DIETARY FIBER IN CHILDHOOD

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Dietary fiber (DF) has important health benefits in childhood, especially in promoting normal laxation. Studies also suggest that DF in childhood may be useful in preventing and treating obesity and also in lowering blood cholesterol levels, both of which may help reduce the risk of future cardiovascular disease. In adults, a high-fiber, low-fat diet has been linked to reduced rates of colon and other human cancers, and although it seems highly likely that this benefit would be even greater if this regimen had been started in childhood, epidemiologic and experimental confirmation is currently lacking. Children's typical DF consumption may not be adequate to maintain good health and prevent disease. Therefore, it would be prudent to recommend that children and adolescents increase DF intake by increasing consumption of fruits, vegetables, legumes, cereals, and other grain products. Several guidelines recommend quantitative ranges of DF intake for children. These include recommendations by the National Academy of Sciences, the Food and Drug Administration's (FDA) food label guide, and the "Age+5" guideline. The goal is to achieve a DF intake that is safe even for children and adolescents with marginal intake of vitamins and minerals, provides sufficient DF for normal laxation, and reduces the risk of future chronic diseases, such as coronary artery disease. Current estimates of DF intake are much lower than recommended levels for a large proportion of the US pediatric population. This article reviews these data. *(J Pediatr 2006;149:S121-S130)*

Dietary fiber (DF) is important in childhood and may contribute to significant present and future health benefits. Research and interest in DF and health has focused primarily on adults, however, and less is known about the physiology and health effects of DF in children and adolescents.

Since the 1950s, the term "dietary fiber" has been used to describe the structural parts of plant foods that are resistant to digestion by humans. A mixture of polysaccharides and lignin, DF usually is divided into 2 major categories based on water solubility and viscosity. The physical properties of viscous and nonviscous DFs in food determine their physiologic effects, which in turn are related to their known and potential health benefits.[1]

Recently, the National Academy of Sciences (NAS) proposed a new definition for fiber based on the rationale that the definition of DF should determine the analytical methods needed to measure it, rather than have the analytical method determine what qualified as fiber and what did not.[2] The new definition proposes that *total fiber = dietary fiber + functional fiber*. Under the new definition, *dietary fiber* consists of nondigestible carbohydrates and lignin (a noncarbohydrate substance bound to fiber), which are intrinsic and intact in plants (eg, gums, cellulose, oat bran, wheat bran), and *functional fiber* consists of isolated, nondigestible carbohydrates that have beneficial physiological effects in humans. Functional fibers may be extracted or modified from plants (eg, resistant starch from green bananas and cooked, cooled potatoes) or may be derived from animal sources (eg, chitin and chitosan found in crab and lobster shells). Functional fiber also must have a beneficial physiological effect in humans.

Modern interest in DF was stimulated by Burkitt et al[3] in the 1970s, who observed lower prevalence rates of chronic disease in Africa as compared to Western industrialized

AAP	American Academy of Pediatrics	NAS	National Academy of Sciences
AI	Adequate intake	NHANES	National Health and Nutrition Examination Survey
BMI	Body mass index	TDF	Total dietary fiber
DF	Dietary fiber	USDA	United States Department of Agriculture
FDA	Food and Drug Administration		
LDL	Low-density lipoprotein		

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countries. They proposed a *dietary fiber hypothesis*, in which common gastrointestinal diseases (eg, colon cancer, diverticulosis, and appendicitis) were due in part to insufficient DF intake.[3]

The known or potential health benefits of DF in childhood include promotion of normal laxation and prevention of gastrointestinal disorders, prevention and treatment of childhood obesity, reduction of blood cholesterol, modulation of postprandial hyperglycemia and glucose intolerance, and possible effects on reducing the risk of future chronic diseases, such as cancer, cardiovascular disease, and adult-onset diabetes.

LAXATION AND GASTROINTESTINAL HEALTH BENEFITS

Constipation is a common clinical problem in childhood.[4] Children with this problem often pass large stools as a result of chronic overdistention and insensitivity of the colon.[5] Incomplete rectal emptying results in chronic overdistention with retention of large fecal masses. The internal rectal sphincter is chronically held open, and overflow diarrhea (encopresis or fecal soiling) occurs.

