Chapter 2
Overview of the Health Benefits of Adequate Fiber Intake

Keywords Dietary fiber • Microbiota • Energy density • Body weight • Coronary heart disease • Blood pressure • Diabetes • Colorectal cancer • Healthy aging • Blood lipids • Systemic inflammation

Key Points

- Low fiber intake is a major public health concern. Inadequate fiber intake is associated with increased risk of weight gain and obesity, chronic disease, and premature aging and mortality.
- Health effects associated with adequate fiber intake include slowing the eating process and reducing food metabolizable energy for better body weight regulation, stimulating laxation and healthy colonic microbiota including, attenuating elevated blood lipids and blood pressure for cardiometabolic health, and increasing insulin sensitivity and lowering systemic inflammation to reduce diabetes, colorectal cancer and premature aging risk (inflammaging).
- Fiber-rich whole (or minimally processed) plant foods and healthy dietary patterns are generally lower in energy density, saturated and trans-fatty acids, sodium, and sugar and higher in essential nutrients and phytochemicals necessary to support optimal health and weight control compared to the usual low fiber Western diets.
- High-viscosity, gel-forming fibers consumed in fiber-rich whole plant foods or supplements tend to have similar effects on attenuating blood lipids and postprandial glycemic response and promoting laxation. However, fiber supplements tend to be less effective than fiber-rich foods at supporting weight loss since they typically do not directly displace higher energy-dense foods.
- Increased fiber intake is consistently associated with better health, reduced chronic disease risk, and healthy aging even when initiated in mid-life (ages 45–65 years).

Introduction

Dietary fiber (fiber) is a major shortfall “nutrient” in the USA and in global populations with high adherence to the Western dietary pattern, as only approximately 5% of these populations consume adequate fiber [1–5]. Low-fiber intake is a major public health concern as the scientific literature has found strong links with it to adverse health outcomes and increased risk of weight

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gain and obesity [1–7]. In contrast, adequate fiber intake, depending on the fiber's composition and physical properties, produces secondary fermentation metabolite-enabled cross-talk signaling capability which can influence many healthy human phenotype processes such as colonic microbiota diversity and health, body weight regulation, reduced cardiovascular disease, colorectal cancer risk, and improved healthy aging and longevity compared to lower fiber intake [1–18]. An overview of potential fiber health-related mechanisms is summarized in Table 2.1 [5, 6, 13–45]. For example, an analysis of the 1999–2010 US National Health and Nutrition Examination Survey (NHANES) observed, after multivariate adjustments, that risk of elevated C-reactive protein (CRP), obesity, and metabolic syndrome are reduced with increasing fiber intake (Fig. 2.1) [41]. Fiber-rich whole or minimally processed foods have the additional benefits of being generally lower in energy density, saturated and trans-fatty acids, sodium, and added sugars and richer in essential nutrients and phytochemicals and represent the majority of foods in all healthy dietary patterns (Appendices 1 and 2). The objective of this chapter is to provide an overview of the health effects of adequate fiber intake.

Table 2.1 Potential fiber-related biological mechanisms associated with better gastrointestinal, and cardio- and energy metabolic health and reduced risk for major chronic diseases [5, 6, 13–45]

Target	Increase	Decrease
Food intake	Eating time	Diet energy density
		Hunger
Stomach	Food volume/bulk/viscosity	Gastric emptying rate
	Satiety/satiation signals	
Small intestine	Food volume/bulk/viscosity	Lipid emulsification
	Release of satiety peptides	Mucosal uptake and re-secretion
		Postprandial macronutrient absorption rates
Pancreas	Digestive enzyme secretion	Insulin response
		β-cell activity
Colon	Laxation	pH
	Fermentation to short chain fatty acids (e.g., butyrate)	Bowel transit time
		Pathogenic bacteria
	Healthy microbiota	Inflammatory activity
	Release of incretins (e.g., GLP-1)	Carcinogen concentrations
		Endotoxin leakage into circulation
		Diverticula and colorectal polyps
Fecal excretion	Bile acids	Metabolizable energy
	Unabsorbed dietary fat and other macronutrients	
Circulatory system	Satiety hormones	Postprandial lipids, glucose, and insulin
	Insulin sensitivity	Fasting total cholesterol and LDL-C
	Adiponectin	Blood pressure in hypertensive individuals
	Leukocyte telomere chain length	C-reactive protein/inflammaging
		Fasting glucose and insulin
Body weight and composition	Weight control	Energy intake
	Energy metabolism	Weight gain/obesity
		Abdominal/visceral body fat
Liver	Lipoprotein uptake	Lipogenesis
	Bile acid synthesis and secretion	Inflammation
	Detoxification processes	

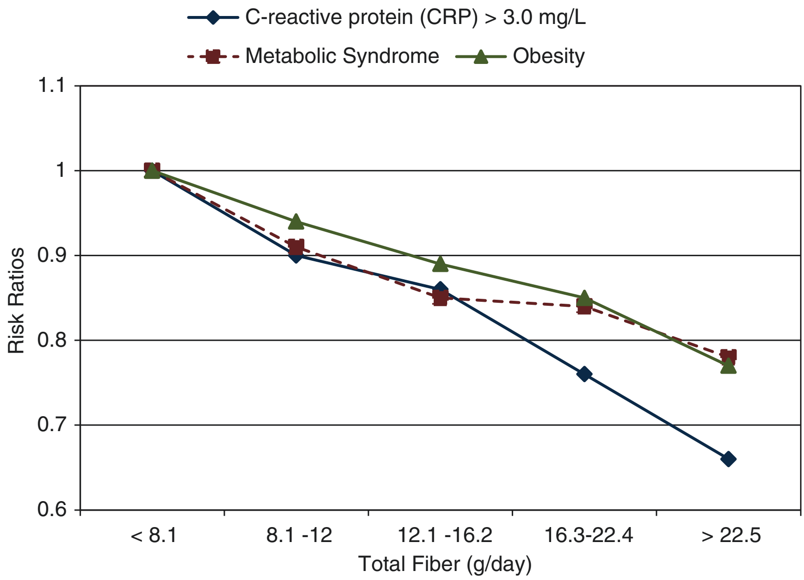

Fig. 2.1 Effect of increasing fiber intake on cardiometabolic risk factors from the 1999–2010 US National Health and Nutrition Examination Survey (CRP *p*-trend <0.001; multivariable adjusted [41]

Digestive Health

The association between coarse bran (fiber) and digestive health was first recognized by Hippocrates who observed in 371 BC that the human body works better with bread made of course rather than finely ground flour [3, 46, 47]. Good digestive health is associated with appropriate nutrient absorption, intestinal motility and immune function, and a balanced colonic microbiota [48]. Fiber is the most important dietary component for good digestive health because of its promotion of laxation, fermentation to bioactive short-chain fatty acids (SCFAs), and maintenance of a healthy colonic microbiota ecosystem [3, 7, 29].

