

Position of the Academy of Nutrition and Dietetics: Health Implications of Dietary Fiber



ABSTRACT

It is the position of the Academy of Nutrition and Dietetics that the public should consume adequate amounts of dietary fiber from a variety of plant foods. Dietary fiber is defined by the Institute of Medicine Food Nutrition Board as “nondigestible carbohydrates and lignin that are intrinsic and intact in plants.” Populations that consume more dietary fiber have less chronic disease. Higher intakes of dietary fiber reduce the risk of developing several chronic diseases, including cardiovascular disease, type 2 diabetes, and some cancers, and have been associated with lower body weights. The Adequate Intake for fiber is 14 g total fiber per 1,000 kcal, or 25 g for adult women and 38 g for adult men, based on research demonstrating protection against coronary heart disease. Properties of dietary fiber, such as fermentability and viscosity, are thought to be important parameters influencing the risk of disease. Plant components associated with dietary fiber may also contribute to reduced disease risk. The mean intake of dietary fiber in the United States is 17 g/day with only 5% of the population meeting the Adequate Intake. Healthy adults and children can achieve adequate dietary fiber intakes by increasing their intake of plant foods while concurrently decreasing energy from foods high in added sugar and fat, and low in fiber. Dietary messages to increase consumption of whole grains, legumes, vegetables, fruits, and nuts should be broadly supported by food and nutrition practitioners.

J Acad Nutr Diet. 2015;115:1861-1870.

POSITION STATEMENT

It is the position of the Academy of Nutrition and Dietetics that the public should consume adequate amounts of dietary fiber from a variety of plant foods.

IN 2005, THE INSTITUTE OF MEDICINE (IOM) published descriptive definitions for fiber.¹ The term *dietary fiber* describes nondigestible carbohydrates and lignin that are intrinsic and intact in plants, whereas *functional fiber* is isolated nondigestible carbohydrates that have beneficial physiological effects in humans. *Total fiber* is the sum of dietary fiber and functional fiber. As all fibers are not hydrolyzed by human digestive enzymes, their constituent sugars are not absorbed in the small intestine. Fiber entering the large intestine may be fermented by gut microbiota or may be resistant to fermentation, passing through the digestive tract relatively unchanged. As no deficiency state has been demonstrated, fiber is not considered a nutrient. Thus, no data are available to determine an Estimated Average Requirement or to calculate a Recommended Dietary Allowance for total fiber.¹ The Adequate Intake (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 total, dietary, or functional fiber. Although the AI for total fiber was set to protect against CHD, the reduction in risk of type 2 diabetes was considered a secondary end point to support the recommended intake level.¹ Total fiber recommendations for children and older adults are also set at 14 g per 1,000 kcal. As older adults require lower energy intakes than do young adults, their AI is also lower. [Table 1](#) gives the AI values for total fiber based on age.

There is no AI for fiber for healthy infants aged 0 to 6 months, as exclusive intake of human milk is recommended.² Human milk contains no dietary fiber based on the IOM definition; however, it contains nondigestible oligosaccharides, providing carbohydrate substrate for fermentation by gut microbiota.³ During the 7- to 12-month age period, complementary food intake becomes more significant and dietary fiber intake increases. The Feeding Infants and Toddlers Study examined 3,273 children

from birth to 47 months of age.⁴ Dietary fiber intakes (mean±standard deviation) of infants 6 to 11, 12 to 23, and 24 to 47 months of age, were 6±0.1 g/day, 9±0.1 g/day, and 10±0.1 g/day, respectively, all far below the AI for total fiber of 19 g/day.

The 2010 Dietary Guidelines for Americans addressed the concern that most people consume inadequate amounts of dietary fiber, and thus recommendations were to choose foods that provide more fiber, such as whole grains.⁵ In general, people consume adequate amounts of total carbohydrate, but too much of it constitutes added sugar and refined grains with added fat and little dietary fiber. MyPlate supports the recommendation for choosing foods that provide more fiber by emphasizing “make half your plate fruits and vegetables” and “make at least half your grains whole grain,” and including beans and peas in both the protein and vegetable groups.⁶ The American Association of Cereal Chemists International defines whole grains as: “. . . intact, ground, cracked or flaked caryopsis, whose principal anatomical components—the

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<http://dx.doi.org/10.1016/j.jand.2015.09.003>

Table 1. Dietary Reference Intakes for total fiber^a by life-stage group and Dietary Reference Intake values (g/1,000 kcal/day)^b

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

^aTotal 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).

^bValues are examples 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.

^cIf sufficient scientific evidence is not available to establish the Estimated Average Requirement, and thus calculate a Recommended Dietary Allowance, an average 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.

