Position of the American Dietetic Association: Health Implications of Dietary Fiber

ABSTRACT

It is the position of the American Dietetic Association that the public should consume adequate amounts of dietary fiber from a variety of plant foods. Populations that consume more dietary fiber have less chronic disease. In addition, intake of dietary fiber has beneficial effects on risk factors for developing several chronic diseases. Dietary Reference Intakes recommend consumption of 14 g dietary fiber per 1,000 kcal, or 25 g for adult women and 38 g for adult men, based on epidemiologic studies showing protection against cardiovascular disease. Appropriate kinds and amounts of dietary fiber for children, the critically ill, and the very old are unknown. The Dietary Reference Intakes for fiber are based on recommended energy intake, not clinical fiber studies. Usual intake of dietary fiber in the United States is only 15 g/day. Although solubility of fiber was thought to determine physiological effect, more recent studies suggest other properties of fiber, perhaps fermentability or viscosity are important parameters. High-fiber diets provide bulk, are more satiating, and have been linked to lower body weights. Evidence that fiber decreases cancer is mixed and further research is needed. Healthy children and adults can achieve adequate dietary fiber intakes by increasing variety in daily food patterns. Dietary messages to increase consumption of high-fiber foods such as whole grains, legumes, fruits, and vegetables should be broadly supported by food and nutrition professionals. Consumers are also turning to fiber supplements and bulk laxatives as additional fiber sources. Few fiber supplements have been studied for physiological effectiveness, so the best advice is to consume fiber in foods. Look for physiological studies of effectiveness before selecting functional fibers in dietetics practice.

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This American Dietetic Association (ADA) position paper uses ADA's Evidence Analysis Process and information from ADA's Evidence Analysis Library. The use of an evidence-based approach provides important added benefits to earlier review methods. The major advantage of the approach is the more rigorous standardization of review criteria, which minimizes the likelihood of reviewer bias and increases the ease with which disparate articles may be compared.

For a detailed description of the methods used in this position paper, access ADA's Evidence Analysis Process (www.adaevidencelibrary.com/category.cfm?cid=7&cat=0).

Conclusion Statements are assigned a grade by an expert work group based on the systematic analysis and evaluation of the supporting research evidence: Grade I=Good, Grade II=Fair, Grade III= Limited, Grade IV=Expert Opinion only, and Grade V=Grade is not assignable (because there is no evidence to support or refute the conclusion). Evidence-based information for this and other topics can be found at the Evidence Analysis Library (www.adaevidencelibrary.com) and subscriptions for non-ADA members can be purchased at the Evidence Analysis Library's on-line store (www.adaevidencelibrary.com/store.cfm).

POSITION STATEMENT

It is the position of The American Dietetic Association that the public should consume adequate amounts of dietary fiber from a variety of plant foods.

In 2002, the Institute of Medicine published a new set of definitions for dietary fiber (1). The new definition suggested that the term *dietary fiber* would describe the nondigestible carbohydrates and lignin that are intrinsic and intact in plants, whereas *functional fiber* consists of the isolated nondigestible carbohydrates that have beneficial physiological effects in human beings. *Total fiber* would then be the sum of dietary fiber and functional fiber. Nondigestible means not digested and absorbed in the human small intestine. Fibers can be fermented in the large intestine or can pass through the digestive tract unfermented. There is no biochemical assay that reflects dietary fiber or functional fiber nutritional status (eg, blood fiber levels cannot be measured because fiber is not absorbed). No data are available to determine an Estimated Average Requirement and thus calculate a Recommended Dietary Allowance for total fiber, so an Adequate Intake (AI) was instead developed. The AI for fiber is based on the median fiber intake level observed to achieve the lowest risk of coronary heart disease (CHD). A Tolerable Upper Intake Level was not set for dietary fiber or functional fiber.

Dietary fiber is part of a plant matrix which is largely intact. Nondigestible plant carbohydrates in foods are usually a mixture of polysaccharides that are integral components of the plant cell wall or intercellular structure. This definition recognizes that the three-dimensional plant matrix is responsible for some of the physicochemical properties attributed to dietary fiber and that dietary fiber contains other nutrients normally found in foods, which are important in the potential health effects. Cereal brans, which are obtained by grinding, are anatomical layers of the grain consisting of intact cells and substantial amounts of starch and protein; they are categorized as dietary fiber sources.

Dietary Reference Intakes (DRIs) for total fiber by life stage group are shown in Table 1. The AIs for total fiber are based on the intake level observed to protect against CHD based on epidemiologic, clinical, and mechanistic data. The reduction of risk of diabetes can be used as a secondary endpoint to support the recommended intake level. The relationship of fiber intake to colon cancer is the subject of ongoing investigation. The DRI development panel suggested the recommended intakes of total fiber may also help ameliorate constipation and diverticular disease, provide fuel for colon cells, reduce blood glucose and lipid levels, and provide a source of nutrient-rich, low-energy-dense foods that could contribute to satiety, although these benefits were not used as the basis for the AI.

Table 1. Dietary Reference Intakes (DRI) for total fiber[a] by life stage group and DRI values (g/1,000 kcal/d)[b]

	Adequate Intake[c]			
Life stage group	**Men**	**g/1,000 kcal/d**	**Women**	**g/1,000 kcal/d**
0-6 mo	ND[d]	ND	ND	ND
7-12 mo	ND	ND	ND	ND
1-3 y	14	19	14	19
4-8 y	14	25	14	25
9-13 y	14	31	14	26
14-18 y	14	38	14	26
19-30 y	14	38	14	25
31-50 y	14	38	14	25
51-70 y	14	30	14	21
>70 y	14	30	14	21
Pregnancy				
<18 y	NA[e]	NA	14	29
19-50 y	NA	NA	14	28
Lactation				
<18 y	NA	NA	14	29
19-50 y	NA	NA	14	29

[a]Total fiber is the combination of dietary fiber (the edible, nondigestible carbohydrate and lignin components in plant foods) and functional fiber (isolated, extracted, or synthetic fiber that has proven health benefits).
[b]Values are example of the total grams per day of total fiber calculated from g/1,000 kcal multiplied by the median energy intake (kcal/1,000 kcal/day) from the Continuing Survey of Food Intakes by Individuals 1994-1996, 1998.
[c]If sufficient scientific evidence is not available to establish an Estimated Average Requirement, and thus calculate a Recommended Dietary Allowance, an Adequate Intake (AI) is usually developed. For healthy, breastfed infants, the AI is the mean intake. The AI for other life stage and sex groups is believed to cover the needs of all healthy individuals in the group, but a lack of data or uncertainty in the data prevents being able to specify with confidence the percentage of individuals covered by this intake.
[d]ND=not determined.
[e]NA=not applicable.

There is no AI for fiber for healthy infants aged 0 to 6 months who are fed human milk because human milk does not contain dietary fiber. During the 7- to 12-month age period, solid food intake becomes more significant, and so dietary fiber intake may increase. However, there are no data on dietary fiber intake in this age group and no theoretical reason to establish an AI. There is also no information to indicate that fiber intake as a function of energy intake differs during the life cycle.

Fiber recommendations for children and elderly persons were also based on the consumption of 14 g fiber per 1,000 kcal consumed. No published studies have defined desirable fiber intakes for infants and children younger than age 2 years. Until there is more information about the effects of dietary fiber in the very young, a rational approach would be to introduce a variety of fruits, vegetables, and easily digested cereals as solid foods are brought into the diet. Although based on limited clinical data, a previous fiber recommendation for children older than 2 years is to increase dietary fiber intake to an amount equal to or greater than their age plus 5 g/day and to achieve intakes of 25 to 35 g/day after age 20 years (2).

Little clinical data are available for fiber needs in the elderly. Thus, the fiber AI for older adults is also based on 14 g/1,000 kcal. As older adults require less dietary energy than young adults, the AI for fiber consumption in older adults decreases. All fiber recommendations need to recognize the importance of adequate fluid intake, and caution should be used when recommending fiber to those with gastrointestinal diseases, including constipation.