Laxation

Fiber affects laxation by increasing fecal bulk, stool softening, reducing transit time, and improving stool regularity as mediated by fiber water-binding capacity and fermentation, which alters osmotic balance and increases fecal biomass (e.g., fiber, bacteria and gas) [49]. Fiber sources that combine low fermentability and high water-binding capacity such as wheat bran, psyllium fiber, and methylcellulose from supplements, food ingredients, or fiber-rich diets are particularly effective in promoting laxation [29, 50]. In randomized controlled trials (RCTs), both wheat bran and psyllium fiber were shown to decrease transit time and increase daily stool regularity as well as promote healthier stool weights and structure, compared to low fiber controls. Wheat bran was more effective at reducing transit time, and psyllium was more effective at increasing stool water content (softer stools) and weight [45]. Individuals with low-fiber intake are five times more likely to have hard stools compared to those with higher-fiber diets, especially diets supplemented with wheat bran or psyllium [45]. Although coarse wheat bran increases stool volume 2 1/2 times more than fine bran when consumed at the same dose, the fine wheat bran is more fermentable resulting in increased prebiotics and SCFAs associated with colon health [51, 52]. A systematic review of 65 intervention studies found that wheat bran improved bowel function by significantly increasing total stool weight by 3.7 g/gram intact wheat fiber and reducing transit time by 45 min/g when baseline transit time was greater than 48 hours [53]. Highly fermentable fiber may cause excessive gastrointestinal distention or flatulence in sensitive individuals at the recommended fiber intake levels [54]. Excessive fiber intake may promote diarrhea because water follows the undigested and unabsorbed carbohydrates into the large intestine. If transit time is too fast for intestinal cells to absorb the excess water, it will be eliminated in the feces [55]. People may experience abdominal cramping, bloating, or gas when they abruptly increase their fiber intakes or excessive intake of guar gum, inulin (chicory root fiber), oligofructose, fructooligosaccharides, polydextrose, or resistant starch [56]. However, a gradually increased intake of fiber-rich foods over a period of time or trying fiber sources individually to determine tolerance can minimize or help avoid these symptoms. An analysis of the US constipation medical costs estimated that if fiber intake was increased by 9 g/day from bran (equivalent to one serving of high-fiber breakfast cereal/day), there could be approximately a billion dollars in annual health-care savings [57]. Studying laxation is a relatively complex process with a wide range of variability in individuals as the rate of bowel laxation can be influenced independently of diet with fast transit times related to stress, extraverted personality, exercise, and slower rates associated with relaxation, introverted personalities, and sedentary lifestyles [58].

Colonic Microbiota

Over the last decade, the colonic microbiota has become recognized as a "symbiotic human organ" which provides a number of important human biological functions (e.g., nutrients absorption, synthesis of vitamins, food fermentation to SCFAs, bile acid transformations, barrier effects against pathogens), immune system function (e.g., inflammatory response, immunoglobulin A, T-cell homeostasis), and metabolic health (e.g., insulin sensitivity, satiety hormones, and cardiometabolic risk factors) [59–63]. The health-promoting effects of the microbiota are significant as its complement of genes are at least 150 times more than that of the whole human genome. The colonic microbiota produces a large number of bioactive compounds that can influence health including beneficial metabolites such as SCFAs, secondary bile acids, choline or potentially toxic metabolites such as ammonia, sulfur-containing compounds, indoles, and phenols. The composition and activity of the microbiota is affected by diet, heredity, lifestyle, disease, and antibiotic use [64].

This symbiotic relationship between the microbiota and human health evolved over millions of years with humans consuming a high-fiber diet [59, 65]. Fiber-rich dietary patterns compared to low-fiber Western dietary patterns promote both healthy colonic microbiota and human health (Fig. 2.2) [61, 62]. Increased fiber is important in reducing colonic pH to increase symbiotic bacteria diversity and decrease pathogenic bacteria, increasing fecal butyrate concentration to promote colonocyte health as a barrier to lipopolysaccharide (LPS) absorption and inhibit colorectal cancer initiation and progression, and attenuating colonic inflammation, secondary bile acid formation, cardiometabolic dysfunction, insulin resistance, and unhealthy aging, especially frailty [59–68]. A crossover RCT (19 healthy normal weight adults; 53% females; age 19–25 years; basal diet supplemented with 40 or 10 g fiber/ day for 5 days; 15-day washout) found higher-fiber diets overall were shown to increase microbiota diversity and stability compared to lower-fiber diets within 5 days [66]. Additionally, the higher-fiber diet promoted a higher *Prevotella/Bacteroides* ratio, increased fecal SCFAs, and modulated the expression of microbiota metabolic pathways such as glycan metabolism, with genes encoding carbohydrate-active enzymes active for fiber, compared to the low-fiber diets. The equilibrium between fiber intake, gut microbiota SCFAs, and colonic pH being maintained in the acidic range provides an