Treatment is aimed at reestablishing normal colonic muscular tone and instituting a plan of therapy that promotes the frequent passage of softer, more normal-sized stools. The latter often includes a dietary recommendation for increased intake of DF and fluid, which together promote the regular passage of softer stools and slowly allows the return of normal rectal function and tone. The physiological effects of DF depend on the type of fiber ingested, the part of the gastrointestinal tract involved, and other factors. In the stomach, DF tends to delay gastric emptying time, whereas in the small intestine, the effects of DF are more variable. DF delays the absorption of many nutrients, which increases or decreases intestinal transit time, depending on the specific effects of the malabsorbed nutrients. In the large intestine, nonviscous DF softens and enlarges the stool by absorbing water, increasing bacterial proliferation, and increasing gas production. This results in decreased stool transit time and increased frequency of bowel movements.[6] Viscous fiber in the large intestine may also increase stool volume and water content and decrease stool transit time. Viscous fibers fermented by intestinal bacteria, as well as the proliferating bacteria themselves, increase fecal mass. Fermentation also produces other byproducts that have laxative effects. Thus, high levels of DF tend to result in more frequent, softer, and larger stools that are passed more easily.

Morais et al[7] evaluated the intake of DF in 52 children (mean age, 6 years) with chronic constipation, age- and sex-matched with children with normal intestinal habits. The children who were constipated consumed significantly less DF than the controls (9.7 vs 12.6 g/day). Only 25% of the constipated group met the “Age+5” g/day DF guideline,[8] compared with 57.5% of controls. With respect to treating constipation in childhood, increasing DF appears to be a component of successful therapy for many children.[9-11]

DIETARY FIBER AND CHILDHOOD OBESITY

Over the past 2 decades, overweight in children and adolescents has increased dramatically worldwide.[12] Based on data from the National Health and Nutrition Examination Survey (NHANES) III, about 10% of US children and adolescents were overweight in 1988-1994; however, the most recent NHANES data (from 1999-2000) indicate that an estimated 15% of children and adolescents are overweight, a 5% increase in overweight prevalence from previous estimates.[13]

An inverse relationship between DF intake and obesity has been suggested from observations that obesity is rare in developing countries where a high proportion of calories come from complex carbohydrates rich in DF.[14] Conversely, obesity is more prevalent in Western countries, where less DF is consumed.[14] DF may influence the development of obesity through effects on food intake, digestion and absorption of nutrients (especially energy), and carbohydrate metabolism.[15] An inverse relationship between intake of DF and dietary fat has been observed in children as well as adults, so that fiber-rich diets tend to be less energy dense compared with fiber-poor diets.

DF also appears to affect satiety.[16] The stomach fills sooner with fiber-rich bulkier foods, and satiety is reached with lower energy intake. Foods rich in DF require more chewing, which increases satiety. Some DF also slows gastric emptying, which tends to reduce hunger and prolong a feeling of fullness.

High-DF diets may also have a negative effect on metabolized energy, because the digestibility of protein and carbohydrate (but not fat) is reduced with a high-fiber diet.[17] Increased bulk also shortens transit time, allowing less time for digestion and adsorption. Increased loss of fecal energy due to high DF intake also has been reported.[18,19] Foods rich in viscous fiber modulate the insulin response to carbohydrate, resulting in a blunted postprandial glucose and insulin response.[20] This may influence satiety, because insulin is an appetite stimulant.

A recent analysis of NHANES II data by Samuel et al[21] found that higher DF intake was associated with lower prevalence of overweight and at risk for overweight. Among all 13- to 18-year-olds and 13- to 18-year-old boys, those with low fiber intake were almost 3 and 4 times more likely to be overweight, respectively, than those with higher fiber intake (15% vs 5.9% and 19.2% vs 4.6%, respectively [lowest vs highest tertiles]). Interestingly, compared with oatmeal users, non-oatmeal users were more likely to be overweight, with body mass index (BMI) at or above the 95th percentile based on the Centers for Disease Control 2000 growth reference (10.4% vs 6.2%). This was especially significant among adolescents and girls. In addition, compared with oatmeal users, almost twice as many 2- to 18-year-old non-oatmeal users were “at risk” of being overweight, with BMI between the 85th and 95th percentiles (24.6% vs 13.3%). This was especially significant among girls and 2- to 5-year-olds. Samuel et al[21] concluded that high-fiber foods, including oatmeal, may be beneficial in helping children and adolescents maintain a healthy weight.

DF also has been used in the treatment of obesity, and studies suggest a beneficial effect on weight reduction, resulting in about 2 kg additional weight loss with fiber supplementation.[22] In a cross-over study with obese children, 15 g/day of DF added to a reduced-calorie diet resulted in greater mean weight loss compared with the non-fiber treatment period.[23] Thus, although there are relatively few studies, some evidence suggests that DF may be beneficial in preventing and treating childhood obesity.