^dND=not determined.

^eNA=not applicable.

starchy endosperm, germ, and bran—are present in the same relative proportions as they exist in the intact caryopsis.⁷ Although whole grains are a recommended source of dietary fiber in the American diet, the dietary fiber content of whole-grain foods ranges greatly, with some not good sources of fiber.⁸ While whole grains are a source of dietary fiber, they also provide key vitamins, minerals, and phytochemicals, all of which may contribute to a health benefit. The Nutrition Facts label's % Daily Value is based on 25 g/day dietary fiber for a 2,000 kcal/day diet or 30 g/day for a 2,500 kcal/day diet. Dietary fiber as noted on the Nutrition Facts label does not comply with the IOM's definition, which causes some confusion among consumers and health professionals.¹ National Health and Nutrition Examination

Survey (NHANES) 2009 to 2010 data confirm that dietary fiber intake in the United States continues to be less than the recommended amount with mean intakes of 17 g/day for adults.⁹ Grain-based foods (not including desserts) are the major source of dietary fiber, with grain mixtures (eg, pasta meals, pizza, and noodle soups) being the highest source of dietary fiber at 17.8%, followed by fruits at 14.9% and vegetables at 13.7%.⁹ Because of low consumption, higher-fiber foods, such as dry beans, peas, other legumes, nuts, and seeds contribute only 6.3% of dietary fiber intake.

ANALYTICAL DEFINITIONS AND SOURCES OF DIETARY FIBER

Descriptive definitions described here provide health professionals and

consumers with a characterization of dietary fiber constituents. Analytical definitions are necessary to provide consistent food composition data. Common analysis methods include AOAC method 985.29 (total dietary fiber) and 991.43 (soluble and insoluble dietary fiber).¹⁰ Of note, these methods do not distinguish between naturally occurring fiber (dietary fiber) and added fiber (functional fiber). Both methods exclude certain subsets of fiber in the analysis, such as low-molecular-weight oligosaccharides and resistant starch. Additional analytical methods can detect these subsets specifically, but this adds expense to food analysis. More recently, AOAC method 2011.25 was developed to quantify both high-molecular-weight and low-molecular-weight fibers. When comparing grain-based fibers, method 2011.25 detected more dietary fiber than method 985.29. This poses a future issue with updating nutrient databases; foods analyzed with older methods will have reportedly lower fiber content than food analyzed with the new methods. These discrepancies may alter the associations between dietary fiber and chronic disease risk, which may affect our current findings on the topic. Dietary fiber contents of selected foods from the “fruit,” “vegetables,” “grains,” and “protein” groups are shown in Table 2.

Solubility is often used as a further criterion for distinguishing fibers from one another. This is an artifact of the analytical method AOAC 991.43 (soluble in water and precipitates in ethanol) and does not necessarily relate to physiological function. Classifying fiber as fermentable and/or viscous, as proposed by the IOM, provides better classification based on physiological function, as there are varying degrees of fermentability and viscosity enhancement, with some fibers exhibiting both properties. Fermentable fibers are degraded by the gut microbiota to yield short-chain fatty acids (SCFAs) and gases. The extent of fermentation depends on fiber type and transit time as well as the bacterial community. Viscous fibers thicken, or more so, increase resistance to flow of intestinal contents. While these are critical characteristics for determining physiological effect, using these descriptors for labeling purposes would be challenging.

Table 2. Dietary fiber content of selected foods^a

Food	Serving size	Total dietary fiber (g/serving)	Energy (kcal/serving)
Fruits			
Prunes, dried	5 prunes	3.4	114
Orange	1 fruit (2 7/8 -in diameter)	3.1	75
Apple with skin	1 large (3 1/4 -in diameter)	5.4	116
Banana	1 large (8-in long)	3.5	121
Raisins	1 small box (1 oz)	1.0	84
Figs, dried	2 figs	1.6	42
Pear	1 medium pear	5.5	101
Raspberries	1/2 c	4.0	32
Strawberries, raw	1 c, sliced	3.3	53
Vegetables			
Beans, kidney, canned	1/2 c	5.5	108
Peas, split, cooked	1/2 c	8.1	116
Lentils, cooked	1/2 c	7.8	115
Lettuce, iceberg	1 c, shredded	0.9	10
Kale, raw	1 c, loosely packed	0.6	8
Spinach, cooked	1/2 c	2.2	21
Peas, green, canned	1/2 c	3.5	59
Carrots, raw	8 baby carrots	2.5	30
Potatoes, boiled	1/2 c	1.4	68
Potato, baked, skin-on	1 medium (2 3/4 -in diameter)	3.3	138
Sweet potato, no skin	1/2 c mashed	4.1	125
Broccoli, raw	1/2 c	1.1	15
Celery, raw	1/2 c chopped	0.8	8
Beets, cooked	1/2 c sliced	1.7	37
Grains			
Raisin bran	1 c	7.4	190
Shredded wheat	2 biscuits	5.5	155
Rice, brown, cooked	1 c	3.5	218
Bread, white (refined wheat)	1 slice	0.8	77
Bread, whole wheat	1 slice	1.9	81
Oatmeal, cooked	3/4 c	3.0	124
Rye crispbread	1 wafer	1.6	37
Crackers, graham	2 squares	0.5	60
Nuts			
Almonds	1/4 cup	4.5	207
Walnuts	1/4 cup, pieces	2.0	196

