A Diet Containing Food Rich in Soluble and Insoluble Fiber Improves Glycemic Control and Reduces Hyperlipidemia Among Patients with Type 2 Diabetes Mellitus

The clinical significance of fiber on metabolic control among people with type 2 diabetes is debatable. Patients with type 2 diabetes who consumed a diet containing food naturally rich in fiber (e.g., 50 g fiber/day, 50% soluble) for 6 weeks had significant improvements in glycemic control and lipid panels when compared with patients who consumed a diet with moderate amounts of fiber (e.g., 25 g fiber/day, 50% soluble). Whether this high intake of fiber-rich food, especially fruits, can be maintained, tolerated without side effects or micronutrient deficiencies, and affordable for longer than 6 weeks in people with type 2 diabetes remains to be determined.

Approximately 16 million, or 6%, of Americans have diabetes mellitus, 83% of which present with type 2, or insulin-resistant, diabetes.[1] Native Americans, Mexican Americans, other Hispanics, and non-Hispanic blacks have approximately a 160%, 100%, 80%, and 60% greater rate of type 2 diabetes, respectively, compared with non-Hispanic whites.[1] People with type 2 diabetes are often sedentary, obese, middle-aged adults with an increased risk of macrovascular disease, retinopathy, nephropathy, neuropathy, and hypertension.[1] These health complications of diabetes lead to increased morbidity and premature death.[1] Total health care costs associated with diabetes were approximately $98 billion in 1997.[1]

According to the American Diabetes Association (ADA),[2] specific goals of medical nutrition therapy for people with diabetes include the following: achieve and maintain near-normal levels of blood glucose through an adequate diet, appropriate level of physical activity, and possible use of hypoglycemic agents and/or insulin; achieve optimal serum lipid levels; consume adequate calories to achieve and maintain desirable or reasonable body weight; prevent and treat diabetes-related diseases; and improve overall health by maintaining a balanced intake of the macronutrients and micronutrients and consume adequate water. With respect to dietary carbohydrate intake, the ADA recommends that patients focus on total carbohydrate intake rather than type of carbohydrate.[2] The ADA recommends daily consumption of 20–35 g/day of total fiber from sources of both soluble and insoluble fibers.[2] Although the ADA recognizes that this level of soluble and insoluble fiber may significantly lower serum lipids, they suggest that the clinical significance of this amount of fiber on glycemic control is negligible.

Reported health benefits of consuming diets rich in soluble and insoluble fiber include inducing satiety,[3-5] reducing total energy intake and adiposity,[4,5] improving glycemic control,[4] reducing blood lipids,[4,6,7] and preventing constipation, diverticuli, and other disorders of the gastrointestinal tract.[7,8] Furthermore, consumption of fruits, vegetables, whole grains, beans, and other foods rich in soluble and insoluble fiber has been suggested to reduce the risk of colon cancer.[9] These potential health benefits of consuming fiber supplements, food fortified with fiber, or fiber-rich foods are influenced by the type and amount of total dietary energy, fiber, carbohydrate, protein, and fat consumed, the physical form of dietary fiber consumed (e.g., purified fiber sources, fortified food, or fiber-rich food), the duration of consumption, and the type and health conditions of subjects consuming the diet.

By contrast with the conservative position taken by the ADA on the recommended intakes and potential benefits of consuming fiber,[2] studies conducted in the early-to-mid-1980s suggested that consuming diets with up to 50 g/day of fiber significantly improved glycemic control in patients with type 2 diabetes.[4] In the late 1980s, O'Dea et al.[10] evaluated the effects of feeding diets with different proportions of carbohydrate, fat, and fiber for 2 weeks on metabolic control in patients with type 2 diabetes in a cross-over design. They found that both the high fiber content (e.g., 45 g/day versus 13–20 g/day) and the low fat content (e.g., 10–12% versus 55% of total energy intake) contributed independently to improved glycemic response (e.g., areas under the glucose and insulin curves following a standard oral glucose tolerance test) and reductions in fasting total and low-density lipoprotein (LDL) cholesterol.

In the mid-1990s, Pick et al.[11] evaluated the effects of consuming bread made with oat bran concentrate for 12 weeks among patients with type 2 diabetes in a cross-over design. The control group ate 19 g/day of fiber and the high fiber group ate 34 g/day of fiber (9 g/day of soluble fiber) for 12 weeks. Total glucose response area under the curve, LDL cholesterol, ratio of LDL cholesterol to high-density lipoprotein (HDL) cholesterol, and total cholesterol were 46%, 23%, 24%, and 14% lower, respectively, in the high fiber group compared with the control group. Patients consuming the bread enriched in oat bran concentrate reported feeling satiated longer compared with the group receiving 19 g/day of fiber.