DIETARY FIBER AND BLOOD CHOLESTEROL IN CHILDHOOD

Hypercholesterolemia in childhood is treated primarily through dietary modification, with drug therapy reserved for very-high-risk children over age 10 years who have low-density lipoprotein (LDL) cholesterol levels of 190 mg alone or lower LDL levels in conjunction with other coronary heart disease risk factors.[24] The recommended diet emphasizes decreased consumption of saturated fats and cholesterol and increased intake of complex carbohydrates, many of which are rich in DF.[24] The addition of viscous DF to the diet has been shown to lower LDL cholesterol further in children without the need for drug therapy. Overall, these studies suggest that adding about 6 g/day of viscous fiber (eg, oat bran or psyllium) achieves approximately an added 6% decrease in LDL cholesterol above and beyond that achieved by a low-saturated fat, low-cholesterol diet alone.[25-29] One study showed no effect, however.[30]

In the Healthy Start preschool study of cardiovascular disease risk factors and diet, Bollella et al[31] followed a cohort of preschool children age 3.9 years at baseline and age 8.2 years at follow-up. Lipid profiles, BMI, blood pressure, and dietary intake were assessed at each time point; the results demonstrated that increasing BMI significantly and adversely affected blood cholesterol levels. An increase in BMI from age 3-4 to 7-10 years was a significant predictor of total cholesterol at 7 to 10 years. Intake of DF and monounsaturated fatty acids had a beneficial effect on blood lipids, however, and was negatively associated with total cholesterol levels at age 7 to 10 years.

CURRENT DIETARY FIBER INTAKE

Before the 1990s, information on DF intake in the United States population was very limited and available primarily for adults.[32-35] In addition, estimates of DF intake were based on analyses using various different measurement protocols and methods of food analysis. Until 1991, the USDA food composition tables provided values only for crude fiber, which underestimated total DF because of the analytical procedure used.[36] In 1991, the USDA released version 4 of their nutrient database that included DF values of foods, which could then be used in other nutrient databases and dietary analyses.

Analysis of data from the 1976-80 NHANES II survey estimated average DF intake of 4-to 19-year-old children at about 12 g/day, or 6 g/1000 kcal.[37] Nicklas et al[38] also reported an average DF intake of 12 g/day for children in Louisiana. Saldanha et al[39] examined trends in DF intake in US children (age 2 to 18 years) from 1977-78 to 1987-88 using the USDA's Nationwide Food Consumption Survey data and reported significant decreases in DF consumption during this decade. Primary sources of DF shifted away from fruits and vegetables to bread, cereals, and combination foods. Children who regularly ate breakfast tended to consume 1 to 3 g/day more DF than breakfast skippers.

Nicklas et al[38] reported that total DF intake remained unchanged from 1976 to 1988 among Louisiana children, even after adjusting for energy intake (mean 12 g/day, or 5 g/1000 Kcal). African-Americans had higher DF intake per 1000 kcal than Caucasians at age 10 to 17 years. Dinner contributed the greatest percentage of total daily DF (34% to 44%), followed by lunch (26% to 33%), snacks (24% to 29%), and breakfast (12% to 19%). NHANES II data were similar, with 1/3 of DF derived from snacks and 13% from breakfast.[37] Vegetables, soups, breads, and cereals accounted for 50% to 75% of the total DF consumed by 10- to 13-year-olds. In adults, vegetables were the leading source of fiber (27%), followed by breads (19%).[35] For 10-year-old Louisiana children, milk and fruit contributed about 25% of total DF intake. Milk was a major source of DF due to addition of chocolate flavoring containing carrageenan, a thickener containing DF. Children in the highest quartile of fiber intake consumed significantly less fat than children in the lowest fiber quartile (34% vs 40% of calories from fat).[38] Children with high DF intake consumed more fruit, fruit juice, vegetables, soup, breads, and grains, whereas children with low DF intakes consumed more high-fat foods like cheese, pork, beef, eggs, and oils. The mean DF intake of 12 g/day (or 5 g/1000 kcal) reported by Nicklas et al[38] is similar to the NHANES II DF intake for children reported by Fulgoni and Mackey.[37]

Among preschool children, the Healthy Start Project, a 3-year cardiovascular risk-reduction program for 3- to 5-year-old preschool children begun in 1995, reported a mean baseline daily fiber intake of almost 11 g/day.[40] Data from the Child and Adolescent Trial for Cardiovascular Health study, a school- and family-based intervention study on reducing the risk of cardiovascular disease in a group of 3rd- to 5th-grade students, reported that children in this study met the Age+5 recommendation for DF.[41]

