

Health benefits of dietary fiber

James W Anderson, Pat Baird, Richard H Davis Jr, Stefanie Ferreri, Mary Knudtson, Ashraf Koraym, Valerie Waters, and Christine L Williams

Dietary fiber intake provides many health benefits. However, average fiber intakes for US children and adults are less than half of the recommended levels. Individuals with high intakes of dietary fiber appear to be at significantly lower risk for developing coronary heart disease, stroke, hypertension, diabetes, obesity, and certain gastrointestinal diseases. Increasing fiber intake lowers blood pressure and serum cholesterol levels. Increased intake of soluble fiber improves glycemia and insulin sensitivity in non-diabetic and diabetic individuals. Fiber supplementation in obese individuals significantly enhances weight loss. Increased fiber intake benefits a number of gastrointestinal disorders including the following: gastroesophageal reflux disease, duodenal ulcer, diverticulitis, constipation, and hemorrhoids. Prebiotic fibers appear to enhance immune function. Dietary fiber intake provides similar benefits for children as for adults. The recommended dietary fiber intakes for children and adults are 14 g/1000 kcal. More effective communication and consumer education is required to enhance fiber consumption from foods or supplements.

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INTRODUCTION

Dietary fiber intake provides many health benefits. A generous intake of dietary fiber reduces risk for developing the following diseases: coronary heart disease,¹ stroke,² hypertension,³ diabetes,⁴ obesity,⁵ and certain gastrointestinal disorders.⁶ Furthermore, increased consumption of dietary fiber improves serum lipid concentrations,⁷ lowers blood pressure,⁸ improves blood glucose control in diabetes,⁹ promotes regularity,¹⁰ aids in weight loss,¹¹ and appears to improve immune function.¹² Unfortunately, most persons in the United States consume less than half of the recommended levels of dietary fiber daily.¹³ This results from suboptimal intake of whole-grain foods, vegetables, fruits, legumes, and

nuts. Dietary fiber supplements have the potential to play an adjunctive role in offering the health benefits provided by high-fiber foods.

Traditionally, dietary fiber was defined as the portions of plant foods that were resistant to digestion by human digestive enzyme; this included polysaccharides and lignin. More recently, the definition has been expanded to include oligosaccharides, such as inulin, and resistant starches.¹⁴ Simplistically, fibers have been classified as soluble, such as viscous or fermentable fibers (such as pectin) that are fermented in the colon, and insoluble fibers, such as wheat bran, that have bulking action but may only be fermented to a limited extent in the colon. Current recommendations for dietary fiber intake are related to age, gender, and energy intake, and the general

Affiliations: *JW Anderson* is with the Department of Internal Medicine and Nutritional Sciences Program, University of Kentucky, Lexington, Kentucky, USA. *P Baird* is with the University of Connecticut, Stamford Campus, Stamford, Connecticut, USA and Westchester Community College, Valhalla, New York, USA. *RH Davis* is with the Department of Medicine, University of Florida, Gainesville, Florida, USA. *S Ferreri* is with the Division of Pharmacy Practice and Experiential Education, UNC Eshelman School of Pharmacy, Chapel Hill, North Carolina, USA. *M Knudtson* is with the University of California, Irvine, Irvine, California, USA. *A Koraym* is with the Ohio State University, Columbus, Ohio, USA and Wright State University, Dayton, Ohio, USA. *V Waters* is a Certified Personal Trainer, Los Angeles, California, USA. *CL Williams* is with Healthy Directions, Inc., New York, New York, USA.

Correspondence: *JW Anderson*, University of Kentucky, 913 Taborlake Court, Lexington, KY 40502, USA. E-mail: jwandersmd@aol.com, Phone: +1-859-269-6642, Fax: +1-859-422-4670.

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Table 1 Dietary fiber intake related to relative risk for disease based on estimates from prospective cohort studies.

Disease	No. of subjects (no. of studies)	Relative risk [†]	95% CI	Reference
Coronary heart disease	158,327 (7)	0.71	0.47–0.95	24
Stroke [‡]	134,787 (4)	0.74	0.63–0.86	1,2,27,28
Diabetes	239,485 (5)	0.81	0.70–0.93	23
Obesity	115,789 (4)	0.70	0.62–0.78	64

[†] Relative risks adjusted for demographic, dietary, and non-dietary factors.

[‡] Estimates related to whole-grain consumption,^{1,2} total dietary fiber,²⁷ and cereal fiber.²⁸

recommendation for adequate intake (AI) is 14 g/1000 kcal.¹⁵ This AI includes non-starch polysaccharides, analogous carbohydrates (e.g., resistant starches), lignin, and associated substances.^{16,17} Using the energy guideline of 2000 kcal/day for women and 2600 kcal/day for men, the recommended daily dietary fiber intake is 28 g/day for adult women and 36 g/day for adult men.¹⁵

The purpose of this review is to summarize the research data related to the effects of dietary fiber on health. Most of the available data on disease prevalence and events are from epidemiological studies. While limited data are available on the effects of consumption of high-fiber foods or specific food sources of fiber, extensive data are available relating to the effects of fiber supplements on serum lipid values, weight management, post-prandial glycemia, and gastrointestinal function. Thus, the general implications of fiber consumption will be reviewed and the potential health benefits of specific high-fiber foods and supplements will be examined.

CARDIOVASCULAR HEALTH AND FIBER

Cardiovascular diseases, including coronary heart disease (CHD), stroke, and hypertension, affect more than 80 million people and are the leading causes of morbidity and mortality in the United States. In 2005, CHD was the leading cause of death and strokes were the third leading cause of death in the United States.¹⁸ While CHD is the most prevalent cause of death, it is probably the most modifiable; an estimated 82% of CHD is attributed to lifestyle practices such as diet, physical activity, and cigarette abuse,¹⁹ and 60% is attributed to dietary patterns.²⁰

High levels of dietary fiber intake are associated with significantly lower prevalence rates for CHD, stroke, and peripheral vascular disease;^{1,21,22} major risk factors, such as hypertension, diabetes, obesity, and dyslipidemia, are also less common in individuals with the highest levels of fiber consumption.⁵ The impact of dietary fiber or whole grain consumption on the prevalence of these conditions is summarized in Table 1. In the analyses of prospective cohort studies, the observed protective effect of dietary

fiber intake was very similar to the effects of whole grains but “fellow travelers” with fiber, such as magnesium, other minerals, vitamins, and antioxidants, may have important complementary beneficial effects.^{23,24}

Coronary heart disease prevalence

Based on astute comparisons of CHD prevalence and dietary habits, Trowell postulated that high-fiber foods were protective against CHD (as cited in Anderson²⁴). Over the three decades following that suggestion, prospective cohort studies documented that high levels of fiber intake and, especially, consumption of whole grains are associated with a significantly lower prevalence of CHD. Seven cohort studies presenting observations for over 158,000 individuals indicate that CHD disease prevalence is significantly lower (29%) in individuals with the highest intake of dietary fiber compared to those with the lowest intake (Table 1). Specifically, the relative risk, computed by variance weighting (fixed-effect meta-analysis²⁵) is 0.71 for individuals in the highest quintile for dietary fiber intake compared to those in the lowest quintile.²³ The effects of cereal fiber intake or whole-grain intake on CHD prevalence are very similar, suggesting that whole-grain intake may be the most protective source of fiber consumption.

While these epidemiologic studies are consistent and persuasive, they do not provide specific information about cause and effect. Prospective randomized controlled clinical trials (RCTs) are required to provide convincing data. One previous RCT did indicate that lifestyle changes slow the progression of CHD²⁶ but the specific effects of fiber have not been documented. In the modern era of fiber research, an early RCT of Welsh men with a history of prior myocardial infarction did not find that doubling their fiber intake affected rates of ischemic cardiac events or death over a short study period of 2 years.²⁷ While a high level of dietary fiber intake is associated with reduced risk for CHD and high protective values for major risk factors, further prospective RCTs are required to clearly document the links between dietary fiber intake and reduced events and deaths from CHD.

Table 2 Effects of soluble fiber intake on serum LDL-cholesterol values in randomized, controlled clinical trials with weighted mean changes based on number of subjects.

Fiber	No. of trials [†]	No. of subjects	Grams/day (median)	Baseline LDL-cholesterol	Weighted net change [‡]
Barley β -glucan	9	129	5	4.1	-11.1
Guar gum	4	79	15	4.4	-10.6
HPMC	2	59	5	4.2	-8.5
Oat β -glucan	13 [§]	457	6	4	-5.3
Pectin	5	71	15	3.9	-13.0
Psyllium	9 [§]	494	6	3.9	-5.5

[†] References are provided as Supporting Information, as noted at the end of this article.

[‡] Net changes are treatment change minus placebo change.

[§] Analysis of high-quality clinical trials.

Abbreviation: HPMC, hydroxypropyl methylcellulose.

Stroke prevalence

Higher intakes of whole grains are associated with a significant 26% reduction in prevalence of ischemic strokes (Table 1). Specifically, data from four studies^{2,21,28,29} including over 134,000 individuals indicate that the relative risk for stroke is 0.74 for individuals with the highest quintile intake of dietary fiber or whole grains compared to those with the lowest quintile intake. Other studies suggest that fruit and vegetable intake is associated with a lower risk for ischemic stroke³⁰ and with favorable effects on the progression of carotid artery atherosclerosis.³¹ While these studies, like those for CHD, suggest that dietary fiber intake reduces risk of ischemic stroke, prospective RCTs are required to support this hypothesis.

Risk factor prevalence

The prevalence of hypertension or dyslipidemia as they relate to fiber intake has not been well characterized. In a small group of Chinese residents, higher consumption of oats or buckwheat was associated with significantly lower body mass index (BMI), systolic and diastolic blood pressure, and serum LDL-cholesterol and triglyceride values; serum HDL-cholesterol values were also lower.³² Total dietary fiber intake was associated with significantly lower serum LDL-cholesterol values while soluble fiber was associated with lower systolic blood pressure and total cholesterol values.³² Among French adults, higher intakes of dietary fiber were associated with a lower prevalence of hypertension and with lower total serum cholesterol and triglyceride values than were lower intakes.⁵

Risk factor effects

One of the following major risk factors for CHD is present in 80–90% of patients with the disease: cigarette smoking, diabetes, dyslipidemia, and hypertension.³³

The favorable effects of fiber consumption on all of these risk factors except cigarette smoking were reviewed.

Lipoproteins. Soluble or viscous fibers have significant hypocholesterolemic effects.⁷ Extensive studies with guar gum focused on diabetic control, body weight, and serum lipoproteins.³⁴ The meta-analysis of Brown et al.⁷ provides estimates of effects of various soluble fibers on serum lipoproteins. To provide broader and updated information, RCTs were reviewed and the net LDL-cholesterol effects (change with fiber treatment minus change with placebo treatment) were weighted by number of subjects per trial and summarized in Table 2. For guar gum, over 40 clinical trial publications were reviewed and RCTs in non-diabetic subjects were selected for analysis. Intakes ranging from 9 to 30 g/day, divided into at least three servings/day, were associated with a weighted mean reduction of 10.6% for LDL-cholesterol values. For pectin, the acceptable-quality RCTs reviewed indicated that consumption of 12–24 g/day in divided amounts was associated with a 13% reduction in LDL-cholesterol values. Barley β -glucan intake of 5 g/day in divided doses was associated with an 11.1% reduction in LDL-cholesterol values. Limited information on hydroxypropyl methylcellulose indicated that 5 g/day in divided doses decreases LDL-cholesterol values by 8.5%. These LDL-cholesterol changes with soluble fibers occur without significant changes in HDL-cholesterol or triglyceride concentrations.