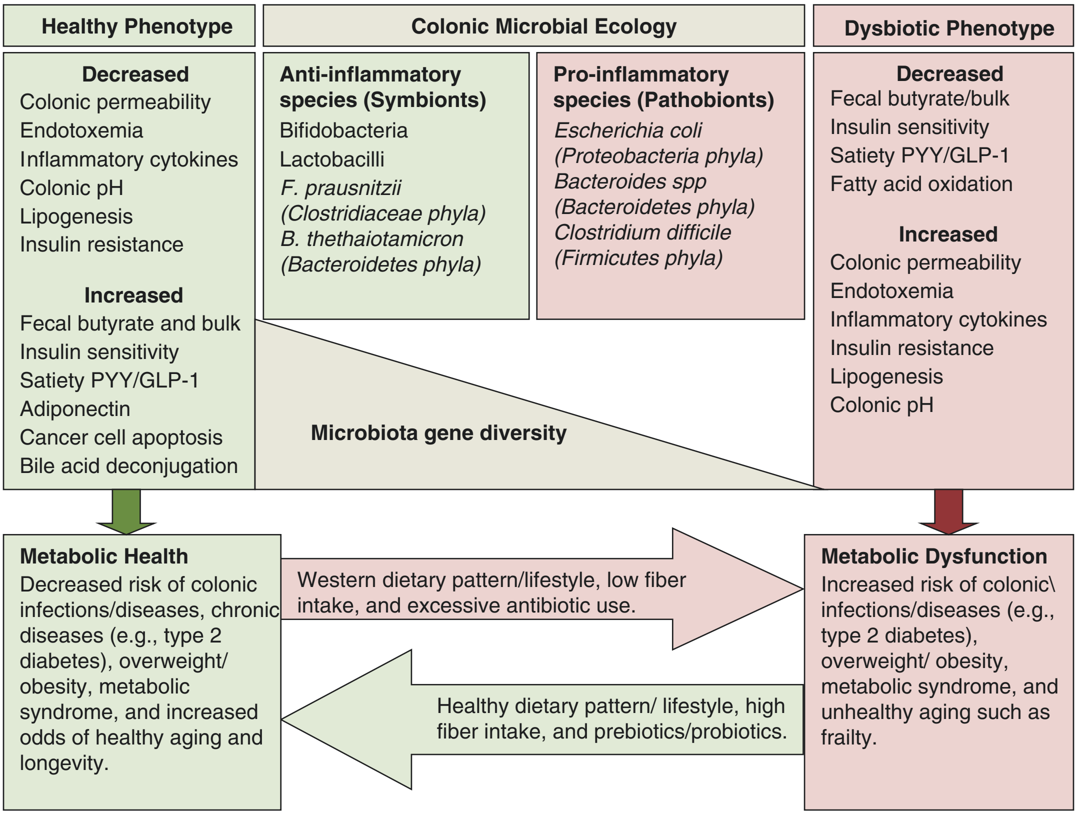

Fig. 2.2 Effect of healthy fiber-rich dietary patterns vs. Western low-fiber dietary patterns on colonic microbiota, cardiometabolic health, and aging [61, 62]

important protective barrier against the expansion of pathogenic bacteria in the colon [60]. With an adequate fiber intake, there are generally higher levels of butyrate-producing bacteria, which maintain an acidic colon at 5.5 pH as butyrate tends to maintain a presence in the colon. Butyrate is also an important energy source for colonocytes and involved in the regulation of cell proliferation, differentiation to reinforcement of the colonic barrier, and colonic anti-inflammatory support. However, when fiber becomes limiting, the colon pH increases to 6.5, which coincides with reduced fermentation and SCFAs, which increases levels of *Proteobacteria*, including a wide variety of pathobionts and increased endotoxemia risk.

The symbiotic relationship between fiber, colonic microbiota, and optimal human health exists throughout the lifecycle [59–63]. These fiber and microbiota interactions begin at birth where active cross-talk signaling between the microbes and human immunity and metabolism begins to take shape [63]. Populations consuming low-fiber Western diets compared with populations consuming a more traditional or healthy fiber-rich diet have more dysfunctional microbiota, which predisposes individuals to a variety of chronic diseases [59, 60, 65, 67]. In contrast, higher-fiber diets are important in maintaining a diverse, healthy microbiota, which may lower the risk of most noncommunicable diseases, including type 2 diabetes, metabolic syndrome, colorectal cancer, and obesity [60–62, 64, 65, 67]. In the elderly, those in longer-term care facilities consuming standardized, low-fiber diets had significantly higher levels of frailty, less diverse and less healthy microbiota, and higher systemic inflammation than those living in their community residences and consuming more diverse, higher-fiber diets [68].

Body Weight Regulation

Adults

The European Food Safety Authority (EFSA) has recommended that adults should consume >25 g fiber/day from whole grains, fruits, and vegetables to improve weight maintenance and sustain weight reduction in overweight and obese individuals [5]. A systematic review of 43 prospective cohort, case-control, and randomized trials found probable evidence that increased fiber intake was predictive of less weight gain, whereas higher-energy diets rich in refined grains, sweets, and desserts were predictive of elevated weight gain and waist size [12]. Observational studies consistently show that populations consuming fiber-rich diets tend to be leaner than those with low-fiber diets [10–14, 69–71]. The 2012 International Study of Macro−/Micronutrients and Blood Pressure (INTERMAP) cross-sectional study (1,794 free living Americans; mean baseline age 49 years; four 24-h dietary recalls and two timed 24-h urine collections) found that normal-weight US adults consumed healthy dietary patterns lower in total energy and higher in nutrient dense foods (e.g., fresh fruit, whole grains bread, cereals and pasta, and brown rice) compared with overweight individuals [69]. Lean participants had lower intakes of meats, fats, sugar-sweetened beverages, carbonated drinks, and nonalcoholic beverages. Their diets were consequently higher in many macro- and micronutrients (vegetable protein, fiber, vitamin A and C, magnesium, and nonheme iron) and lower in animal protein, fats, dietary cholesterol, and sodium. The Nurses' Health Study (74,091 US women; mean baseline age 50 years; mean BMI 25; 12-year follow-up) found that women with the greatest increased intake of total fiber gained an average of 1.5 kg less than those with the smallest increase in intake of fiber (p trend <0.0001) independent of body weight at baseline, age, and changes in covariate status [70]. Women in the highest quintile of fiber intake had a significant 49% lower risk of major weight gain than women in the lowest quintile. In a US prospective study (252 women; mean baseline age 40 years, mean BMI 24; 20-month follow-up), each 1 g increase in fiber consumed significantly reduced weight by 0.25 kg and body fat by 0.25% [71]. Three long-term clinical trials (1–4 years) showed that consuming high-fiber diets >30 g fiber/day can effectively promote weight loss similar to reduced energy diet regimens [42, 72, 73]. Also, in a 12-week RCT, various combinations of fiber-rich diets with and without psyllium (>30 g/day) were significantly more effective in reducing body weight and improving body composition than lower-fiber diets (20 g/day) [74]. A systematic review of RCTs used for the 2015 US Dietary Guidelines Advisory Committee, found that after weight loss is achieved, healthy fiber-rich dietary patterns can slow weight regain to maintain a 4–10 kg weight loss after 1 year and 3–4 kg after 2 years [2]. Fiber supplements tend to be less effective in promoting satiety, reduced energy intake, or weight loss than healthy dietary patterns (≥30 g/fiber/day), in part because some physical property changes occur in processing and fiber supplements do not displace other high-energy-density foods [75].

Children and Adolescents

Several longitudinal studies consistently find that healthy dietary patterns or added fiber are associated with lower BMI and body fat in children and adolescents [76, 77]. A study of overweight Latino youth (85 adolescents; mean baseline age 14 years; 56% male; 2-year follow-up) found that adolescents who decreased total fiber intake (mean decrease of 3 g/1000 kcal) significantly increased visceral adipose tissue volume by 21% compared with those who had increased fiber intake (Fig. 2.3) [76]. A US longitudinal study (170 overweight/obese children; age 7–11 years; 16-week family-based behavioral weight loss study) found that decreased food away from home was associated with significantly improved diet quality (e.g., higher-fiber and lower-sugar and fat intake) and greater reductions in BMI

