Review Article
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Role of fiber and healthy dietary patterns in body weight regulation and weight loss

Abstract

This review provides a comprehensive assessment of the human studies and mechanisms related to the role of dietary fiber (fiber) and dietary patterns in body weight regulation and weight loss. Fiber is one of the most under-consumed healthy food components in the western diet. Typical intakes are about one half of the recommended level, which contributes to a daily positive energy balance and increased risk of significant weight gain overtime. Prospective studies consistently find that populations consuming higher fiber dense diets rich in whole grains, fruit, vegetables, pulses, and/or nuts are leaner than those that eat lower fiber diets. A number of randomized trials show that fiber-rich whole-food diets containing ≥30g fiber/day, as a replacement for higher energy dense and lower fiber diets, can promote weight loss and reduce the risk or rate of weight regain in overweight or obese individuals. High adherence to a variety of healthy fiber-rich dietary patterns including the US Dietary Guidelines, Dietary Approaches to Stop Hypertension (DASH), Mediterranean (MedDiet), or healthy vegetarian diets can improve body weight regulation and achieve weight loss compared to the western or other control diets. In general, fiber-rich diets are more effective at promoting weight loss than are fiber supplements. There are a number of unique fiber and fiber-rich food related mechanisms that can help to improve weight regulation and weight loss overtime.

Keywords: sweight gain, weight loss, energy density, satiety, dietary guidelines, dietary approaches to stop hypertension (dash) diet, mediterranean diet (MedDiet), vegetarian diet, short chain fatty acids, metabolizable energy, energy metabolism

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Abbreviations: BMI, body mass index; EFSA, european food safety authority; FFAR, free fatty acid receptors; SCFAs, short chain fatty acids, AHA, american heart association; EPIC, european prospective investigation in to cancer and nutrition

Introduction

The worldwide overweight and obesity pandemic is among the greatest public health challenges of our time.[1,2] From 1980 through 2013, the global prevalence of overweight and obesity increased by 28% for adults and 47% for children, resulting in an increase from about 850 million overweight or obese people in 1980 to over 2 billion in 2013.[2] Elevated body mass index (BMI) or excessive adiposity in adulthood and increasingly in childhood is a growing risk factor for major chronic diseases such as diabetes, cardiovascular disease, non-alcoholic fatty liver disease, chronic kidney disease, and a number of obesity related cancers.[3–12] It is estimated that about 300,000 premature adult deaths each year are directly attributable to overweight or obesity in the US.[13]

Individuals generally don't take notice of weight gain until substantial weight gain has occurred. In recent decades, there has been a global increased exposure to higher energy dense foods that are low in fiber. This has been combined with an increasingly sedentary lifestyle including less physically active forms of work, changing modes of transportation, increasing urbanization, and easier access to information and services, leading to a net habitual positive energy balance and weight gain overtime.[8–10] A small daily positive energy balance of 50kcals/day, by increased energy intake and/or reduced activity can lead to an annual weight gain of 0.4 to 0.9kg/year.[11–13] Further, a higher habitual intake of 200kcal/day above energy balance in overweight or obese women may increase weight gain by as much as 9kg/year.[14] Energy dense diets, common in the Western diet, are positively associated with higher BMI and risk of obesity.[15–19] Moreover, since people tend to eat approximately the same amount or volume of food on a day-to-day basis, regardless of the food energy density, the common advise of just eating less of all foods may not be the optimal approach for weight management.[13] However, fiber-rich foods have properties that can help foster the type of negative energy balance needed for improved weight control and loss. The objective of this review is to provide a comprehensive assessment of the human studies and mechanisms related to the role of fiber and dietary patterns in body weight regulation and weight loss.