Psyllium and oat β -glucan are the most widely used sources of soluble fiber and have been approved for health claims related to protection from CHD by the FDA.^{35,36} A recent review of RCTs published since the FDA health claim yielded eight high-quality RCTs for psyllium and 11 high-quality studies for oat β -glucan (Anderson JW; unpublished data). Our analysis is consistent with the meta-analysis of Brown et al.⁷ with respect to the LDL-cholesterol changes found with our weighted analysis and the meta-analysis; the respective values were

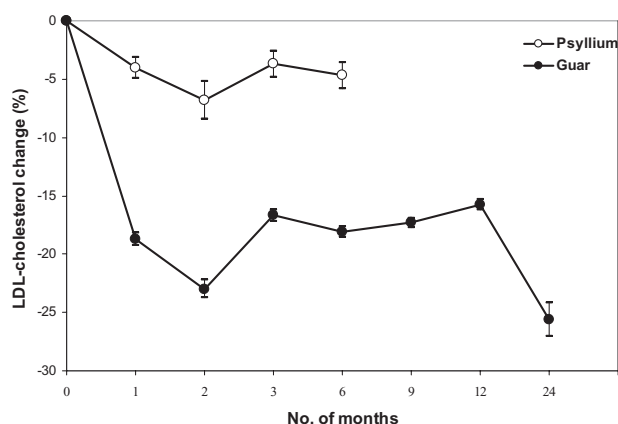


Figure 1 Long-term effects of soluble fibers on LDL-cholesterol values.

−5.5% and −5.2% for psyllium and −5.3% and −5.6% for oat β-glucan. These analyses indicate that psyllium or oat β-glucan do not significantly affect serum HDL-cholesterol or triglyceride values.

The limited data available for Konjac mannan (glucomannan) indicates that it has significant hypocholesterolemic effects.³⁷ Gum arabic (acacia gum),³⁸ partially hydrolyzed guar gum,³⁹ and methylcellulose⁴⁰ appear to have only modest hypocholesterolemic effects.

These short-term studies with mean durations of 4–8 weeks indicate that the widely used psyllium or oat β-glucan decrease serum LDL-cholesterol values by about 5.5%. These reductions would be expected to reduce the risk for cardiovascular disease by 7–11%.⁴¹ The best long-term data available for soluble fiber are for the use of psyllium for 6 months and the use of guar for 12–24 months (Figure 1). Use of psyllium for 6 months maintains the LDL-cholesterol reduction of 6.7%⁴² and long-term use of guar sustains reductions of LDL-cholesterol values of 16.1% at 1 year and 25.6% at 24 months.^{43–45} While the levels of guar used in these studies may not be practical for widespread use, these data do indicate that regular use of a soluble fiber can sustain significant hypocholesterolemic effects for long-term periods. These changes were maintained without changes in body weight, HDL-cholesterol, or serum triglyceride values.⁴⁵

Blood pressure. Increasing consumption of dietary fiber is often accompanied by a reduction in systolic and diastolic blood pressure. Early studies suggested that high-fiber diets were associated with a significant reduction in blood pressure, but these studies were not well-controlled clinical trials.^{46,47} The effects of increasing oat fiber intake on blood pressure have been reported in several studies, with the net results suggesting a modest-to-moderate

reduction in systolic and diastolic blood pressure.^{8,48,49} Early studies also suggested that fiber supplement use had a significant effect on reducing blood pressure.^{50,51} Two meta-analyses recently assessed the effects of fiber intake on blood pressure. A meta-analysis of the effects of fiber supplements on blood pressure in RCTs reported that the effects of fiber supplements averaging 11.5 g/day were modest, with decreases in systolic blood pressure of 1.1 mm Hg and diastolic blood pressure of 1.3 mm Hg; reductions were greater in hypertensive subjects and in older subjects.⁵² Similarly, a meta-analysis of 25 RCTs indicated that dietary fiber intake was associated with nonsignificant changes in systolic blood pressure (−1.2 mm Hg) and significant reductions in diastolic blood pressure (−1.7 mm Hg); significant reductions in systolic (−6.0 mm Hg) and diastolic (−4.2 mm Hg) blood pressure occurred in hypertensive subjects or with treatment for ≥8 weeks.³ Thus, increasing dietary fiber intake or fiber supplementation may have a modest independent effect in reducing blood pressure, especially in hypertensive individuals.

Other risk factors. In addition to having favorable effects on serum lipoproteins and blood pressure, dietary fiber consumption has favorable effects on body weight, visceral adiposity, and insulin sensitivity,^{53,54} as discussed subsequently, as well as on inflammatory markers.⁵⁵

Proposed mechanisms. The hypocholesterolemic effects of dietary fiber have been studied extensively and are the best-characterized effects of fiber consumption on risks for CVD. Soluble or viscous fibers appear to exert primary effects on serum cholesterol and LDL-cholesterol values by binding bile acids in the small intestine and increasing their excretion in the feces.⁵⁶ Fermentation of fibers in the colon with production of the short-chain fatty acid propionate may contribute to hypocholesterolemia by attenuating cholesterol synthesis.⁵⁷

Comments

In the United States, CVD affects approximately one-third of the adult US population and CHD is the leading cause of death. Higher intakes of dietary fiber compared to lower consumption levels are associated with significantly lower rates of CVD and lower prevalence of CVD risk factors. Persons with the highest levels of fiber consumption have a 29% lower risk for CHD than those with the lowest intakes. Soluble fiber intake of about 6 g/day is accompanied by reductions in serum LDL-cholesterol values of around 5.4% and estimated risk for CHD of about 9%. Increased fiber intake modestly lowers the blood pressure of the general population but is accompanied by reductions of systolic and diastolic blood pres-

sure, respectively, of -6 mm Hg and -4 mm Hg for hypertensive individuals. Higher fiber intakes are associated with improved measures for body weight, visceral adiposity, insulin sensitivity, and inflammatory markers. Moderate increases in fiber intake, especially soluble fiber, are likely to have significant favorable effects on risk and progression of CVD.

DIABETES PREVENTION AND MANAGEMENT: ROLE OF FIBER

Prevalence

Diabetes is increasing at an alarming rate worldwide.⁵⁸ In the United States almost half of all the individuals have diabetes, prediabetes, or are at substantial risk for developing diabetes because of the presence of the metabolic syndrome.^{59,60} For 2008, the estimated prevalence rates for diabetes and related conditions for all ages in the US population are as follows: diabetes, 8% or 23.6 million; prediabetes, 23% or 70.3 million; and the metabolic syndrome, 20.3% or 62 million.^{59,60} Of those with diagnosed diabetes, approximately 90% have type 2 diabetes and around 80% of these are obese.⁶¹ The incidence of diabetes in the United States appears to be increasing because of the following major factors and other contributors: a greater percentage of Americans who are overweight or obese;^{61,62} changes in the racial and ethnic diversity of the population;⁶³ and dietary changes resulting in less fiber and more fat in the diet.⁶⁴ The prevalence of diabetes is two to four times higher among females in the following groups than among non-Hispanic white women: non-Hispanic blacks, Hispanic/Latino Americans, American Indians, and Asian/Pacific Islanders.⁶³

High levels of dietary fiber intake are associated with a significant reduction in the prevalence of diabetes based on estimates from prospective cohort epidemiological studies. Five epidemiological studies suggested 19% experienced a protective effect from high total dietary fiber intake (Table 1) while 11 estimates based on over 427,000 individuals with high levels of whole grain or cereal fiber consumption suggested there was a 29% reduction in the development of diabetes.⁶⁴ Thus, epidemiological studies suggest that higher levels of dietary fiber intake play a significant protective role with respect to diabetes that is independent of other dietary factors. Recently, the Finnish Diabetes Prevention Study reported a RCT in which individuals with the highest level of fiber consumption had a 62% reduction in progression of prediabetes to diabetes over a 4.1-year period compared to those with the lowest fiber intake.⁶⁵ This appears to be the first long-term documentation of the protective effects of fiber consumption with regard to the progression of prediabetes to diabetes.

Glycemia and insulin sensitivity

About 30 years ago the clinical effects of dietary fiber related to health began to shift from a fairly exclusive focus on gastrointestinal function to effects on glycemia and lipidemia.⁶⁴ Subsequent studies clearly indicated that increasing fiber intake for individuals with type 1 or type 2 diabetes was associated with substantial improvements in glycemic control and reductions in the use of oral medication and insulin doses.^{66,67} A meta-analysis of eight randomized controlled trials (RCTs) including 136 subjects with type 1 or type 2 diabetes indicated that the moderate-carbohydrate, high-fiber diets, compared to the moderate-carbohydrate, low-fiber diets, produced the following significant changes: postprandial plasma glucose, -21% ; LDL-cholesterol, -7.9% ; and triglycerides, -8.3% .⁹ These studies clearly indicate that increasing dietary fiber consumption without altering the energy intake from carbohydrates, proteins, or fats significantly improves glycemic control and reduces the need for medication and insulin in individuals with type 1 or type 2 diabetes.^{66,67}

The metabolic syndrome, which is a cluster of abnormalities including insulin resistance, dyslipidemia, visceral adiposity, and hypertension, can be ameliorated and, perhaps, reversed by high levels of dietary fiber or whole grain intake.⁶⁴ Short-term studies indicate that dietary fiber intake decreases postprandial glycemia and insulinemia and enhances insulin sensitivity.^{68,69}

Recent prospective RCTs document improved postprandial glycemia and increased insulin sensitivity with increased fiber intake from foods or fiber supplements in nondiabetic and diabetic subjects. Three RCTs including a total of 47 nondiabetic subjects examined the effects of 10–30 g/day of fiber (median 15 g/day) from Konjac mannan,⁷⁰ arabinoxylan,⁷¹ or guar.⁷² After an average of 5 weeks of treatment, two studies reported significant reductions in fasting plasma glucose values (mean net change, -3.8%) and one study reported significant reductions in fasting plasma insulin values (mean net change, -9.0%); insulin sensitivity was reported to be significantly improved in two of the studies. Three RCTs including a total of 71 nondiabetic subjects also examined the effects of high-fiber foods adding 6–20 g/day of fiber (median 10 g/day) from rye bread,⁷³ whole-grain foods,⁷⁴ or powdered high-fiber foods.⁷⁵ After an average of 10 weeks of treatment, two studies reported significant reductions in fasting plasma glucose values (mean net change, -8.7%) and two studies reported significant reductions in fasting plasma insulin values (mean net change, -8.5%); insulin sensitivity was reported to be significantly improved in all three of the studies. These studies indicate that moderate increases in fiber intake from food or supplements are associated with a significant reduction in fasting plasma

glucose and insulin values and increased insulin sensitivity in non-diabetic subjects. Further studies are required to confirm and extend these observations.

