

Dietary Fiber in the Management of Diabetes

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It generally is accepted that a diet high in fiber, particularly soluble fiber, is useful in the management of the plasma glucose concentration in individuals with diabetes. This is one of the reasons several national diabetes associations have recommended that diabetic individuals ingest a diet high in fiber-containing foods. However, more recent data obtained in carefully controlled studies with more definitive end points, indicate this may not be the case. It has been shown clearly that addition of water-soluble, gel-forming fiber in the form of guar gum and perhaps gum tragacanth to an ingested glucose solution or to a mixed meal will reduce the expected rise in glucose concentration. This has been demonstrated in both normal subjects and subjects with IDDM and NIDDM. However, it is only observed when large amounts of fiber are added. The fiber also must be mixed with the administered glucose or food. Other less viscous soluble fiber sources such as the pectins and psyllium powder are not effective. In long-term, well-controlled trials, guar gum, pectin, beet fiber, or cereal bran fiber ingested with meals has been of little or no value in controlling the plasma glucose concentration in individuals with NIDDM. Several studies have been conducted in which a high-carbohydrate diet has been reported to reduce the plasma glucose concentration. In these diets, foods with a high fiber content have been emphasized. In general, they were not well controlled, and several confounding variables such as weight loss, decreased food energy intake, different food sources with potential for differences in starch digestibility, and

decreased dietary fat content were present. Thus, it has not been possible to determine if dietary fiber was playing a significant role. The results of studies in which specific, defined fibers have been added to the diet would suggest that the naturally occurring fiber in foods is likely to play only a minor role. *Diabetes* 42:503–508, 1993

In 1987, the ADA published a position statement entitled "Nutrition Recommendations and Principles for Individuals with Diabetes Mellitus: 1986" (1). In that statement it was suggested that the fiber content of the diet be increased. One of the justifications for this recommendation was that soluble dietary fiber improves CHO metabolism. The meaning of this statement was not made clear. However, subsequently in that publication it was stated that in individuals with diabetes "careful attention must be paid to insulin dose, because hypoglycemia can result if there is a radical change in fiber intake." The implication of this statement is that a large increase in dietary fiber results in a profound decrease in the blood glucose concentration and/or a striking increase in insulin sensitivity.

Over the past several years, numerous scientific publications dealing with the issue of dietary fiber and blood glucose control in diabetic individuals have appeared in the literature, including several that have appeared since the ADA position statement was published. In this report, I would like to review much of this literature and offer my own perspective regarding the state of affairs at present. Most of the studies in the literature have been conducted with NIDDM subjects. Therefore, the focus will be on these people.

That dietary soluble fiber in large amounts can result in a modest decrease in total and LDL cholesterol in people with (2–4) or without diabetes (5–7) has been demonstrated in several excellent studies and is not an issue. It will not be discussed further.

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IDDM, insulin-dependent diabetes mellitus; NIDDM, non-insulin-dependent diabetes mellitus; ADA, American Diabetes Association; LDL, low-density lipoprotein; CHO, carbohydrate.

TABLE 1
Water-soluble and water-insoluble food fiber

Food fiber	
Water soluble	Water insoluble
Hemicelluloses	Celluloses
Pectins	Unidentified polysaccharides high
Gums	in pentose sugars
Mucilages	Resistant starch
Carageenan	
Agar	

DEFINITION OF DIETARY FIBER AND CLASSIFICATION

The term dietary or plant fiber generally refers to the non-starch polysaccharides and lignin present in plant products. They are not digestible or are very poorly digestible by the enzymes present in the upper gastrointestinal tract. These substances are classified in many ways. However, from a metabolic standpoint, it is most useful to classify them as either water soluble or not water soluble. As indicated later, the ability to form viscous gels also may be important.

Only the water-soluble fibers have been reported to have a significant effect on the postmeal glucose concentration and on the serum cholesterol concentration (Table 1). In general, they are fermented by bacteria present in the colon and result in the formation of short-chain fatty acids and carbon dioxide, methane, and hydrogen gas. An undetermined proportion of the short-chain fatty acids are absorbed and may be metabolized in the liver or elsewhere (8–10). They play an important functional role in colonic epithelial cell metabolism (8). Whether they have significant metabolic effects in other organs remains uncertain.