Fiber in weight loss and maintenance

Overview

The human gastrointestinal and energy regulatory systems evolved over most of the last 40,000years or so on diets with 50g or more fiber per day.[20] These high fiber diets are in sharp contrast to the present low fiber, high energy dense Western diets, a relatively recent occurrence in human evolution. These ancestral fiber-rich whole foods diets stimulated the evolution of important colon mechanisms to increase levels of satiation (the process that terminates eating) and satiety (the process that inhibits further eating after a meal has been finished) to help promote energy balance and weight stability (along with physical activity).[21] About 95% of Americans do not consume an adequate level of fiber daily, 14g fiber/1,000kcals or 25g/day for women and 38g/day for men.[22,23] In the US, the mean fiber intake is about 16g/day, which is about half the recommended level.[24] Also, in the EU the recommended fiber intake for adults is >25g fiber /day (from whole-

grain cereals, fruit, and vegetables) with a majority of the population consuming less than this fiber level.[25]

Weight loss

Two common dietary approaches for weight loss include: (1) reducing daily energy intake by 20-35% for a negative energy balance or (2) eating lower energy dense and fiber-rich foods instead of higher energy dense and low fiber foods to reduce dietary energy density, hunger, and total energy intake.[26–28] In a randomized trial with obese adults with metabolic syndrome, it was shown that those who simply consumed a high fiber diet had similar weight loss to those on a more complex multi-component, hypocaloric diet plan after one year.[29]

Weight maintenance

For overweight or obese individuals who successfully lose weight, as many as 80% typically drift back to their original weight or more.[25,30] This is because after weight loss there are an array of metabolic regulatory processes at work to promote weight regain so it is difficult to maintain weight loss.[28] After fat loss, thermogenesis reduces, and leads to fat loss resistance. Also, a drop in hormone levels, such as leptin and thyroid hormones, causes the risk of increased energy intake after weight loss. In this period, adipocytes face cellular stress associated with the physical forces that arise within the shrinking cells, causing them to actively promote renewed fat storage. The determinants of weight maintenance are genetics, behavior, and environment with diet behavior thought to be the most important factor that influences weight regain, as weight loss triggers strong overeating signals sent to the brain's hypothalamus to increase appetite.[21] A cross-sectional study of weight loss maintainers who lost >10% of their body weight and maintained that loss for ≥5years reported that they consumed a diet with lower energy density (1.4kcal/g) than the weight regain individuals (1.8kcal/g).[30] These weight maintainers consumed more fiber-rich foods such as vegetables (4.9 servings/day) and whole-grain products (2.2 servings/day) compared to less than 1 daily serving of vegetables and whole grains for the weight regainers.[30] In addition to eating a low energy dense and high fiber diet, successful long-term weight loss maintenance is associated with 5 additional strategies to help counteract weight regain metabolic processes: (1) engaging in physical activity; (2) eating breakfast; (3) self-monitoring weight on a regular basis; (4) limiting consumption of higher energy dense foods; and (5) catching dietary "miss-steps" before they turn into a habit.[26,30,31]

Fiber: human studies

Fiber-rich foods: Populations with higher fiber diets tend to be leaner than those with low fiber diets.[32–35] A systematic review of 43 prospective cohort, case-control and randomized trials found moderately strong evidence that fiber-rich foods have a protective role against weight gain and increased waist size.[34] In 2010, the European Food Safety Authority (EFSA) recommended that adults should consume >25g fiber per day (from whole-grain cereals, fruit, and vegetables) to improve weight maintenance and sustain weight reduction in overweight and obese individuals.[25]

Prospective studies: Prospective cohort studies generally support an inverse relationship between fiber intake from foods and body weight, BMI, body fatness or waist size as summarized in Table 1.[35–43] These studies suggest that doubling fiber density from about 6-9g fiber/1,000kcals to 11-14g fiber/1,000kcals or the intake of >25g fiber/day from whole plant foods helps to prevent weight gain and/or promote modest weight loss. Increasing fiber intake by ≥10-12g fiber/day, especially as a replacement for refined low fiber foods, can have a significant effect on improved weight control[36,37,43] and increasing fiber intake by 20g/day may promote long-term weight loss.[38] Also, a dietary pattern characterized by high-fiber foods, such as breakfast cereals, fruits and vegetables and low-fat food choices, was significantly associated with prevention of excess body weight gain.[39] Children may be extra responsive to the effects of low fiber dense diets in body weight and fat gain, especially for visceral fat.[41]