For diabetic subjects, four RCTs including a total of 116 subjects also documented improved glycemic control and improved insulin sensitivity with fiber supplements. Three used psyllium (10.2–15 g/d, median 10.2 g/d)^{76–78} and one used guar gum (10 g three times daily).⁵⁰ After an average of 10 weeks of treatment, two studies reported significant reductions in fasting plasma glucose values (mean net change, –12.5%). Net postprandial plasma glucose values were reported to be significantly decreased (–4.2%) in one study. Hemoglobin A1c values were significantly decreased in one study after 8 weeks and the mean change for two studies was –5.3% below baseline values. These studies indicate that psyllium intake in usual doses is accompanied by significant improvements in fasting plasma glucose values, and in one study, by improvements in postprandial glucose concentrations. Further studies are required to confirm and extend these observations.

Dietary fiber recommendations for diabetic individuals

General nutrition guidelines for persons with diabetes from nine influential international agencies were recently reviewed and aggregated as “Evidence-Based Recommendations”.⁹ The recommendations are as follows: attain and maintain desirable weight ($\text{BMI} \leq 25 \text{ kg/m}^2$); regulate carbohydrate intake to 55–65% of energy; choose whole grains, legumes, and vegetables; use fruits and other sources of mono- and disaccharides in moderation; incorporate GI into exchanges and teaching material; and regulate other intake levels as follows – fiber, 25–50 g/day (15–25 g/1000 kcal); protein, 12–16% of energy; total fat, <30% of energy; saturated/trans fatty acids, <10% of energy; monounsaturated fat, 12–15% of energy; polyunsaturated fat, <10% of energy; and cholesterol, <200 mg/day. The practical applications of these recommendations were recently outlined.⁷⁹ Because approximately 80% of type 2 diabetic individuals are obese, weight loss and management are high priorities for their management.^{61,62} Because of the beneficial effects of increased fiber intake on weight management, increased consumption of high-fiber foods or supplements should be considered.

Comments

In the United States almost half of all individuals have diabetes, prediabetes, or the metabolic syndrome associated with high risk for the development of diabetes.⁶⁰ Persons with the highest level of dietary fiber consumption, compared to those with the lowest intake, appear to

have a 29% reduced risk for developing diabetes.⁶⁴ Recent data indicate that persons with the highest intake of fiber have a 62% reduction in progression of prediabetes to diabetes over a 4-year period.⁶⁵ Three RCTs indicated that moderate increases in dietary fiber intake are associated with improved fasting glycemia and insulinemia and increased insulin sensitivity for persons without diabetes. Four RCTs of diabetic individuals suggest that moderate increases in fiber intake improve glycemic control. Increased consumption of fiber from high-fiber foods or supplements is likely to also improve serum lipoproteins and blood pressure as well as assist in weight management for diabetic individuals.

OBESITY PREVALENCE AND MANAGEMENT: DIETARY FIBER EFFECTS

Prevalence

Epidemiological studies indicate that dietary fiber intake, especially intake of whole grains or cereal fiber, protect against development of obesity. These studies were recently reviewed and summarized.⁶⁴ Two cross-sectional studies (including more than 100,000 persons) and four prospective cohort studies (including more than 100,000 persons) indicated a strong negative association between fiber intake and obesity. The cross-sectional studies indicated that men and women with the highest level of fiber consumption have a relative risk for obesity of 0.77 (95% CI, 0.68–0.87) compared to those with the lowest fiber intake level. The prospective cohort studies (Table 1) reported that women and men with the highest level of fiber consumption had lower rates of weight gain and less obesity than those with the lowest level of fiber intake, with relative risks of 0.70 (95% CI, 0.62–0.78). Thus, these studies suggest that high-level fiber consumption reduces risk for gaining weight or developing obesity by approximately 30%. Because these studies include a wide diversity of ethnic/racial groups, they would appear to have wide applicability and strongly suggest that individuals who have higher levels of fiber consumption have lower weights than those with the lowest fiber intakes.

Effects on satiety and energy intake

For millennia, keen observers have noted that high-fiber foods were more filling than low-fiber foods. Clinical trials initiated over 50 years ago used fiber supplements as an aid to weight loss.⁶⁴ Haber et al.⁸⁰ illustrated that intact apples with their natural fiber were significantly more satiating than fiber-free apple juice, although both test foods provided 60 grams of carbohydrate. Subsequent clinical laboratory experiments documented that a high

level of fiber intake decreased within-meal food intake as well as food intake at the next meal. Meals containing pectin resulted in delayed gastric emptying and enhanced satiety. Recent studies have linked satiation to changes in orexigenic or anorexigenic hormones; with more than 20 gut hormones involved in regulation of eating behavior; the effects of different fibers on gut hormone secretion are currently unclear.⁶⁴ Systematic measurements of the responses of key gut hormones to different types and formulations of fiber is likely to provide important contributions to our understanding of this area.

High-fiber diet effects

The role of dietary fiber in preventing and managing obesity in humans is strongly supported by epidemiological and physiological studies. Clinical trials using high-fiber foods also provide support for the hypothesis that higher-level fiber consumption has a beneficial role in weight management.

Five RCTs (some of which were of suboptimal quality) have assessed the effects of high-fiber foods or fiber-enhanced food products in weight-loss studies. These data were recently reported and summarized.⁶⁴ Reported mean weight losses over an 8-week period were approximately 1 kg greater with high-fiber diets than with control diets. The effects of a diet high in complex carbohydrates (and higher in dietary fiber) provides persuasive data that this type of diet promotes greater weight loss than a high simple-carbohydrate (and lower fiber) diet.⁸¹ Since blinding of subjects is usually not possible when high-fiber foods are compared with low-fiber foods, future studies may need to be more innovative in order to clearly address research questions related to weight management.

Fiber supplement effects

Sixteen RCTs previously examined the effects of fiber supplements on weight loss for individuals on weight-reducing diets.⁶⁴ The numbers of subjects completing the trials were 391 in control interventions and 423 in fiber-supplemented interventions. Usually volunteers in both treatment arms were instructed in the use of energy-restricted diets. In most trials, the fiber was provided in the form of tablets that were given three times daily. The fiber intake ranged from 4.5 to 20 g/day and averaged about 2.5 g three times daily with meals. In most trials, the fiber was predominantly in insoluble form but guar gum or glucomannan were used in several studies.⁶⁴

The amount of weight loss achieved with fiber supplements administered as an adjunct to an energy-restricted diet was modestly greater than the weight loss achieved with placebo. The estimated effects of fiber

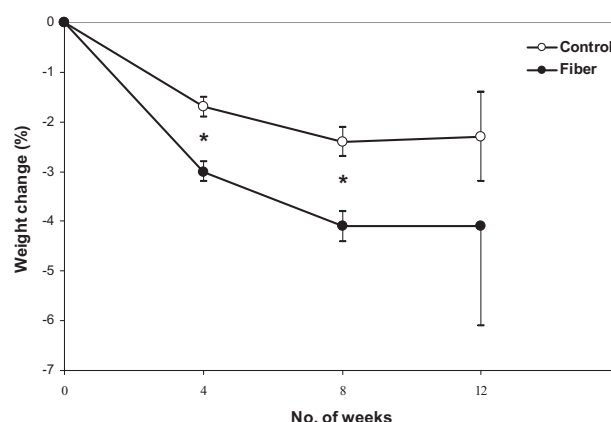


Figure 2 Weight losses achieved with fiber-supplemented diets versus control diets. Values are means \pm SEM. Data in 15 studies obtained at 4 and 8 weeks and additional data in 9 of those studies obtained at 12 weeks. Significant differences were seen at 4 weeks ($P = 0.0063$) and 8 weeks ($P = 0.0088$).

supplements on weight loss were as follows for placebo and fiber-supplemented groups, respectively: 4 weeks, -1.7 kg (95% CI, -1.3 to -2.0 kg) and -3.0 kg (95% CI, -2.6 to -3.4 kg) ($P = 0.0129$ versus placebo); 8 weeks, -2.4 kg (95% CI, -1.9 to -2.9 kg) and -4.9 kg (95% CI, -3.5 to -4.5 kg) ($P = 0.0104$ versus placebo); and 12 weeks, -2.7 kg (95% CI, -0.6 to -4.0) and -4.9 (95% CI, -0.1 to -8.0). The percentages of weight loss, compared to initial body weight, for placebo and fiber-supplemented diets, respectively, were as follows: 4 weeks, 2.0% and 3.2%; 8 weeks, 2.9% and 4.9%; and 12 weeks, 2.7% and 4.9% (Figure 2).⁶⁴

Comments

Animal experiments, epidemiological data, and clinical trials clearly indicate that higher fiber intake is associated with less weight gain than lower fiber intake. Intake of fiber tends to delay gastric emptying and create a sense of fullness. Increased fiber intakes are associated with increases in satiating gut hormones. The limited number of clinical trials comparing high-fiber foods with low-fiber foods have not provided consistent data indicating that these diets are more efficacious for weight loss than low-fiber control diets; however, randomized, placebo-controlled, clinical trials have clearly documented that fiber supplements are accompanied by significantly more weight loss than use of placebos. Thus, the weight of clinical evidence strongly indicates that consumption of dietary fiber, especially from fiber supplements, has beneficial effects on weight management.

GASTROINTESTINAL FUNCTION AND HEALTH: EFFECTS OF DIETARY FIBER

Physiologic effects

Dietary fibers affect the entire gastrointestinal tract from the mouth to the anus. High-fiber foods usually have lower energy density and take longer to eat.⁸⁰ Soluble fibers usually delay gastric emptying. Soluble fibers may act to slow transit of food materials through the small intestine while insoluble fibers tend to create “intestinal hurry”.¹⁰ In the small intestine, dietary fibers can elicit responses of a wide variety of gastrointestinal hormones that serve as incretins to stimulate insulin release and affect appetite.⁶⁴ Some fibers bind bile acids and impede micelle formation, thus increasing fecal excretion of bile acids and cholesterol.⁵⁶ In the colon, fermentable fibers increase bacterial mass with some acting as prebiotics to promote health-promoting bacteria such as lactobacilli and bifidobacteria.⁸² Insoluble fibers are especially effective in increasing fecal mass and promoting regularity.¹⁰

Prevalence of gastrointestinal disorders

Early observers suggested that dietary fiber intake decreased the prevalence of hiatal hernias and gastroesophageal reflux disease (GERD), peptic ulcer disease, gallbladder disease, appendicitis, diverticular disease, colorectal cancer, and hemorrhoids.⁸³ Rigorous evaluation of the prevalence of these diseases suggests that high levels of dietary fiber intake, compared to low levels, may be associated with a decreased prevalence of the following conditions: esophageal cancer,⁸⁴ GERD,⁸⁵ gastric cancer,⁸⁴ peptic ulcer disease,⁸⁶ gallbladder disease,⁸⁷ diverticular disease,⁸⁸ constipation, and hemorrhoids.¹⁰

The incidence of new cases of colorectal cancer in the United States has recently been estimated at approximately 148,000 per year.⁸⁹ The majority of colon cancers arise from sporadic adenomatous polyps which take an estimated 10 years to transform into a cancer.⁸⁹ The hypothesis that dietary fiber may prevent the formation of these polyps or delay their progression to cancer has been debated for years. The strong theoretical bases for this suggestion are that dietary fiber dilutes fecal carcinogen and procarcinogen concentrations, decreases the resident time of these compounds in the colon, leads to production of short-chain fatty acids with protective effects, and binds carcinogenic bile acids.¹³ Earlier analyses of ecological studies supported this hypothesis.⁹⁰ However, Park et al.¹³ reviewed a series of prospective cohort studies and prospective clinical trials that failed to show a significant difference in the prevalence of colorectal cancer or adenomatous polyps in groups with higher fiber intakes

compared to those with lower fiber intakes. In this analysis of 13 prospective cohort studies with follow-up periods of 6–20 years (median 9 years), approximately 725,000 patients were followed and 8,081 cases of colorectal cancer were reported. Persons with the highest quintile of fiber intake had an insignificant 6% reduction in the development of colorectal cancer. Another recent prospective cohort study of almost 490,000 persons followed for 5 years noted that total dietary fiber intake was not associated with the development of colorectal cancer, but persons with the highest quintile for whole-grain intake had a 14% lower risk for colorectal cancer ($P=0.01$) compared to those in the lowest quintile for whole-grain intake.⁹¹ Thus, the available data do not provide strong support for the hypothesis that consumption of total dietary fiber, cereal fiber, and fiber from fruits or vegetables is protective against colorectal cancer, but whole-grain intake may offer protection.