The 2005 US Dietary Guidelines recommend high-fiber food such as whole grains and vegetables and fruits, and fiber intake levels of 14 g/1,000 kcal (3). MyPyramid also supports this recommendation (4). Nutrition Facts labels use 25 g dietary fiber per day for a 2,000 kcal/day diet or 30 g/day for a 2,500 kcal/day diet as goals for American intake.

Dietary fiber intake continues to be less than recommended in the United States with usual intakes averaging only 15 g per day (1). When asked about their perceptions of their dietary fiber intake, 73% of individuals with a mean fiber intake below 20 g/d think the amount of fiber they consume is "about right" (5). Many popular American foods contain little dietary fiber. Servings of commonly consumed grains, fruits, and vegetables contain only 1 to 3 g dietary fiber (6) (Table 2). Major sources of dietary fiber in the US food supply include grains and vegetables (7). White flour and white potatoes provide the most fiber to the diet, about 16% and 9%, respectively, not because they are concentrated fiber sources, but because they are widely consumed. Legumes are very rich in dietary fiber, but because of low consumption only provide about 6% of the fiber in the US diet. Fruits provide only 10% of the fiber in the overall US diet because of low fruit consumption and the low amount of fiber in fruits, except for dried fruits.

Table 2. Dietary fiber content of commonly consumed fruits, vegetables, grains, and other foods[a]

Food	Serving size	Total dietary fiber (g/serving)
Fruits		
Prunes, dried	5 prunes	3.0
Orange	1 orange	3.1
Apple, large with skin	1 apple	3,7
Banana	1 banana	2.8
Raisins	1 miniature box (14 g)	0.6
Figs, dried	2 figs	4.6
Pear	1 pear	4.0
Peaches, canned	½ c	1.3
Strawberries, raw	1 c, sliced	3.8
Vegetables		
Beans, kidney, canned	½ c	4.5
Peas, split, cooked	½ c	8.1
Lentils, cooked	½ c	7.8
Lettuce, iceberg	1 c, shredded	0.8
Peas, green, canned	½ c	3.5
Brussels sprouts	½ c	2.0
Spinach, cooked	½ c	2.2
Carrots, raw	½ c	1.8
Potatoes, boiled	½ c	1.6
Broccoli, raw	½ c	1.3
Celery, raw	½ c	1.0
Grains		
Wheat bran flakes	¾ c	4.6
Raisin bran	1 c	7.5
Shredded wheat	2 biscuits	5.0
Rice, brown, cooked	1 c	3.5
Bread, white wheat	1 slice	0.6
Bread, whole wheat	1 slice	1.9
Oatmeal, cooked	¾ c	3.0
Oat bran muffin	1 muffin	2.6
Rye crispbread	1 wafer	1.7
Crackers, graham	2 squares	0.4
Other		
Apple pie	1 piece	1.9
Nuts, mixed, dry roast	1 oz	2.6
Chocolate cake	1 slice	1.8
Yellow cake	1 slice	0.2

[a]Source: Adapted from the US Department of Agriculture Nutrient Database for Standard Reference, Release 14 (http://www.nal.usda.gov/fnic/foodcomp/Data/SR14/sr14.html).

DEFINITION AND SOURCES OF FIBER

A variety of definitions of dietary fiber exist (8). Some are based primarily upon analytical methods used to isolate and quantify dietary fiber whereas others are physiologically based. Dietary fiber is primarily the storage and cell wall polysaccharides of plants that cannot be hydrolyzed by human digestive enzymes. Lignin, which is a complex molecule of polyphenylpropane units and present only in small amounts in the human diet, is also usually included as a component of dietary fiber. For labeling the dietary fiber content of food products within the United States, dietary fiber is defined as the material isolated by analytical methods approved by the Association of Official Analytical Chemists (AOAC), generally AOAC Method 985.29 (8). A variety of low molecular carbohydrates such as resistant starch, polydextrose, and nondigestible oligosaccharides including fructo- and galacto-oligosacchardies are being developed and increasingly used in food processing. Generally these compounds are not captured by AOAC Method 985.29. Other AOAC-accepted methods to measure the fiber content of these novel fibers have been developed or are currently in development (8).

Although the Institute of Medicine report recommended that the terms *soluble fiber* and *insoluble fiber* not be used (1), food labels still may include soluble and insoluble fiber data. The water-soluble fiber is precipitated in a mixture of enzymes and ethanol. Dietary fiber was divided into soluble and insoluble fiber in an attempt to assign physiologic effects to chemical types of fiber. Oat bran, barley bran, and psyllium, mostly soluble fiber, have health claims for their ability to lower blood lipid levels. Wheat bran and other more insoluble fibers are typically linked to laxation. Yet, scientific support that soluble fibers lower blood cholesterol, whereas insoluble fibers increase stool size, is inconsistent at best.

Resistant starch (the sum of starch and starch-degradation products not digested in the small intestine) (9) reaches the large intestine and would function as dietary fiber. Legumes are a primary source of resistant starch, with as much as 35% of legume starch escaping digestion (10). Small amounts of resistant starch are produced by processing and baking of cereal and grain products. Many new functional fibers increasingly being added to processed foods are resistant starches. Murphy and colleagues (11) estimated resistant starch intakes in the United States. A database of resistant starch concentrations in foods was developed from published values. These values were linked to foods reported in 24-hour dietary recalls from participants in the 1999-2002 National Health and Nutrition Examination Surveys to estimate resistant starch intakes. Americans aged 1 year and older were estimated to consume approximately 4.9 g resistant starch per day (range 2.8 to 7.9 g/day).

Other functional fibers were reviewed by the DRI committee and are listed in the Figure. Dietary fiber includes plant nonstarch polysaccharides (eg, cellulose, pectin, gums, hemicellulose, β-glucans, and fiber contained in oat and wheat bran), plant carbohydrates that are not recovered by alcohol precipitation (eg, inulin, oligosaccharides, and fructans), lignin, and some resistant

Characteristic	Dietary fiber
Nondigestible animal carbohydrate	No
Carbohydrates nonrecovered by alcohol precipitation[a]	Yes
Nondigestible mono- and disaccharides and polyols	No
Lignin	Yes
Resistant starch	Some
Intact, naturally occurring food source only	Yes
Resistant to human enzymes	Yes
Specifies physiological effect	No

Figure. Characteristics of dietary fiber. Source: Adapted from reference 7. [a]Includes inulin, oligosaccharides (three to 10 degrees of polymerization), fructans, polydextrose, methylcellulose, resistant maltodextrins, and other related compounds.

starch. Potential functional fibers include isolated, nondigestible plant (eg, resistant starch, pectin, and gums), animal (eg, chitin and chitosan), or commercially produced carbohydrates (eg, resistant starch, polydextrose, inulin, and indigestible dextrins) (1).

BENEFITS OF ADEQUATE FIBER INTAKE

This American Dietetic Association (ADA) position paper uses ADA's Evidence Analysis Process and information from ADA's Evidence Analysis Library (12). Four topics were included in the evidence analysis for dietary fiber: cardiovascular disease, gastrointestinal health and disease, weight control, and diabetes. The Evidence Analysis Library does not include the topic of dietary fiber and cancer.

Cardiovascular Disease

What is the evidence that dietary fiber from whole foods and dietary supplements is beneficial in cardiovascular disease?

Conclusion Statement. Based on current data, dietary fiber intake from whole foods or supplements may lower blood pressure, improve serum lipid levels, and reduce indicators of inflammation. Benefits may occur with intakes of 12 to 33 g fiber per day from whole foods or up to 42.5 g fiber per day from supplements. **Grade II–Fair.**

The DRI recommendations for dietary fiber are based on protection against cardiovascular disease (CVD), so there is consistent and strong data for this relationship (1). The committee used epidemiologic, cohort studies that estimated dietary fiber intake from food frequencies and followed subjects prospectively until CVD was detected. Dietary fiber intake levels found to be protective against CVD were then used to determine an AI for dietary fiber. Although there were recommendations for dietary fiber intake before 2002, there were no official recommendations until the 2002 DRIs (1).