The sources of soluble fiber most widely studied have been the pectins, guar gum, psyllium hydrophilic muciloid powder, and oat bran. Studies using these sources will be the focus of this review.

To put the amounts of dietary fiber used in these studies into perspective, it is estimated that the total fiber content of the diet in the U.S. is ~3–23 g daily (11). The soluble fiber content is not known.

BACKGROUND

The possibility that plant-derived fibers may be useful in the management of blood glucose in individuals with NIDDM was apparently first suggested in 1976 by Dr. James Anderson in the U.S. and Dr. David Jenkins in the U.K. Dr. Jenkins and his colleagues also have been responsible for many of the fundamental investigations in this field.

Dr. Anderson et al. (12) reported that a diet high in CHO and in foods containing a large amount of dietary fiber resulted in an improvement in blood glucose control in patients with diabetes. In some cases, the need for insulin was completely eliminated. Based on their results, they suggested that a high-CHO, high-fiber diet may be useful in the treatment of diabetes.

This was not a well-controlled study, was of short duration, and a decreased food energy intake and weight

loss may have been as important as the type of diet used. These authors later reported similar results in another study in which a high-CHO, high-fiber diet was used (13). In this study, they pointed out that it was likely to be the high CHO content and not the naturally occurring dietary fiber that played a significant role in the results obtained. In addition, review of the data suggests that a modest weight loss or reduced amount of food energy could have played a role in this study. The fasting glucose concentration in individuals with NIDDM is very sensitive to a reduction in food energy (14).

In 1976, Dr. Jenkins et al. (15) reported the results of a study in which 11 subjects with diabetes (8 NIDDM, 3 IDDM) ingested a mixed breakfast meal (the composition of which was not provided in the publication). On one occasion, 14 g guar gum powder and 10 g pectin were added. On another occasion, these non-starch polysaccharides were not added. Addition of fiber clearly resulted in an attenuated rise in glucose and insulin concentrations (15). These data suggested to the authors that dietary fiber may be useful in the dietary management of diabetes.

SOLUBLE FIBER EFFECT ON GLUCOSE ABSORPTION

The smaller rise in glucose concentration when guar gum was added to a mixed meal could have been attributable primarily to an impaired digestion of the CHO-containing foods or to a slowed or impaired absorption of the resulting glucose. To distinguish between these possibilities, the effect of guar gum added to an ingested glucose solution was studied. A rather striking flattening of the glucose rise was observed in normal subjects (16).

To further demonstrate that added guar gum could impair the absorption of water-soluble substances, xylose was added to the ingested glucose solution. Xylose is a poorly absorbable and poorly metabolizable pentose. The absorbed xylose is excreted in the urine largely unchanged. Addition of guar gum modestly reduced the absorption rate of the xylose as reflected in the quantity of xylose appearing in the urine at 2 h after the solution was ingested (16).

Subsequently, Holt et al. (17) used the appearance of glucuronidated paracetamol (acetaminophen) in the urine as an index of intestinal absorption. They more clearly demonstrated an impairment in absorption rate when a large amount of guar gum and pectin were added to ingested orange juice containing paracetamol. Paracetamol is readily absorbed from the intestine, is largely glucuronidated in the liver, and then is excreted in the urine.

Because guar gum appeared to impair glucose absorption and also was known to form a very viscous gel when added to water, Jenkins et al. (16) considered the latter property to be potentially important mechanistically. To test this hypothesis, they correlated the viscosity of the gel formed when a fiber is mixed in water with the effect of that fiber (12 g) on the glucose rise after ingestion of 50 g glucose in normal subjects. In general, a correlation existed between the two. That is, the more viscous the gel formed the greater the effect on glucose rise when fiber

was mixed in a glucose solution. Guar gum formed the most viscous solution by far of those studied. Guar tragacanth formed the next most viscous gel. Only these fibers attenuated the rise in glucose concentration and extended the time required for the glucose to return to a fasting value. The viscosity of a pectin solution was considerably less, and it did not affect the glucose rise.

