Dietary Fiber: All Fibers
Are Not Alike

Joanne Slavin and David R. Jacobs Jr.

Key Points

• Dietary fiber intake protects against chronic disease, especially cardiovascular disease.
• Usual dietary fiber intake is less than half of recommended levels, so most consumers need to increase consumption of high-fiber foods, such as whole grains, legumes, vegetables, and fruits.
• Fiber may have a role in the prevention and treatment of digestive disorders such as constipation. For more complicated digestive disorders, such as irritable bowel syndrome and ulcerative colitis, fiber may be helpful.
• While some health benefits of dietary fiber clearly pertain to its physical properties (e.g., colonic bulk), fiber and phytochemicals are almost impossible to separate in epidemiologic studies. Much of the health effect of fiber may be due to the phytochemicals with which it is associated. Therefore, best medical practice is to encourage fiber consumption from foods. Fiber supplements may be recommended for laxation and cholesterol lowering, but whole foods high in dietary fiber also contain phytochemicals that provide additional health benefits.

Key Words: Fiber; dietary fiber; whole grain; colon function

1. INTRODUCTION

In 2002, the Food and Nutrition Board of the National Academy of Sciences published a new set of definitions for dietary fiber (1). Dietary fiber describes the nondigestible carbohydrates and lignin that are intrinsic and intact in plants while functional fiber consists of the isolated nondigestible carbohydrates that have beneficial physiological effects in humans. Total fiber is 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, e.g., blood fiber levels cannot be measured because fiber is not absorbed. No data are available to determine an Estimated Average Requirement (EAR) and thus calculate a Recommended Dietary Allowance (RDA) for total fiber, so an adequate intake (AI) was developed instead. 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 (UL) was not set for either dietary fiber or functional fiber.

In addition to the compositional definition provided, dietary fiber must be a 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 two key facts: first, that the three-dimensional plant matrix is responsible for some of the physicochemical properties attributed to dietary fiber and, second, that dietary fiber is associated with other macronutrients and phytochemicals normally found in foods which are important in the potential health effects. Cereal brans are anatomical layers of the grain consisting of intact cells and substantial amounts of starch and protein and are categorized as sources of dietary fiber.

Dietary Reference Intakes (DRI) for total fiber by life stage are shown in Table 1. The AIs for total fiber are based on the intake level observed to protect against CHD based on epidemiological, 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 panel suggested the recommended intakes of total fiber may also help ameliorate constipation and diverticular disease, provide fuel for colonic cells, reduce blood glucose and lipid levels, and provide a source of nutrient-rich foods of low energy density that could contribute to satiety, although these benefits were not used as the basis for the AI.

Although based on limited clinical data, a 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 25–35 g/day after age 20 (2). No published studies have defined desirable fiber intakes for infants and children younger than 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. Other specific recommendations for the elderly have not been published so the DRI based on 14 g/1000 kcal should be used. All recommendations need to recognize the importance of adequate
Table 1
Dietary Reference Intakes for Total Fiber\(^a\) by Life Stage Group – (g/day)

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<thead>
<tr>
<th>Life Stage Group</th>
<th>Males(^b)</th>
<th>Females</th>
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<tr>
<td>0–6 mo</td>
<td>ND(^c)</td>
<td>ND</td>
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<tr>
<td>7–12 mo</td>
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<td>1–3 yr</td>
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<td>&gt;70 yr</td>
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Pregnancy

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<tr>
<td>&lt;18 yr</td>
<td>29</td>
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<td>19–50 yr</td>
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Lactation

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\(^a\)Total fiber is the combination of dietary fiber (the edible, nondigestible carbohydrate and lignin components in plant foods) and functional fiber (which refers to isolated, extracted, or synthetic fiber that has proven health benefits).

\(^b\)AI = adequate intake. If sufficient scientific evidence is not available to establish an Estimated Average Requirement (EAR), and thus calculate a Recommended Dietary Allowance (RDA), an AI is usually developed. For healthy breastfed infants, the AI is the mean intake. The AI for other life stage and gender 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.

\(^c\)Not determined.

fluid intake, and caution should be used when recommending fiber to those with gastrointestinal diseases, including constipation. Patients should expect increased intestinal gas as the digestive tract adjusts to higher fiber intake.

Dietary fiber intake continues to be at less than recommended levels in the United States, with usual intakes averaging only 15 g/day (1). Many popular American foods contain little dietary fiber. Servings of commonly consumed
grains, fruits, and vegetables contain from 1 to 3 g of dietary (3). Legumes and high-fiber bread and cereal products supply more dietary fiber, but are not commonly consumed.

2. DEFINITION AND SOURCES OF DIETARY FIBER

A variety of definitions of dietary fiber exist (4). Some are based primarily upon analytical methods used to isolate and quantify 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 polyphenyl-propane 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, fiber is defined as the material isolated by analytical methods approved by the Association of Official Analytical Chemists (4). A variety of low molecular carbohydrates, that are being developed and increasingly used in food processing, are not digested by human digestive enzymes (sugar alcohols such as sorbitol and mannitol, polydextroses, and various fructo- and galacto-oligosaccharides). These small polymers and oligosaccharides are not measured by the AOAC-approved methods for dietary fiber, but methods specific for each material are being approved by AOAC to measure these compounds (4).