Since the publication of the DRIs, other epidemiologic studies also support that dietary fiber intake protects against CVD. Bazzano and colleagues (13) examined the relationship between total and soluble dietary fiber intake and the risk of CHD and CVD in 9,776 adults who were free of CVD at baseline and who participated in the National Health and Nutrition Examination Survey I Epidemiologic Follow-up Study. A 24-hour dietary recall was used to assess dietary intake. A higher intake of dietary fiber, particularly water-soluble fiber, reduced risk of CHD.

Pereira and colleagues (14) completed a pooled analysis of cohort studies of dietary fiber and risk of CHD. Ten prospective cohort studies from the United State and Europe were used to estimate the association between dietary fiber intake and risk of CHD. During 6 to 10 years of follow-up, each 10 g/day increment of energy-adjusted and measurement error-corrected total dietary fiber was associated with a 14% decrease in risk of all coronary events and a 27% decrease in risk of coronary death. Only fiber from cereals and fruits was found to be inversely associated with risk of CHD.

The link between fiber intake and CVD was also measured in older adults (15). A population-based, multicenter study among 3,588 men and women aged 65 years or older and free of known CVD at baseline was conducted. During 8.6 years mean follow-up, there were 811 incident CVD events among 3,588 men and women. Cereal fiber consumption was inversely associated with incident CVD with 21% lower risk in the highest quintile of intake, compared with the lowest quintile. Neither fruit fiber nor vegetable fiber was associated with incident CVD. The authors suggest that cereal fiber consumption late in life is associated with lower risk of incident CVD, supporting recommendations for older adults to increase consumption of dietary cereal fiber.

Whole grain intake is also known to protect against CVD and Jensen and colleagues (16) attempted to determine which parts of the whole grain are most important for protection. They measured whole grains, bran, and germ intake in a prospective cohort study of 42,850 male health professionals aged 40 to 75 years at baseline in 1986 who were free from CVD. Whole grain intake and added bran were protective, while added germ was not. This suggests that whole grains are protective against CVD and that the bran component of whole grains is the important factor in the protection.

Although epidemiologic, prospective studies are consistent in their support that dietary fiber protects against CVD, there is much confusion about which components of dietary fiber are most protective. The DRI committee concluded that fiber from cereals seems most protective. In addition, certain functional fiber, particularly those that are soluble and viscous may alter biomarkers of interest in CVD. Several mechanisms have been suggested to explain fiber's protective properties in CVD. Viscous fibers lower blood cholesterol levels, specifically that fraction transported by low-density lipoproteins (LDL) (17). Meta-analysis by Brown and colleagues (18) showed that daily intake of 2 to 10 g soluble fiber significantly lowered serum total cholesterol and LDL-cholesterol concentrations. The majority of these studies showed no change in high-density lipoprotein cholesterol or triacylglycerol concentrations with soluble fiber. Fibers that lower blood cholesterol levels include foods such as apples, barley, beans and other legumes, fruits and vegetables, oatmeal, oat bran, and rice hulls, and purified sources such as beet fiber, guar gum, karaya gum, konjac mannan, locust bean gum, pectin, psyllium seed husk, soy polysaccharide and xanthan gum (17). Three of these fibers, namely β-glucan in oats, β-glucan in barley, and psyllium husk, have been sufficiently studied for the US Food and Drug Administration to authorize a health claim that foods meeting specific compositional requirements and containing 0.75 g to 1.7 g soluble fiber per serving can reduce the risk of heart disease (19,20).

The mechanism by which these fiber sources lower blood cholesterol levels has been the focus of many investigations, and characteristics such as solubility in water, viscosity, fermentability, and the kinds and amounts of protein and tocotrienols have been explored as possible basis for this physiological effect of fiber (21). Viscosity is thought to be an important factor in cholesterol lowering, although solubility and molecular weight of fibers also determine cholesterol lowering ability. In general, when a soluble fiber that is not viscous is evaluated or the fiber is treated to reduce viscosity sufficiently, the cholesterol-lowering ability is lost (22,23). As components in foods are digested and absorbed from the small intestine, fiber becomes a major component in the gut lumen, making the viscosity evident. This viscosity interferes with bile acid absorption from the ileum (23,24). In response, LDL cholesterol is removed from the blood and converted into bile acids by the liver to replace the bile acids lost in the stool. Changes in the composition of the biliary bile acid pool accompanying ingestion of some viscous fibers dampen cholesterol synthesis (25). Because endogenous synthesis accounts for about three quarters of the total body cholesterol pool, slowing synthesis (as do statin drugs) could have a favorable influence on blood cholesterol concentrations. In fact, studies of a portfolio diet, including a wide range of foods known to lower serum cholesterol (eg, viscous fiber), reported cholesterol-lowering ability similar to statin drugs (26).

Results of trials with concentrated β-glucans from oats or barley have been inconsistent (27). Potential reasons for these inconsistencies include low effectiveness because of processing techniques used to isolate β-glucans, the molecular weight and/or viscosity of the β-glucans, and the delivery method of the β-glucans. Higher molecular weight fibers are associated with increased viscosity. Higher viscosities may be linked to greater reductions in serum cholesterol concentrations and CVD risk, but this relationship is not well established. Keenan and colleagues (28) reported a 9% to 15% decrease in LDL-cholesterol with a 6-week intervention of low and high molecular weight barley β-glucan when given at doses of 3 and 5 g/day in a parallel study of 155 subjects. The high molecular weight barley was most effective in cholesterol lowering, although the difference was not statistically significant. In contrast, Keogh and colleagues (29) found no changes in cholesterol when 10 g/day isolated barley β-glucan was fed in a metabolic study.

No differences in effects on blood lipid levels were found when both high- and low-molecular-weight β-glucan isolated from oats was given to human subjects (30). Isolated β-glucan from oats (5 g/day) lowered LDL cholesterol when incorporated into a fruit drink (31), but when oats and barley were compared in a similar design only the lower dose of oat β-glucan (5 g/day) lowered serum lipid levels whereas the 10 g/day dose did not (32). In contrast to oats, barley β-glucans did not lower serum lipid levels in this study. Concentrated oat β-glucan (6 g/day) lowered serum cholesterol levels in adults with hypercholesterolemia (33).

Other Mechanisms Whereby Fiber can Protect Against CVD. Fibers also affect blood pressure and C-reactive protein (CRP), additional biomarkers linked to risk of CVD. Dietary fiber intake was inversely associated with CRP in the National Health and Nutrition Examination Survey 1999-2000 (34). Ma and colleagues (35) found similar results in 524 subjects enrolled in the Seasonal Variation of Blood Cholesterol Levels Study. In an intervention study, fiber intake of about 30 g/day from a diet naturally rich in fiber reduced levels of CRP (36). Results with blood pressure are equally promising. A meta-analysis of randomized placebo-controlled trials found that fiber intake was linked to lower blood pressure (37). Reductions in blood pressure tended to be larger in older subjects and in populations with hypertension. Whelton and colleagues (38) also reported that increased intake of dietary fiber reduced blood pressure in patients with hypertension.

Thus, epidemiologic support that dietary fiber, especially from grains, protects against CVD is strong enough to use to set standards for dietary guidance on intake of dietary fiber. These studies find that maximum CVD protection requires intake of 14 g dietary fiber per 1,000 kcal intake, or 38 g in men and 25 g in women based on estimated median energy intakes in Americans. Whether isolated, functional fibers provide protection against CVD remains controversial, although US Food and Drug Administration-approved health claims exist for oats, barley, and pysllium.

Bowel Function

What is the evidence that dietary fiber from whole foods and dietary supplements is beneficial in gastrointestinal health and disease?