Bran, methylcellulose, and cholestyramine, all of which adsorb water but do not increase the viscosity (form gels), had only a modest effect on the glucose rise and did not delay the return of the glucose concentration to the fasting value.

Lactulose also was added to the glucose solution as an estimate of the transit time from the stomach to the colon. Review of the data suggest that only guar gum and perhaps gum tragacanth caused a significant delay.

MECHANISM OF ACTION

If viscous gels result in a delayed glucose absorption, the next question is how do these gels diminish the rate of glucose absorption after a glucose load or ingestion of a mixed meal?

Several possibilities have been considered. They include 1) an effect on gastric emptying; 2) an effect on the diffusion of glucose toward the brush border of the intestine; 3) a change in the unstirred layer adjacent to the mucosa in the intestinal lumen; 4) an effect on the convective transfer of both glucose and water toward the brush border; 5) an effect on the rate of enzymatic digestion of foods in the intestinal lumen; and 6) an effect on the release of regulatory gut hormones into the circulation; that is, the release of hormones that regulate the motility and secretory activity of the stomach and intestine and the secretory activity of the pancreas.

An effect on gastric emptying rate does not appear to be mechanistically important. A soluble fiber-induced slowing of gastric emptying for both liquids and solids (17–20) has been demonstrated by numerous investigators, but there was little correlation with an effect on the glucose rise (21–23) or with the viscosity of the solution formed by the gels. It was suggested that the so-called unstirred layer is increased, and that glucose diffusion is affected (24). However, more recent data indicate that this is not likely to be the case (26). The major effect on the glucose absorption rate of a very viscous gel such as guar gum is an impairment in the convective movement of both glucose and water in the intestinal lumen toward the absorptive surface of the intestine (25,26). The convective movement of the two is facilitated by the mixing action of the intestinal motor activity (25,26). That is, the glucose trapped in the gel matrix must be squeezed out with associated water before the glucose can be absorbed. It also is possible that some impairment in digestive enzymatic activity in the lumen, and an alteration in hormonal secretion by cells in the gut mucosa are playing a role (21,27). A reduced gut motility as manifest by a delayed transit time (16) also may contribute.

In addition to guar, numerous other water-soluble food fiber sources have been studied by other investigators. Oat gum, when mixed in a glucose solution, reduced the

expected plasma glucose rise, and the reduction was similar to that observed when the same amount of guar gum (14.5 g) was added to the glucose solution. The viscosity of an oat gum solution approaches that of guar but is reported to be more palatable (28). Pectin, psyllium powder, and soy polysaccharide had little or no effect on the glucose rise after glucose ingestion (29–35) (Table 2). The viscosity of the solution formed by these fibers is known to be considerably less than with guar (16,23,28).

Interestingly, several authors have reported second-meal effects of food fiber ingestion with guar (36,37) or pectin (29). That is, dietary fiber ingested in one meal affects the glucose rise after the subsequent meal, even though fiber was not ingested with the second meal. The mechanism by which this occurs is unknown. It may be caused by a residual effect of the fiber on glucose absorption (19,37). Also, it may be attributable to an increased glucose utilization rate. The latter could be secondary to a decreased free fatty acid concentration, which in turn results in an increased glucose oxidation rate (36).

In summary, there is little question that large amounts of water-soluble fiber added to a glucose solution or mixed with food can reduce the expected rise in blood glucose concentration after a single meal. Mechanistically, the ability of the food fiber to form a viscous gel and thus impair convective transfer of glucose and water to the absorptive surface of the intestine appears to be of greatest importance. Large amounts of fiber must be mixed with the food or with CHO solutions. A consistent, significant effect on the postmeal glucose rise has been seen only with guar gum. Preliminary data indicate that gum tragacanth and oat gum may produce similar results. It is not a property of soluble fiber in general.