Table I provides estimates of DF intake for children in US national surveys in the past 40 years (the Nationwide Food Consumption Survey, the Continuing Survey of Food Intake in Individuals, and NHANES).[42-45] The most recent data reported from NHANES III (1988-1994) estimates DF intake for all 2- to 18-year-olds at 13.2 g/day, including 10.7 g/day for 2- to 5-year-olds, 13.4 g/day for 6- to 11-year-olds, and 14.6 g/day for 12- to 18-year-olds. Overall, DF intake for US children has remained fairly steady over time, with the leading food sources of DF including yeast bread, ready-to-

Table I. Dietary fiber intake (mean g/day) in US children in selected national surveys

Age/sex*	1965 NFCS	1977-78 NFCS	1987-88 NFCS	1989-91 CSFII	1994-96 CSFII	NHANES III, phase 1, 1988-91	NHANES III, 1988-94
2-5 yr	8.9		8.2		11.2 (2-5 yr)	10.2 (3-7F)	
					9.9 (2-3 yr)	11.2 (3-7M)	10.7
					11.5 (4-5 yr)		
6-11 yr	12.1		11.5		12.2 (4-8 yr)	11.8 (8-11F)	13.4 (6-12 yr)
					12.7 (8-11F)	13.1 (8-11M)	
					14.0 (8-11M)		
12-18 yr, M	15.2		14.0		17.4 (12-18M)	11.5 (12-15F)	
	13.5 (11-18 yr)	13.0 (11-18 yr)		14.0 (11-18 yr)	15.0 (11-18 yr)	15.1 (12-15M)	
					17.7 (14-18M)		14.6 (13-18 yr)
12-18 yr, F	11.0		10.6		12.7 (12-18F)	12.6 (16-18F)	
					12.9 (9-13F)	17.4 (16-18M)	
					12.8 (14-18F)		
All 2-18 yr							13.2
							12.0F
							14.3M

Data adapted from reported values in analyses of US surveys: the Nationwide Food Consumption Survey (NFCS) 1965, 1977-78, and 1987-88; the Continuing Survey of Food Intake by Individuals (CSFII) 1989-91 and 1994-96; and the NHANES III survey, phase I (1988-91).

*Values given are for age and sex category, unless otherwise specified.

eat cereals, white potatoes, dried beans and lentils, tomatoes, and potato chips (Table II).

Comparing DF intake in the Continuing Survey of Food Intake in Individuals-95 and NHANES III surveys with the recommended intake based on the Age+5 guideline shows that fiber intake is minimally adequate in both boys and girls up through age 11 (based on mean intake in the 6- to 11-year old category).[8,44] This is consistent with previous data on fiber intake in young children, as well as data from the Healthy Start Project and the Child and Adolescent Trial for Cardiovascular Health studies.[40,41] After age 11, however, fiber goals based on either the Age+5 formula or the 0.5 g/kg/day American Academy of Pediatrics (AAP) guideline are not met, despite the modest increase in fiber intake in the 16- to 18-year-old category for both boys and girls reported in the NHANES III survey.[44,46]

Samuel et al[21] evaluated DF intake using the NHANES III (1988-1994) survey data, which included a sample of 9814 children age 2 to 18 years. The data were examined by tertiles of total DF (TDF) intake for all children and for specific age-sex subgroups. Fiber intake estimates were computed and coded using the United States Department of Agriculture (USDA) survey nutrient database. The mean total DF (TDF) intake for all children and adolescents age 2 to 18 years was 13.2 g. Mean TDF intake by TDF tertiles was significantly different for all 2- to 18-year-olds in the lowest versus highest TDF tertiles: 6.4 ± 0.1 g/day versus 21.5 ± 0.3 g/day. Similar results were observed across all age-sex subgroups.

Hampl et al[47] studied the DF intake of children and found that less than half (45%) of 4- to 6-year-olds and less than 1/3 (32%) of 7- to 10-year-olds met the Age+5 fiber guideline. Children with low DF intake had significantly higher energy-adjusted intake of fat and cholesterol. Children who met the Age+5 guideline consumed more breads and cereals, fruits, vegetables, legumes, nuts, and seeds and had significantly higher energy-adjusted intakes of DF, iron, magnesium, vitamins A and E, and folate.