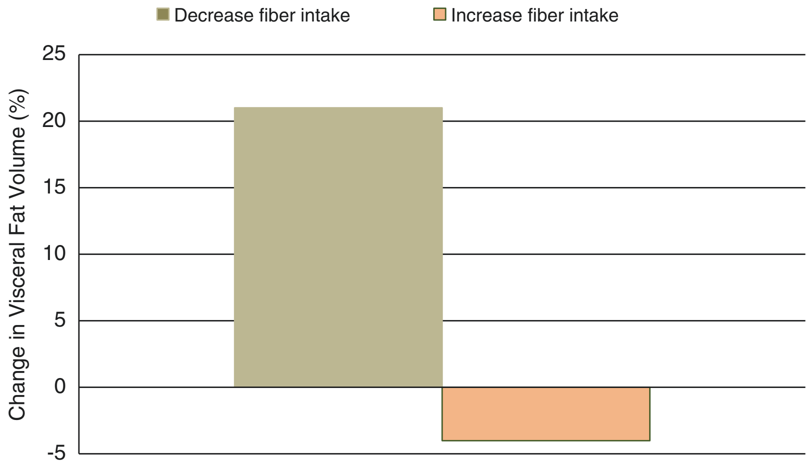

Fig. 2.3 Effect of change of fiber density by increasing or lowering fiber intake by 3 g/1000 kcal on visceral fat volume over 2 years in overweight Latino youth ($p = 0.02$) [76]

and percent body fat [77]. As fiber is a major shortfall "nutrient" in Western children and adolescent diets, these studies demonstrate the importance of healthy dietary patterns with adequate fiber in youth to prevent weight and abdominal fat gain or to promote weight loss in overweight or obese youth.

Chronic Disease Risk

Cardiovascular Disease (CVD)

A number of review articles conclude that adequate fiber intake significantly reduces the risk of CVD [3–9]. Several dose-response meta-analyses of prospective cohort studies suggest an inverse association between fiber intake and CVD risk with a 9–11% reduction per 7–10 g fiber increment/day [78, 79]. There is strong clinical evidence that healthy dietary patterns can significantly lower the CVD risk by 22–59% depending on the level of adherence [2]. In 2008, after thorough evaluation of the available data, the Academy of Nutrition and Dietetics Evidence Analysis Library Committee concluded that higher-fiber intakes may help to attenuate elevated serum lipid levels, blood pressure, and systemic inflammatory markers as key mechanisms to explain fiber's CVD protective properties [3]. The European Prospective Investigation of Cancer (EPIC) Norfolk cohort (22,915 participants; mean age 58 years; mean BMI 26) found fiber intake to be inversely associated with total cholesterol, LDL-C, and triglycerides and positively associated with HDL-C regardless of genetic profile such as APOE polymorphism [80].

Coronary Heart Disease (CHD)

The US Academy of Sciences, Institute of Medicine established the fiber adequate intake primarily based on fiber's effects on reducing coronary heart disease (CHD) risk [6]. Dose-response meta-analyses of prospective studies estimate that for each 10 g/day increment of fiber, there is decreased risk of all coronary events by 8–11% and CHD deaths by 24% [79, 81]. Numerous randomized trials have consistently demonstrated that intakes of ≥26–30 g total fiber/day from whole foods (including whole grains, especially oats and barley, fruit, vegetables, legumes, nuts) or ≥3–12 g isolated soluble, viscous fiber supplements/day (including oat/barley beta-glucan, psyllium, guar, or pectin) can lower LDL-C by 4–8% [31–35]. The National Cholesterol Education Program (Adult Treatment Panel III) recommends early treatment of hypercholesterolemic patients with high-fiber diets and soluble, viscous fiber supplements [82]. A large randomized, double-blind, placebo trial in Finnish men (21,930 smokers; aged 50–69 years; 6.1-year follow-up; 1,399 first nonfatal myocardial infarction cases and 635 coronary heart disease deaths) reported a 31% reduction in CHD risk (35 g vs. 16 g fiber/day), with cereal fiber having a stronger effect than vegetable or fruit fibers and soluble fiber being more effective than insoluble fiber [37]. Additionally, the 2015 US Dietary Guideline Advisory Committee Scientific analysis showed that healthy dietary patterns can significantly lower the CHD risk with the MedDiet by 29–61%, the US Dietary Guidelines pattern by 24–31%, and DASH diets by 14–27% [2].

Blood Pressure

Adequate fiber intake is associated with modestly lower blood pressure, especially in individuals with hypertension. Three meta-analyses of randomized trials report that increased fiber intake by 6–11.5 g/day can modestly lower pooled mean systolic blood pressure by 0.9–1.2 mm Hg and diastolic blood pressure by 0.7–1.7 mm Hg [30, 83, 84]. However, after stratification of subjects, blood pressure reductions were significantly greater in older (>40 years) and in hypertensive populations with reduced systolic blood pressure by 6 mm Hg and diastolic blood pressure by 4.2 mm Hg. Beta-glucan was found to be among the most effective blood pressure lowering fibers with 4 g/day lowering systolic blood pressure by 2.9 mm Hg and diastolic blood pressure by 1.5 mm Hg [30]. The 2015 US Dietary Guidelines Advisory Committee Scientific analysis concluded that healthy dietary patterns, especially the DASH-style diets, can significantly lower systolic blood pressure by 6 mm Hg and diastolic blood pressure by 3 mm Hg compared to Western patterns mainly because of the increased fiber, potassium and carotenoids, and lower saturated fat and sodium content [2].

Stroke

Adequate intake of fiber is associated with lower total stroke risk. Several meta-analyses of prospective studies consistently found an inverse dose-response relationship between fiber intake and stroke risk [85–88]. One meta-analysis (6 prospective studies; 314,864 subjects; 8–18 years of follow-up; 8,920 stroke events) reported a 12% reduction in stroke risk for each 10 g fiber/day [85]. Another meta-analysis of dietary patterns (21 prospective studies; 1,023,131 participants; age 34–79 years; cohorts from the USA, Europe, and Asia) showed a 17% lower stroke risk for the highest- vs. lowest-fiber intakes [87]. The 2015 US Dietary Guidelines Advisory Committee Scientific analysis found that healthy dietary patterns such as the MedDiet and US Dietary Guidelines patterns can significantly lower stroke risk by13–60%, depending on the level of adherence [2].

Type 2 Diabetes (Diabetes)

Adequate intake of fiber, particularly with low-glycemic foods, is associated with a lower incidence of diabetes. A dose-response meta-analysis (17 prospective studies; 488,293 participants; 4–14 years of follow-up; 19,033 diabetes cases) found a significant nonlinear inverse association between total fiber intake and diabetes risk with intake below 25 g fiber/day and a linear reduction