Resistant starch (the sum of starch and starch-degradation products not digested in the small intestine) reaches the large intestine and functions like dietary fiber there. Legumes are a primary source of resistant starch, with as much as 35% of legume starch escaping digestion. Small amounts of resistant starch are produced by processing and baking of cereal and grain products.

Dietary fiber includes plant nonstarch polysaccharides (e.g., cellulose, pectin, gums, hemicellulose, beta-glucans, and fiber contained in oat and wheat bran), plant carbohydrates that are not recovered by alcohol precipitation (e.g., inulin, oligosaccharides, and fructans), lignin, and some resistant starch. Potential functional fibers include isolated, nondigestible plant (e.g., resistant starch, pectin, and gums), animal (e.g., chitin and chitosan), or commercially produced (e.g., resistant starch, polydextrose, inulin, and indigestible dextrins) carbohydrates (1).

3. BENEFITS OF ADEQUATE FIBER INTAKE

3.1. Cardiovascular Disease

There is consistent and strong data for the protection afforded by fiber against CHD. This relationship is the basis of the DRI recommendations
for dietary fiber (1). The committee used epidemiologic, cohort studies that estimated dietary fiber intake from food frequencies and followed subjects prospectively until CHD was detected. Fiber intake levels found to be protective against CHD were then used to determine an adequate intake (AI) of dietary fiber. Traditionally, nutrient requirements are established by determining an Estimated Average Requirement (EAR) and then calculating a Recommended Dietary Allowance (RDA). When sufficient evidence is not available to establish an EAR, an AI is usually developed.

There is much confusion regarding which components of fiber are most protective against CHD. The DRI committee concluded that fiber from cereals seems most protective. Additionally, certain functional fiber, particularly those that are soluble and viscous may alter biomarkers of interest in CHD. Viscous fibers lower blood cholesterol levels, specifically that fraction transported by low-density lipoproteins (LDL). Meta-analysis by Brown et al. (5) showed that daily intake of 2–10 g of soluble fiber significantly lowered serum total cholesterol and LDL-cholesterol concentrations. Three fibers, namely beta-glucan in oats and barley and psyllium husk, have been sufficiently studied for the FDA to authorize health claims that the soluble fibers in these foods in specified amounts can reduce the risk of heart disease.

Fibers also affect blood pressure (BP) and C-reactive protein (CRP), additional biomarkers linked to risk of CHD. Fiber intake was inversely associated with CRP in the National Health and Nutrition Examination Survey 1999–2000 (NHANES) (6). A meta-analysis of randomized placebo-controlled trials found that fiber intake was linked to lower BP (7). Reductions in BP tended to be larger in older subjects and in hypertensive populations.

3.2. Weight Control

The effects of dietary fiber on hunger, satiety, energy intake, and body weight have been reviewed (8). The majority of studies with controlled energy intake reported an increase in postmeal satiety and a decrease in subsequent hunger with increased fiber intake. With ad libitum energy intake, the average effect across all the studies indicates that an additional 14 g of fiber per day results in a 10% decrease in energy intake and a weight loss of over 1.9 kg through about 17 weeks of intervention (9). Additionally, the effects of increasing fiber were reported to be even more impressive in obese individuals. This group concluded that increasing the population mean dietary fiber intake from the current average of about 15 g/day to 25–30 g/day would be beneficial and may help reduce the prevalence of obesity.

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 et al. (10) compared test lunches with 200 g of 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.

Foods rich in fiber tend to have a high volume and a low energy density and should promote satiety and energy balance (11). However, research on the effects of different types of fiber on appetite and food intake has been inconsistent. Results differ according to the type of fiber and whether it is added as an isolated fiber supplement rather than naturally occurring in food. Short-term studies in which fiber is fed to subjects, followed by assessment of food and energy intake at subsequent meals, suggest that large amounts of total fiber are most successful at reducing subsequent energy intake.

3.3. Type 2 Diabetes

Kaline et al. (12) reviewed the value of dietary fiber in the prevention of type 2 diabetes. They suggest that whole grain cereal products appear especially effective in the prevention of the disease and recommend a fiber intake of at least 30 g/day. The Nurses Health Study cohort was evaluated for the relationship among whole grain, bran, and germ intake and risk of diabetes (13). 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. The investigators found that a 2 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 BMI. This subject is explored in more detail in chapter 24 by Franz.

3.4. Cancer

3.4.1. Large Bowel Cancer

Epidemiologic evidence supports the theory that dietary fiber may protect against large bowel 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 (14). 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 risk of both colon and rectal cancers (15). 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.

Intervention studies focused on colonic polyps do not support the protective properties of fiber against colon cancer (16, 17). The studies found no significant effect of high-fiber intakes on the recurrence of colorectal adenomas. The European Prospective Investigation into Cancer and Nutrition (EPIC) is a prospective cohort study comparing the dietary habits of more than a half-million people in 10 countries with colorectal cancer incidence (18). People who ate the most fiber (those with total fiber 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.