It is noteworthy that the two available cohort studies compared persons with low dietary fiber intakes (13 g/day for the lowest quintile) to persons with recommended levels (26 g/day for the highest quintile)⁹¹ and 13 g/day (lowest quintile) versus 27 g/day (highest quintile).¹³ The dietary fiber intakes for the lowest quintiles were less than half the recommended level, while the individuals in the upper quintile consumed approximately the recommended level of 14 g/1000 kcal/day.^{5,92}

Role of dietary fiber in the management of gastrointestinal disorders

The use of high-fiber foods or fiber supplements is recommended for a large variety of gut disorders including the following: GERD, duodenal ulcers, inflammatory bowel disease, irritable bowel syndrome, diverticular disease, constipation, and hemorrhoids. There are strong theoretical arguments to support the use of fiber in each condition. Epidemiological data establishing a role for fiber in the prevention of most of these conditions are limited. Clinical trial data and expert opinions are also lacking for these very common disorders.

Limited data suggest that individuals with higher fiber intakes have a lower prevalence of GERD.⁸⁵ Guar gum and, possibly, other soluble fibers are associated with low levels of gastric acid production, which may protect from GERD and duodenal ulcer disease.⁹⁵ The available evidence strongly indicates that high fiber intakes are associated with lower prevalence of duodenal ulcer disease than lower fiber intakes, and the epidemiological evidence is moderately well supported by clinical trials.⁹⁴

Irritable bowel syndrome is one of the most common gastrointestinal functional disorders worldwide. It is a complex disorder with a variety of pathogenetic factors

and includes the following symptoms: abdominal pain or discomfort, bloating, and diarrhea and/or constipation. While wheat bran often increases symptoms⁹³ other fiber supplements such as methylcellulose,⁹⁵ partially hydrolyzed guar gum,⁹⁶ and psyllium⁹⁷ have been reported to alleviate symptoms. In clinical trials, reductions in symptoms in groups receiving placebo as well as those receiving fiber are usually dramatic and statistically significant, thus confounding the assessment of the therapeutic intervention. The sympathetic support of the primary care provider combined with highly selective therapeutic interventions with dietary fiber in foods or supplements can often be very effective in reducing symptoms.⁹⁶

The inflammatory bowel diseases (IBD) including Crohn's disease and ulcerative colitis are chronic diseases that usually become symptomatic during adolescence and are commonly associated with intermittent periods of moderate-to-disabling symptoms. Current therapies are expensive and associated with frequent side effects. Based on experiments with animal models of IBD and preliminary clinical trials in humans, further trials are in progress using probiotics and prebiotics (such as inulin).⁹⁸ Judicious use of soluble fibers or psyllium may offer benefits for persons with ulcerative colitis in remission.⁹⁹

Diverticular disease is the fifth most common gastrointestinal condition in Western countries and is one of the classical fiber-deficiency diseases. A generous intake of dietary fiber is considered to be protective, ameliorative, and preventive of recurrences.¹⁰⁰ Because of the condition's intermittency and the various degrees of colon pathology for this chronic disease, high-quality clinical trials are difficult to execute; the limited data support the use of fiber supplements but are inconclusive.⁶ Because of their anti-inflammatory properties, the inulin-type soluble fibers may have a role in reducing recurrent inflammation of colon diverticuli,¹⁰¹ but no clinical trials have yet been reported.

Increased intake of dietary fiber is commonly used for the prevention and management of constipation or hemorrhoids. Wheat bran, high-fiber cereals, and fiber supplements are widely used by consumers, which represents common knowledge of their beneficial effects. As indicated in Table 3, several of the available supplements are approved by the FDA for their proven laxation effects. Cummings¹⁰ has tabulated the efficacy of different fibers in terms of increased fecal weight per gram of administered fiber as follows: wheat bran, 5.4; fruit or vegetables, 4.7; psyllium, 4.0; cellulose, 3.5; oats, 3.4; corn, 3.2; legumes, 2.2; and pectin, 1.2. First-line therapy for constipation usually includes increased dietary fiber and fluid intake.¹⁰² Increased fiber intake also appears to be effective for the prevention and management of hemorrhoids.¹⁰³

Table 3 Comparison of fiber supplement products.

Property of active ingredient	Active ingredient			
	Psyllium husk	Inulin	Partially hydrolyzed guar	Methyl-cellulose
Natural/synthetic	Natural	Natural	Modified natural ingredient	Semisynthetic
FDA approved for laxation	Yes	No; mild laxation	No	Yes
Soluble/insoluble fiber	70% soluble	100% soluble	100% soluble	100% soluble
Holds water	Yes	Yes	No	Yes
Forms a gel	Yes	No	No	No
Bulks stools	Yes	Slightly	No	Partially
Traps bile acids	Yes	No data	No	Yes
Fermentable	Partially fermentable	100% fermentable	100% fermentable	No
Helps lower blood cholesterol	Yes	No	No	Minimal
Helps lower blood pressure	Yes	No data	No data	No data
Helps control obesity	Yes	No data	No data	No data
Helps lower blood sugar	Yes	No data	Yes	No data
Helps lower the risk of heart disease	Yes	No data	No data	No data
				Calcium polycarbophil
				Synthetic
				Yes
				0% soluble
				Yes
				Yes
				Yes
				No data
				No
				No
				No data
				No data
				No data
				No data
				No data

Comments

Gastrointestinal disorders such as GERD, IBS, diverticulitis, and constipation are extremely common. Diet appears to contribute to the symptoms for a large percentage of persons with these disorders. Considerable evidence suggests that dietary fiber may play a preventive or ameliorative role for GERD, duodenal ulcers, diverticulitis, constipation, and hemorrhoids. Judicious use of dietary fiber, soluble or insoluble based on the predominant symptoms or stage, may contribute to the management of IBS and be helpful for some individuals with IBD. The role of inulin-type soluble fiber in association with prebiotics is emerging and has exciting potential for treating inflammatory conditions of the gut.

DIETARY FIBER AND THE IMMUNE SYSTEM

The gastrointestinal tract is the largest immune organ for humans. The gut-associated lymphoid tissue contains about 60% of all lymphocytes in the body and includes the Peyer's patches and other non-aggregated and intracellular lymphocytes. Optimal function of the gut immune system is dependent on dietary constituents, especially prebiotics (substances that stimulate growth of health-promoting bacteria in the colon).^{104,105} Most prebiotics are nondigestible carbohydrates that are fermented in the colon.⁸² Inulin and other oligofructoses have been the most extensively studied dietary fibers; they act, in part, to stimulate growth of bifidobacteria in the colon. Bifidobacteria and lactobacilli are health-promoting bacteria that generate short-chain fatty acids and stimulate the immune system.¹⁰⁴ Fairly extensive animal studies have documented the favorable effect of inulin on the immune system and preliminary studies in humans support the hypotheses generated from animal studies.¹⁰⁵ Inulin and oligofructoses are not digested by pancreatic or brush border enzymes; thus, they enter the colon virtually intact. In the colon, inulin is fermented completely by the microbacteria and it promotes the growth of bifidobacteria. Short-chain fatty acids (SCFA) result from this fermentation process. Other fibers are also fermented to generate SCFA, but the bifidobacteria effects of non-oligofructose fibers are not as well characterized. The proposed health benefits of bifidobacteria include the following: protection from intestinal infection; lowering of intestinal pH for formation of acids after assimilation of carbohydrates; reduction of the number of potentially harmful bacteria; production of vitamins and antioxidants; activation of intestinal function and assistance in digestion and absorption, especially of calcium; bulking activity to prevent and treat constipation; stimulation of the immune response; and potential reduction in the risk for colorectal cancer.^{104,105}

Limited studies in humans have indicated that inulin supplementation increases the fecal bacterial contents of bifidobacteria and has favorable effects on the types and amounts of circulating lymphocytes.¹² Inulin and oligofructoses have been studied most extensively, but favorable effects of fermentable soluble fibers have been demonstrated for oat β -glucan, gum Arabic, and others.¹⁰⁶

The role of prebiotic fibers in infant nutrition and health, especially for non-breastfed infants, is generating a great deal of interest. These studies suggest that supplementation with a prebiotic fiber mixture has the following benefits: promotes postnatal immune development; decreases respiratory infections and atopic dermatitis; and improves bowel function.¹⁰⁷

The therapeutic potential for using prebiotic fibers in the treatment of inflammatory bowel disease is being examined. In animal studies, prebiotic fibers have reduced gut inflammation in a number of animal experimental models.^{98,108} Early studies also indicate that prebiotic fibers significantly reduce the risk of infection in liver transplant patients.¹⁰⁹ Preliminary human studies have shown favorable responses for individuals with ulcerative colitis, Crohn's disease, or pouchitis, but further studies are required.^{98,108}

DIETARY FIBER IN CHILDHOOD

Dietary fiber is important in childhood and may contribute to significant immediate and future health benefits. These benefits include the following: promotion of normal gastrointestinal function, especially laxation; prevention and treatment of childhood obesity; maintenance of normal blood glucose and lipid values and blood pressure; and risk reduction for future chronic diseases, such as cancer, cardiovascular disease (CVD), and type 2 diabetes. Children with higher intakes of dietary fiber also tend to consume diets that are more nutrient dense and they are more likely to meet recommended daily intakes for key nutrients.¹¹⁰

Gastrointestinal function

Inadequate intake of dietary fiber has been linked to constipation, a common clinical problem in childhood.¹¹¹ In one study of 52 young children with chronic constipation, Morais et al.¹¹² found that their intake of dietary fiber was significantly lower than that of comparable children with normal intestinal habits (9.7 versus 12.6 g/d). The benefits of increasing dietary fiber or prescribing fiber supplements in the treatment of childhood constipation are well documented.¹¹³ In a study of preschool children, 10 grams of added bran fiber consumed daily for 4 weeks in the form of two servings of a raisin bran cereal,

increased stool weight by 60%, increased stool frequency, and was associated with increased intake of iron, zinc, and vitamins A, D, and E.¹¹⁴

Obesity

Some evidence suggests that fiber intake may also play a role in the prevention and treatment of childhood obesity, a growing health problem linked to serious comorbidities.¹¹⁵ At present, 16% of children in the United States are overweight, compared with only 5% in the early 1970s.¹¹⁶ In one study by Samuel et al.,¹¹⁷ data from the NHANES III study showed that among 13–18 year olds, those with low fiber intakes were three to four times more likely to be overweight compared to those with higher fiber intakes. Pashankar et al. reported that children with chronic constipation were twice as likely to be obese as children without this problem (22.4% versus 11.7%), and that one contributing factor was a diet with a low intake of dietary fiber.¹¹⁸ Dietary fiber has also been used in the treatment of childhood obesity, with some studies suggesting that fiber supplements, when added to traditional weight-control regimens, result in approximately 2 kg of added weight loss. In a crossover study with obese children, 15 g/day of dietary fiber added to a reduced-calorie diet resulted in greater mean weight loss compared with the non-fiber treatment period.¹¹⁹ Thus, although more research is needed, some evidence suggests that dietary fiber may be beneficial in the prevention and treatment of childhood obesity.