^aData from US Department of Agriculture, Agricultural Research Service.⁸

International differences in energy value of fiber pose problems. Regulations in the European Union state that fiber should be assigned 2 kcal/g due to energy derived from fermentation.¹⁰ The justification for this energy value is that approximately 70% of dietary fiber is fermented, yielding, on average 2 kcal/g. One-quarter of food composition databases in the European Union comply with this regulation. In the United States, the US Department of Agriculture nutrient database calculates energy based on Atwater factors. Total carbohydrate content for this energy calculation assigns soluble fiber, 4 kcal/g, and insoluble fiber, 0 kcal/g.¹¹ This approach is inherently flawed because not all soluble fiber is fermentable. Fermentation of fiber by the average human gut microbiota is estimated to yield approximately 2.5 kcal/g and may provide up to 10% of daily energy intake in humans.¹² The energy contributions of fiber fermentation over the course of months or years could result in miscalculated energy intakes.

BENEFITS OF DIETARY FIBER INTAKE

This position update considered current research on dietary fiber rather than functional fibers and their relationships to chronic disease and physiological function. There is considerable epidemiological evidence that higher dietary fiber intakes reduce the risk of disease, including cardiovascular disease (CVD), type 2 diabetes, and cancer.¹³⁻¹⁹ However, the protective effect of dietary fiber may extend to other disease states and conditions, impacting all-cause mortality. Data from the National Institutes of Health-AARP Diet and Health Study, a large prospective cohort, demonstrated that dietary fiber intake and dietary fiber from grains are inversely associated with total death rates, specifically cardiovascular, infectious, and respiratory deaths in both men and women, and cancer deaths in men.²⁰ Baer and colleagues,²¹ reporting on the Nurses' Health Study, has also shown an inverse association between cereal fiber and all-cause mortality.

Cardiovascular Disease

The AI for total fiber is based on protection against CHD using evidence

from cohort studies that estimated dietary fiber intake from food frequencies.¹ Dietary fiber intake levels found to be protective against CHD were then used to determine the AI for fiber. This recommendation is supported by a recent systematic review and dose–response meta-analysis of cohort studies that reported an inverse association between total dietary fiber intake and risk of CVD and CHD, specifically a risk reduction of 9% for each 7 g/day increase in dietary fiber.¹³ Insoluble, cereal and vegetable fiber were inversely associated with CVD and CHD, whereas fruit fiber was associated with reduced CVD only.

Ye and colleagues¹⁴ systematically examined longitudinal studies relating fiber and whole-grain intake to CVD risk and found inverse associations with total fiber, cereal fiber, and whole-grain intake. The favorable inverse association of cereal fiber and risk of CVD is also supported by the position of the American Society of Nutrition after a recent review of literature.¹⁵ Further, Ning and colleagues¹⁶ examined 11,113 participants, aged 20 to 79 years with no history of CVD, from the 2005 to 2010 NHANES. Greater dietary fiber consumption was associated with a low to medium overall lifetime CVD risk. This protective effect extends to elderly adults at high risk for CVD, as data from the Prevención con Dieta Mediterránea (PREDIMED) study showed that dietary fiber intakes were associated with a reduction in total mortality.²² Although extensive evidence supports the protective association of dietary fiber and CVD risk, limited long-term, randomized controlled trials have been undertaken and therefore causal relationships have not been demonstrated.