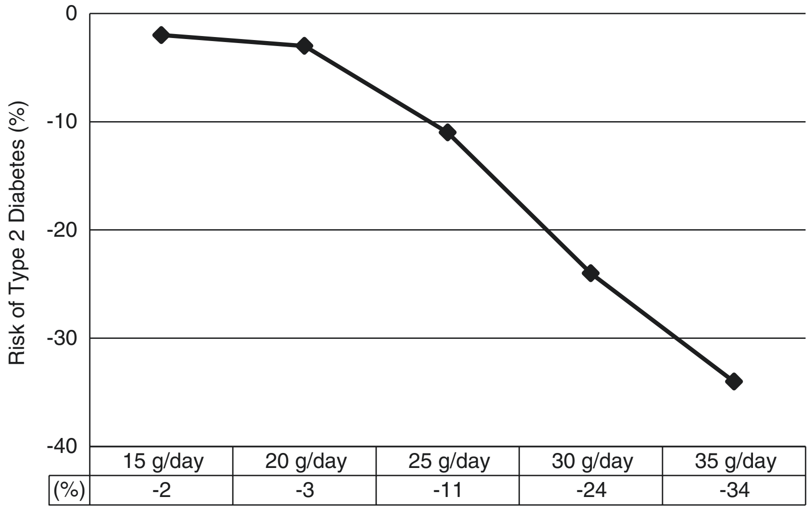

Fig. 2.4 Effect of increasing fiber intake on type 2 diabetes risk from a dose-response meta-analysis of 17 prospective cohort studies (p for nonlinearity <0.01) [15]

in risk above 25 g fiber/day (Fig. 2.4) [15]. This analysis also found that the risk of diabetes decreased with cereal fiber, fruit fiber, and insoluble fiber intake. The InterAct study meta-analysis (19 cohort studies; 617,968 participants; age 21–79 years; 4–16 years of follow-up; 41,066 diabetes cases) reported a diabetes risk reduction per 10 g fiber/day increase in total fiber by 9%, cereal fiber by 25%, fruit fiber by 5%, and vegetable fiber by 7%. The overall evidence indicates that the intake of total and cereal fiber is significantly inversely related to the risk of diabetes [89]. The EPIC-InterAct Study (26,088 participants; mean baseline age 52 years; 10.8 years of follow-up; 11,559 participants with diabetes) reported that fiber intake of 26.5 g/day was associated with a significant 18% lower risk of diabetes vs. 19 g fiber/day, after multivariate adjustments [89]. A Finnish Diabetes Prevention Trial (522 middle-aged, overweight subjects; 172 men and 350 women; mean age 55 years; mean BMI 31; 3 years) showed that a comprehensive lifestyle program with 15 g fiber/1000 kcal, exercise, and 5% weight loss significantly lowered diabetes risk by 58% over 3 years [90]. A pooled analysis of three large US cohort studies suggests that diets high in glycemic index or glycemic load foods and low in cereal fiber (refined carbohydrates) are associated with a significantly higher risk of diabetes [91]. The 2015 US Dietary Guidelines Advisory Committee Scientific Report analysis showed that healthy dietary patterns significantly lower the risk of developing diabetes by 21% compared to a 44% increased risk seen with a low-fiber Western-type diet [2]. The association between fiber and diabetes is partially explained by fiber's effect on reducing the risk of body weight gain and obesity [90].

Cancer

Fiber was hypothesized to reduce cancer risk, especially colorectal cancer, in the early1970s based on data showing lower rates of colorectal cancer among Africans who consumed a traditional diet high in fiber compared to those with an urban Western diet [92]. There are a number of postulated fiber anticancer mechanisms affecting the initiation and/or progression of cancer, such as the effects of SCFAs on colon pH, butyrate's control of cell division rates, and fiber effects on reducing obesity risk and associated metabolic and signaling changes related to cancer risk [3, 93–95].

Colorectal Cancer

Adequate fiber intake is associated with a reduced risk of colorectal cancer. In 2011, the World Cancer Research Fund (WCRF) and American Institute of Cancer Research (AICR) Continuous Update report concluded that there is convincing evidence that fiber-rich diets are protective against the risk of colorectal cancer [96]. A dose-response meta-analysis (16 prospective studies; 1,985,552 participants; 4.5–26 years of follow-up; 14,514 colorectal cancer cases) found a significantly lower colorectal cancer risk by 10% for each 10 g/day intake of total fiber and cereal fiber and a 17% reduction for each three servings (90 g/day) of whole grain daily with further reductions at higher intake [17]. The EPIC cohort study (477,312 EU participants; mean age 51 years; 30% men; women 43% postmenopausal; mean BMI for men 26 and for women 25; mean follow-up of 11 years, 4517 colorectal cancer cases) observed an inverse association between total fiber intake and colorectal risk with10 g/day increase in fiber reducing colorectal cancer by 13% (Fig. 2.5) [97]. Similar linear associations were observed for colon and rectal cancers. The US Prostate, Lung, Colorectal, and Ovarian Cancer Screening Trial (57,774 adults; mean age 62 years; flexible sigmoidoscopy at baseline and 3 or 5 years) found that those consuming ≥12.8 g fiber/1000 kcal had a significantly lower risk of any incident distal colorectal adenoma or rectal adenoma by 24% compared to those consuming <9.9 g fiber/1000 kcal with cereal and fruit fiber sources being the most effective, after adjusting for potential confounders [98]. Although the association was not statistically significant for colorectal cancer overall (15% risk reduction; p-trend = 0.10), a reduced risk of distal colon cancer was observed with increased total fiber intake (38% risk reduction; p-trend = 0.03). A Cochrane systematic review of five RCTs lasting 2–4 years reported that total fiber had insignificant effects on colorectal adenoma

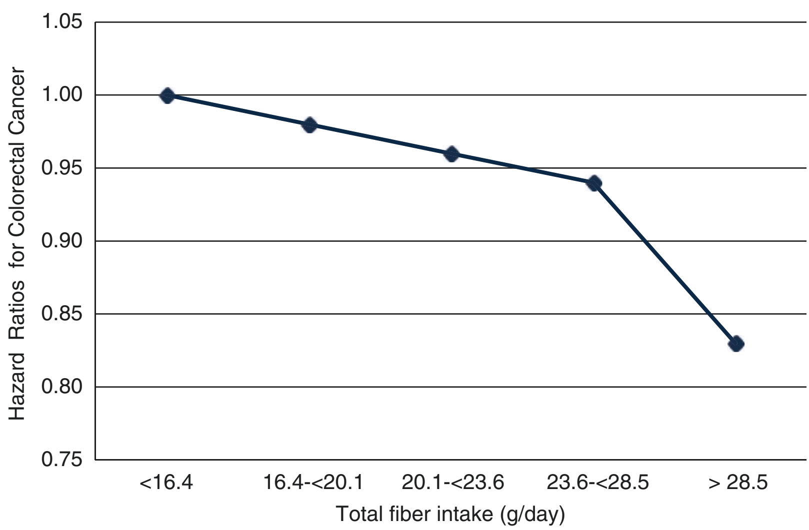

Fig. 2.5 Effect of increasing fiber intake on colorectal cancer risk in adults (mean age 52 years) followed for 11 years (p-trend ≤0.017, multivariate adjusted) [97]

recurrence [99], which is thought to be a result of short study duration and dietary compliance issues [100]. A large North American cohort trial (96,354 Seventh-Day Adventist adults) found that vegetarian diets reduced overall colorectal cancer risk by 22% compared to nonvegetarian diets [101].