Conclusion Statement. There is a lack of data examining the impact of fiber from whole foods on outcomes in gastrointestinal diseases. This may be due to the complexity and cost of these studies. However, fiber supplements may produce benefits in the laxation of healthy individuals. More research is needed to clarify dose and type of fiber in gastrointestinal health and disease management. **Grade III–Limited.**

Many fiber sources, including cereal brans, psyllium seed husk, methylcellulose, and a mixed high-fiber diet, increase stool weight, thereby promoting normal laxation. Stool weight continues to increase as fiber intake increases (39,40), but the added fiber tends to normalize defecation frequency to one bowel movement daily and gastrointestinal transit time to 2 to 4 days. The increase in stool weight is caused by the presence of the fiber, by the water that the fiber holds, and by fermentation of the fiber, which increases bacteria in stool. If the fiber is fully and rapidly fermented in the large bowel, as are most soluble fiber sources, there is no increase in stool weight (37). It is a common but erroneous belief that the increased stool weight is due primarily to water. The moisture content of human stool is 70% to 75% and this does not change when more fiber is consumed (41). Fiber in the colon is no more effective at holding water in the lumen than the other components of stool. The one known exception is psyllium seed husk,which does increase the concentration of stool water to about 80% (42). But as more fiber is consumed stool weight does increase and increased fluid consumption should be recommended to account for this increase in fecal water loss.

Unlike blood, fecal samples have not been collected and evaluated for a large cohort of healthy subjects. Cummings and colleagues (43) conducted a meta-analysis of 11 studies in which daily fecal weight was measured accurately in 26 groups of people (N=206) on controlled diets of known fiber content. Fiber intakes were significantly related to stool weight (r=0.84). Stool weight varied greatly among subjects from different countries, ranging from 72 to 470 g/day. Stool weight was inversely related to colon cancer risk in this study. Spiller (44) suggested that there is a critical fecal weight of 160 to 200 g/day for adults, below which colon function becomes unpredictable and risk of colon cancer increases. Stool weights in healthy United Kingdom adults averaged only 106 g/day (43). It is likely that average stool weights in the United States are also low as Cummings and colleagues (43) report that stool weights in Westernized populations range from 80 to 120 g/day.

Constipation and diarrhea are two extremes of abnormal bowel function. Constipation is defined as three or fewer spontaneous bowel movements per week (45). The longer feces remain in the large intestine, the more water is absorbed into the intestinal cells, resulting in hard feces and increased defecation difficulty. The rectum becomes distended, which may cause abdominal discomfort and other adverse symptoms such as headache, loss of appetite, and nausea (46). Leung (47) reviewed the literature on etiology of constipation and found essentially no evidence-based publications. He suggests that teaching on constipation is based on myths handed down from one generation to the next. Etiologic factors thought to be related to constipation, dietary fiber intake, fluid intake, physical activity, drugs, sex hormones, and disease status, have not been systematically evaluated for their relationship to constipation.

Clinical diarrhea is defined as an elevated stool output (>200 to 250 g/day); watery, difficult to control bowel movements; and more than three bowel movements per day (48). Laxation refers to a slight increase in the frequency of bowel movements and a softer consistency of feces (49). Other symptoms that are associated with laxation include increased stool weight and water content, decreased gastrointestinal transit time, loose stools, bloating and distention, borborygmi, abdominal discomfort, and flatus (50). Carbohydrates that reach the large intestine are fermented to different degrees, depending on the degree of polymerization, solubility, and structure of the carbohydrates (51). Fermentation of the carbohydrates in the large intestine produces gases, which may cause bloating, distention, borborygmi, and flatulence. If the carbohydrates are not fermented in the large intestine, either because the bacteria do not metabolize the carbohydrates or because intake exceeds the fermentation capacity of the bacteria, the water remains bound to the carbohydrates that are eliminated in the feces, which increases fecal bulk, but also may produce a watery stool or diarrhea.

The total amount of poorly digested carbohydrates in the diet affects tolerance. Many foods are natural laxatives because they contain indigestible carbohydrates and other compounds with natural laxative properties: cabbage, brown bread, oatmeal porridge, fruits with rough seeds, vegetable acids (oxalic acid), aloe, rhubarb, cascara, senna, castor oil, honey (fructose), tamarinds, figs, prunes, raspberries, strawberries, and stewed apples (52).

Studies have been conducted where fiber intakes are standardized and fed in addition to controlled diets. Fecal weight increased 5.4 g/g wheat bran fiber (mostly insoluble), 4.9 g/g fruits and vegetables (soluble and insoluble), 3 g/g isolated cellulose (insoluble), and 1.3 g/g isolated pectin (soluble) (Table 3) (43). When subjects were fed 15, 30, or 42 g/day diet fiber from a mixed diet, there was a significant increase in stool weight on all diets. Most of the increased stool weight was from undigested dietary fiber, although the midrange of fiber intake was also associated with an increase in bacterial mass (53).

Not just fiber in foods determines stool weight. Slavin and colleagues (54) fed liquid diets containing 0, 30, and 60 g soy fiber and compared stool weights to those when subjects were consuming their habitual diets. Daily fecal weight averaged 145 g/day on the habitual diets. On the liquid diets with added fiber stool weight averaged 67 g/day, 100 g/day, and 150 g/day. Estimated fiber intake on the habitual diet was less than 20 g/day, supporting that other factors in solid foods besides dietary fiber increase stool weight.

Besides food intake, other factors also affect stool size. These are often noted in studies, but are not well studied in research trials. Stress associated with exams or competition can speed intestinal transit. Exercise may speed intestinal transit (55), although data on this are conflicting. Bingham and Cummings (56) found that on a controlled dietary intake, transit time increased in nine subjects and decreased in five when a 9-week exercise program was introduced. Other measures of bowel function, including stool weight or fecal frequency, were not changed by the exercise program.

Even on rigidly controlled diets of the same composition, there is a large variation in daily stool weight among subjects. Sex is known to alter colonic function (57). Tucker and colleagues (58) examined the predictors of stool weight when completely controlled diets were fed to normal volunteers. They found that personality was a better predictor of stool weight than dietary fiber intake, with outgoing subjects more likely to produce higher stool weights.

Weight Control

What is the evidence that dietary fiber from whole foods and dietary supplements is beneficial in obesity?

Conclusion Statement. Based on current data, dietary fiber intake from whole foods or supplements may have some benefit in terms of weight loss and

Table 3. Average increase in fecal weight per gram fiber fed to men and women[a]

Fiber type	Weight (g/g fiber fed)
Wheat	5.4
Fruits and vegetables	4.7
Gums and mucilages	3.7
Cellulose	3.5
Oats	3.4
Corn	3.3
Legumes	2.2
Pectin	1.2

[a]Data from reference 43.

other health outcomes. Benefits may occur with intakes of 20 to 27 g/day from whole foods or up to 20 g fiber per day from supplements. **Grade III–Limited.**

Heaton (59) proposed that fiber acts as a physiological obstacle to energy intake by at least three mechanisms:

- fiber displaces available energy and nutrients from the diet;
- fiber increases chewing, which limits its intake by promoting the secretion of saliva and gastric juice, resulting in an expansion of the stomach and increased satiety; and
- fiber reduces the absorption efficiency of the small intestine.

Human beings may consume a constant weight of food and as such, a constant weight of lower energy (ie, high fiber) food per unit weight may promote a reduction in weight (60). High-fiber foods have much less energy density compared to high-fat foods. Thus, high-fiber foods can displace other energy sources. The bulking and viscosity properties of dietary fiber are predominantly responsible for influencing satiation and satiety. Fiber-rich foods usually are accompanied by increased efforts and/or time of mastication, which leads to increased satiety through a reduction in rate of ingestion.