In 2008, after thorough evaluation of the available data, the Academy's Evidence Analysis Library committee concluded that higher dietary fiber intakes may improve serum lipid levels, lower blood pressure, and reduce inflammatory marker levels, indicators of inflammation, summarizing potential mechanisms to explain fiber's protective properties in CVD.²³ Total dietary fiber intake has been inversely associated with total cholesterol, low-density lipoprotein (LDL) cholesterol, and triglycerides, and positively associated with high-density lipoprotein cholesterol.²⁴ Overall fiber intake in children has also been inversely associated with

serum cholesterol, independent of fat intake.²⁵ In addition, a recent cross-sectional study of meat eaters, fish eaters, vegetarians, and vegans demonstrated that vegans, compared with meat eaters (with dietary fiber intakes of 27±9 g/day and 19±7 g/day, respectively) had lower total cholesterol but also had lower saturated fat and higher polyunsaturated fat intakes confounding the potential effects of fiber.²⁶ This epidemiological evidence is supported by intervention trials with various types of diets higher in dietary fiber. Ye and colleagues,¹⁴ in a systematic analysis of randomized controlled trials (RCTs), found decreased total and LDL cholesterol with whole-grain interventions of varied doses. A meta-analysis of RCTs testing non-soybean legumes, also known as pulses, demonstrated reductions in total and LDL cholesterol with 80 to 440 g of pulses incorporated into the experimental diets.²⁷ Furthermore, a recent systematic review and meta-analysis of RCTs investigating the impact of low glycemic index (GI) diets on blood lipids, reported reduced total cholesterol and LDL cholesterol independent of weight loss. However, lower GI diets were only effective when the intervention included increased fiber ranging from 1 to 14 g/day.²⁸ Viscous fibers, through reductions in bile acid reabsorption, are known to lower blood cholesterol levels. This has been thought to be a major mechanism by which fiber affects CVD risk. However, most intervention studies have tested functional fibers vs dietary fiber.²⁹ The strong evidence for cereal fiber, predominantly nonviscous and insoluble, with the exception of oats and barley, suggests that other mechanisms need further exploration, such as the effects of fermentation products on cholesterol levels.³⁰

Although cholesterol lowering has been thought to be the major CVD risk factor affected by fiber intake, there is mounting research suggesting a relationship between dietary fiber intake and inflammatory status. Ning and colleagues,¹⁶ using NHANES data, reported that higher dietary fiber intake, age-stratified 12 to 14 g/day differences between quartiles 1 and 4, was associated with lower C-reactive protein, overall inflammation, and CVD risk. Xu and colleagues³¹ reported that higher dietary fiber intakes comparing quartiles from <14.5 g/day

to >19.2 g/day were inversely associated with C-reactive protein, while directly associated with kidney function. In addition, Gaskins and colleagues³² found >1 serving/day of whole grains to be associated with reduced C-reactive protein in premenopausal women. Furthermore, there is evidence that exposure to whole grains, but not fiber, can be predictive of inflammatory status in young adulthood. Goletzke and colleagues,³³ in a prospective cohort study, found that whole-grain intake during adolescence was inversely associated with interleukin-6 concentrations in young adulthood; however, dietary fiber was not an independent factor. Intervention studies are needed to confirm a causative effect of dietary fiber and its companion phytochemicals on inflammatory status.

Higher dietary fiber intakes are associated with lower blood pressure, providing an additional mechanism for CVD reduction. Data from the French Nutrition and Health Survey (ENNS, 2006–2007) supports that dietary fiber and whole grains are inversely associated with systolic blood pressure.³⁴ Prospective studies in adolescent females have shown that higher dietary fiber intakes are associated with lower blood pressure years later.^{35,36} In addition, NHANES data have shown that higher intakes of dietary fiber are related to a reduced risk for metabolic syndrome, including blood pressure.³⁷ Dietary fiber reduces risk factors for CVD through several mechanisms. Meeting recommended intakes for dietary fiber by including sources of soluble, viscous fibers from a variety of plant sources, as well as insoluble fibers from whole grains, can reduce risk of CVD.

Type 2 Diabetes

The association between dietary fiber intake and risk of type 2 diabetes has been confirmed with a number of recent meta-analysis.^{14,17,18,38} Yao and colleagues¹⁷ published a meta-analysis of observational studies from 1974 to 2013. In 19,033 cases out of 488,293 participants, risk of type 2 diabetes decreased with total dietary fiber, cereal fiber, fruit fiber, and insoluble fiber intake. Ye and colleagues,¹⁴ examining data of 3,202,850 person-years, showed a decreased risk of type

2 diabetes with dietary fiber, cereal fiber, and whole-grain intake. Three large US cohort studies showed that diets high in GI or glycemic load and low in cereal fiber are associated with a dramatically higher risk of type 2 diabetes.³⁸ Furthermore, one study of a cohort of older British men suggested that a diet higher in fiber (>20 g/d) may reduce the risk of type 2 diabetes, potentially due to reduced inflammatory status.¹⁸ Although considerable experimental evidence demonstrates that the addition of viscous dietary fibers slows gastric emptying rates, digestion, and absorption of glucose to benefit immediate postprandial glucose metabolism, the mechanisms of how fiber affects insulin sensitivity are not clear. Increasing dietary fiber intakes, particularly by choosing low GI foods, may reduce risk of type 2 diabetes. Further work is needed to determine the role of dietary fiber in prediabetes prevention.