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In the late 1990s, Anderson et al.[12] evaluated the effects of supplementing male patients with type 2 diabetes and mild hypercholesterolemia with supplements containing either psyllium (5.1 g pysllium husk fiber, which is rich in soluble fiber) or cellulose (insoluble fiber) placebo twice daily for 8 weeks. Subjects consuming the psyllium supplement had 8.9% and 13.0% lower serum total cholesterol and LDL cholesterol, respectively, compared with the placebo group. Mean daily and lunch postprandial serum glucose concentrations were 11.0% and 19.2% lower, respectively, in the psyllium group compared with the placebo group. Both supplements were reportedly well tolerated by the study participants.

More recently, Meyer et al.[13] reported the results of a prospective cohort study of 35,988 women from Iowa who initially did not have diabetes. During the 6-year study, 1141 new cases of diabetes were reported. There was a significant decrease in the incidence of diabetes among these women as the levels of total grain, whole grain, total dietary fiber, and cereal fiber increased. No significant associations between diabetes risk and the intakes of total carbohydrates, refined grains, fruits, vegetables, soluble fiber, and the glycemic index, were detected. Data from this prospective study support data cited above from clinical trials demonstrating dietary fiber–induced improvements in glycemic control in humans. However, it was still unknown whether food rich in fiber—rather than fiber supplements or food fortified with fiber—improved glycemic control in people with diabetes. Therefore, a well-controlled clinical trial demonstrating the beneficial effects of consuming food rich in soluble and insoluble fiber—not fiber supplements or fiber-fortified food—on glycemic control in people with type 2 diabetes was needed to answer these questions. Furthermore, the effects of consuming high-fiber diets with unfortified, fiber-rich food on metabolic control among people with type 2 diabetes were unknown.

To answer these questions, Chandalia et al.[14] fed 13 patients with type 2 diabetes diets with either moderate levels of soluble and insoluble fiber (e.g., 24 g/day of fiber, 50% soluble), levels currently recommended by the ADA,[2] or higher levels of soluble and insoluble fiber (e.g., 50 g/day of fiber, 50% soluble) in a 6-week cross-over study.

Diets were balanced for total nutrients and energy, and provided 15%, 30%, and 55% of total energy from protein, fat, and carbohydrate, respectively. Saturated, monounsaturated, and polyunsaturated fatty acids contributed 7%, 17%, and 6% of the total energy, respectively. Food not fortified with fiber such as oranges, oatmeal, papaya, whole wheat bread, zucchini, cantaloupe, grapefruit, raisins, lima beans, okra, sweet potato, winter squash, granola, and oat bran were used to enhance the fiber content of the diet. All food was prepared in the research kitchen of the general clinical research center and was supplied as packaged meals or consumed on site. Compliance was monitored by interviews with patients and by examining returned, uneaten packaged or on-site food. Patients were asked to refrain from eating food that was not supplied by the investigators.

Subjects consisted of one female and 12 male patients (nine non-Hispanic white and four black) previously diagnosed with type 2 diabetes mellitus (mean age at diagnosis >40 years of age); the average age (±SD) was 61 ± 9 years and average body mass index (BMI, kg/m^2) was 32.3 ± 4. Patients were asked not to change their exercise habits and to report any changes in hypoglycemic agent prescriptions during the study (10 patients were on glyburide at various doses throughout the study, but their doses were not changed during the study).

Fasting blood samples were drawn from patients at baseline, during, and/or at the end of the study for measurements of plasma glucose, glycosylated hemoglobin, insulin, and lipid panels. On the last day of each treatment period, blood was drawn at 2-hour intervals for 24 hours to measure glucose and insulin levels under a 24-hour curve. Urine samples were collected for glucose determination during the last 5 days of each treatment period. To examine the influence of fiber on the rate of cholesterol absorption and fecal sterol balance, patients consumed cold and radiolabelled sitostanol and radiolabelled cholesterol three times daily during the last 7 days of each diet treatment. Fecal samples were collected before and during administration of the radiolabelled compounds and frozen until analyses.

Indicators of glycemic control included fasting plasma glucose, glycosylated hemoglobin, urinary glucose, and area under the 24-hour glucose and insulin curves. Lipid panels included fasting plasma total cholesterol, triglycerides, very low–density lipoprotein (VLDL) cholesterol, LDL cholesterol, and HDL cholesterol. Pooled fecal samples were analyzed for neutral and acidic fecal sterols using gas-liquid chromatography (GLC). Cholesterol absorption was determined using GLC-mass spectrophotometry.