Intrinsic, hormonal, and colonic effects of dietary fiber decrease food intake by promoting satiation and/or satiety (61). *Satiation* is defined as the satisfaction of appetite that develops during the course of eating and eventually results in the cessation of eating. *Satiety* refers to the state in which further eating is inhibited and occurs as a consequence of having eaten. Dietary fiber also decreases gastric emptying and/or slows energy and nutrient absorption leading to lower postprandial glucose and lipid levels. Dietary fiber may also influence fat oxidation and fat storage.

The effects of dietary fiber on hunger, satiety, energy intake, and body weight have been reviewed (62). The majority of studies with controlled energy intake reported an increase in postmeal satiety and a decrease in subsequent hunger with increased dietary fiber. With ad libitum energy intake, the average effect of increasing dietary fiber across all the studies indicated that an additional 14 g fiber per day resulted in a 10% decrease in energy intake and a weight loss of more than 1.9 kg through about 3.8 months of intervention. In addition, the effects of increasing dietary fiber were reported to be even more impressive in individuals with obesity. This group concluded that increasing the population's mean dietary fiber intake from the current average of about 15 g/day to 25 to 30 g/day would be beneficial and may help reduce the prevalence of obesity.

In the prospective Nurses Health Study, women who consumed more fiber weighed less than women who consumed less fiber (63). In addition, women in the highest quintile of dietary fiber intake had a 49% lower risk of major weight gain. More recently, Maskarinec and colleagues (64) reported that plant-based foods and dietary fiber were most protective against excess body weight in a large ethnically diverse population. Howarth and colleagues (65) examined the association of dietary composition variables with body mass index among US adults aged 20 to 59 years in the Continuing Survey of Food Intakes by Individuals 1994-1996. For women, a low-fiber, high-fat diet was associated with the greatest increase in risk of overweight or obesity compared with a high-fiber, low-fat diet. Davis and colleagues (66) matched 52 normal-weight women to 52 overweight-obese women and found that the normal weight subjects had higher fiber and fruit intake than the subjects with obesity.

Fiber dose is an important consideration. Mattes (67) compared a control breakfast bar to a breakfast bar containing alginate and guar gum (0.6 g fiber vs 4.5 g fiber) in subjects with obesity. No significant treatment effect or cumulative effects of satiety were found with the higher fiber containing bar. In general, large intakes of fiber are needed to alter satiety. Few studies find any acute changes in satiety when <10 g dietary fiber are consumed (68).

Traditionally, high-fiber foods have been solid foods. However, some of the newer functional fibers, such as resistant starches and oligosaccharides, can be easily added to drinks and may not alter viscosity. Few studies on the satiating effects of drinks supplemented with these soluble, nonviscous fibers have been published. Moorhead and colleagues (69) compared test lunches with 200 g whole carrots, blended carrots, or carrot nutrients. Whole carrots and blended carrots resulted in significantly higher satiety. Ad libitum food intake for the remainder of the day decreased in this order: carrot nutrients, blended carrots, whole carrots. The researchers concluded that both fiber content and food structure are important determinants of satiety. A similar study was conducted using apples, applesauce, and apple juice (with added fiber) as a preload before a meal (70). Although the three foods contained the same energy and fiber, subjects ate significantly less lunch when consuming the whole apple compared to the applesauce, apple juice, or no preload. Again, this suggests that adding fiber to a beverage may not necessarily enhance satiety and that solid foods may be more satiating than liquids.

As reviewed by Green and Slavin (68), many studies support that increased dietary fiber intake promotes satiety, decreases hunger, and thus helps provide a feeling of fullness. Foods rich in dietary fiber tend to have a high volume and a low energy density and should promote satiation and satiety, and play a role in the control of energy balance. However, research on the effects of different types of fiber on appetite, energy, and food intake has been inconsistent. Results differ according to the type of fiber, whether it is added as an isolated fiber supplement rather than naturally occurring in food sources. Short-term studies in which fiber is fed to subjects and food and energy intake assessed at subsequent meals suggest that large amounts of total fiber are most successful at reducing subsequent energy intake. In addition, more viscous fiber may be more successful in promoting satiety. Longer-term studies of fiber intake which examine the effects of both intrinsic and functional fibers and satiety are required. Yet there is ample evidence that increasing consumption of high fiber foods and the addition of viscous fibers to the diet may decrease feelings of hunger by inducing satiation and satiety.

Diabetes

What is the evidence that dietary fiber from whole foods and dietary supplements is beneficial in diabetes?

Conclusion Statement. Based on the current data, diets providing 30 to 50 g fiber per day from whole food sources consistently produce lower serum glucose levels compared to a low-fiber diet. Fiber supplements providing doses of 10 to 29 g/day may have some benefit in terms of glycemic control. **Grade III–Limited.**

Although emphasis has been placed on specific effects that can be detected as statistically significant when a particular fiber source is consumed, dietary fiber has many subtle, less easily quantifiable effects that are beneficial. This is particularly true for fiber provided by foods. A fiber-rich meal is processed more slowly and nutrient absorption occurs over a greater time period (71). Further, a diet of foods providing adequate fiber is usually less energy dense and larger in volume than a low-fiber diet that may limit spontaneous intake of energy (72). This larger mass of food takes longer to eat and its presence in the stomach may bring a feeling of satiety sooner, although this feeling of fullness is short term. A diet of a wide variety of fiber-containing foods also is usually richer in micronutrients.

When viscous fibers are isolated and thereby concentrated, their effects on digestion are frequently easier to detect. When these types of fibers are added to a diet, theoretically, the rate of glucose appearance in the blood is slowed and insulin secretion is subsequently reduced. These beneficial effects on blood glucose and insulin concentrations are most evident in individuals with diabetes mellitus. In healthy individuals, the rapid insulin secretion that causes rapid removal of glucose from the blood frequently makes it impossible to detect a difference between blood glucose concentrations during a test meal with and without a fiber supplement.

Considerable experimental evidence demonstrates that the addition of viscous dietary fibers slow gastric emptying rates, digestion, and the absorption of glucose to benefit immediate postprandial glucose metabolism (73) and long-term glucose control (74,75) in individuals with diabetes mellitus. The long-term ingestion of 50 g dietary fiber per day for 24 weeks significantly improved glycemic control and reduced the number of hypoglycemic events in individuals with type 1 diabetes (76). Some studies of individuals with type 2 (non–insulin-dependent diabetes) suggest that high fiber intakes diminish insulin demand (77). Two cohort studies found that fiber from cereals, but not from fruits and vegetables, had an inverse independent relationship with risk of non–insulin-dependent diabetes (78,79).

The mechanisms around how fiber affects insulin requirements or insulin sensitivity are not clear. Glucagon-like peptide 1 reduced gastric emptying rates, promoted glucose uptake and disposal in peripheral tissues, enhanced insulin-dependent glucose disposal, inhibited glucagon secretion, and reduced hepatic glucose output in animals and human beings (80). These multiple effects of glucagon-like peptide 1 may reduce the amount of insulin required by individuals with impaired glucose metabolism when consuming a high-fiber diet. As more is learned about the gastrointestinal regulation of food intake, it is clear that dietary fiber may play a role throughout the gastrointestinal tract (81).

Some soluble fibers increase the viscosity of the contents of the stomach and digestive tract. Higher molecular weight fibers increase viscosity. This altered viscosity may be responsible for effects on body weight and attenuated glucose and insulin response because nutrients become trapped and emptying from the stomach is delayed. Few studies have been published on the effectiveness of isolated β-glucans and glucose and insulin control (82). Poppitt and colleagues (83) found that a high dose, barley β-glucan supplement improved glucose control when added to a high-carbohydrate starch food, but not when added to a high-carbohydrate beverage. Compared to control, 5 g β-glucans from oats significantly lowered postprandial concentrations of glucose and insulin, while barley β-glucan did not (84). Barley β-glucan reduced plasma glucose and insulin responses in male subjects (85).