Cancer

Colorectal Cancer. The inverse association between dietary fiber intake and risk of colon cancer has become increasingly strong in recent years. In 2011, the World Cancer Research Fund updated their consensus on the current body of research from “probable” to “convincing.”¹⁹ Data from this report have been published in several articles. One such publication, based on a meta-analysis of 16 prospective studies, noted a 10% cancer risk reduction for every 10 g of total dietary fiber consumed daily.³⁹ When specific sources of fiber were analyzed separately, cereal fiber was associated with a dose-dependent reduction in risk (10% reduction for every 10 g consumed daily). Fruit fibers, vegetable fibers, and legume fibers were not associated with a significant risk reduction. A recent meta-analysis of 16 case-control studies and 4 cohort studies on dietary fiber intake and occurrence of colorectal adenoma reported similar findings.⁴⁰ For every 10 g total dietary fiber consumed daily, the risk of cancer was reduced by 9%. Fruit fiber (21% risk reduction/10 g) and cereal fiber (30% risk reduction/10 g) were significantly and inversely associated with colorectal adenoma development. Vegetable fiber was not significantly associated with colorectal adenoma

occurrence. The stage of colorectal adenoma (advanced or nonadvanced) did not affect the association with dietary fiber. It should be noted that the findings of Ben and colleagues⁴⁰ are based primarily on case-control studies, while the findings of Aune and colleagues³⁹ are based on prospective cohort, case-cohort, or nested case-control studies.

The European Prospective Investigation into Cancer and Nutrition (EPIC) study continues to follow subjects, and the most recent publication on dietary fiber and colorectal cancer supports the protective effect mentioned previously.⁴¹ Fiber intake quintiles ranged from <16.4 g/day (Q1) to ≥28.5 g/day (Q5), with Q1 being most representative of average American intake and Q5 being representative of the recommended intake. Risk of colorectal cancer, colon cancer (all sites), and colon cancer (distal) were significantly and inversely associated with dietary fiber intake. Rectal cancer risk was inversely associated with dietary fiber. This report confirmed previous findings of a protective effect of cereal fiber for colorectal cancer, colon cancer, and rectal cancer. Also, a significant inverse association was noted between colon cancer and combined fruit and vegetable fiber intake. This study is limited by dietary intake assessment, which was conducted only at baseline.

The HELGA prospective study conducted in Scandinavia agrees with previous findings.⁴² These authors reported a more substantial decrease in colon cancer risk in men, a 26% risk reduction for every 10 g/day dietary fiber consumed. The association was not significant in women. These differences suggest that dietary fiber may be protective, but other factors, such as phytochemicals, energy intake, body weight, and genetics may be equally influential. General dietary pattern may also play a role in colorectal cancer risk. A case-control study in Japan showed no significant association between dietary fiber intake and colorectal cancer risk.⁴³ However, rice intake was significantly, inversely associated with colorectal cancer risk ($P=0.03$ for trend). Total dietary fiber calculated in this study may be underrepresented due to the exclusion of resistant starch. Intakes for fiber ranged from 9.2 g/day (Q1) to

19.8 g/day (Q5), significantly lower than the intakes reported in the EPIC study. It is possible that dietary fiber intakes must be near recommended intakes to exert a protective effect.

The evidence demonstrates that dietary fiber from a variety of sources (grains, fruits, vegetables) protects against the development of colorectal cancer in a dose-dependent manner. Additional fiber sources, such as legumes, may be protective, but intake in the United States is too low to draw conclusions. Dietary fiber may protect against cancer development through increased fecal bulk and decreased transit time, thereby exposing the colorectal epithelium to lower concentrations of carcinogens for shorter amounts of time. In addition, SCFAs, such as butyrate, enhance the health of colonocytes, thereby preventing the development of colorectal cancer.

