, and carbohydrate in an intact food. Nevertheless, it should be recognized that not only carbohydrate, but also protein, and perhaps in some situations, fat, can affect the blood glucose response to a food.

The Metabolic Effects of Fiber

In recent years claims have been made that dietary fiber improves many clinical conditions including abnormal glucose tolerance or diabetes. During the past century in the United States, the fiber content of the diet has declined and studies demonstrate that diets containing higher fiber and carbohydrate levels are associated with lower blood glucose and serum lipid levels. While it seems possible that differences in fiber content could be responsible for the differences seen in glycemic response between foods, studies previously discussed indicate that fiber content alone does not appear to be the major factor in determining subsequent metabolic response (32–36) to cereal foods. When fiber does have an effect, it is when it is present in the natural form, creating a physical barrier that limits access of hydrolytic enzymes to the starch. The lack of an effect of fiber in cereal foods on the postprandial blood glucose levels is consistent with studies of isolated, purified fibers added to foods. These studies demonstrated that water-insoluble fibers such as those found in whole-meal bread or brown rice in general do not have a significant impact on postprandial glycemic responses to carbohydrate loads (58, 59). However, water-insoluble fibers may contribute to long-term control of blood glucose through some mechanism other than the acute reduction of blood glucose level. On the other hand, isolated, viscous, water-soluble fibers, such as guar and some pectins found in fresh fruits and vegetables, have greater influence on the rate of glucose absorption in vivo and are the predominant fibers in the legume family of foods eliciting exceptionally low glycemic responses (30) (see Tables 2 and 3). However, the correlation between glycemic response and fiber content of foods that are naturally high in viscous fibers is not always consistent (27, 34, 60).

While high-carbohydrate, high-fiber diets have been shown to improve diabetic control and to allow reduced insulin or oral hypoglycemic agent dosages (61, 62), it has been difficult to quantify the contribution of fiber to the glycemic results. Diets high in simple carbohydrate were shown to improve insulin action (3, 4) and were associated with improved blood glucose control without high fiber intake. Anderson (63) also found that high-carbohydrate, low-fiber diets allowed reduced insulin doses for diabetic subjects, reductions similar to those observed on high-carbohydrate, high-fiber diets. However, other researchers (64–66) found that increases in carbohydrate content of the diabetic diet without concomitant increases in fiber are not associated with overall improvement in blood glucose or lipid control. The variability in effects among different diets may be due in part to particular food choices rather than to the absolute fiber levels attained. Thus, it is possible that the effect of high-carbohydrate, high-fiber diets on blood glucose control is largely due to factors other than just the absolute fiber content of the diet. Indeed, it has been suggested (66) that dietary fiber primarily lowers postprandial glycemia while digestible carbohydrate primarily lowers basal glucose levels.

As previously mentioned, fiber can be given in purified form as an additive to the diet. Results from studies of fiber additions to meals or foods reflect, however, several factors. (*a*) How was the fiber incorporated into the diet? It must be mixed with the food to have an effect (67, 68). (*b*) What was the percentage of carbohydrate in the diet? Fiber is most effective when the percentage of total carbohydrate in the diet is high (69). (*c*) What type of fiber was used? Soluble, viscous fibers such as guar have effects on postprandial blood glucose, while insoluble fibers such as many cereal brans seem to have more chronic effects on blood glucose (68–73). (*d*) What was the viscosity of the fiber? Those fibers with low viscosity (i.e. low methoxylated pectin) have a poor acute ability to lower blood glucose (52, 74). Although certain viscous, soluble fibers lower glycemic responses when added to foods, use of such fibers is generally not practical because of their unpalatability and gastrointestinal side-effects.

Many questions about the glycemic effects of fiber remain, not the least of which is defining the amount of dietary fiber in foods. Even attempting to estimate the amount of fiber in a prepared food from fiber analysis of the raw food may not be appropriate. But it should be recognized that even if there were no correlation at all between the fiber content of foods and the degree of postprandial glycemia, this would not mean that the fiber content of foods is not important. Fiber does appear to lower blood lipids (75, 76), improve chronic glycemic responses (61, 62, 69, 77), and improve bowel function. In addition, there is suggestive evidence that higher-fiber diets are associated with lower incidence rates of certain cancers. Thus, fiber may be one of a number of factors that affect blood glucose control we well as other aspects of health. While recommendations to increase natural fiber content of the diet may not be essential for controlling blood glucose levels, increased dietary fiber may provide definite benefit in a total dietary program. The degree of fiber supplementation necessary to provide such benefit, however, is not well defined.

In Vitro Starch Hydrolysis Rates and In Vivo Glycemic Responses

In vitro studies of digestibility using human digestive juices provide a unique means of evaluating the differences in foods. Such studies indicate that when a variety of natural foods are incubated in vitro with a fixed amount of digestive enzymes, an excellent relationship is observed between the rate at which foods release their products of carbohydrate digestion in vitro and the degree to which the same foods raise blood glucose levels in humans in vivo (78, 79). For example, in vitro studies of legumes reveal that they are digested less rapidly than are other carbohydrate foods, and this corresponds with the markedly flattened glycemic responses that they induce (80). These studies indicate that the rate of intestinal hydrolysis of starch is an extremely important determinant of the metabolic responses to a particular starch (78). It is possible that glycemic response can eventually be predicted from the rate at which a food is digested in vitro, which would eliminate the need for invasive techniques in the study of food digestion and glycemic potential.