EFFECT OF NATURALLY OCCURRING FIBER IN FOODS

Single-meal studies. Because added viscous, gel-forming fiber, such as guar, can reduce the glucose rise after ingestion of glucose or of a mixed meal, the next question is, does the presence of naturally occurring fiber in foods affect the glucose rise after ingestion of that food? Currently available data suggest the answer is no. When brown rice versus white rice, whole wheat versus white bread, brown spaghetti versus white spaghetti, or whole oranges versus orange juice were studied, little difference was observed in glucose response (38,39). A significant difference in glucose rise after ingestion of apples (high fiber) versus apple juice (low fiber) has been reported (40), but we were unable to confirm this (41).

Long-term studies. To my knowledge, no long-term studies have been conducted in which an unequivocal effect of an increase in naturally occurring dietary fiber has been shown to significantly improve blood glucose control in individuals with diabetes.

In several studies, an improvement in blood glucose control has been reported to be associated with an increase in fiber content of the diet. However, interpretation of the data is complicated by weight loss, a decrease in total food energy, changes in the total CHO content of

TABLE 2
Food fiber and plasma glucose rise (added to glucose solution or mixed meal)

	Fiber used	Amount of fiber (g)	Reduction in glucose rise	
			Yes	No
Jenkins et al. (16)	Guar	12	+	
Morgan et al. (27)	Guar	10	+	
Levitt et al. (31)	Guar	5.0	+	
	Pectin	5.0		
Williams et al. (32)	Guar	10		+
Blackburn et al. (25)	Guar	9–14.5	+	
Jarjis et al. (30)	Guar	2.5–14.5	+	
Jenkins et al. (16)	Gum tragacanth	12	+	
Jenkins et al. (16)	Pectin	12		+
Holt et al. (17)	Pectin	14.5	+	
Williams et al. (32)	Pectin	10		+
Sandhu et al. (20)	Pectin	7.5–15		+
Jarjis et al. (30)	Psyllium	7.0		+
Pastors et al. (29)	Psyllium	6.8	+	(14%)
Thomas et al. (33)	Soy polysaccharide	10		+
Williams et al. (32)	Locust bean	10		+
Tredger et al. (34)	Beet fiber*	20		+
Hagander et al. (35)	Beet fiber*	11	+	(25%)
Braaten et al. (28)	Oat gum†	14.5	+	

*Beet fiber is composed primarily of pectins, hemicelluloses, and cellulose (35). It has low viscosity (34).

†Oat gum used in (28) had a high viscosity.

the diet, changes in the types of CHOs in the diet, and the inclusion of large amounts of legumes (peas and beans) (42–46). Legumes are high in fiber, and the starch present in legumes is known to be poorly digestible. However, this is not merely because of the fiber present but rather is attributable to the organization and structure of the starch granules in these leguminous seeds. The organization and structure of starch granules and how the starch-containing food is prepared, are known to have a profound effect on starch digestibility (10).

Several studies have been conducted in which an increased fiber content had no effect (47). Whether ingestion of large amounts of fibers as they occur naturally in foods have a salutary effect on the blood glucose concentration in individuals with diabetes remains an open issue. It is one that will be difficult to resolve.

In many of these studies, a decrease in serum cholesterol also has been noted. This decrease is likely to have been attributable, at least in part, to a decrease in total

dietary fat and saturated fatty acid content. A relative increase in plant derived mono- and polyunsaturated fatty acids also may have played a role. In most studies, an independent effect attributable to the fiber content of the diet cannot be determined.

Long-term studies in which refined, concentrated fiber was added to the diet. To more directly test the concept that dietary fiber affects blood glucose control, large amounts of well-characterized sources of fiber have been added to the diet of NIDDM subjects. Several studies have been reported. Some of these are very well controlled and a crossover design has been used; in others the design was less stringent. Guar gum, pectin, psyllium powder, soy beans, polysaccharides, oat bran, and others have been used (Tables 3 and 4) (2–4,48–59). In early studies, an improvement in blood glucose concentration was reported in most, but not all, of the studies. The improvement, when present, generally, was very modest and was manifest primarily by a reduction in

TABLE 3
Effect of dietary fiber addition on glucose control (guar)