Serum lipoproteins

Increased dietary fiber has also been shown to have therapeutic benefits in lowering blood cholesterol values in childhood, a risk factor for atherosclerosis and coronary heart disease in later life. Overall, several investigators reported that adding about 6 grams of water-soluble, viscous fiber (such as oat bran or psyllium) to children's diets could lower serum LDL-cholesterol by 6% more than a low-saturated-fat, low-cholesterol diet alone.^{120–122} Similarly, in a longitudinal study of 2–5-year-old preschool children, Williams et al.¹²³ found that intake of dietary fiber was negatively associated with increasing blood cholesterol levels, i.e., higher dietary fiber intake was associated with a lower prevalence of elevated cholesterol levels at 7–10 years of age.

Although adequate intake of dietary fiber has documented health benefits in childhood, the levels of intake among children and youth in the United States are far from adequate. In the NHANES III national survey (1988–1994), the intake of dietary fiber for all children 2–18 years of age was 13.2 grams per day. This varied depending on the age of child, e.g., 10.7 g/day for 2–5 year

olds, 13.4 g/day for 6–11 year olds, and 14.6 g/day for 12–18-year-old adolescents.¹²⁴ Common food sources of fiber are yeast bread, ready-to-eat cereal, white potatoes, dried beans and lentils, tomatoes, and potato chips. In a study by Hampl et al.,¹²⁵ children with higher intakes of dietary fiber consumed more breads and cereals, fruits, vegetables, legumes, nuts, and seeds and had significantly higher energy-adjusted intakes of dietary fiber, iron, magnesium, and vitamins A, E, and folate, while those with low fiber intakes had significantly higher energy-adjusted intakes of fat and cholesterol.

Dietary guidelines

There are several guidelines recommending specific quantitative fiber intakes for children and adolescents, including the American Academy of Pediatrics guideline,¹²⁶ Williams' Age + 5 guideline,¹²⁷ the FDA food label guideline,¹²⁸ and, most recently, the National Academy of Sciences 2002 recommendations for adequate intake, or AI.¹²⁹ The last recommends a daily intake of 14 grams per 1000 kcal for all children 1 year of age and older. The National Academy of Sciences guideline is based on epidemiologic studies of dietary intake levels associated with reduced risk of coronary heart disease, extrapolating adult data and applying it to children.^{130–132} For specific age groups, at estimated mean energy intakes, the recommended AIs for dietary fiber intake would be as follows: 1–3 years, 19 g/d; 4–8 years, 25 g/d; 9–13-year-old boys, 31 g/d; 9–13-year-old girls, 26 g/d; 14–18-year-old boys, 38 g/d; and 14–18-year-old girls, 26 g/day.

Recommendations for increasing dietary fiber intake in childhood emphasize greater consumption of fiber-rich fruits, vegetables, legumes, cereals, and whole-grain products. In addition, fiber supplements may be prescribed as an adjunct to the dietary treatment of constipation, hypercholesterolemia, and obesity. Since dietary fiber increases water retention in the colon, resulting in bulkier, softer stools, recommendations for water intake should be increased commensurate with increases in dietary fiber. The Institute of Medicine recommends the following daily levels of adequate total water intake for children and adolescents: 1–3 years, 1.3 L; 4–8 years, 1.7 L; 9–13-year-old boys, 2.4 L; 9–13-year-old girls, 2.1 L; 14–18-year-old boys, 3.3 L; and 14–18-year-old girls, 2.3 L.¹³³

Comments

Adequate intake of dietary fiber has been associated with a variety of health benefits in childhood. These include promotion of normal gastrointestinal function, especially laxation; prevention and treatment of childhood obesity; maintenance of normal blood glucose values; sustaining

optimal blood pressures; and reduced risk for future chronic diseases, such as cancer, cardiovascular disease, and type 2 diabetes. Children with higher intakes of dietary fiber also consume diets that are more nutrient dense and more likely to meet recommended daily intakes for key nutrients. Unfortunately, current levels of intake among youth in the United States are far from adequate. Therefore, increased emphasis on nutrition education and strategies to help children and youth achieve current intake goals for dietary fiber are recommended.

FIBER INTAKE

Total dietary fiber intake in adults in the United States appears to be less than half the acceptable intake (AI). Results of 12 clinical cohort epidemiological studies reporting dietary fiber intake, as assessed between 1993 and 2000, were tabulated.^{13,31,91,134–139} These reports provided data for seven groups of men ($n = 424,410$) and 11 groups of women ($n = 544,984$). The unweighted mean intake values for total dietary fiber were 16.7 g/day for men and 15.6 g/day for women. Using the AI value of 14 g/1000 kcal, the recommended intake level for adult men is approximately 36 g/day and for women it is approximately 28 g/day.¹⁵ Dietary fiber intake appears to have been decreasing over the past decade and is lower in African American adults than Caucasian adults.¹⁴⁰

Most health advisory groups provide guidance for obtaining the recommended levels of fiber consumption from foods, especially fruits, vegetables, and whole grains.^{15,141,142} This may be an idealistic recommendation that may not be achieved by many US residents. The Women's Health Initiative¹⁴³ recruited over 48,000 postmenopausal women and randomized them to continue their usual diet or follow a prescribed healthy diet. The women were followed for 8 years to determine if a lower fat and higher fiber diet including more fruits, vegetables, and grains, i.e., a healthy diet, would reduce risk for CHD. Women in the healthy-diet group received an intensive behavioral education program including 18 sessions in the first year and quarterly sessions thereafter. The goal was to reduce total fat intake to 20% of energy and increase fruit and vegetable intake to five servings per day and grains to at least six servings per day. Baseline mean intakes for the usual diet and the healthy diet did not differ and were as follows: dietary fiber, 15.4 g/day (8.6 g/1000 kcal); fruits and vegetables, 3.6 servings/day; and grains, 4.7 servings/day. At years 1 and 6 the healthy-diet group had the following mean intakes, respectively: total dietary fiber, 18.1 and 16.9 g/day (11.8 g/1000 kcal); fruit and vegetables, 5.1 and 4.9 servings/day; and grains, 5.1 and 4.3 g/day. After 38 intensive behavioral education sessions implemented over 6 years, increases in fiber

intake (1.5 g/day) were modest, increases in fruit and vegetable intake were statistically significant (+1.3 servings/day) and intake of grains decreased (−0.4 servings/day). Of additional interest, there were no significant differences in rates of CHD or stroke events or deaths between the two groups.¹⁴³

The observations from the Women's Health Initiative¹⁴³ and recent observations by the FDA indicate that consumers are not as effective in modifying dietary habits as they try to be. "The findings of FDA's latest survey on health and nutrition underscore that while US consumers have good health intentions, this does not carry through to their dietary habits."¹⁴⁴ These reports suggest that the recommendations of health advisory groups, which focus almost exclusively on foods, may have a low probability of empowering the general population to achieve recommended goals. Furthermore, these dietary guidelines may not empower the average consumer to reduce risk for CHD, stroke, hypertension, diabetes, or obesity. Clearly, there are strong implications for strengthening educational initiatives – beyond guidelines – for consumers and health professionals. These initiatives should be focused, positive, and achievable. These suggestions go beyond education; there is a strong cost-effect component to consider. Any tool that will contain the costs for reducing the risks and complications of CHD, diabetes, and obesity and for improving immune function should receive a high priority.

There do not appear to be any prospective, long-term studies evaluating fiber supplements related to disease (e.g., diabetes) or outcomes (e.g., CHD or stroke). The majority of evidence related to clinical markers such as serum lipoprotein changes,⁷ weight loss,¹¹ improved glycemic control in diabetes,⁷⁷ improved gastrointestinal function,¹⁰ and enhanced immune function¹⁰⁴ has been documented with fiber supplements rather than with high-fiber foods. Because serum LDL-cholesterol values appear to be the most specific marker for risk for CHD events and death, it seems likely that reductions of serum LDL-cholesterol values with fiber supplements would reduce risk for CHD. While most fiber supplements (such as psyllium) do not have the array of protective phytochemicals that oatbran provides,⁶⁴ reductions of LDL-cholesterol values by 6% are nevertheless likely to reduce risk for CHD by 7–12% by either intervention.⁴¹ Likewise, since the clinical trial data clearly indicate that a variety of fiber supplements significantly enhance weight loss, whereas the data for high-fiber foods are inconclusive, until better strategies for empowering overweight individuals to increase their intake of high-fiber foods are found, it seems reasonable to recommend a practical use of fiber supplements twice or three times daily for individuals engaged in a weight-reduction effort.

Currently available over-the-counter fiber supplements are summarized in Table 3.¹⁴⁵ These products are available in a variety of dosage forms such as multidose containers of powdered fiber, capsules, or caplets. Inulin and psyllium are natural products that are packaged without chemical modification.¹⁴⁵ Wheat dextrin, a newly available supplement, is a natural resistant starch (class 3 or RS3) extracted from cooked and cooled wheat flour.¹⁷ Guar gum is a natural product that is produced from the seed of the guar plant; it is hydrolyzed to a smaller molecular size to produce partially hydrolyzed guar gum.¹⁴⁶ Methylcellulose is a semisynthetic product produced by methylating a natural product (cellulose), and calcium polycarbophil is a synthetic product. Fiber supplements are most commonly used to promote laxation. Calcium polycarbophil, methylcellulose, and psyllium have FDA approval for laxation.¹⁴⁵ Inulin also has modest fecal-bulking effects.¹⁰⁵ Psyllium is the only fiber supplement that has clearly documented cholesterol-lowering properties¹⁴⁷ and has a health claim with respect to CHD.³⁶ Psyllium or other soluble fiber supplements have been associated with reduced blood pressure⁵² as well as improved glycemia and insulin sensitivity in individuals without diabetes,⁷¹ and improved glycemia control in persons with diabetes.⁷⁷ Inulin is emerging as the best-documented prebiotic and stimulus for immune function with other soluble fibers such as oat and barley β -glucans sharing this function.¹⁰⁴ Overall, these active fiber supplements appear to promote a number of the specific health benefits similar to those provided by high-fiber foods. Current scientific evidence suggests that the use of fiber supplements to complement dietary fiber intake from foods would provide protection from CHD, improve insulin sensitivity and glycemia, enhance intestinal function and stimulate immune function.