Kaline and colleagues (86) reviewed the importance and effect of dietary fiber in diabetes prevention. They suggest that whole-grain cereal products appear especially effective in the prevention of type 2 diabetes mellitus and suggest a dietary fiber intake of at least 30 g/day for protection. The Nurses Health Study cohort was evaluated for the relationship among whole grain, bran, and germ intake and risk of type 2 diabetes (87). Associations for bran intake were similar to those for total whole grain intake, whereas no significant association was observed for germ intake after adjustment for bran. They found that a two serving per day increment in whole grain consumption was associated with a 21% decrease in risk of type 2 diabetes after adjustment for potential confounders and body mass index.

Cancer

The relationship between cancer and dietary fiber was not included in the dietary fiber Evidence Analysis Library. Some of the studies reviewed in the gastrointestinal health and disease question are relevant to this discussion, but the studies on dietary fiber and cancer are inconsistent.

Large-Bowel Cancer. Extensive epidemiologic evidence supports the theory that dietary fiber may protect against large-bowel cancer. Epidemiologic studies that compare colorectal cancer incidence or mortality rates among countries with estimates of national dietary fiber consumption suggest that fiber in the diet may protect against colon cancer. Data collected from 20 populations in 12 countries showed that average stool weight varied from 72 to 470 g/day and was inversely related to colon cancer risk (88). When results of 13 case-control studies of colorectal cancer rates and dietary practices were pooled, the authors concluded that the results provided substantive evidence that consumption of fiber-rich foods is inversely related to risks of both colon and rectal cancers (89). The authors estimated that the risk of colorectal cancer in the US population could be reduced by about 31% with an average increase in fiber intake from food sources of about 13 g/day.

Three intervention studies do not support the protective properties of dietary fiber against colon cancer (90-92). The studies found no significant effect of high-fiber intakes on the recurrence of colorectal adenomas. Each article describes a well-planned dietary intervention to determine whether high-fiber food consumption could lower colorectal cancer risk, as measured by a change in colorectal adenomas, a precursor of most large-bowel cancers. Several reasons have been given for the failure to demonstrate a benefit. Perhaps the fiber interventions were not long enough, the fiber dose was not high enough, recurrence of adenoma is not an appropriate measure of fiber's effectiveness in preventing colon cancer, or these individuals had already optimized their diets because the fiber intake by the low-fiber control subjects exceeded that of the American population. Yet increasing dietary fiber consumption during 3 years did not alter recurrence of adenomas. Despite the inconsistency in the results of fiber and colon cancer studies, the scientific consensus is that there is enough evidence on the protectiveness of dietary fiber against colon cancer that health professionals should be promoting increased consumption of dietary fiber (93).

Recent follow-up of the Polyp Prevention Trial also found no effect of a low-fat, high-fiber, high-fruit and vegetable diet on adenoma recurrence 8 years after randomization (94). The Polyp Prevention Trial was a 4-year trial and there was some thought that differences with dietary intervention would take longer to occur. Even though the trial had ended, the experimental group continued to consume more fiber in their diet. Still they found no effect of the intervention on later polyp recurrence.

The European Prospective Investigation into Cancer and Nutrition is a prospective cohort study comparing the dietary habits of more than a half-million people in 10 countries with colorectal cancer incidence (95). They found that people who ate the most fiber (those with total fiber from food sources averaging 33 g/day) had a 25% lower incidence of colorectal cancer than those who ate the least fiber (12 g/day). The investigators estimated that populations with low average fiber consumption could reduce colorectal cancer incidence by 40% by doubling their fiber intake. Dukas and colleagues (96) reported that in the Nurses' Health Study, women in the highest quintile of dietary fiber intake (median intake 20 g/day) were less likely to experience constipation than women in the lowest quintile (median intake 7 g/day).

Although dietary fiber intake may not protect against colorectal cancer in prospective studies, some support exists for the protective properties of whole-grain intake. Schatzkin and colleagues (97) investigated the relationship between whole-grain intake and invasive colorectal cancer in the prospective National Institutes of Health-AARP Diet and Health Study. Total dietary fiber intake was not associated with colorectal cancer risk whereas whole grain consumption was associated with a modest reduced risk. The association with whole grain intake was stronger for rectal than for colon cancer.

Breast Cancer. Limited epidemiologic evidence has been published on fiber intake and breast cancer risk in human beings. Because the fat and fiber contents of the diet are generally inversely related, it is difficult to separate the independent effects of these nutrients, and most research has focused on the fat and breast cancer hypothesis. International comparisons show an inverse correlation between breast cancer death rates and consumption of fiber-rich foods (98). An interesting exception to the high-fat diet hypothesis in breast cancer was observed in Finland, where intake of both fat and fiber is high and the breast cancer mortality rate is considerably lower than in the United States and other Western countries where the typical diet is high in fat (99). The large amount of fiber in the rural Finnish diet may modify the breast cancer risk associated with a high-fat diet. A pooled analysis of 12 case-control studies of dietary factors and risk of breast cancer found that high dietary fiber intake was associated with reduced risk of breast cancer (100). Dietary fiber intake also has been linked to lower risk of benign proliferative epithelial disorders of the breast (101). Not all studies find a relationship between dietary fiber intake and breast cancer incidence, including a US prospective cohort study (102). A pooled analysis of eight prospective cohort studies of breast cancer found that fruit and vegetable consumption during adulthood was not significantly associated with reduced breast cancer risk (103). However, a large, case-control study reported protective effects with high intake of cereals and grains, vegetables and beans (104).

Jain and colleagues (105) found no association among total dietary fiber, fiber fractions, and risk of breast cancer. Still, nutrition differences, including dietary fiber intake, appear to be important variables that contribute to the higher rate of breast cancer experienced by younger African-American women (106). In addition, a diet high in vegetables, fruits, and fiber did not reduce additional breast cancer events or mortality during 7.3 years of follow-up in the Women's Health Eating and Living randomized trial (107). This study was conducted among survivors of early stage breast cancer and the intervention group received a telephone counseling program supplemented with cooking classes and newsletters that promoted daily targets of five vegetable servings plus 16 oz vegetable juice, three fruits, 30 g fiber, and reduced fat intake. Thus, results on breast cancer and dietary fiber are mixed, with large US prospective studies finding little relationship between dietary fiber intake and breast cancer. In addition, fruit and vegetable intake does not appear protective against breast cancer (103).

Other Cancers. Similar to colon and breast cancer, results with other cancers are mixed on whether fiber intake is protective. In general, results of case-control studies are more positive than results with prospective trials. Cereal fiber intakes were found to reduce risk of gastric adenocarcinomas in the EPIC-EURGAST study (108). Bandera and colleagues (109) conducted a meta-analysis of the association between dietary fiber and endometrial cancer. They found support from case-control studies, but no support for the single prospective study that had been conducted. Preliminary finding from the European Prospective Investigation into Cancer and Nutrition study show no association between fruit and vegetable consumption and prostate or breast cancer (110). Although case-control studies show promise for protection against cancer with dietary fiber intake, prospective cohort studies fail to see that fiber intakes protects against cancer, except by perhaps indirect methods, including obesity protection.

Other Roles for Fiber in Health

As a result of fiber serving as a substrate for bacteria in the large bowel, changes in intestinal bacterial populations, especially with the consumption of large amounts of purified, homogenous fibers (eg, fructooligosaccharides and arabinogalactans) have been reported. A prebiotic is "a selectively fermented ingredient that allows specific changes, both in the composition and/or activity in the gastrointestinal microflora that confers benefits upon host well being and health" (111). The most data for prebiotic activity have been published on inulin, a fructooligosaccharide, although *trans*-galactooligosaccharides also meet the criteria needed for prebiotic classification according to Roberfroid (111). Accepted methods to document whether a fiber is deemed a prebiotic are still developing; other functional fibers known to alter the intestinal microflora may eventually be deemed prebiotics.