	Fiber added (g)	Duration	CHO content changed	Result
Jenkins et al. (48)	14–26	1 yr	No	Urine glucose decreased
Aro et al. (2)	21	3 mo (x-over)*	Unknown	Improved modestly†
Ray et al. (49)	30	8 wk	Unknown	Improved
Smith (50)	14–20	3 mo	Unknown	Improved modestly†
Najemnik et al. (51)	15	2 wk (x-over)*	Unknown	Improved modestly†
Holman et al. (52)‡	15	8 wk (x-over)*	No	Not improved
Beattie et al. (53)‡	15	20 wk (x-over)*	No	Not improved
Uusitupa et al. (4)‡	15	3 mo (x-over)*	No	Not improved
Lalor et al. (3)	15	3 mo (x-over)*	No	Improved modestly†

*x-over refers to a crossover design.

†Modest improvement, decrease of $\leq 1-1.5$ mM in plasma glucose.

‡GHb used to assess effect on integrated glucose concentration.

TABLE 4
Effect of dietary fiber addition on glucose control

	Fiber added (g)	Duration	CHO content changed	Result
Pectin				
Jenkins et al. (57)	36	6 wk	No	Not improved
Gardner et al. (58)*	20	3 mo	No	Not improved
Mahalko et al. (59)	26–52	4 wk	No	Not improved
Schwartz (19)	20	2 wk	No	Fasting glucose increased
Cereal/bran fiber				
Karlstrom et al. (54)	22	3 wk (x-over)†	No	Improved modestly‡
Monnier et al. (55)	23–37	10–15 days	No	Improved modestly‡
Beattie et al. (53)*	10–15	20 wk	No	Not improved
Beet fiber				
Karlander et al. (56)*	16	6 wk (x-over)†	No	Not improved

*GHb used to assess effect on integrated glucose concentration.

†x-over refers to a crossover design.

‡Modest improvement, decrease of ≤ 1 –1.5 mM in plasma glucose.

the overnight fasting glucose concentration. However, in several of these studies the data are difficult to interpret because of the study designs used and differences in the type and amount of fiber added. In addition, in some studies the diet was not controlled (Tables 3 and 4).

More recently, several long-term studies have appeared in which excellent, randomized, crossover designs were used and the dietary content has been controlled. In addition, GHbs were used as an index of glucose control rather than just isolated plasma or urine glucose determinations, as done in earlier studies. In these latter studies, little or no improvement in glucose control was noted (4,48,52,56).

SUMMARY

In summary, it has been shown clearly that the ingestion of a highly viscous fiber such as guar will reduce the rate at which glucose is absorbed. However, ingestion of a very large amount of fiber is required for a significant effect to be seen. A second-meal effect on CHO absorption also has been demonstrated. In long-term studies, addition of large amounts of gel-forming fiber have had, at best, a modest effect on blood glucose control in individuals with diabetes. In these studies the major effect, if an effect was present, was on the fasting glucose concentration rather than on the postmeal rise as might be expected from the single-meal studies in which a reduced but prolonged glucose rise was observed with viscous gels. Poor palatability and unpleasant side effects such as bloating, excessive flatus, diarrhea, and increased numbers of stools limit the use of guar gum, the only source of fiber that has been extensively studied.

It is not possible to assess the effect of an increase in ingested fiber from naturally occurring foods. Almost always the CHO content is increased and the fat content is decreased. Also, of necessity, the sources and types of CHO change. Differences in starch digestibility may play a significant role. The quantity of starch-derived glucose that is malabsorbed still is uncertain.

CONCLUSION

Many reasons exist for considering fiber content to be an important aspect of the diet for individuals both with and

without diabetes. However, current data would suggest that a significant glucose-lowering effect in individuals with NIDDM is not one of them. Overall, the data available suggest that dietary fiber, even in large amounts, has very limited use in the management of the blood glucose concentration in individuals with NIDDM. Soluble fiber has a significant effect on the serum total and LDL-cholesterol concentrations in such patients. Therefore, a high soluble fiber diet in which fruits and vegetables are emphasized may be justified on this basis.

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