Both groups consumed similar amounts of energy, received the same amount of glyburide, and had similar body weights during the last week of the study. Patient compliance was reportedly excellent and few side effects were reported on either diet. Patients consuming the high-fiber diet had significantly lower fasting plasma and urinary glucose levels (8.9% and 56%, respectively) and lower area under daily plasma glucose and insulin curves (10% and 12%, respectively) at the end of study compared with those fed the ADA diet. Plasma glycosylated hemoglobin levels tended ($P < 0.09$) to be lower (4.2%) in the high-fiber group. Patients consuming the high-fiber diet had significantly lower fasting plasma total cholesterol, triglyceride, and VLDL cholesterol levels (6.7%, 10.2%, and 12.5%, respectively) compared with the group fed the ADA diet.

HDL cholesterol levels were similar between the two groups. Although not statistically significant, plasma LDL cholesterol levels were 6.3% lower in the high-fiber group compared with the low-fiber group. Compared with people consuming the ADA diet, patients fed the high-fiber diet absorbed significantly less cholesterol (10%) and excreted more acidic (41%), but not neutral, fecal sterols.

The study by Chandalia et al.[14] is timely because of the increasing prevalence of type 2 diabetes and obesity in the United States; the low fiber intakes among people with and without diabetes in the United States (16 and 17 g/day,[15] respectively); ADA's recommendation of 20–35 g/day of fiber; and data from recent studies suggesting that increasing dietary fiber improves blood lipids,[6,11,12] improves blood glucose,[11–13] promotes satiety,[3–5] and reduces energy intake and excess body weight.[4,5] Chandalia et al.[14] fed diets that had similar amounts of energy and nutrients instead of diluting dietary energy with fiber. This made it possible to examine the direct impact of fiber on metabolic control rather than a concomitant increase in fiber and a decrease in the energy density of the diets. Those consuming the high-fiber diet consumed greater amounts of food compared with those consuming the ADA diet, which apparently was not a problem in this study. The study is also important because it used food naturally rich in fiber instead of using food fortified with fiber or fiber supplements. Therefore, the foods used in this study are commercially available to people who have the financial resources and access to purchase them.

Chandalia et al.[14] demonstrated that compared with the low-fiber diet, the high-fiber diet clearly improved glycemic control in patients with type 2 diabetes, a finding that has not been consistently demonstrated by earlier studies.[4] Furthermore, lipid panels were improved in patients consuming the high-fiber diet. Possible mechanisms for the glucose- and lipid-lowering effects of dietary fiber are illustrated in Figures 1 and 2, respectively. As shown in Figure 1, soluble fibers may improve glycemic control by delaying gastric emptying, thereby reducing the rate of glucose absorption and plasma insulin levels. This response may also contribute to lower blood lipids by limiting glucose availability for hepatic lipogenesis, which is increased in the presence of insulin. As shown in Figure 2, fiber may lower plasma lipid levels, especially plasma cholesterol, by delaying gastric emptying, thereby limiting hepatic lipogenesis owing to less glucose as substrate and less insulin as an activator; by interfering with digestive enzymes, rendering less substrates available for hepatic lipid synthesis; by interfering with micelle formation, resulting in less cholesterol absorbed and more cholesterol sequestered from the blood by upregulation of hepatic LDL receptors; and by inhibition of hepatic cholesterol biosynthesis owing to the proposed inhibitory effects of proprionate derived from fiber fermentation on

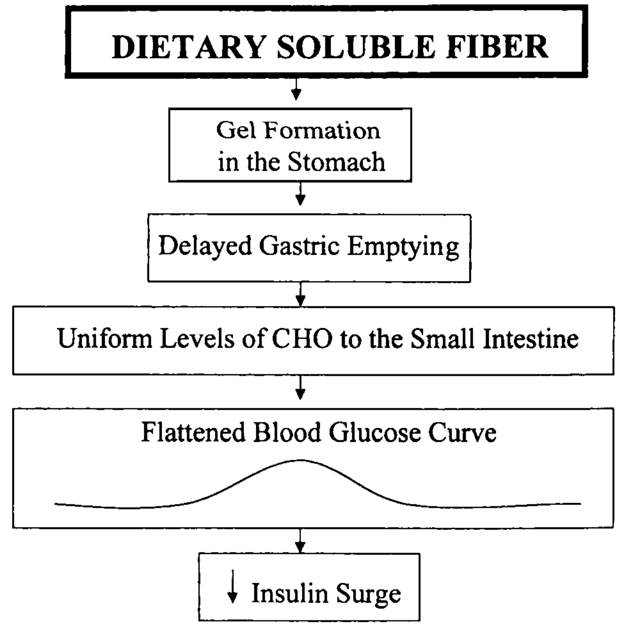

Figure 1. Possible mechanism by which soluble dietary fiber lowers serum glucose.
Note: CHO = carbohydrate.