Fibers have also been found to affect mineral absorption, bone mineral content, and bone structure (112). Although we typically think of dietary fibers as decreasing mineral absorption, inulin, oligosaccharides, resistant starch, and other fibers have been found to enhance mineral absorption, particularly for calcium. Most of the supportive trials in human beings have been conducted in adolescents (113) and postmenopausal women (114), two groups generally with poor calcium intakes. Whether the prebiotic fibers will enhance calcium absorption in the general population remains to be seen.

Other Components in Fiber-Containing Foods

There is substantial scientific evidence that vegetables, fruits, and whole grains reduce risk of chronic diseases, including cancer and heart disease (115,116). In epidemiologic studies, it is often easier to count servings of whole foods than translate information on food frequency questionnaires to nutrient intakes. In addition, recent studies suggest that whole foods offer more protection against chronic diseases than dietary fiber, antioxidants, or other biologically active components in foods. Thus, associations between dietary fiber and disease identified through epidemiologic studies may actually be reflections of a synergy among dietary fiber and these associated substances, or of an effect of only the associated materials. This suggests that the addition of purified dietary fiber to foodstuffs is less likely to be beneficial as opposed to changing American diets to include whole foods high in dietary fiber. The concept of synergy among components in whole foods and the attendant overall healthfulness of a varied diet are important aspects of any dietary counseling.

DISEASE RISK REDUCTION AND THERAPEUTIC USES OF FIBER

A lot of what is known about the benefits of a higher-fiber diet comes from epidemiologic studies and DRI recommendations for dietary fiber intake are based on epidemiologic findings. Sometimes there are disparities between epidemiologic and metabolic studies. One possible source of discrepancy is the time of collection of diet information because the food supply and food habits change continuously. Foods in current databases may not be reflective of what was consumed more than a decade ago; this is particularly true for data for dietary fiber in foods that have been gathered largely in the past 15 years. There are now fewer differences among methods of determination of total dietary fiber in US foods so that current fiber databases are improved over those that were available previously and are reasonably useful for epidemiologic diet studies.

In contrast, the division of total fiber between soluble and insoluble remains very method dependent. The proportion of the total fiber that is soluble varies by two- to threefold across major methods of analysis, meaning that there is the same extent of variation among the values for insoluble fiber. Thus, the use of databases to differentiate the effects of soluble vs insoluble fiber with disease could produce statistically significant relationships, when in fact there are none. Also, the use of isolated, frequently single, fiber sources in metabolic studies is not representative of a mixed, high-fiber diet.

Clinical Uses of Dietary Fiber

Diverticulosis. Movement of material through the colon is stimulated in part by the presence of residue in the lumen. When chronic insufficient bulk characteristic of a low-fiber diet occurs in the colon, the colon responds with stronger contractions to propel the smaller mass distally. This chronic increased force leads to the creation of diverticula, which are herniations of the mucosal layer through weak regions in the colon musculature. Adequate intake of dietary fiber may prevent the formation of diverticula by providing bulk in the colon so that less forceful contractions are needed to propel it. Although few clinical studies have been conducted on dietary fiber and diverticular disease, case-control studies and case studies report success with high-fiber intakes (117).

A high-fiber diet is standard therapy for diverticular disease of the colon (118). Formed diverticula will not be resolved by a diet adequate in fiber, but the bulk provided by such a diet will prevent the formation of additional diverticula, lower the pressure in the lumen, and reduce the chances that one of the existing diverticula will burst or become inflamed. Generally, small seeds or husks that may not be fully digested in the upper gastrointestinal tract are eliminated from a high-fiber diet for a patient with diverticulosis as a precaution against having these small pieces of residue become lodged within a diverticulum.

Prevention of diverticular disease with dietary fiber is still unclear from the limited research. About 10% to 25% of individuals with diverticular disease will develop diverticulitis and it is not clear if dietary fiber could protect against diverticulitis (119).

Irritable Bowel Syndrome (IBS). Gastrointestinal motility has been related to psyche. IBS affects about 20% of adults in the United States and Europe. IBS may disturb gastrointestinal motility and reduce small intestinal absorption, resulting in an increase in water that reaches the large intestine and diarrhea if the large intestinal lumen cannot absorb the excess water; other disruptions to motility may cause constipation. In addition to diarrhea and constipation, symptoms of IBS include bloating, straining, urgency, feeling of incomplete evacuation, and passage of mucus (120).

The composition and health of colonic microflora affect the fermentation of carbohydrates. Antibiotic treatments may alter colonic bacteria, reducing fermentation and causing diarrhea. In addition, viral or bacterial infections, common in children, cause secretory diarrhea in which increased chloride ions and water are secreted into the small intestine but not reabsorbed. Although large doses of fermentable carbohydrates may cause diarrhea, people may adapt over time, likely because the fermentation capacity of the colonic bacteria increases.

Individuals with inflammatory bowel disease (eg, Crohn's disease and ulcerative colitis) may experience exudative diarrhea when nutrient absorption is diminished, which adds to the increased osmotic load from the presence of mucus, blood, and protein from an inflamed gastrointestinal tract. Dietary fiber intake may improve symptoms of patients with inflammatory bowel disease.

A recent review (121) suggests that a strong case cannot be made for a protective effect of dietary fiber against colorectal polyp or cancer. Also, fiber shows inconsistent results in chronic constipation, IBS, and diverticulosis. Thus, clinically, dietary fiber should be considered as a therapy for bowel syndromes, but not be applied across the board as the proven therapy.

Role of Fiber in Critical Illness and Use in Enteral Formulas

No recommendations exist for fiber intake in several disease states or for patients in long-term-care facilities. Two types of enteral formulas that contain dietary fiber include blenderized formulas made from whole foods and formulas supplemented with purified fiber sources. Purified fiber sources used in enteral products include oat, pea, hydrolyzed guar gum, and sugar beet fibers, as well as others. Some formulas use a mixture of fiber sources. Many enteral formulas now contain fructooligosaccharides. Fructooligosaccharides are short-chain oligosaccharides (usually 2 to 10 monosaccharide units) that are not digested in the upper digestive tract and therefore have some of the same physiologic effects as soluble fiber (122). Fructooligosaccharides are rapidly fermented by intestinal bacteria that produce short-chain fatty acids. Short-chain fatty acids stimulate water and electrolyte absorption and may help treat diarrhea. Fructooligosaccharides are a preferred substrate for bifidobacteria, but are not used by potentially pathogenic bacteria, thus helping to maintain and restore the balance of healthful gut flora. Fructooligosaccharides are not isolated by the standard AOAC fiber method (AOAC Method 985.29), but new methods to analyze fructooligosaccharides content have been developed and accepted by AOAC.

The original rationale for adding dietary fiber to enteral formulas was to normalize bowel function. Dietary fiber is usually promoted as a preventive against constipation for normal healthy populations. Enteral formulas containing fiber are also used in acute-care settings to prevent diarrhea associated with tube feeding. Bowel function is affected by more than fiber level, and there is much individual variation in the amount of fiber needed for optimal bowel function. Studies on the biologic effects of enteral formulas containing fiber are few; even less information is available from patients. The addition of soy polysaccharide to an enteral formula significantly increased stool weights of healthy male adults (123), although no differences in stool weight or stool frequency were observed in one study when soy polysaccharide was added to the enteral formula of patients in a long-term-care facility (124). However, in another study of the same population that was 1 year in length, soy polysaccharide fiber did significantly increase daily stool frequency, weight, and moisture (125). Thus, existing clinical studies do not uniformly support the assertion that the addition of dietary fiber to an enteral formula improves bowel function.