Breast Cancer

The 2014 Continuous Update of the World Cancer Research Fund and American Institute for Cancer Research (WCRF and AICR) found a limited-suggestive consistent significant inverse association between consumption of foods rich in fiber by women before or ≥12 months after diagnosis for primary breast cancer and risk of all-cause mortality [102]. Although the 2017 WCRF and AICR Continuous Update Project Report found the relationship between fiber and breast cancer to be inconclusive [103], several subsequent meta-analyses of prospective studies show modest but significant reduction in breast cancer risk of 5–7% for each approximately 10 g/day increase in fiber intake [16, 104]. An EPIC prospective study (334,849 women; mean age 50 years; 11.5 years of median follow-up; 11,576 breast cancer cases) found significantly reduced breast cancer risk by 5% for intakes of total fiber and fiber from non-starchy vegetables by 10% but not with fiber from fruit, cereals, or legumes. For vegetable fiber, stronger significant associations were observed for estrogen receptor-negative and progesterone receptor-negative tumors by 26% than for estrogen receptor-positive and progesterone receptor-positive tumors with a reduced risk by 8% at higher vs. lower intake [105]. The Nurses' Health study II (90,534 premenopausal women; mean age 36 years; 20-year follow-up; 2,833 invasive breast cancer cases) suggests that adequate fiber intake during adolescence and early adulthood may be particularly protective against breast cancer risk with the risk of breast cancer reduced by 25% at higher vs. lower intake [106]. Fiber-rich, healthy dietary patterns are associated with moderate reduced risk of postmenopausal breast cancer, but the evidence for premenopausal breast cancer risk is more limited and inconclusive at this time [2]. Several proposed mechanisms for fiber's protective effect include the sequestration of estrogen in the digestive system and reduction of β-glucuronidase activity in the colon resulting in increased estrogen excretion in the feces [105].

Other Cancers

Two additional cancers that may be affected by adequate fiber intake are prostate and gastric cancer. The 2014 WCRF and AICR continuous update report concluded that there is no or limited evidence that increased fiber intake is directly protective against the risk of prostate cancer [107]. However, the Physicians' Health Study (926 men diagnosed with nonmetastatic prostate cancer; diet questionnaires for a median of 5.1 years after diagnosis; followed for 10 years) suggests that a low-fiber, Western dietary pattern was associated with higher prostate cancer-specific and all-cause mortality, and a high-fiber prudent dietary pattern was associated with lower all-cause mortality (Fig. 2.6) [108]. A meta-analysis (19 case-control and 2 cohort studies; 580,064 subjects) reported that fiber had a significant inverse dose-response effect on gastric cancer risk with a reduction of 44% for each 10 g increased fiber consumed daily [109].

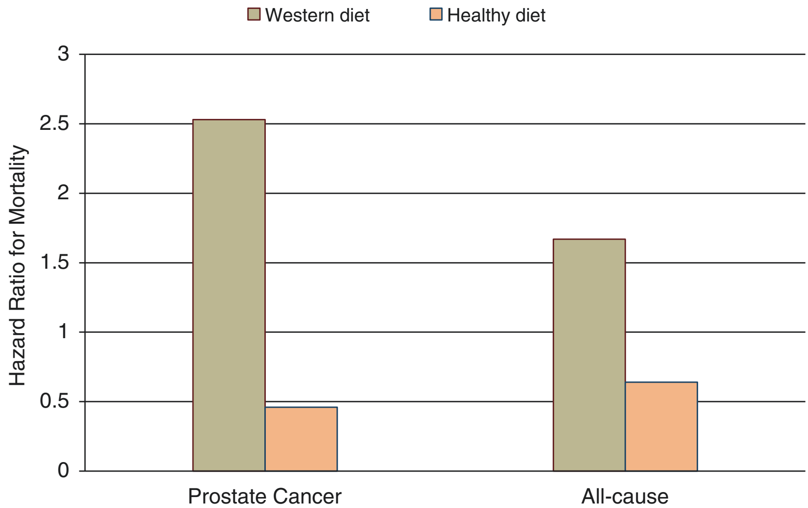

Fig. 2.6 Effect of a high prudent (healthy) vs. Western dietary pattern score on post-diagnosis prostate cancer specific and all-cause mortality risk over 10 years (*p*-trends ≤0.02; multivariate adjusted) [108]

Healthy Aging

The consumption of healthy dietary patterns in midlife (45–65 years) that provide adequate micronutrients, fiber, and antioxidants while controlling energy intake can promote healthy aging defined as (1) staying free of premature major chronic diseases, (2) maintaining good physical and cognitive function with no limitations in core activities of daily living, (3) experiencing no serious depressive symptoms, and (4) having good overall self-perceived health. A prospective study of French midlife adults (2,796 participants; mean age 52 years; 13 years of follow-up) observed that individuals consuming moderate energy healthy dietary patterns (≤2,500 kcal/day in men and ≤1,820 kcal/day in women) had significantly improved odds of healthy aging by 46%, and those consuming above this energy target had an insignificant 7% improved odds of healthy aging [110]. In an exploratory study, individuals with higher-fiber intake were significantly better at controlling caloric intake, which translated into lower BMI and more dietary satisfaction [111]. A number of intervention trials and cohort studies suggest that fiber-rich diets can significantly lower systemic inflammation, which is an important factor in the aging process (inflammaging) [38, 40, 41, 112]. Several longitudinal studies and an intervention trial have suggested that fiber-rich diets can significantly reduce periodontal disease markers [113–115]. In a cross-sectional analysis of the Nurses' Health Study (2,284 women; mean age 59 years; mean BMI 26; 87% postmenopausal), waist circumference was negatively associated and fiber was positively associated with leukocyte telomere length with a significant increase in telomere length by 0.19 units between the extremes of fiber intake, after multivariate adjustment [43]. Several review articles suggest that SCFAs from the fermentation of fibers by colonic microbiota can reduce the inflammaging processes by target signaling modifications in physiological functions, epigenetic changes involved in alterations in DNA methylation patterns, posttranslational modification of histones, and chromatin remodeling which represent important emerging avenues for healthy aging research [116, 117]. The Australian Blue Mountains Eye Study (1,609 adults; aged 49 years and older;

free of cancer, coronary artery disease, and stroke; followed for 10 years) observed that subjects with the highest vs. lowest intake of total fiber intake had a 79% increased odds of aging successfully, multivariate-adjusted [118]. These findings suggest that increasing intake of fiber-rich foods could be a successful strategy for reaching old age disease free and fully functional.