SAFETY OF HIGH DIETARY FIBER INTAKE IN CHILDHOOD

Although DF is associated with important health benefits in childhood, there have been concerns that very-high-fiber diets could result in adverse health effects. Some have urged caution in the use of high-fiber foods for children, although a prudent diet emphasizing increased consumption of complex carbohydrates rich in DF has been recommended by the AAP since 1986.[48]

In 1991, the National Cholesterol Education Program's Expert Panel on Cholesterol in Children and Adolescents, in collaboration with the AAP, recommended a fat-modified Step One diet for all children over age 2 years.[49] Although this diet recommends that 50% to 60% of calories be derived from carbohydrates, it does not specify a recommended DF intake.[49-51]

Concerns about the safety of a high-DF diet in childhood caution that high-fiber diets could limit caloric intake and reduce the bioavailability of minerals and other nutrients. High-fiber diets could reduce caloric intake in small children, because these children have a smaller stomach capacity than adults, and high-fiber foods are bulkier and lower in caloric density than low-fiber foods. Thus, a high-fiber diet could lead to inadequate caloric intake for normal growth. Food fiber may displace available nutrients in the diet, slow down the intake of food by requiring more chewing, and reduce the

Table II. Top 10 food sources of dietary fiber in US children age 2 to 18 years (Continuing Survey of Food Intake in Individuals, 1989-91)

		% of fiber intake				
Rank	Food group	2-18 years, males and females	2-5 years, males and females	6-11 years, males and females	12-18 years, males	12-18 years, females
1	Yeast bread	14.3	14.4	13.9	14.2	15.3
2	Ready-to-eat cereal	9.3	10.6	8.7	10.8	6.9
3	White potatoes	7.1	5.7	7.1	7.6	7.7
4	Dried beans and lentils	6.7	4.5	6.3	9.5	6.4
5	Tomatoes	6.0	4.7	5.6	6.5	7.3
6	Potato chips, corn chips, popcorn	5.3	3.3	4.6	6.2	7.8
7	Pasta	4.9	5.8	5.1	3.9	5.1
8	Cakes, cookies, quick breads, donuts	4.3	4.1	4.5	4.3	4.1
9	Corn	4.1	5.1	3.8	4.0	3.6
10	Apples and applesauce	4.0	5.3	5.2	2.3	1.9

Yeast bread: white and whole grains, each contributing about half.
Source: Adapted from CSFII 1989-91 survey data reported in Subar AF, Krebs-Smith SM, Cook A, Kahle LL. Dietary sources of nutrients among US children, 1989-1991. Pediatrics 1998;102:913-23.

absorptive efficiency of the small intestine.[52] Refined products, stripped of DF, are easier to digest, are more completely absorbed, and have a higher energy-to-satiety ratio. But while providing a ready source of energy for children, such refined products may promote obesity. On the other hand, reverting to more natural, higher-fiber products could result in decreased caloric intake. The questions are how much of a reduction in energy intake occurs when DF is increased, and whether this decrease is likely to be beneficial or harmful with respect to the present nutritional status of US children.

Studies in adults have reported some loss of energy as DF is increased. Southgate and Durnin[53] fed young British women 23 g/day of DF for 7 days and observed an increase in fecal loss of energy (4%), nitrogen (8%), and fat (4%). Energy absorption was reduced by about 1% for every 6 g of added DF, a decrease unlikely to be biologically significant unless the intake of major nutrients is frankly deficient.

Levine et al[54] reported a 10% decrease in calories consumed during breakfast and lunch after adults consumed a very-high-fiber (20 g/serving of DF) breakfast cereal. Stevens et al[55] reported decreased energy intake and increased fecal energy loss when young women consumed an added 23 g/day of DF. Because the DF intake of adult UK women is about 18 g/day, DF intake in this study may have been $>$ 40 g/day, much higher than the recommended adult intake of about 25 to 35 g/day.

Far less data are available for children. In the classic 1943 study of Hummel et al,[56] 18 preadolescent children consumed diets containing 4 to 6 g/day of crude fiber for 1 to 6 months. Good health and normal bowel function was reported, with no evidence of adverse effects on absorption of nitrogen or mineral balance. These authors also noted an age-dependent increase in the ability to ferment DF.

Hamaker et al[57] reported increased fecal energy loss (52 to 118 kcal/day) when Peruvian toddlers were fed 9 to 22 g/day of DF from maize, amaranth, or cassava flours. It is difficult to extrapolate these findings to industrialized countries such as the United States, however, because these undernourished children had weight-ages and length-ages half or less of their chronologic ages, suggesting significant chronic malnourishment.