Dietary fiber is thought to normalize bowel function in healthy subjects, and there is anecdotal evidence of reduction of diarrhea in patients receiving fiber-containing formulas. No convincing data have been published to document that fiber-containing enteral formulas prevent diarrhea in tube-fed patients (126). Unfortunately, there are no standard, accepted ways of defining diarrhea. The reported incidence of diarrhea in tube-fed patients ranges from 2% to 63%. Stool frequency, stool consistency, and stool quantity are the three features of bowel elimination usually used to define diarrhea. In addition to fiber, oral agents such as sorbitol and magnesium have been suggested as important intake variables affecting stool consistency. Dietary fiber may improve fecal incontinence. Patients with fecal incontinence who consumed dietary fiber as psyllium or gum arabic had significantly fewer incontinent stools than with placebo treatment (127). Improvements in fecal incontinence or stool consistency did not appear to be related to unfermented dietary fiber.

The results of some clinical studies with dietary fiber have been disappointing, although the model proposed, that fiber is fermented by anaerobic intestinal bacteria that generate short-chain fatty acids that serve as energy sources for colonic mucosal cells, is probably correct (128). To study the physiologic effects of dietary fiber, especially in a sick population, is extremely difficult. Most studies have been too short, measurements are semiquantitative, and dietary fiber and short-chain fatty acid levels were frequently not measured. It is not clear that results from in vitro fermentation studies have direct application in vivo.

Yang and colleagues (129) evaluated the effects of dietary fiber as a part of enteral nutrition formula on diarrhea, infection, and length of hospital study. Seven randomized controlled trials with 400 patients were included. The supplement of dietary fiber in enteral nutrition was compared with standard enteral formula in five trials. Combined analysis did not show a significant reduction in occurrence of diarrhea. Combined analysis of two trials of infection also did not show any support that dietary fiber could decrease infection rate. Hospital stay was significantly reduced.

Few studies have been published on the effectiveness of enteral formulas supplemented with prebiotics or symbiotics. Standards for prebiotics are in development and attempts have been made to limit use of the term prebiotic unless significant changes in gut microflora have been shown in vivo. Symbiotics are usually defined as the combination of prebiotics and probiotics. When a fiber-free formula was compared to a fiber-containing formula, no differences were seen in body weight, cholesterol, lymphocyte count, renal function, or electrolyte balance (130). The fiber-containing formula did improve albumin and hemoglobin levels and diabetes control. The authors suggest the fiber-containing formula would be preferred in long-term care.

An enteral formula supplemented with prebiotic fiber was compared to standard enteral formula in patients with sever acute pancreatitis (131). Hospital stay was shorter with the fiber-supplemented formula, and there were fewer complications in the patients receiving the fiber-supplemented formula. When continuous infusion of formula was fed to elderly, hospitalized patients, the addition of fiber to enteral formula reduced the rate of diarrhea (132). Thus, overall there is mixed clinical support for inclusion of dietary fiber in enteral formulas, although results with shortening of hospital stay are promising.

Few feeding studies have been conducted on whether prebiotics added to enteral formula will alter gut microflora in healthy subjects. Whelan and colleagues (133) conducted a small study (n=10) of healthy subjects consuming enteral formulas with or without prebiotic fructooligosaccharides. The FOS formula increased bifidobacteria and reduced clostridia. The fructooligosaccharides formula also increased total short-chain fatty acids in feces.

POTENTIAL NEGATIVE EFFECTS OF DIETARY FIBER

Potential negative effects of excessive dietary fiber include reduced absorption of vitamins, minerals, proteins, and energy. It is unlikely that healthy adults who consume dietary fiber in amounts within the recommended ranges will have problems with nutrient absorption; however, high dietary fiber intakes may not be appropriate for children and older because so little research has been conducted in these populations.

Generally, dietary fiber in recommended amounts is thought to normalize transit time and should help when either constipation or diarrhea is present; however, case histories have reported diarrhea when excessive amounts of dietary fiber are consumed (134), so it is difficult to individualize fiber intake based on bowel function measures. Thus, stool consistency cannot be used as a benchmark of appropriate dietary fiber intake. Intestinal obstruction caused by a cecal bezoar was reported in a seriously ill male given fiber-containing tube feedings and who was also receiving intestinal motility suppressing medications (135). The bezoar resulted in mesenteric hemorrhage.

Esophageal obstruction from a hygroscopic pharmacobezoar containing glucomannan has been recently described (136). This soluble fiber holds water and forms a highly viscous solution when dissolved in water. Glucomannan has been promoted as a diet aid because it swells in the gastrointestinal tract, theoretically producing a feeling of satiety and fullness. This report described a 37-year-old woman who developed delayed esophageal obstruction after ingesting an over-the-counter diet aid containing glucomannan. This case illustrates potential negative effects of using highly viscous fiber supplements in patients with a history of upper gastrointestinal pathologies.

Because fiber is not digested and absorbed in the small intestine, it can have a laxative effect and increase the ease and/or frequency of laxation (137). Fiber is just one low-digestible carbohydrate. Sugar alcohols and resistant starch are also poorly digested and absorbed. Thus, all of these poorly digested carbohydrates may cause diarrhea and other gastrointestinal symptoms such as flatulence, bloating, and abdominal discomfort. A large intake of sugar alcohols can cause osmotic diarrhea because water follows the undigested and unabsorbed carbohydrates into the large intestine; if time is inadequate for the intestinal cells to absorb the excess water, it will be eliminated in the feces. The dose of dietary fiber or other poorly digested carbohydrate that will have a laxative effect or contribute to other gastrointestinal symptoms depends on a number of factors related to the food and the consumer. Gastrointestinal symptoms, although transient, may affect consumers' perception of well-being and their acceptance of food choices containing fiber and other resistant carbohydrates. Educational messages to expect some gastrointestinal symptoms with increased dietary fiber consumption are needed.

Fermentation of dietary fiber or other nondigested carbohydrates by anaerobic bacteria in the large intestine produces gas, including hydrogen, methane, and carbon dioxide, which may be related to complaints of distention or flatulence. When dietary fiber is increased, fluid intake should be also, and fiber should be increased gradually to allow the gastrointestinal tract time to adapt. Furthermore, normal laxation may be achieved with smaller amounts of dietary fiber, and the smallest dose that results in normal laxation should be accepted.

Fiber-enriched enteral formulas may cause blockages in small-bore feeding tubes. This is most problematic with gums and other viscous fibers. Formulas containing fiber tend to be more expensive than standard formulas, making them a difficult choice in the absence of compelling clinical data. Few data have been published on the effectiveness of fiber-containing formulas in the long-term setting, and less expensive and more effective laxation aids are available.

Research-based recommendations about which patients are good candidates for fiber-containing enteral formulas cannot be made at this time. Tube-fed patients with constipation or diarrhea who are known to have otherwise healthful gastrointestinal tracts could be considered candidates for fiber-containing enteral formulas. Because of the potential protective role of fiber against diverticulosis, colon cancer, diabetes, and heart disease, a fiber-enriched enteral formula may be indicated for patients in long-term enteral feeding. Fiber-containing enteral formulas may work better for certain patients, and they should be used if they produce positive results. Clinicians should be cautious in prescribing fiber-containing enteral products. Because of the wide individual variability of responses to dietary fiber and the potential problems with large doses, the smallest dose of dietary fiber that gives the desired result should always be used.

CONCLUSIONS

Chronic insufficient intake of dietary fiber represents a challenge for food and nutrition professionals that can be met with enthusiastic recommendations for a healthful dietary pattern. Increased consumption of fruits, vegetables, legumes, and whole- and high-fiber grain products as recommended by MyPyramid would bring the majority of the North American adult population close to the recommended range of dietary fiber of 14 g/1,000 kcal. In addition, a higher fiber intake provided by foods is likely to be less calorically dense and lower in fat and added sugar. The benefits of such a varied dietary plan cannot be overemphasized. Many of the diseases of public health significance—obesity, cardiovascular disease, and type 2 diabetes—as well as the less prevalent, but no less significant diseases of colonic diverticulosis and constipation, can be prevented or treated by increasing the amounts and varieties of fiber-containing foods. Promotion of such a food plan by food and nutrition professionals and implementation by the adult population should increase fiber intakes of children.

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