Longer Life Expectancy

Prospective studies suggest that healthy dietary patterns improve the odds of longer life expectancy [119]. A number of studies suggest that adequate fiber intake has an independent role in reducing risk of all-cause and disease-specific mortality. The Nurses' Health Study (72,113 women; mean age 50 years; mean BMI 25; 18 years of follow-up; 6,011 deaths occurred, including 1,154 cardiovascular deaths and 3,139 cancer deaths) observed that women with higher prudent diet scores and adequate fiber intake had significantly lower all-cause mortality risk by 17%, whereas women with higher Western diet scores and low-fiber intake had significantly higher all-cause mortality risk by 21%, after multivariate adjustments (Fig. 2.7) [120]. A meta-analysis (25 cohort studies; 1,752,848 midlife individuals; average 12.4 years of follow-up) suggests that fiber is inversely associated with mortality risk (Fig. 2.8) [121]. The large US National Institutes of Health (NIH)-AARP Diet and Health Study (567,169 men and women; mean age 62; mean BMI 27; 9 years of follow-up; 20,126 deaths in men and 11,330 deaths in women) found that increased fiber intake by 15 g/day significantly reduced all-cause mortality rates by 22% in both men and women and CVD mortality in men by 24% and women by 34% (multivariate adjusted) [122]. Also, an inverse association between fiber intake and cancer death was observed in men, but not in women. Similarly, an EPIC prospective study (452,717 men and women; mean age 51 years; mean BMI 25.5; mean 12.7 years of follow-up; 23,583 deaths) found an inverse association with total mortality and circulatory mortality risk with a 10% reduction in risk per 10 g fiber/day [123].

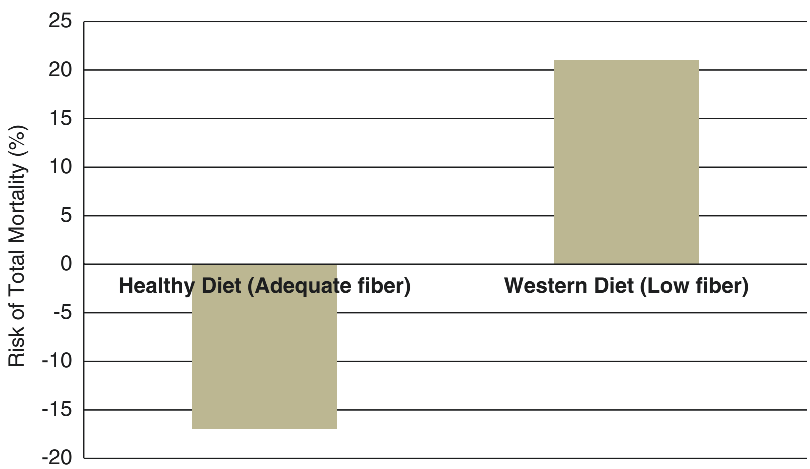

Fig. 2.7 Effect of a prudent (healthy) or Western dietary pattern type on total mortality of women in midlife (45–65 years) over an 18-year follow-up from the Nurses' Health Study (p-trend <0.001) [120]

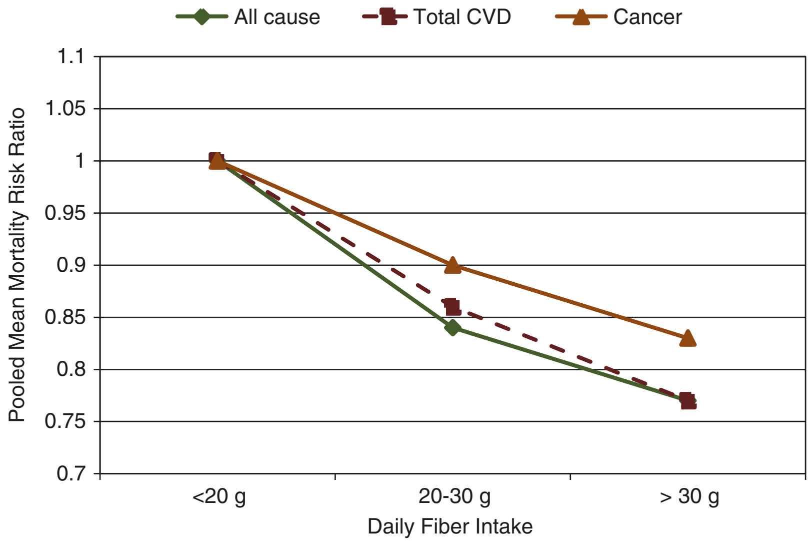

Fig. 2.8 Effect of daily fiber intake and all-cause, total cardiovascular disease (CVD), and cancer mortality risks from a meta-analysis of 25 prospective cohort studies [121]

Conclusions

Low fiber intake is a major public health concern as the scientific literature shows strong associations with increased risk of weight gain and obesity, chronic disease, and premature aging and mortality. Health effects associated with adequate fiber intake include slowing the eating process and reducing food metabolizable energy for better body weight regulation, stimulating laxation and healthy colonic microbiota (including lower colorectal cancer risk), attenuating elevated blood lipids and blood pressure for cardiometabolic health, and increasing insulin sensitivity and lowering systemic inflammation to reduce diabetes and premature aging risk (inflammaging). Fiber-rich foods are also typically lower in energy density, saturated and trans-fatty acids, sodium, and sugar, which supports better health and weight control, especially when displacing high energy-dense and low-nutrient-quality foods in Western diets. High-viscosity, gel-forming fibers consumed in either fiber-rich whole or minimally processed plant foods or as supplements tend to have similar effects on attenuating postprandial glycemic response, improving blood lipid profiles, and promoting laxation. However, fiber supplements tend to be less effective than fiber-rich foods at supporting weight loss since they typically do not directly displace higher energy-dense foods. Increased fiber intake is consistently associated with better health, reduced chronic disease risk, and healthy aging even when initiated in mid-life (ages 45–65 years).

Appendix 1. Fifty High-Fiber Whole or Minimally Processed Plant Foods Ranked by Amount of Fiber Per Standard Food Portion[a]