In summary, DF tends to increase dietary bulk, decrease caloric density, and reduce caloric intake. Fecal energy loss may increase as intestinal transit time decreases, leaving less time for digestion and absorption of nutrients.[58] These effects may be beneficial for most US children, who typically consume a calorically-dense, highly-refined, high-fat diet. On the other hand, increasing DF in malnourished children from underdeveloped countries with inadequate nutrient intake could further reduce available energy.[59-63]

A second safety concern has been that high-fiber diets in childhood may reduce the bioavailability of minerals. This reflects the fact that some high-DF foods contain phytate (inositol hexaphosphate), which may form insoluble compounds with minerals, making them unavailable for normal absorption and metabolism. Other plant foods contain oxalic acid, which also can interfere with iron absorption.[64]

Studies of the effects of DF on mineral balance generally have been acute, short-duration, high-dose feeding studies. A gradual dietary increase in DF containing added phytate, which bound minerals and decreased bioavailability, would trigger a compensatory physiological response to increased intestinal absorption.[65,66] Thus, decreased bioavailability of minerals is likely to be a chronic problem only when the mineral intake is inadequate and absorption cannot be increased.[65,67,68] In the United States and other industrialized countries, vitamin/mineral intake generally is adequate and DF intake is moderately low.

There are special segments of the population in which caution is prudent, including preschool children, adolescents with mineral-deficient diets, impoverished children with inadequate nutritional support, and some vegetarian children who have nutritionally inadequate diets. Although DF intake may be very high (2 to 4 times the recommended intake) and be accompanied by poor growth, the high DF may not be the cause of the latter.[69] Growth stunting has been linked to lack of essential nutrients, low energy intake, and underutilization of health care services.

In reviewing studies of DF and mineral deficiencies in childhood, it is important to compare the actual concentrations of DF and phytate in the study population with intake levels in US children. Cooking and baking processes also must be considered. Phytate is destroyed by leavening; thus, mineral deficiencies due to phytate binding are rare in countries in which leavened bread is consumed.

In the 1970s, poor physical growth was reported for rural Iranian children, in whom unleavened whole-grain pita bread provided 75% of energy intake and the main dietary source of zinc.[70] In US children, however, only about 20% of zinc intake comes from bread and cereal; intake of animal protein is high, and most bread consumed is leavened. Phytate intake in Iran was 2 g/day, compared to an estimated intake of 0.4 g/day in the United States.[71] One-third of the rural Iranian children had iron-deficiency anemia, compared to about 5% of US children.[72] In the US diet, bioavailability of iron is enhanced significantly by calcium and magnesium, which competitively form salts with phytic acid and neutralize the phosphate in phytic acid. US children also consume more animal foods, which are a source of highly bioavailable heme iron. Vitamin C, generally abundant in US diets, also increases iron absorption.

More recent studies have evaluated the effects of DF on mineral balance. Drews et al[73] fed 14 g/day of DF to adolescent males for 4 days and found that although fecal zinc, copper, and magnesium levels increased, serum levels remained unchanged. Kawatra et al[74] found that 25 g/day of psyllium increased fecal excretion and decreased serum levels of zinc, copper, and manganese in adolescent Indian girls; however, anemia was not present. Dennison and Levine[30] found that children's growth and serum vitamin (A, D, E, and folic acid) and mineral (iron, zinc, and calcium) levels were not affected when 12 g/day of DF was added to their usual diet for 1 to 2 months, suggesting that a doubling of usual DF intake for US children with adequate intake of essential vitamins and minerals may not adversely affect growth, serum vitamin, or mineral levels.

McClung et al[75] treated constipated children with a doubling of DF to 0.6 g/kg (about 18 g/day) and found no decrease in serum vitamin, mineral, or hemoglobin levels during 6 months of treatment. Kelsay[76] reviewed the effects of DF on mineral bioavailability and concluded that up to 32 g/day of DF and 2 g/day of phytic acid had no adverse effect on mineral balance. Even among US vegetarian children with very high DF intake, anemia is not common, perhaps because higher vitamin C intake enhances iron absorption.[77,78]

In summary, studies suggest that although a small energy loss may occur with a high DF intake, this small decrease is unlikely to be significant for children with adequate nutrient intake. Increases in DF up to a doubling of current intake are not likely to adversely affect growth or serum vitamin and mineral levels in healthy US children on adequate diets. Thus, for US children, a moderate increase in DF would be more healthful than harmful.