Table 1 Prospective studies on the role of fiber and fiber-rich diets in body weight regulation and weight loss

Study	Method	Results
The Coronary Artery Risk Development in Young Adults (CARDIA) Study[35]	This US prospective study included about 3,000 healthy black and white adults between 18 to 30years of age at baseline. The effects of fiber on weight gain and cardiovascular disease were evaluated after a 10year follow-up.	Fiber density was significantly inversely associated with body weight and waist-to-hip ratio in both white and black adults with an approximate doubling of the fiber intake (Q-5 [>10.5g fiber/1,000kcal] vs Q-1 [<5.9g fiber/1,000kcal]).
Nurses' Health Study[36]	This US prospective cohort analysis included 74,000 female nurses, aged 38-63years at baseline who were followed for 12years for changes in body weight.	Weight gain was inversely associated with fiber and whole-grain food intake and positively related to refined-grain food intake. With an approximate doubling of the fiber intake there was a 49% lower risk of weight gain or 1.5kg less weight gain than those on lower fiber diets, independent of body weight at baseline, age, and changes in covariate status.
Health Professionals' Follow-up Study - lifestyle and waist size[37]	This US prospective cohort was comprised of 16,587 men aged 40-75years at baseline who were evaluated for the effect of fiber intake and lifestyle on their waist size over a 9year follow-up period	An increase of 12g total fiber/day was associated with a significant 0.6cm decrease in waist size, whereas a 20-h/wk increase in television watching was associated with a significant 0.6-cm waist gain. Also, increases in vigorous physical activity and in weight training were associated with significant 0.4cm and 0.9cm decreases in waist size, respectively.
Health Professionals Follow-up Study - Fiber[38]	This US prospective analysis included 27,000 men aged 40 to 75years to assess the associations between changes in fiber and whole-grain intake on weight gain among US men over an 8year follow-up.	Total fiber was inversely related to weight gain independent of whole grains. For every 20g/day increase in total fiber, weight gain was reduced by 5.5kg (multivariate adjusted). Cereal and fruit fiber, and added bran were also associated with significant weight loss.

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Table Continued....

Study	Method	Results
Dietary Patterns[39]	This German prospective analysis included 25,000 men and women as part of the European Prospective Investigation into Cancer and Nutrition (EPIC) -Potsdam cohort over 4years of follow-up periods to determine dietary patterns predictive of weight change.	A dietary pattern characterized by high-fiber, whole-grain foods such as breakfast cereals, fruits and vegetables and low-fat food choices, was significantly associated with prevention of excess body weight gain (Q-5 [13.5g fiber/1,000 kcal] vs Q-1 [8.8g fiber/1,000 kcal]).
Weight and Fat Gain in Women[40]	This US prospective analysis included 252 women with a follow-up of 20 months. Diet was measured using 7-day food records. Body fat was assessed by the Bod Pod and physical activity was measured using accelerometers over 7 consecutive days.	For each 1g fiber/1,000kcal increase in fiber intake there was a significant decrease in body weight and fat by 0.25kg and 0.25%, respectively. After adjustment for energy intake, the values were alternated by 33% but the value still retained significance.
Visceral Fat in Latino Children[41]	Overweight Latino youths (n=85; aged 11–17y) underwent the following measures over 2years: dietary intake by 2-day diet recalls, body composition by dual-energy X-ray absorptiometry and magnetic resonance imaging.	A reduction in fiber intake by 3 g/1,000kcals significantly increased visceral fat by 21% compared to an increase of 3g fiber/1,000kcals which reduced visceral fat by 4% over 2years.
Waist Size in Adults[42]	This prospective analysis including 48,631 men and women from 5 countries participating in the EPIC study evaluated anthropometric measurements over a median follow-up time of 5.5years.	Diets with a higher energy density (ED) by 1kcal/g) and glycemic index (GI) by 10 units were significantly associated with increased waist size, by up to 0.15cm and 0.06cm, respectively. In contrast, an increase of 10g fiber/day by women, significantly reduced waist size by 0.06cm.
Body Weight and Waist Size[43]	In this European prospective analysis 89,432 men and women as part of the EPIC study, were followed for an average of 6.5years. Dietary information was collected by using validated country-specific food-frequency questionnaires.	There were small but statistically significant inverse associations of total and cereal fiber intake w/ changes in both weight and waist size and of fruit and vegetable fiber w/ changes in waist size, but not in weight. Per 10g/day increased intake: (1) total fiber reduced body weight by 39g/year and waist size by 0.08cm/year and (2) cereal fiber intake reduced body weight by 77g/year and waist size by 0.10cm/year.