CONCLUSION

A high level of fiber intake has health-protective effects and disease-reversal benefits. Persons who consume generous amounts of dietary fiber, compared to those who have minimal fiber intake, are at lower risk for developing CHD, stroke, hypertension, diabetes, obesity, and certain gastrointestinal diseases. Increasing the intake of high-fiber foods or fiber supplements improves serum lipoprotein values, lowers blood pressure, improves blood glucose control for diabetic individuals, aids weight loss, and improves regularity. Emerging research indicates that intake of inulin and certain soluble fibers enhances immune function in humans. Dietary fiber intake also provides health benefits for children and the recommended acceptable intakes for children above the age of 1 year are 14 g/1000 kcal, which is the same as for adults. The recommended acceptable intakes of dietary fiber for

adults are 28 g/day for women and 36 g/day for men. Recent estimates suggest that the mean intakes of dietary fiber for adults in the United States are less than half of these recommended levels. The recent Women's Health Initiative Study, which included over 48,000 postmenopausal women who received 38 educational sessions related to dietary guidelines and fiber intake over a 6-year period, was only successful in achieving modest increases in the intakes of dietary fiber and fruits and vegetables and showed decreases in whole-grain intake despite intensive behavioral education sessions.

The use of fiber supplements is not widely recommended by authoritative health organizations in the United States. Dietary sources of fiber contribute vitamins, minerals, water, and a variety of phytonutrients. However, fiber supplements may play an important role in helping some individuals achieve fiber intakes approaching the recommended guidance levels. The available clinical trial data suggest that the use of fiber supplements is more efficacious than the use of high-fiber foods for improving serum lipoprotein values, enhancing weight loss, and improving gastrointestinal function. These improved health benefits for fiber supplements compared to high-fiber foods are probably related to better adherence to supplement use than making substantial improvements in dietary practices. Thus, the wealth of data related to the health benefits of dietary fiber supplements suggest that health advisory bodies should reconsider their recommendations related to fiber supplement use. Because of the undesirably low levels of dietary fiber intake in the US population, partnerships between fiber supplement manufacturers, food producers, and health authorities may be required to educate consumers about the health benefits of dietary fiber intakes from a variety of supplements and foods. New and innovative ways to educate the public about the strong health effects of dietary fiber and fiber supplements must be an essential element of these partnerships.

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P Baird serves as Vice Chair of the National Fiber Council.

RH Davis is a member of the National Fiber Council, the National Heartburn Alliance, and has been a consultant to Procter and Gamble, and TAP Pharmaceuticals.

S Ferreri, M Knudtson, A Koraym, and V Waters are members of the National Fiber Council.

CL Williams is a member of the National Fiber Council, member of the McNeil Splenda Scientific Advisory Board, and consultant for the American Beverage Association.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1. Effects of soluble fiber intake on serum LDL-cholesterol values in randomized, controlled clinical trials with weighted mean changes based on number of subjects.

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REFERENCES

- Liu S, Stampfer MJ, Hu FB, et al. Whole-grain consumption and risk of coronary heart disease: results from the Nurses' Health study. *Am J Clin Nutr*. 1999;70:412–419.
- Steffen LM, Jacobs DR Jr, Stevens J, Shahar E, Carithers T, Folsom AR. Associations of whole-grain, refined grain, and fruit and vegetable consumption with risks of all-cause mortality and incident coronary artery disease and ischemic stroke: the Atherosclerosis Risk in Communities (ARIC) Study. *Am J Clin Nutr*. 2003;78:383–390.
- Whelton SP, Hyre AD, Pedersen B, Yi Y, Whelton PK, He J. Effect of dietary fiber intake on blood pressure: a meta-analysis of randomized, controlled clinical trials. *J Hypertens*. 2005;23:475–481.
- Montonen J, Knekt P, Jarvinen R, Aromaa A, Reunanen A. Whole-grain and fiber intake and the incidence of type 2 diabetes. *Am J Clin Nutr*. 2003;77:622–629.
- Lairon D, Arnault N, Bertrais S, et al. Dietary fiber intake and risk factors for cardiovascular disease in French adults. *Am J Clin Nutr*. 2005;82:1185–1194.
- Petruzziello L, Iacopini F, Bulajic M, Shah S, Costamagna G. Review article: uncomplicated diverticular disease of the colon. *Aliment Pharmacol Ther*. 2006;23:1379–1391.
- Brown L, Rosner B, Willett WW, Sacks FM. Cholesterol-lowering effects of dietary fiber: a meta-analysis. *Am J Clin Nutr*. 1999;69:30–42.
- Keenan JM, Pins JJ, Frazel C, Moran A, Turnquist L. Oat ingestion reduces systolic and diastolic blood pressure in patients with mild or borderline hypertension: a pilot trial. *J Fam Practice*. 2002;51:369–375.
- Anderson JW, Randles KM, Kendall CWC, Jenkins DJA. Carbohydrate and fiber recommendations for individuals with diabetes: a quantitative assessment and meta-analysis of the evidence. *J Am Coll Nutr*. 2004;23:5–17.
- Cummings JH. The effect of dietary fiber on fecal weight and composition. In: Spiller G, ed. *Dietary Fiber in Human Nutrition*. Boca Raton, FL: CRC Press; 2001:183–252.
- Birketvedt GS, Shimshi M, Erling T, Florholmen J. Experiences with three different fiber supplements in weight reduction. *Med Sci Monit*. 2005;11:15–18.
- Watzl B, Gierbach S, Roller M. Inulin, oligofructose and immunomodulation. *Br J Nutr*. 2005;93(Suppl 1):S49–S55.
- Park Y, Hunter DJ, Spiegelman D, et al. Dietary fiber intake and risk of colorectal cancer: a pooled analysis of prospective cohort studies. *JAMA*. 2005;294:2849–2857.
- Jones JR, Lineback DM, Levine MJ. Dietary reference intakes: implications for fiber labeling and consumption: a summary of the International Life Sciences Institute North American Fiber Workshop, June 1–2, 2004. Washington, DC. *Nutr Rev*. 2006;64:31–38.
- US Department of Agriculture (USDA), US Department of Health and Human Services. *Dietary Guidelines for Americans*. Washington, DC: USDA; 2005.
- DeVries JW, Rader JI. Historical perspective as a guide for identifying and developing applicable methods for dietary fiber. *J AOAC Int*. 2005;88:1349–1366.
- Witwer RS. Natural resistant starch in glycemic management: from physiological mechanisms to consumer communications. In: Pasupuleti VK, Anderson JW, eds. *Nutraceuticals, Glycemic Health and Type 2 Diabetes*. Ames, Iowa: Blackwell Publishing Professional; 2008:401–438.
- American Heart Association. *Cardiovascular Disease Statistics*. 2008. Available at: www.americanheart.org/presenter.jhtml?identifier=4478. Accessed 6 May 2008.
- Stampfer MJ, Hu FB, Manson JE, Rimm EB, Willett WC. Primary prevention of coronary heart disease in women through diet and lifestyle. *New Engl J Med*. 2000;343:16–22.
- Kris-Etherton PM, Etherton TD, Carlson J, Gardner C. Recent discoveries in inclusive food-based approaches and dietary patterns for reduction in risk for cardiovascular disease. *Curr Opin Lipidol*. 2002;13:397–407.
- Liu S, Manson JE, Stampfer MJ, et al. Whole grain consumption and risk of ischemic stroke in women: a prospective study. *J Amer Med Assoc*. 2000;284:1534–1540.
- Merchant AT, Hu FB, Spiegelman D, Willett WC, Rimm EB, Ascherio A. Dietary fiber reduces peripheral arterial disease risk in men. *J Nutr*. 2003;133:3658–3663.
- Anderson JW, Conley SB. Whole grains and diabetes. In: Marquart L, Jacobs DR Jr, McIntosh GH, Poutanen K, Reicks M, eds. *Whole Grains and Health*. Ames, Iowa: Blackwell Publishing Professional; 2007:29–45.
- Anderson JW. Whole grains and coronary heart disease: the whole kernel of truth. *Am J Clin Nutr*. 2004;80:1459–1460.
- Anderson JW, Johnstone BM, Cook-Newell ME. Meta-analysis of effects of soy protein intake on serum lipids in humans. *New Engl J Med*. 1995;333:276–282.
- Ornish D, Brown SE, Scherwitz LW, et al. Can lifestyle changes reverse coronary heart disease? The Lifestyle Heart Trial. *Lancet*. 1990;336:129–133.