Breast Cancer. Dietary fiber has not been shown to impact breast cancer survival when considered on a time-frame basis (before diagnosis, <12 months after diagnosis, >12 months after diagnosis).⁴⁴ Dietary fiber intake was consistently inversely associated with all-cause mortality, but more high-quality data are needed. The 2010 conclusions by the World Cancer Research Fund stated that there were limited data, with no conclusion regarding the relationship between dietary fiber intake and breast cancer risk.⁴⁵ The studies included in the World Cancer Research Fund Continuous Update Project were stated to possess low-quality data or provide inconsistent conclusions, and the reduction in risk was deemed nonsignificant. An expanded meta-analysis, including four studies published since 2008, reported a significant dose-dependent reduction in risk (5% per 10 g fiber/day).⁴⁶ Source of fiber was nonsignificant (fruit, vegetable, cereal); however, soluble fiber had a strong inverse association with breast cancer risk (9% risk reduction). Insoluble fiber was not significantly associated with breast cancer risk. The EPIC study reported a similar association for total fiber (5% risk reduction), with a maximum benefit estimated at 24 g/day intake.⁴⁷ Fiber from vegetables was also inversely associated with breast cancer risk, with a 10% reduced risk observed in the highest

intake group. Both total fiber and vegetable fiber intake were significantly associated with reduced risk in estrogen receptor and progesterone receptor–positive cancers. Mechanisms for the protective effect of dietary fiber have been proposed, sequestration of estrogen in the digestive system and reduction of β -glucuronidase activity in the digestive system, resulting in increased estrogen excretion in the feces.⁴⁶ As noted by the World Cancer Research Fund, more well-designed studies are needed to determine if breast cancer risk is affected by dietary fiber intake.

Other Cancers. In an analysis of 21 studies (19 case-control and 2 cohort), dietary fiber exerted a significant protective effect against gastric cancer (high intake vs low intake, odds ratio=0.58; 95% CI 0.49 to 0.67).⁴⁸ When calculated as a dose-dependent risk, a similar protective effect was demonstrated (odds ratio=0.56; 95% CI 0.41 to 0.82) for every 10 g consumed daily. Fruit fiber, vegetable fiber, cereal fiber, soluble fiber, and insoluble fiber reduced gastric cancer risk.

The role of fiber in the protection against endometrial cancer, ovarian cancer, and prostate cancer is unclear. This is due to a limited number of studies and inconsistency in study results. Evidence of a protective effect against prostate cancer is emerging, but further studies are necessary. Dietary fiber intake examined over many decades may be needed to determine its influence on cancer risk. The current literature supports the protective effect of dietary fiber from grains, fruits, and vegetables. This reinforces the importance of consuming dietary fiber from a variety of food sources for maximum health benefits.

Body Weight

It has been suggested that populations that consume diets higher in dietary fiber have lower body weights. In the United States, normal-weight and overweight individuals have consistently higher fiber intakes than obese individuals.⁴⁹ This evidence is supported by a recent meta-analysis of longitudinal studies showing a small but significant reduction in weight gain over time with increased consumption of dietary fiber and whole grains.¹⁴

American data from the International Study of Macro-/Micronutrients and Blood Pressure (INTERMAP) demonstrated that a lower intake of dietary fiber was associated with a higher body mass index.⁵⁰ The Nurses' Health Study and Nurses' Health Study II data support the premise that whole grains protect against weight gain.⁵¹ Although many mechanisms have been proposed, the majority of research on appetite, short- and long-term energy intake, and body weight has been conducted using isolated fibers.⁵² In a meta-analysis of short-term (<24-hour) intervention studies examining fiber (including mixed dietary fiber interventions) vs low or no fiber controls on satiety and food or energy intake, it was concluded that most isolated fibers do not induce satiety or reduce energy intake.⁵³ In a recent meta-analysis of acute studies, pulses (non-soybean legumes) were shown to contribute to satiety, but not second-meal effects,⁵⁴ suggesting a need for more specific food-based intervention trials. In children, although it has been suggested that dietary fiber may limit energy intake, a prospective RCT in children concluded that dietary fiber intake was not associated with weight.²⁵ Additional long-term intervention studies examining the impact of diets higher in dietary fiber on body weight and factors affecting intake are needed due to the limited application of acute studies to long-term weight status.

Digestive Health

Dietary fiber is known for its association with digestive health. The American Gastroenterological Association defines good digestive health as “. . . a digestive system that has appropriate nutrient absorption, intestinal motility, immune function and a balanced microbiota (the community of microorganisms that live in the gut). A balanced diet has an important role in maintaining digestive health and can prevent digestive symptoms. Most people with good digestive health do not regularly experience digestive symptoms such as heartburn, rumbling, nausea, bloating, excessive flatulence, constipation, diarrhea, or abdominal pain and discomfort.”⁵⁵ Dietary fiber promotes digestive health through its modulation of laxation,

fermentation, and effects on gut microbiota.