RECOMMENDATIONS FOR DIETARY FIBER INTAKE IN CHILDHOOD

Several guidelines recommend specific quantitative fiber intakes for children and adolescents, including the AAP guidelines,[66] Williams' et al Age+5 guideline,[8] the FDA food label guidelines,[79] and the National Academy of Sciences adequate intake (AI) recommendation.[2] The USDA Food Guide Pyramid[80] and the National Cholesterol Education Program's dietary goals[24] apply to children over age 2, with age 2 to 3 years suggested as a transition period. Some suggest that DF may not be needed during the first year of life,[81] whereas others recommend that weaning diets include at least 5 g/day of DF.[82]

The AAP's Committee on Nutrition has recommended a DF intake of 0.5 g/kg of body weight.[66] Based on this recommendation, and median weight for age based on the Centers for Disease Control's 2000 pediatric growth charts, DF intake would range from about 7 to 35 g/day for 3- to 19-year-old boys and about 6 to 29 g/day for 3- to 19-year-old girls. In contrast, current DF intake plateaus at 12 to 15 g/day for US adolescents. The AAP's recommended DF intake for older, heavier adolescents with body weight significantly above the median weight for age, could well approach 40 g/day; however, the AAP guideline places a cap on recommended daily DF intake at 35 g/day. From a safety perspective, a DF intake $>$ 30 g/day for adolescents with inadequate intake of minerals (calcium, iron, zinc) potentially could lead to deficiencies.[58] Up to 25 g/day during adolescence should not be deleterious, however, even with suboptimal mineral intake.[58,83]

The FDA food labeling program bases DF recommendations on calories consumed and does not distinguish between adults and children. At 2000 kcal/day, 25 g/day of DF is recommended (12.5 g/1000 kcal) and at 2,500 kcal/day, 30 g/day DF ($\sim$12 g DF/1000 kcal).[79] DF intake based on 12 g/1000 kcal is lower than the AAP's recommended levels for most adolescents, especially girls. On the other hand, DF intake based on this formula may be somewhat high for preschool children.

The USDA MyPyramid (replacing the original Food Guide Pyramid) does not specify a recommended amount of DF per day, but estimates may be made based on number of servings and usual serving size.[80] At caloric intakes of 2200 and 2800 kcal/day, DF intake may be estimated at 32 to 40 g/day (2 g DF per serving of bread group, small fruit, or half cup of vegetables). For preschool children who consume 1600 kcal/day and half-size servings of vegetables, DF intake could be about 19 g/day.

Williams et al[8] proposed a reasonable goal for DF intake during childhood and adolescence approximately as equivalent to the child's age plus 5 g/day (Age+5). Based on Age+5, minimal DF intake would range from 8 g/day at age 3 to 25 g/day by age 20, the lower level of adult recommended intake. Based on current levels of DF intake, 55% to 89% of 2- to 18-year-old US children consume less than the Age+5 goal.

The Age+5 level of DF intake for children is similar to the AAP's recommendation (0.5 g/kg/day)[66] up to age 10; however, it is lower for older adolescents. The Age+5 level of DF intake is felt to represent a level that would provide health benefits, such as normal laxation, without compromising mineral balance or caloric intake in children over age 2 years. In addition, the Age+5 recommendation is consistent with current guidelines for adult DF intake (25 to 35 g/day),[2,84-89] because the minimal adult DF intake of 25 g/day would be reached by age 20 applying the Age+5 rule.

Williams et al[8] also suggested a range of DF intake between Age+5 to Age+10 (g/day) as a safe and tolerable level for most children based on current knowledge.[58] The Age+10 upper level of DF intake is similar to levels based on 10 to 12 g/1000 kcal. These levels have been suggested as safe even for Japanese adolescents, who have low calcium intake.[83]

The newest quantitative recommendation for DF in childhood is the 2002 AI level proposed by the NAS.[2] The NAS guide for children is set at an AI of 14 g/1000 kcal (for all age groups 1 year and up) and reflects fiber intake as a function of energy intake. For specific age groups in childhood, this translates as follows (where E = energy in kcal):

- 1 to 3 years: (median E intake = 1372 kcal), 19 g/day total fiber (TF)
- 4 to 8 years (E = 1759 kcal), 25 g/day TF
- 9 to 13 years: boys, 31 g/day TF; girls, 26 g/day TF
- 14 to 18 years: boys, 38 g/day TF; girls, 26 g/day TF

The NAS guideline of 14 g of fiber per 1000 kcal is based on epidemiologic data for a reduced risk of coronary heart disease, extrapolating adult data and applying it to children.[90-92]

All of the recommendations for DF in childhood suggest that DF be increased gradually by encouraging greater consumption of a variety of fiber-rich fruits, vegetables, legumes, cereals, and whole-grain products. Fiber supplements for children to meet DF requirements are not recommended; however, such supplements may be clinically useful as an adjunct to the dietary treatment of constipation, hypercholesterolemia, and obesity in childhood.