Randomized trials: In a comprehensive review of clinical studies, it was reported that increasing fiber intake by 14g fiber/day in overweight or obese individuals, with *ad libitum* energy intake, was associated with a mean 10% decrease in energy intake and a reduction of weight by 1.9kg after 4months.[44] Randomized trials of *ad libitum* fiber-rich diets showed diets with ≥ 30g fiber/day can help to prevent weight gain and promote sustained weight loss compared with <20g fiber/day diets[29,45–50] (Table 2). One large randomized trial found that a high fiber diet (goal to consume >30g fiber/day) was as effective as a reduced energy weight loss plan in promoting weight loss over 1year.[29] In order to consume ≥30g fiber/day, individuals consuming the usual western diet need to double their fiber intake (or add about 15g fiber/day) and this could be accomplished by the daily substitution of one fiber-rich food for a lower fiber, energy dense food at each meal and one snack. Examples of potential food switches might include: (1) replacing a low fiber, high glycemic breakfast cereal with a fiber-rich bran, low glycemic breakfast cereal ; (2) eating an apple instead of a cookie at lunch; (3) adding artichokes or chickpeas to a salad; and (4) snacking on nuts, sunflower seeds or popcorn instead of potato chips. A list of 50 of the top fiber containing foods are listed in Table 3.[51,52]

Table 2 Randomized trials on the role of fiber and fiber rich diets in body weight regulation and weight loss

Study	Method	Results
High Fiber vs Low Fiber Diets (2004)[45]	This parallel ad libitum Mediterranean diet trial included 180 overweight (mean BMI 28kg/m^2) middle aged adults with metabolic syndrome. The subjects were randomized into either a high fiber diet (32g fiber/day including about 500g of whole-grains, vegetables, fruit, legumes and nuts) or a low fiber diet (15g fiber/day including about 200g of whole-grains, vegetables, fruit, legumes, and nuts) with similar percent energy from fat, carbohydrates, protein and alcohol, and guidance to exercise 30 minutes/day for 2 years.	The subjects consuming 32g fiber/day Mediterranean diet lost significantly more weight, BMI, and waist size than those subjects on the 15g fiber/day Mediterranean diet.
Fiber Density Dose Effects[46]	This diabetes prevention trial included 522 obese (mean BMI 30kg/m^2) adults with impaired glucose tolerance. They were randomized to either maintain their standard lifestyle or receive high fiber, low-fat dietary and exercise counseling for 4years.	Participants consuming the low-fat, high-fiber diet lost significantly 2.4kg more weight than did those on the high-fat, low-fiber diet after 3 years. The fiber density of the diet was inversely associated with weight and waist size.
High Fiber Vegan vs Western Diets[47]	This GEICO Corporate study included 113 overweight (>25kg/m^2) adults who were randomized into a low-fat, vegan diet group (29g fiber/day) or asked to continue their habitual diet (15g fiber/day) for 22 weeks.	After about 6 months, the 29g fiber/day vegan diet group lost significantly more weight (-5.2kg) and waist size (-5.5cm) compared to the 15g fiber/day habitual western diet group.