27. Burr ML, Fehily AM, Gilbert JF. Effects of changes in fat, fish and fibre on death and myocardial reinfarction: Diet and Reinfarction Trial (DART). *Lancet*. 1989;2:757–761.
28. Ascherio A, Rimm EB, Hernan MA, et al. Intake of potassium, magnesium, calcium, and fiber and risk of stroke among US men. *Circulation*. 1998;98:1198–1204.
29. Mozaffarian D, Kumanyika SK, Lemaitre RN, Olson JL, Burke GL, Siscovick DS. Cereal, fruit, and vegetable fiber intake and the risk of cardiovascular disease in elderly individuals. *JAMA*. 2003;289:1659–1666.
30. Johnsen SP, Overvad K, Stripp C, Tjonneland A, Husted SE, Sorensen HT. Intake of fruit and vegetables and the risk of ischemic stroke in a cohort of Danish men and women. *Am J Clin Nutr*. 2003;78:57–64.
31. Wu H, Dwyer KM, Fan Z, Shircore A, Fan J, Dwyer JH. Dietary fiber and progression of atherosclerosis: the Los Angeles Atherosclerosis Study. *Am J Clin Nutr*. 2003;78:1085–1091.
32. He J, Klag MJ, Whelton PK, et al. Oats and buckwheat intakes and cardiovascular disease risk factors in an ethnic minority of China. *Am J Clin Nutr*. 1995;61:366–372.
33. Greenland P, Knoll MD, Stamler J, et al. Major risk factors as antecedents of fatal and nonfatal coronary heart disease events. *J Amer Med Assoc*. 2003;290:891–897.
34. Butt MS, Shahzadi N, Sharif MK, Nasir M. Guar gum: a miracle therapy for hypercholesterolemia, hyperglycemia and obesity. *Crit Rev Food Sci Nutr*. 2007;47:389–396.
35. US Department of Health and Human Services FaDA. Health claims: oats and coronary heart disease – final rule. *Fed Regist*. 1997;62:3583–3601.
36. US Department of Health and Human Services FaDA. Health claims: soluble fiber from certain foods and coronary heart disease – final rule. *Fed Regist*. 1998;63:8103–8121.
37. Chen HL, Sheu WH, Tai TS, Liaw YP, Chen YC. Konjac supplement alleviated hypercholesterolemia and hyperglycemia in type 2 diabetic subjects – a randomized double-blind trial. *J Am Coll Nutr*. 2003;22:36–42.
38. Haskell WL, Spiller GA, Jensen CD, Ellis BK, Gates JE. Role of water-soluble dietary fiber in the management of elevated plasma cholesterol in healthy subjects. *Am J Cardiol*. 1992;69:433–439.
39. Yamada K, Tokunaga Y, Ikeda A, et al. Dietary effect of guar gum and its partially hydrolyzed product on the lipid metabolism and immune function of Sprague-Dawley rats. *Biosci Biotechnol Biochem*. 1999;63:2163–2167.
40. Anderson JW, Gilinsky NH, Deakins DA, et al. Hypocholesterolemic effects of different bulk-forming hydrophilic fibers as adjuncts to dietary therapy in mild to moderate hypercholesterolemia. *Arch Intern Med*. 1991;151:1597–1602.
41. Katan MB, Grundy SM, Jones P, Law M, Miettinen T, Paoletti R. Efficacy and safety of plant stanols and sterols in the management of blood cholesterol levels. *Mayo Clin Proc*. 2003;78:965–978.
42. Anderson JW, Davidson MH, Blonde L, et al. Long-term cholesterol-lowering effects of psyllium as an adjunct to diet therapy in the treatment of hypercholesterolemia. *Am J Clin Nutr*. 2000;71:1433–1438.
43. Tuomilehto J, Silvasti M, Aro A, et al. Long term treatment of severe hypercholesterolemia with guar gum. *Atherosclerosis*. 1988;72:157–162.
44. Simons LA, Gayst S, Balasubramaniam S, Ruys J. Long-term treatment of hypercholesterolaemia with a new palatable formulation of guar gum. *Atherosclerosis*. 1982;45:101–108.
45. Salenius JP, Harju E, Jokela H, Riekkinen H, Silvasti M. Long term effects of guar gum on lipid metabolism after carotid endarterectomy. *BMJ*. 1995;310:95–96.
46. Anderson JW. Plant fiber and blood pressure. *Ann Intern Med*. 1983;98:842–846.
47. Dodson PM, Pacy PJ, Cox EV. Long-term follow-up of the treatment of essential hypertension with a high-fibre, low-fat and low-sodium dietary regimen. *Hum Nutr Clin Nutr*. 1985;39:213–220.
48. Pins JJ, Geleva D, Keenan JM, Frazel C, O'Connor PJO, Cherney LM. Do whole-grain oat cereals reduce the need for antihypertensive medications and improve blood pressure control? *J Fam Practice*. 2002;51:353–359.
49. Davy BM, Melby CL, Beske SD, Ho RC, Davrath LR, Davy KP. Oat consumption does not affect resting casual and ambulatory 24-h arterial blood pressure in men with high-normal blood pressure to stage I hypertension. *J Nutr*. 2002;132:394–398.
50. Uusitupa M, Tuomilehto J, Karttunen P, Wolf E. Long term effects of guar gum on metabolic control, serum cholesterol and blood pressure levels in type 2 (non-insulin-dependent) diabetic patients with high blood pressure. *Ann Clin Res*. 1984;16(Suppl 43):S126–S131.
51. Krotkiewski M. Effect of guar gum on the arterial blood pressure. *Acta Med Scand*. 1987;222:43–49.
52. Streppel MT, Arends LR, Grobbee DE, Geleijnse JM. Dietary fiber and blood pressure: a meta-analysis of randomized placebo-controlled trials. *Arch Intern Med*. 2005;165:150–156.
53. Delzenne NM, Cani PD. A place for dietary fibre in the management of the metabolic syndrome. *Curr Opin Clin Nutr Metab Care*. 2005;8:636–640.
54. Davy BM, Melby CL. The effect of fiber-rich carbohydrates on features of Syndrome X. *J Am Diet Assoc*. 2003;103:86–96.
55. Bo S, Durazzo M, Guidi S, et al. Dietary magnesium and fiber intakes and inflammatory and metabolic indicators in middle-aged subjects from a population-based cohort. *Am J Clin Nutr*. 2006;84:1062–1069.
56. Kirby RW, Anderson JW, Sieling B, et al. Oat-bran intake selectively lowers serum low-density lipoprotein cholesterol concentrations of hypercholesterolemic men. *Am J Clin Nutr*. 1981;34:824–829.
57. Wright RS, Anderson JW, Bridges SR. Propionate inhibits hepatocyte lipid synthesis. *Proc Soc Exp Biol Med*. 1990;195:26–29.
58. Zimmet P. *Diabetes – The Biggest Epidemic in Human History*. 2007. Available at: www.medscape.com/viewarticle/561261. Accessed 28 August 2007.
59. American Diabetes Association. *Total Prevalence of Diabetes and Pre-diabetes*. 2008. Available at: www.diabetes.org/diabetes-prevalence.jsp. Accessed 26 July 2008.
60. Anderson JW, Pasupuleti VK. Nutraceuticals and diabetes prevention and management. In: Pasupuleti VK, Anderson JW, eds. *Nutraceuticals, Glycemic Health and Type 2 Diabetes*. Ames, Iowa: Blackwell Publishing Professional; 2008:1–10.
61. Anderson JW, Kendall CWC, Jenkins DJA. Importance of weight management in type 2 diabetes: review with meta-analysis of clinical studies. *J Am Coll Nutr*. 2003;22:331–339.
62. Klein S, Sheard N, Pi-Sunyer FX, et al. Weight management through lifestyle modification for the prevention and management of type 2 diabetes: rationale and strategies. *Diabetes Care*. 2004;27:2067–2073.

63. Egede LE, Dagogo-Jack S. Epidemiology of type 2 diabetes: focus on ethnic minorities. *Med Clin North Am.* 2005;89: 949–975.
64. Anderson JW. Dietary fiber and associated phytochemicals in prevention and reversal of diabetes. In: Pasupuleti VK, Anderson JW, eds. *Nutraceuticals, Glycemic Health and Type 2 Diabetes*. Ames, Iowa: Blackwell Publishing Professional; 2008:111–142.
65. Lindstrom J, Peltonen M, Eriksson JG, et al. High-fibre, low-fat diet predicts long-term weight loss and decreased type 2 diabetes risk: the Finnish Diabetes Prevention Study. *Diabetologia.* 2006;49:912–920.
66. Anderson JW, Ward K. Long-term effects of high-carbohydrate, high-fiber diets on glucose and lipid metabolism: a preliminary report on patients with diabetes. *Diabetes Care.* 1978;1:77–82.
67. Anderson JW, Zeigler JA, Deakins DA, et al. Metabolic effects of high-carbohydrate, high-fiber diets for insulin-dependent diabetic individuals. *Am J Clin Nutr.* 1991;54: 936–943.
68. Weickert MO, Mohlig M, Schofl C, et al. Cereal fiber improves whole-body insulin sensitivity in overweight and obese women. *Diabetes Care.* 2006;29:775–780.
69. Lu ZX, Walker KZ, Muir JG, Mascara T, O'Dea K. Arabinoxylan fiber, a product of wheat flour processing, reduces the postprandial glucose response in normoglycemic subjects. *Am J Clin Nutr.* 2000;71:1123–1128.
70. Vuksan V, Sievenpiper JL, Owen R, et al. Beneficial effects of viscous dietary fiber from Konjac-mannan in subjects with the insulin resistance syndrome: results of a controlled metabolic trial. *Diabetes Care.* 2000;23:9–14.
71. Garcia AL, Otto B, Reich SC, et al. Arabinoxylan consumption decreases postprandial serum glucose, serum insulin and plasma total ghrelin response in subjects with impaired glucose tolerance. *Eur J Clin Nutr.* 2007;61:334–341.
72. Landin K, Holm G, Tengborn L, Smith U. Guar gum improves insulin sensitivity, blood lipids, blood pressure, and fibrinolysis in healthy men. *Am J Clin Nutr.* 1992;56:1061–1065.
73. Juntunen KS, Laaksonen DE, Poutanen KS, Nikanen LK, Mykkanen HM. High-fiber rye bread and insulin secretion and sensitivity in healthy postmenopausal women. *Am J Clin Nutr.* 2003;77:385–391.
74. Pereira MA, Jacobs DR Jr, Pins JJ, et al. Effect of whole grains on insulin sensitivity in overweight hyperinsulinemic adults. *Am J Clin Nutr.* 2002;75:848–855.
75. Jang Y, Lee JH, Kim OY, Park HY, Lee SY. Consumption of whole grain and legume powder reduces insulin demand, lipid peroxidation, and plasma homocysteine concentrations in patients with coronary artery disease: randomized controlled clinical trial. *Arterioscler Thromb Vasc Biol.* 2001;21:2065–2071.
76. Ziai SA, Larijani B, Akhoondzadeh S, et al. Psyllium decreased serum glucose and glycosylated hemoglobin significantly in diabetic outpatients. *J Ethnopharmacol.* 2005; 102:202–207.
77. Anderson JW, Allgood LD, Turner C, Oelgten PR, Daggy BP. Effects of psyllium on glucose and serum lipid responses in men with type 2 diabetes and hypercholesterolemia. *Am J Clin Nutr.* 1999;70:466–473.
78. Rodriguez-Moran M, Guerrero-Romero F, Laczano-Burciaga L. Lipid- and glucose-lowering efficacy of plantago psyllium in type II diabetes. *J Diabetes Complicat.* 1998;12: 273–278.
79. Anderson JW. Diabetes mellitus: medical nutrition therapy. In: Shils ME, Shike M, Ross AC, Caballero B, Cousins RJ, eds. *Modern Nutrition in Health and Disease*. Philadelphia: Lea & Febiger; 2006:1043–1066.
80. Haber GB, Heaton KW, Murphy D, Burroughs LF. Depletion and disruption of dietary fibre. Effects on satiety, plasma-glucose, and serum-insulin. *Lancet.* 1977;2:679–682.
81. Poppitt SD, Keogh GF, Prentice AM, et al. Long-term effects of ad libitum low-fat, high-carbohydrate diets on body weight and serum lipids in overweight subjects with metabolic syndrome. *Am J Clin Nutr.* 2002;75:11–20.
82. Roberfroid MB. Introducing inulin-type fructans. *Br J Nutr.* 2005;93(Suppl 1):S13–S25.
83. Burkitt DP, Trowell HC. *Refined Carbohydrate Foods and Diseases: Some Implications of Dietary Fibre*. London: Academic Press; 1975.
84. Wu AH, Tseng CC, Hankin J, Bernstein L. Fiber intake and risk of adenocarcinomas of the esophagus and stomach. *Cancer Causes Control.* 2007;18:713–722.
85. El-Serag HB, Satia JA, Rabeneck L. Dietary intake and the risk of gastro-oesophageal reflux disease: a cross sectional study in volunteers. *Gut.* 2005;54:11–17.
86. Aldoori WH, Giovannucci EL, Stampfer MJ, Rimm EB, Wing AL, Willett WC. Prospective study of diet and the risk of duodenal ulcer in men. *Am J Epidemiol.* 1997;145:42–50.
87. Tsai CJ, Leitzmann MF, Willett WC, Giovannucci EL. Long-term intake of dietary fiber and decreased risk of cholecystectomy in women. *Am J Gastroenterol.* 2004;99:1364–1370.
88. Aldoori WH. The protective role of dietary fiber in diverticular disease. *Adv Exp Med Biol.* 1997;427:291–308.
89. American Cancer Society. *Incidence of colon and rectal cancer in the U.S.* 2006. Available at: www.cancer.org/downloads/stt/CAFF06EsCsEc.pdf. Accessed 12 April 2008.
90. Block G, Patterson B, Subar A. Fruit, vegetables, and cancer prevention: a review of the epidemiological evidence. *Nutr Cancer.* 1992;18:1–29.
91. Schatzkin A, Mouw T, Park Y, et al. Dietary fiber and whole-grain consumption in relation to colorectal cancer in the NIH-AARP Diet and Health Study. *Am J Clin Nutr.* 2007; 85:1353–1360.
92. Panel on Dietary Reference Intakes for Macronutrients, National Academy of Sciences. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fatty Acids, Cholesterol, Protein, and Amino Acids*. Washington, DC: National Academies Press; 2002.
93. Harju E. Guar gum benefits duodenal ulcer patients by decreasing gastric acidity and rate of emptying of gastric contents 60 to 120 minutes postprandially. *Am Surg.* 1984;50:668–672.
94. Ryan-Harshman M, Aldoori W. How diet and lifestyle affect duodenal ulcers. Review of the evidence. *Can Fam Physician.* 2004;50:727–732.
95. Smits BJ. The irritable bowel syndrome. *Practitioner.* 1974;213:37–46.
96. Giannini EG, Mansi C, Dulbecco P, Savarino V. Role of partially hydrolyzed guar gum in the treatment of irritable bowel syndrome. *Nutrition.* 2006;22:334–342.
97. Prior A, Whorwell PJ. Double blind study of ispaghula in irritable bowel syndrome. *Gut.* 1987;28:1510–1513.
98. Ewaschuk JB, Dieleman LA. Probiotics and prebiotics in chronic inflammatory bowel diseases. *World J Gastroenterol.* 2006;12:5941–5950.
99. Seidner DL, Lashner BA, Brzezinski A, et al. An oral supplement enriched with fish oil, soluble fiber, and antioxidants