3.4.2. Breast Cancer

Limited epidemiologic evidence has been published on fiber intake and human breast cancer risk. A pooled analysis of 12 case-control studies found that high intake of dietary fiber was associated with reduced risk (19). Not all studies reported a relationship between dietary fiber intake and breast cancer incidence. 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 risk (20). Results with other cancers are similar to colon and breast cancer in being mixed on whether fiber intake is protective. In general, results of case–control studies are more positive than results with prospective trials.

3.5. Bowel Function

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 (21), but the added fiber tends to normalize defecation frequency to one bowel movement daily and gastrointestinal (GI) transit time to 2–4 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. It is a common but erroneous belief that the increased stool weight is due primarily to water. The moisture content of human stool is 70–75% and this does not change when more fiber is consumed.

Unlike blood, fecal samples have not been collected and evaluated for a large cohort of healthy subjects. Cummings et al. (21) conducted a meta-analysis of 11 studies in which daily fecal weight was measured accurately in 26 groups of people (n = 2 06) 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 (22) suggested that there is a critical fecal weight of 160–200 g/day for adults, below which colon function becomes unpredictable and risk of colon cancer increases. Stool weights in Westernized populations range from 80–120 g/day so to increase stool weight to recommended levels would require an increase of about 20 g/day of effective fiber, such as that supplied by wheat bran.

Constipation and diarrhea are two extremes of abnormal bowel function. Constipation is defined as three or fewer spontaneous bowel movements per week. 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. Leung (23) 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. Etiological 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.

Patients often relate the importance of that morning cup of coffee (24) or smoking on regular bowel habit. Gender is known to alter colonic function (25). Even on rigidly controlled diets of the same composition, there is a large variation in daily stool weight among subjects. Tucker et al. (26) 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.

3.6. Colon Disease

3.6.1. Diverticulosis

A high-fiber diet is standard therapy for diverticular disease of the colon (27). 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, for a patient with diverticulosis small seeds or husks that may not be fully digested in the upper GI tract are eliminated from a high-fiber diet as a precaution against having these small pieces of residue become lodged within a diverticulum. Prevention of diverticular disease with fiber is still unclear from the limited research. About 10–25% of individuals with diverticular
disease will develop diverticulitis. Whether fiber is protective against that condition is not known (28).

3.6.2. Irritable Bowel Syndrome

GI motility has been related to psyche. Irritable bowel syndrome (IBS) affects about 20% of adults in the United States and Europe. IBS may disturb GI motility and reduce small intestinal absorption, resulting in an increase in water that reaches the large intestine; diarrhea may result 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 (29).

Individuals with inflammatory bowel disease (IBD; 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 the inflamed gastrointestinal tract. Dietary fiber intake may improve symptoms of patents with IBD.

4. Potential Negative Effects of Dietary Fiber

Potential negative effects of fiber include reduced absorption of vitamins, minerals, protein, and calories. It is unlikely that healthy adults who consume fiber in amounts within the recommended ranges will have problems with nutrient absorption; however, high-fiber intakes may not be appropriate for children and the elderly.

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 fiber are consumed so it is difficult to individualize fiber intake based on bowel function measures. Thus, stool consistency cannot be used as a benchmark of appropriate fiber intake. Esophageal obstruction from a hygroscopic pharmacobezoar containing glucomannan has been described (30). This soluble fiber holds water and forms a highly viscous solution when dissolved in water. Glucomannan has been promoted as a diet aid since it swells in the GI tract, theoretically producing a feeling of satiety and fullness. This case illustrates potential negatives of use of highly viscous fiber supplements in patients with a history of upper GI pathologies.

Fiber is just one low-digestible carbohydrate in the diet. Sugar alcohols and resistant starch are also poorly digested and absorbed. Thus, all of the low-digestible carbohydrates may cause diarrhea and other GI symptoms, such as flatulence, bloating, and abdominal discomfort (31). A large intake
of sugar alcohols can cause osmotic diarrhea because water follows the undi-
gested and unabsorbed carbohydrates into the large intestine; if time is inad-
equate 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 GI symptoms depends
on a number of factors related to the food and the consumer. GI symptoms,
although transient, may affect consumers’ perception of well-being and their
acceptance of food choices containing fiber and other resistant carbohy-
drates. Educational messages to expect some GI symptoms with increased
fiber consumption and to increase fluid intake are needed.

5. CONCLUSIONS

Dietary fiber is inversely associated with risk of several chronic diseases,
including obesity, cardiovascular diseases, and type 2 diabetes, although
effects on cancer are uncertain. High-fiber foods and bulk laxatives may
improve laxation and should be cautiously introduced in those with con-
stipation and colonic disorders. While some health benefits of fiber clearly
pertain to its physical properties (e.g., colonic bulk), fiber and the phyto-
chemicals that it marks are almost impossible to separate in epidemiologic
studies. Much of the health effect of fiber may be due to the phytochemicals
with which it is associated. Therefore, the medical profession should encour-
age consumption of foods high in fiber, such as whole grains, legumes, fruits,
and vegetables.

SUGGESTED FURTHER READING

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