Laxation. It is well established that dietary fiber aids in laxation.⁵⁶ Many dietary fibers impact laxation by increasing fecal bulk, increasing stool frequency, and reducing intestinal transit time.⁵⁷ These effects are mediated by the water-binding capacity of the dietary fiber and by fermentation, which alters osmotic balance and increases fecal biomass.⁵⁷ Fiber from wheat bran has been shown to have a high bulking effect (5.4 g stool weight increase per 1 g of wheat fiber) due to its resistance to fermentation.⁵⁸ Other fibers, such as fruit and vegetable fiber, oat fiber, and corn fiber, increase stool weight, 4.7 g, 3.4 g, and 3.3 g stool weight increase per 1 g of fiber, respectively. Many of the published clinical trials report on fiber supplementation (functional fiber) rather than increased intake of dietary fiber. Further trials, especially in children, are necessary to confirm a beneficial intake level and specific type(s) of dietary fiber for the prevention of constipation.⁵⁹ Although excessive fiber intake has been linked with adverse gastrointestinal events, these effects have been seen with certain functional fibers, as opposed to dietary fiber.⁶⁰ Vegetarian diets may provide >50 g fiber/day, and high intakes of dietary fiber have not been confirmed to cause adverse health effects in adults, as demonstrated by the lack of Tolerable Upper Intake Level.¹ Little work has been conducted in this area since the last position article was published.

Fermentation. The bacterial production of SCFAs, in response to fermentable dietary fiber reaching the colon, results in a wide variety of physiological effects.⁶¹ Fermentable fibers, such as oligosaccharides, β -glucans, gums, some hemicelluloses, and some resistant starches yield SCFAs, primarily acetate, propionate, and butyrate. These compounds lower the pH in the colonic lumen, thus increasing bioavailability of some minerals and inhibiting the growth of pathogenic bacteria. SCFA uptake from the lumen is thought to be efficient, with a proportion of propionate and butyrate remaining in the enterocyte.⁶² After absorption, butyrate is utilized primarily in the enterocyte, while most

acetate and propionate may reach systemic circulation. Many systemic effects have been proposed based on *in vitro* and in animal studies, but further work is needed in humans to confirm these effects. *In vitro* studies and animal studies have implicated propionate with reduced hepatic lipogenesis, increased satiety via increased/decreased satiety hormones, and cell cycle alterations, specifically increasing differentiation and apoptosis. However, the SCFA concentration applied in many studies is higher than what could be achieved through colonic fiber fermentation. There is evidence that both propionate and butyrate are involved in chemotaxis of immune cells and reduced cell adhesion, but this is affected by many variables.⁶³ These two mechanisms suggest that SCFAs may be protective against systemic inflammation. Butyrate is well known for its role in cell cycle alterations, with the effect being cell type-dependent, sometimes referred to as the “butyrate paradox.”⁶³ This diverse effect of butyrate on cell proliferation is dependent on cell status, whereby healthy cells experience a proliferative effect of butyrate and abnormal cells (precancer) experience an antiproliferative effect of butyrate.

Prebiotics and the Gut Microbiota. SCFA production is dependent not only on fiber type, but also on the microbiota. The microbiota shifts rapidly in response to dietary changes.⁶⁴ This is attributed to changes in dietary fiber intake as well as intake of macronutrients. However, it is unclear how long these changes persist. The microbiota can also be altered by consuming prebiotic fibers. A substance with *prebiotic* activity exhibits “the selective stimulation of growth and/or activity(ies) of one or a limited number of microbial genus(era)/species in the gut microbiota that confer(s) health benefits to the host.”⁶⁵ Physiological benefit associated with consuming prebiotics and improving the gut microbiota include improvement of laxation and digestive health, reduced risk of obesity, type 2 diabetes, and colon cancer, and improve mineral bioavailability.⁶⁵ Prebiotics are most commonly consumed as functional fibers, such as inulin and fructooligosaccharides. Natural food sources of prebiotics as dietary fibers include

onions, leeks, garlic, wheat, oats, chicory root, and Jerusalem artichoke.⁶⁶ A review of dietary fiber and prebiotics was published recently.⁶⁶ Although much of the data demonstrating changes in microbiota by fiber are based on functional fibers, whole foods may exert these effects. A 3-week, whole-grain breakfast cereal intervention increased fecal *Bifidobacteria* counts compared with a wheat-bran breakfast cereal intervention, suggesting that whole-grain foods may act as prebiotics.⁶⁷ This effect has also been shown in children consuming the recommended intake of whole grains for 6 weeks.⁶⁸ Peas, as a whole food, also have a potential prebiotic effect based on previous *in vitro* work and a limited number of clinical trials.⁶⁹ Nuts are an emerging food that may improve the bacterial community, but the effects may not be exclusively due to dietary fiber.⁷⁰ Current *in vitro* work suggests that dietary fiber from rye, barley, wheat, lentils, and chickpeas may exert a prebiotic effect.⁷¹ Further work, particularly clinical trials, is necessary to confirm the prebiotic effect of whole foods.