At the present time, there are no specific guidelines as to specific intake of viscous (soluble) versus nonviscous DF in childhood. Both types of fiber are associated with important health benefits, and both are consumed in generous amounts by following the Food Pyramid Guide. A soluble-to-insoluble DF ratio of 1:4 or 1:3 has been recommended for adults.[93] Very young children consume more viscous fiber than nonviscous fiber (especially from fruits), with intake of the latter increasing gradually with age.[82]

Because DF increases water retention in the colon, resulting in bulkier, softer stools, recommendations for water intake should be increased commensurate with increases in DF. The amount of water needed for children to produce soft bulky stools is estimated as 6 to 8 cups/day.[94] Others have recommended 6 cups/day for children weighing 26 pounds, increasing up to 10.5 cups/day for those weighing 100 pounds (mean weight of a 13-year-old boy).[81] Water intake for older adolescents with higher DF intakes should be higher.

NOVEL HEALTH BENEFITS OF DIETARY FIBERS: PREBIOTIC EFFECTS

Inulin, oligofructose, and fructo-oligosaccharides are fibers present in plant foods but not currently analyzed as DF (and hence not included in the USDA database) because they are soluble in ethanol. The new NAS fiber definition will include these fibers, which in turn may be classified as DF or as functional fiber, depending on whether they are intrinsic and intact in plants or have been synthesized or extracted.[2] These fibers are important because they are known to have prebiotic effects, that is, they stimulate the growth and activity of intestinal lactic acid bacteria, such as bifidobacteria. This effect on intestinal microflora provides a key health benefit.[95]

Because human milk contains oligosaccharides, and breast-fed infants establish a healthier intestinal microflora compared with formula-fed infants, some infant formulas in Japan and Europe have been supplemented with prebiotics in an attempt to modulate intestinal microflora to mimic the effects of human milk.[96-100] In Japan, 90% of infant formulas are supplemented with prebiotics in the form of galacto-oligosaccharides. In Europe, prebiotics have been added to infant formula in the past 5 years, using a mixture of fructo-oligosaccharides and galacto-oligosaccharides. To date, relatively few studies have reported on their benefit in infants. Moro et al[98] showed that adding a mixture of prebiotic oligosaccahrides to infant formula could increase the survival of bifidobacteria in the gut. Another study found no significant decrease in the incidence of acute diarrhea, although the severity was decreased.[97]

Inulin-like fructans eventually may offer a number of other health benefits for children and adolescents; they have been shown to modulate blood lipids and to reduce glycemia and insulin resistance in adults.[95] Nondigestible viscous DFs, such as inulin and fructo-oligosaccharides, do not contribute to the glycemic index or glycemic load of a meal, and exert beneficial effects on postprandial glycemia and insulinemia.[101] Inulin has been shown to lower total cholesterol, LDL, very-low-density lipoprotein, and triglycerides in young adults.[102] Inulin also has been shown to decrease fasting insulin levels in adults.[103] No studies in children have been reported; however, this is likely to be an important area of future research, as the prevalence of obesity in youth, along with related comorbidities, including insulin resistance and type II diabetes mellitus, has increased dramatically in the last several decades.

CONCLUSION

In summary, DF has important health benefits in childhood, especially in promoting normal laxation. In addition, research suggests that DF in childhood may be useful in preventing and treating obesity and in lowering blood cholesterol levels, both of which may help reduce the risk of future cardiovascular disease. In adults, a high-fiber, low-fat diet has been linked to reduced rates of colon and other human cancers, and although it seems highly likely that this benefit would be even greater if begun in childhood, epidemiologic and experimental confirmation are currently lacking.

US children on average currently consume amounts of DF that appear inadequate for healthy gastrointestinal function and disease prevention. Therefore, it is recommended that children over age 1 year increase DF intake by increasing consumption of fruits, vegetables, legumes, cereals, and other whole-grain products. A moderate and safe range of DF intake for children and adolescents may be between age+5 and age+10 g/day. After age 20, adult levels of 25 to 35 g/day are recommended. This range of DF intake is felt to be safe even for children and adolescents with marginal intake of some vitamins and minerals, should provide sufficient DF for normal laxation, and may provide enough added DF to help prevent future chronic disease. The recent NAS-recommended AI for DF is significantly higher than the Age+5 guideline, and there is a paucity of pediatric research data that can help pediatricians determine whether this level of intake is appropriate or excessive, especially for younger children.

Although there are some safety concerns related to very high fiber intake in childhood, the potential health benefits of a moderate increase in DF for children probably outweigh the potential risks, especially in highly industrialized countries such as the United States, where constipation, high blood cholesterol levels, and obesity are common in children and where coronary heart disease is the leading cause of death for adults.

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