HMG-CoA reductase activity.[7,8,14] The authors demonstrated that patients consuming the high-fiber diet excreted 41% more acidic fecal sterols and absorbed 10% less cholesterol, suggesting the high-fiber diet decreased bile and cholesterol absorption, thereby lowering plasma cholesterol levels.

Several practical questions are raised by this study. The first question is whether people with diabetes can achieve and maintain an intake of 25–50 g/day of fiber? The usual intake of fiber averages 16–17 g/day in the United States.[15] Thus, achieving an intake of 50 g/day is a

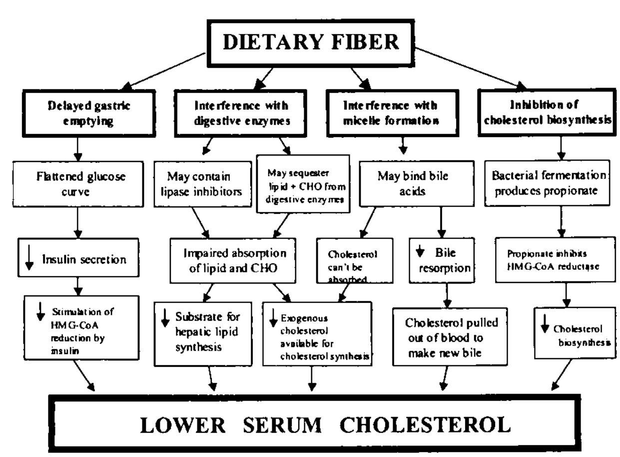

Figure 2. Possible mechanisms by which dietary fiber lowers serum cholesterol.
Note: CHO = carbohydrate; HMG-CoA reductase = hydroxy-3-methylglutaryl-coenzyme A reductase.

significant increase in fiber consumption for many Americans. Most consumers will need additional nutrition education to incorporate more high-fiber food into their usual diet. Additional research is needed to determine the acceptability of a high-fiber diet among people with diabetes, especially people of different ethnic groups.

Second, prior research found that some people with diabetes believed the cost of eating more healthfully was prohibitive.[16] Fresh fruits and vegetables were perceived by the participants to be too expensive to be consumed as recommended. Fruits and vegetables are rich sources of fiber, especially soluble fiber. Thus, consumers with diabetes will need additional education to address the perception that a high-fiber diet is expensive and to facilitate the incorporation of a variety of high-fiber food into their meal plans.

Third, will this high level of dietary fiber, especially soluble fiber, cause any significant health problems including micronutrient deficiencies owing to malabsorption? Cations such as calcium, magnesium, sodium, and potassium can bind to fiber, rendering them unavailable for absorption. Furthermore, soluble fiber is fermented to a greater extent than insoluble fiber, thereby reducing fecal bulk and stream, decreasing the pH of luminal contents, altering colonic microflora, and changing the profile of short-chain fatty acids produced from fermentation. These fatty acids influence the rate of growth, differentiation, and apoptosis of colonocytes.[8] Furthermore, soluble fiber brings sequestered bile and fatty acids from the intestinal tract into the colon where they can be metabolized by colonic bacteria into potential carcinogens.

The fourth question is whether the glucose- and lipid-lowering effects of the high-fiber diet found in these patients—77% of which were on oral hypoglycemic agents—would be similar to that of patients in better or worse glycemic control? Given the wide range of plasma glucose (i.e., glycosylated hemoglobin 6.0% to 9.8%) and lipid (i.e., 151–324 mg/dL and 67–390 mg/dL total cholesterol and triglycerides, respectively) levels among the patients at the beginning of the study, it would have been interesting to determine which patients benefited most from each diet, those with poor versus optimal metabolic control. Additionally, what was the degree of improvement in metabolic control for each group after consuming each diet for 6 weeks compared with baseline measurements? Furthermore, what would happen among people on insulin or on insulin plus oral hypoglycemic agents?

Consuming a high-fiber diet may help people with type 2 diabetes achieve reductions in blood glucose and lipid levels. Whether people with diabetes can achieve and maintain a fiber intake of 25–50 g/day for more than 6 weeks is unknown. Many consumers with diabetes need additional nutrition education to incorporate more high-fiber food into their usual diets. The impact of increasing fiber consumption among people with diabetes in poor metabolic control is worthy of further investigation given the results of this study.

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