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Study	Method	Results
Fiber-Rich Foods vs Psyllium Supplementation[48]	This fiber-rich food versus fiber supplemented controlled trial included 72 obese (mean BMI about 34kg/m^2) adults randomized into 4 diets: (1) control diet plus placebo (20g fiber/day); (2) control diet plus psyllium supplement (55g fiber/day); (3) healthy fiber-rich food diet plus placebo (31g fiber/day); or (4) healthy fiber-rich food diet plus psyllium supplement (59g fiber/day) for 12 weeks.	Compared to the control 20g fiber/day diet group, all higher fiber diets significantly reduced body weight, BMI, and % body fat after 12 weeks
High Fiber Diet vs General Nutrition Education[49]	This ad libitum high fiber trial included 50 obese adults who were randomized into a high-fiber diet group (32g fiber/day/ 540g fruits and vegetables /day) or into a control group receiving general nutrition education (17g fiber/day). Each group was given similar increased physical programs for 10 weeks	After 10 weeks, the high fiber diet subjects lost significantly 4% more weight and BMI, and had a significantly7% smaller waist than the lower fiber control group.
Beans vs Variety of Fiber-Rich Foods[50]	This fiber-rich food trial included 20 obese (mean BMI 31 kg/m^2; 90% women) adults randomized into high fiber diets with either 1.5 cups beans/day or a variety of fruits, vegetables, and whole grains for 4 weeks.	Both fiber-rich food groups increased fiber intake from about 17g/day to about 29 /fiber/day and lowered energy intake by about 300-400 kcal/day or energy density by 38% for the bean group and 29% for the variety of fiber foods group. Both groups lost significant weight with -1.6kg for the bean group and -1.1kg for the variety of fiber food group.
High Fiber Diet vs Hypocaloric Diets[29]	In this parallel high fiber diet versus multi-component diet (AHA guideline, hypocaloric diet) trial, 240 obese (mean BMI 35kg/m^2) adults with metabolic syndrome were randomized into either a ≥30g fiber/day diet goal or an AHA diet plan including caloric reduction of 500-1,000 kcal/day for 1 year.	After one year, there were no significant differences in weight loss, BMI or waist size between the ad libitum fiber diet and the hypocaloric diet plan. The subjects in the high fiber group (target >30g fiber/day) consumed more fiber than the AHA hypocaloric diet (approx. 21g/day). This study suggests that simply consuming a high fiber diet may be a reasonable alternative to a traditional, challenging, hypocaloric weight loss diet plan.

Table 3 Fifty high fiber foods ranked by amount of fiber per standard food portion.[51,52]

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 (90g)	9.6	127	1.4
Small white beans, cooked	1/2 cup (90g)	9.3	127	1.4
Shredded wheat ready-to-eat cereal	1-1 1/4 cup (50-60g)	5.0-9.0	155-220	3.2-3.7
Black bean soup, canned	1/2 cup (130g)	9	117	1
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)	6	100	1
Pumpkin seeds. whole, roasted	1 ounce (about 28 g)	5	126	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	73	3.3

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Table Continued....