Food	Standard portion size	Dietary fiber (g)	Calories (kcal)	Energy density (calories/g)
High-fiber bran ready-to-eat cereal	1/3–3/4 cup (30 g)	9.1–14.3	60–80	2.0–2.6
Navy beans, cooked	1/2 cup cooked (90 g)	9.6	127	1.4
Small white beans, cooked	1/2 cup (90 g)	9.3	127	1.4
Shredded wheat ready-to-eat cereal	1–1 1/4 cup (50–60 g)	5.0–9.0	155–220	3.2–3.7
Black bean soup, canned	1/2 cup (130 g)	8.8	117	0.9
French beans, cooked	1/2 cup (90 g)	8.3	114	1.3
Split peas, cooked	1/2 cup (100 g)	8.2	114	1.2
Chickpeas (garbanzo) beans, canned	1/2 cup (120 g)	8.1	176	1.4
Lentils, cooked	1/2 cup (100 g)	7.8	115	1.2
Pinto beans, cooked	1/2 cup (90 g)	7.7	122	1.4
Black beans, cooked	1/2 cup (90 g)	7.5	114	1.3
Artichoke, global or French, cooked	1/2 cup (84 g)	7.2	45	0.5
Lima beans, cooked	1/2 cup (90 g)	6.6	108	1.2
White beans, canned	1/2 cup (130 g)	6.3	149	1.1
Wheat bran flakes ready-to-eat cereal	3/4 cup (30 g)	4.9–5.5	90–98	3.1–3.3
Pear with skin	1 medium (180 g)	5.5	100	0.6
Pumpkin seeds, whole, roasted	1 ounce (about 28 g)	5.3	126	4.5
Baked beans, canned, plain	1/2 cup (125 g)	5.2	120	0.9
Soybeans, cooked	1/2 cup (90 g)	5.2	150	1.7
Plain rye wafer crackers	2 wafers (22 g)	5.0	73	3.3
Avocado, Hass	1/2 fruit (68 g)	4.6	114	1.7
Apple, with skin	1 medium (180 g)	4.4	95	0.5
Green peas, cooked (fresh, frozen, canned)	1/2 cup (80 g)	3.5–4.4	59–67	0.7–0.8
Refried beans, canned	1/2 cup (120 g)	4.4	107	0.9
Mixed vegetables, cooked from frozen	1/2 cup (45 g)	4.0	59	1.3
Raspberries	1/2 cup (65 g)	3.8	32	0.5
Blackberries	1/2 cup (65 g)	3.8	31	0.4
Collards, cooked	1/2 cup (95 g)	3.8	32	0.3
Soybeans, green, cooked	1/2 cup (75 g)	3.8	127	1.4
Prunes, pitted, stewed	1/2 cup (125 g)	3.8	133	1.1
Sweet potato, baked	1 medium (114 g)	3.8	103	0.9
Multigrain bread	2 slices regular (52 g)	3.8	140	2.7
Figs, dried	1/4 cup (about 38 g)	3.7	93	2.5
Potato baked, with skin	1 medium (173 g)	3.6	163	0.9
Popcorn, air-popped	3 cups (24 g)	3.5	93	3.9
Almonds	1 ounce (about 28 g)	3.5	164	5.8

(continued)

Appendix 1 (continued)

Food	Standard portion size	Dietary fiber (g)	Calories (kcal)	Energy density (calories/g)
Whole wheat spaghetti, cooked	1/2 cup (70 g)	3.2	87	1.2
Sunflower seed kernels, dry roasted	1 ounce (about 28 g)	3.1	165	5.8
Orange	1 medium (130 g)	3.1	69	0.5
Banana	1 medium (118 g)	3.1	105	0.9
Oat bran muffin	1 small (66 g)	3.0	178	2.7
Vegetable soup	1 cup (245 g)	2.9	91	0.4
Dates	1/4 cup (about 38 g)	2.9	104	2.8
Pistachios, dry roasted	1 ounce (about 28 g)	2.8	161	5.7
Hazelnuts or filberts	1 ounce (about 28 g)	2.7	178	6.3
Peanuts, oil roasted	1 ounce (about 28 g)	2.7	170	6.0
Quinoa, cooked	1/2 cup (90 g)	2.7	92	1.0
Broccoli, cooked	1/2 cup (78 g)	2.6	27	0.3
Potato baked, without skin	1 medium (145 g)	2.3	145	1.0
Baby spinach leaves	3 ounces (90 g)	2.1	20	0.2
Blueberries	1/2 cup (74 g)	1.8	42	0.6
Carrot, raw or cooked	1 medium (60 g)	1.7	25	0.4

[a]Dietary Guidelines Advisory Committee. Scientific Report of the 2010 Advisory Guidelines Advisory Report to the Secretary of Health and Human Services and the Secretary of Agriculture. Part B. Section 2: Total Diet. 2010; Table B2.4

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Appendix 2. Estimated Range of Energy, Fiber, Nutrients, and Phytochemicals Composition of Whole or Minimally Processed Foods/100 g Edible Portion[a,b]

Components	Whole grains	Fresh fruit	Dried fruit	Vegetables	Legumes	Nuts/seeds
Nutrients and phytochemicals	Wheat, oats, barley, brown rice, whole grain bread, cereal, pasta, rolls, and crackers	Apples, pears, bananas, grapes, oranges, blueberries, strawberries, and avocados	Dates, dried figs, apricots, cranberries, raisins, and prunes	Potatoes, spinach, carrots, peppers, lettuce, green beans, cabbage, onions, cucumber, cauliflower, mushrooms, and broccoli	Lentils, chickpeas, split peas, black beans, pinto beans, and soy beans	Almonds, Brazil nuts, cashews, hazelnuts, macadamias, pecans, walnuts, peanuts, sunflower seeds, and flaxseed
Energy (kcal)	110–350	30–170	240–310	10–115	85–170	520–700
Protein (g)	2.5–16	0.5–2.0	0.1–3.4	0.2–5.0	5.0–17	7.8–24

Appendix 2 (continued)

Components	Whole grains	Fresh fruit	Dried fruit	Vegetables	Legumes	Nuts/seeds
Available carbohydrate (g)	23–77	1.0–25	64–82	0.2–25	10–27	12–33
Fiber (g)	3.5–18	2.0–7.0	5.7–10	1.2–9.5	5.0–11	3.0–27
Total fat (g)	0.9–6.5	0.0–15	0.4–1.4	0.2–1.5	0.2–9.0	46–76
SFA[a] (g)	0.2–1.0	0.0–2.1	0.0	0.0–0.1	0.1–1.3	4.0–12
MUFA[a] (g)	0.2–2.0	0.0–9.8	0.0–0.2	0.1–1.0	0.1–2.0	9.0–60
PUFA[a] (g)	0.3–2.5	0.0–1.8	0.0–0.7	0.0.0.4	0.1–5.0	1.5–47
Folate (ug)	4.0–44	<5.0–61	2–20	8.0–160	50–210	10–230
Tocopherols (mg)	0.1–3.0	0.1–1.0	0.1–4.5	0.0–1.7	0.0–1.0	1.0–35
Potassium (mg)	40–720	60–500	40–1160	100–680	200–520	360–1050
Calcium (mg)	7.0–50	3.0–25	10–160	5.0–200	20–100	20–265
Magnesium (mg)	40–160	3.0–30	5.0–70	3.0–80	40–90	120–400
Phytosterols (mg)	30–90	1.0–83	N/A	1.0–54	110–120	70–215
Polyphenols (mg)	70–100	50–800	N/A	24–1250	120–6500	130–1820
Carotenoids (ug)	N/A	25–6600	0.6–2160	10–20,000	50–600	0.0–1200

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[a]SFA (saturated fat), MUFA (monounsaturated fat), and PUFA (polyunsaturated fat)

[b]U.S. Department of Agriculture, Agriculture Research Service, Nutrient Data Laboratory. 2014. USDA National Nutrient Database for Standard Reference, Release 27. http://www.ars. usda.gov./nutrientdata. Accessed 17 February 2015

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