THE CONCEPT OF GLYCEMIC INDEXING

The suggestion has been made that recommendations regarding carbohydrate usage in diets aimed at controlling blood glucose levels be based on the physiologic response to foods rather than on the chemical content (see Figure 2). Dr. David Jenkins and his colleagues at the University of Toronto suggested the use of a glycemic index, as was previously discussed (27, 28).

The relative glycemic response to different foods in diabetic patients is qualitatively similar to those in normals, although the magnitude of the response is obviously much greater in the diabetic individuals. Thus, small differences between foods ingested by nondiabetic individuals may be magnified in diabetic individuals. However, when the total diet is assessed, glycemic differences among foods may be dampened to such a degree that clinically significant effects may not be seen. Ultimately, the relative benefit of diets based

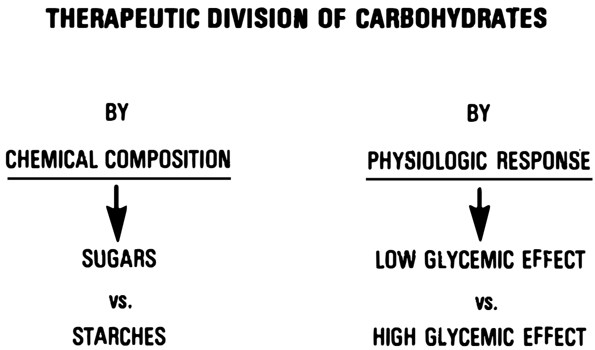

Figure 2 Therapeutic division of carbohydrates.

on glycemic responses, as compared to other methods, must be evaluated by prospective, clinically relevant investigations. In addition, when assessing clinical benefits, the potential for positive dietary impact on other health parameters must also be considered. A desirable effect on serum lipids, for example in itself could provide benefit (81).

At this point it is clear that high-carbohydrate, high-fiber diets that use a large percentage of foods with low glycemic effect are associated with improved blood glucose control (61, 62). Such results suggest that when low-glycemic foods are chosen correctly, significant beneficial effects will be seen. However, researchers cannot yet consistently and accurately predict the blood glucose response to foods that have not been previously tested or ones that are prepared in different ways or combined with other foods. It may be some time before patients can do such selecting from accurate tables containing a large variety of foods.

There is much left to be learned. We are only beginning to discover the complex nature of the relationship between food ingestion and metabolic response. Current research provides new directions, but not the final answers. Nevertheless, change is already happening on an individual basis. Many persons with diabetes are currently monitoring their own blood glucose levels to assess the control of their diabetes. This technique puts the individual in a position to test his own responses to foods, as they are eaten, and along with his physician or health educator, determine his own most effective diet. He can then tailor his own diet to one that elicits the lowest glycemic response. While a person must do this keeping in mind nutrient content of foods and other physiological or metabolic needs, such as a need to reduce total and saturated fats, it does put patients in the position of constructing a diet that is effective and to their liking. It puts them in charge, and it casts the professional in the role of helping interpret individual response data and teaching basic nutritional concepts and diabetes management principles. As science progresses, comprehensive and accurate tables detailing the expected physiological response to foods can, it is hoped, be designed.

It is important to distinguish between Type I or insulin-dependent diabetes and Type II or non-insulin-dependent diabetes in terms of dietary goals and modifications (Table 4). In both situations, dietary modifications are aimed at normalizing blood glucose and correcting existing lipid abnormalities, but in Type I diabetes this is accomplished by developing a standardized daily regimen of food intake considering the timing of meals in relation to insulin ingestion, caloric content, and levels of physical activity. Since individuals with Type I diabetes are usually young and lean, they must consume the calories necessary for normal growth and development. Between 80 and 90% of individuals with Type II diabetes are overweight, and the usual first principle of therapy is the restriction of calories to effect weight loss.

It has been recommended that all persons with diabetes limit their intake of glucose or glucose-containing simple sugars, decrease their intake of dietary fat and cholesterol, and through the liberal consumption of complex carbohydrate, increase their use of fiber-containing foods. While new research suggests that additional manipulation of food choices may allow even better dietary management, i.e. improve upon the above recommendations, this must for now be achieved on an individual basis. Much research is still necessary before any comprehensive answers to the question of how different foods affect blood glucose will be available.

CONCLUSIONS

It becomes clear that we need to work toward a system that allows us to make dietary recommendations on the basis of the expected biologic response to a food. As previously noted, Jenkins et al (27, 28) suggested the use of a glycemic index to characterize the blood glucose response to foods (Tables 2 and 3). Such a categorization system could eventually be a useful tool for dietary planning, but it is still a prototype at this point and the final system will

Table 4 Diet goals in diabetes[a]

Type I (IDDM)	Type II (NIDDM)
Develop a standardized daily regimen of food intake, considering timing of meals, diet compostiion, caloric content and level of physical activity.	Restrict calories to effect weight loss if necessary or to maintain ideal body weight.
Consume calories necessary for normal growth and development.	

[a]Aimed at normalizing blood glucose and correcting existing lipid abnormalities.

depend upon the elucidation of the underlying mechanisms of the observed differences among foods. Once the underlying mechanisms are determined, the chemical composition of food could possibly be used to predict glycemic responses and allow a means of food categorization. Even though this has not yet come about, the potential exists for improving our ability to control blood glucose through dietary means. However, dietary advice must take into account the caloric, nutrient, fat, and cholesterol content of foods, and must, in the end, be aimed at achieving optimal overall health. Information about glycemic effects of foods are only one criterion of food selection.

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