Adequate dietary fiber intake, particularly cereal fiber, promotes optimum laxation. In addition, as diet modulates microbiota,⁶⁴ adequate dietary fiber may be a requirement for an optimal balance of the microbiota.

Mineral Bioavailability

Mineral bioavailability is affected by dietary fiber content, as sources of dietary fiber often contain other compounds, such as phytate, oxalates, and tannins, which reduce mineral uptake in the intestines. SCFAs have been suggested to enhance mineral uptake, but this mechanism cannot outcompete the effects of other bioactive compounds in the lumen. Functional fibers, such as inulin, have resulted in enhanced mineral uptake.⁶⁶

POTENTIAL ADVERSE EFFECTS

No Tolerable Upper Limit has been set for total fiber, concluding that there is no intake level of dietary fiber that has been shown to cause significant adverse effects on mineral balance or gastrointestinal function.¹ Achieving the AI of fiber through foods high in dietary fiber is achievable, and intakes may well exceed the AI if primarily

whole grains, whole fruits, vegetables, legumes, and nuts are consumed at recommended levels. Although very high intakes of certain functional fibers can contribute to excessive flatulence, bloating, and diarrhea,⁷² there is little evidence that dietary fiber from a variety of sources causes significant adverse effects in healthy individuals. On the contrary, this premise is supported by data from subpopulations consuming much higher intakes of fiber than the current North American recommendations.⁷³ Fermentation of dietary fiber, as well as other undigested carbohydrates and protein, produces intestinal gas, and some gastrointestinal side effects, particularly flatulence, are unavoidable but certainly tolerable in exchange for the many health benefits derived from higher intakes of dietary fiber.

Choosing naturally occurring, fiber-rich foods instead of fiber supplements is encouraged to achieve the recommended intakes of whole grains, fruits, vegetables, and other foods. This approach maximizes the nutritional value of the diet and the health benefits, as the effects of fiber supplementation on chronic disease risk are not known. Registered dietitian nutritionists should guide patients and clients toward choosing the recommended fiber-rich foods from varied, naturally occurring sources, in moderate portions throughout the day.

EMERGING AREAS OF DIETARY FIBER RESEARCH

In recent years, the role of the gut microbiota in human health has reached the forefront of nutrition and medical research.⁷⁴ Dietary fiber is a key substrate for the gut microbiota, so alteration of dietary fiber intake has an immediate and direct impact on the gut microbial population.⁶⁴ As mentioned previously, dietary fibers have the potential to modulate the gut microbiota and impact health and wellness. Further research on foods containing dietary fiber is needed to better understand this effect. It should be noted, however, that other compounds in foods containing dietary fiber, such as flavonoids, may also modulate the gut microbiota.⁷⁵ The immune system is closely linked with the gut microbiota. The development of a health-promoting gut microbiota is thought to start early

in life (at pre- and postnatal life stages) and subsequently affect immune function.⁷⁶ Dietary fiber intake likely impacts immune function via the gut microbiota, but additional work is needed to clarify these associations and determine relevant mechanisms. Further work is needed to elucidate the role of dietary fiber on inflammation and chronic disease risk, such as CVD, diabetes, and kidney disease.

CONCLUSIONS

Dietary fiber is beneficial to health and, if consumed in adequate amounts, reduces the risk of several chronic diseases, such as CVD, type 2 diabetes, and some cancers. Inconsistencies in definitions of dietary fiber and labeling of dietary fiber on food products are barriers to fully understanding fiber's health effects. Sources of dietary fiber, as opposed to functional fiber, have the added benefit of naturally occurring micronutrients and phytochemicals that may synergistically improve human health. Furthermore, dietary patterns that favor foods high in dietary fiber are likely to also be lower in saturated and *trans*-fatty acids, sodium, and added sugars. The current literature supports the role of dietary fiber in reducing the risk of CVD, type 2 diabetes, some cancers, and weight gain, while supporting digestive health. Meeting the recommended intake of fiber through an increased intake of plant-based foods has the potential to reduce the leading chronic diseases in the United States, especially if these behaviors are initiated early in life and maintained throughout adulthood.

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We thank the reviewers for their many constructive comments and suggestions. The reviewers were not asked to endorse this position or the supporting paper.