- for corticosteroid sparing in ulcerative colitis: a randomized, controlled trial. *Clin Gastroenterol Hepatol*. 2005;3:358–369.
100. Frieri G, Pimpo MT, Scarpignato C. Management of colonic diverticular disease. *Digestion*. 2006;73(Suppl 1):S58–S66.
101. Guarner F. Studies with inulin-type fructans on intestinal infections, permeability, and inflammation. *J Nutr*. 2007;137(Suppl 11):S2568–S2571.
102. Schaefer DC, Cheskin LJ. Constipation in the elderly. *Am Fam Physician*. 1998;58:907–914.
103. Ho YH, Tan M, Seow-Choen F. Micronized purified flavonoid fraction compared favorably with rubber band ligation and fiber alone in the management of bleeding hemorrhoids: randomized controlled trial. *Dis Colon Rectum*. 2000;43:66–69.
104. Vos AP, M'Rabet L, Stahl B, Boehm G, Garssen J. Immune-modulatory effects and potential working mechanisms of orally applied nondigestible carbohydrates. *Crit Rev Immunol*. 2007;27:97–140.
105. Roberfroid MB. Inulin-type fructans: functional food ingredients. *J Nutr*. 2007;137(Suppl):S2493–S2502.
106. Schley PD, Field CJ. The immune-enhancing effects of dietary fibres and prebiotics. *Br J Nutr*. 2002;87(Suppl 2):S221–S230.
107. Veereman G. Pediatric applications of inulin and oligofructose. *J Nutr*. 2007;137(Suppl):S2585–S2589.
108. Guarner F. Inulin and oligofructose: impact on intestinal diseases and disorders. *Br J Nutr*. 2005;93(Suppl 1):S61–S65.
109. Guarner F. Prebiotics in inflammatory bowel diseases. *Br J Nutr*. 2007;98(Suppl 1):S85–S89.
110. Nicklas TA, Myers L, O'Neil C, Gustafson N. Impact of dietary fat and fiber intake on nutrient intake of adolescents. *Pediatrics*. 2000;105:E21–E27.
111. Hatch TF. Encopresis and constipation in children. *Pediatr Clin North Am*. 1988;35:257–280.
112. Morais MB, Vitolo MR, Aguirre AN, Fagundes-Neto U. Measurement of low dietary fiber intake as a risk factor for chronic constipation in children. *J Pediatr Gastroenterol Nutr*. 1999;29:132–135.
113. McClung HJ, Boyne L, Heitlinger L. Constipation and dietary fiber intake in children. *Pediatrics*. 1995;96:999–1001.
114. Williams CL, Bollella MC, Strobino BA, Boccia L, Campanaro L. Plant stanol ester and bran fiber in childhood: effects on lipids, stool weight and stool frequency in pre-school children. *J Am Coll Nutr*. 1999;18:572–581.
115. Johnson L, Mander AP, Jones LR, Emmett PM, Jebb SA. Energy-dense, low-fiber, high-fat dietary pattern is associated with increased fatness in childhood. *Am J Clin Nutr*. 2008;87:846–854.
116. Ogden CL, Flegal KM, Carroll MD, Johnson CL. Prevalence and trends in overweight among US children and adolescents, 1999–2000. *J Amer Med Assoc*. 2002;288:1728–1732.
117. Samuel P, Keast DR, Williams CL, Bartholmey SJ. Dietary fiber and its role in childhood obesity (Abstract). *FASEB J*. 2003;14:A746.
118. Pashankar DS, Loening-Baucke V. Increased prevalence of obesity in children with functional constipation evaluated in an academic medical center. *Pediatrics*. 2005;116:e377–e380.
119. Gropper SS, Acosta PB. The therapeutic effect of fiber in treating obesity. *J Am Coll Nutr*. 1987;6:533–535.
120. Williams CL, Bollella M, Spark A, Puder D. Effectiveness of a psyllium enriched step I diet in hypercholesterolemic children. *J Am Coll Nutr*. 1991;14:251–257.
121. Glassman M, Spark A, Berezin S, Schwarz S, Medow M, Newman LJ. Treatment of type IIa hyperlipidemia in childhood by a simplified American Heart Association diet and fiber supplementation. *Am J Dis Child*. 1990;144:973–976.
122. Taneja A, Bhat CM, Arora A, Kaur AP. Effect of incorporation of isabgol husk in a low fibre diet on faecal excretion and serum levels of lipids in adolescent girls. *Eur J Clin Nutr*. 1989;43:197–202.
123. Williams CL, Strobino BA. Childhood diet, overweight, and CVD risk factors: the Healthy Start project. *Prev Cardiol*. 2008;11:11–20.
124. Alaimo K, McDowell MA, Briefel RR, et al. *Dietary Intake of Vitamins, Minerals, and Fiber of Persons Ages 2 Months and Over in the United States: Third National Health and Nutrition Examination Survey, Phase 1, 1988–91*. Report 258. Hyattsville, MD: National Center for Health Statistics; 1994:1–28.
125. Hampl JS, Betts NM, Benes BA. The “age + 5” rule: comparisons of dietary fiber intake among 4- to 10-year-old children. *J Am Diet Assoc*. 1998;98:1418–1423.
126. Barnes LA. Carbohydrate and dietary fiber. In: Kleinman RE, ed. *Pediatric Nutrition Handbook*. Elk Grove Village, Illinois: American Academy of Pediatrics; 1993:104–124.
127. Williams CL, Bollella M, Wynder EL. A new recommendation for dietary fiber in childhood. *Pediatrics*. 1995;96:985–988.
128. Food and Drug Administration. *Focus on Food Labeling*. An FDA Consumer Special Report. 93–2262. Washington, DC: US Government Printing Office; 1993.
129. Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and Amino Acids*. Washington, DC: National Academy of Sciences; 2002.
130. Rimm EB, Ascherio A, Giovannucci E, et al. Vegetable, fruit, and cereal fiber intake and risk of coronary heart disease among men. *J Amer Med Assoc*. 1996;275:447–451.
131. Wolk A, Manson JE, Stampfer MJ, et al. Long-term intake of dietary fiber and decreased risk of coronary heart disease among women. *J Amer Med Assoc*. 1999;281:1998–2004.
132. Pietinen P, Rimm EB, Korhonen P, et al. Intake of dietary fiber and risk of coronary heart disease in a cohort of Finnish men: the Alpha-Tocopherol, Beta-Carotene Cancer Prevention Study. *Circulation*. 1996;94:2720–2727.
133. Panel on Dietary Reference Intakes for Electrolytes and Water. Standing Committee on the Scientific Evaluation of Dietary Reference Intakes. *Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate*. Washington, DC: National Academies Press; 2004.
134. McCullough ML, Robertson AS, Chao A, et al. A prospective study of whole grains, fruits, vegetables and colon cancer risk. *Cancer Cause Control*. 2003;14:959–970.
135. Wang L, Gaziano JM, Liu S, Manson JE, Buring JE, Sesso HD. Whole- and refined-grain intakes and the risk of hypertension in women. *Am J Clin Nutr*. 2007;86:472–479.
136. McKeown NM, Meigs JB, Liu S, Saltzman E, Wilson PW, Jacques PF. Carbohydrate nutrition, insulin resistance, and the prevalence of the metabolic syndrome in the Framingham Offspring Cohort. *Diabetes Care*. 2004;27:538–546.
137. Elmer PJ, Obarzanek E, Vollmer WM, et al. Effects of comprehensive lifestyle modification on diet, weight, physical fitness, and blood pressure control: 18-month results of a randomized trial. *Ann Intern Med*. 2006;144:485–495.
138. Schulze MB, Liu S, Rimm EB, Manson JE, Willett WC, Hu FB. Glycemic index, glycemic load, and dietary fiber intake and incidence of type 2 diabetes in younger and middle-aged women. *Am J Clin Nutr*. 2004;80:348–356.

139. Pereira MA, Jacobs DR, Slattery ML, et al. The association between whole grain intake and fasting insulin in a bi-racial cohort of young adults: the CARDIA study. *CVD Prev.* 1998;1:231–242.
140. Stevens J, Ahn K, Juhaer I, Houston D, Steffan L, Couper D. Dietary fiber intake and glycemic index and incidence of diabetes in African-American and white adults. *Diabetes Care.* 2002;25:1715–1721.
141. Lichtenstein AH, Appel LJ, Brands M, et al. Diet and lifestyle recommendations revision 2006: a scientific statement from the American Heart Association Nutrition Committee. *Circulation.* 2006;114:82–96.
142. American Diabetes Association. Nutrition principles and recommendations in diabetes. *Diabetes Care.* 2004;27(Suppl): S36–S46.
143. Howard BV, Van Horn L, Hsia J, et al. Low-fat dietary pattern and risk of cardiovascular disease: the Women's Health Initiative Randomized Controlled Dietary Modification Trial. *J Am Med Assoc.* 2006;295:655–666.
144. Douaud C. *Nutrition Message Still Not Reaching Americans, FDA Survey.* 2008. Available at: www.foodnavigator-usa.com/news/printNewsbis.asp?id=85119. Accessed 7 May 2008.
145. Berardi RR, Kroon LA, McDermott JH, et al. *Handbook of Non-prescription Drugs*, 15th edn. Washington, DC: American Pharmacists Association; 2006
146. Slavin JL, Greenberg NA. Partially hydrolyzed guar gum: clinical nutrition uses. *Nutrition.* 2003;19:549–552.
147. Anderson JW, Allgood LD, Lawrence A, Altringer LA, Jerdack GR, Hengehold DA. Cholesterol-lowering effects of psyllium intake adjunctive to diet therapy in men and women with hypercholesterolemia: meta-analysis of 8 controlled trials. *Am J Clin Nutr.* 2000;71:472–479.