Food	Standard portion size	Dietary fiber (g)	Calories (kcal)	Energy density (calories/g)
Avocado, Hass	1/2 fruit (68g)	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	59	0.7
Raspberries	1/2 cup (65g)	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
Multi-grain 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 (173g)	3.6	163	3.9
Popcorn, air-popped	3 cups (24 g)	3.5	93	3.9
Almonds	1 ounce (about 28 g)	3.5	164	5.8
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	178	2.7
Vegetable soup	1 cup (245 g)	2.9	91	1.5
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
Quinoa, cooked	1/2 cup (90 g)	2.7	92	1.2
Broccoli, cooked	1/2 cup 978 g)	2.6	114	1.5
Potato baked, without skin	1 medium (145g)	2.3	145	3.9
Baby spinach leaves	3 ounces (90 g)	2.1	20	0.2
Blueberries	1/2 cup (74 g)	1.8	178	2.4
Carrot, raw or cooked	1 medium (60 g)	1.7	25	0.4

Fiber supplements: Although the consumption of fiber supplements or fiber enriched foods may help to promote weight loss in overweight and obese individuals, their effects are heterogeneous and often less effective than fiber-rich whole foods.[53–58] In a systematic review of 66 randomized trials that examined the effects of isolated fibers used as supplement or for food, the overall weight reduction was a modest 0.1kg per 10g fiber after 4weeks with a high degree of variability.[51] Systematic reviews and clinical studies of guar gum, glucomannans, and inulin-type fructans showed insignificant or inconsistent weight loss effects.[52–56] Most fiber supplements cannot be presumed to have weight loss benefits because they are not a replacement for high energy dense, low fiber foods and their physical properties are generally not potent enough to trigger weight loss mechanisms as effectively as fiber-rich whole foods.

Healthy dietary patterns: human studies

Compared with the usual western diet, the consumption of healthy dietary patterns including the US dietary guidelines diet, MedDiet, DASH diet, and healthy vegetarian (ovo-lacto) diets by overweight

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and obese individuals can result in weight loss or at least prevent weight gain depending on the degree of adherence and fiber level.[59] The 2015 US Advisory Guidelines Advisory Committee scientific report concluded that there was strong evidence showing that overweight and obese adults, preferably as part of a comprehensive lifestyle intervention, can achieve clinically meaningful weight loss ranging from 4 to 12kg after 6-months through a variety of healthy dietary patterns that achieve an energy deficit.[59] Thereafter, slow weight regain is observed, with total weight loss at 1year of 4 to 10kg and at 2years of 3 to 4kg. Table 4 summarizes the important weight control related food and nutrient attributes of each of these dietary patterns.[60–62] All these healthy dietary patterns double the fiber content from about 16g/day in the usual Western diet to >30g/day and decreased added sugars intake by more than half by emphasizing the increased consumption of plant-based foods, such as whole grains, fruits, vegetables, pulses and nuts. A pooled analysis of the large Nurses' Health Study I and II and Health Professionals Follow-Up studies found that higher adherence to all types of healthy dietary patterns were significantly associated with less weight gain over a 4year period in both men and women, especially in younger women or overweight individuals.[63]

Table 4 Comparison of usual US and healthy fiber-rich dietary patterns per 2,000 k cals.[60–62]

Attributes	Usual intake adults (us)	USDA base pattern	DASH diet Pattern	Healthy mediterranean pattern	Healthy vegetarian pattern (Lact-ovo based)
Emphasizes	Western dietary pattern	Vegetables, fruit, whole-grains, low-fat milk	Potassium rich vegetables, fruits and low fat milk products	Whole grains, vegetables, fruit, dairy products, olive oil, and moderate wine	Plant foods-vegetables, fruit, whole-grains, legumes, nuts, seeds, milk products and soy foods
Includes	Refined grains/ sweets, red meats, sugar sweetened beverages, and solid fats	Enriched grains, lean meat, fish and vegetable oils	Whole-grains, poultry, fish and nuts	Fish, nuts and pulses	Eggs, non-dairy milk alternatives and vegetable oils
Limits	N/A	Solid fats and added sugars	Red meats, sweets and sugar-sweetened beverages	Red meats, refined grains, and sweets	No meats, poultry, or fish; limited sweets
Estimated Nutrients/Components					
Energy (kcal)/day	2,000	2,000	2,000	2,000	2,000
Carbohydrates (% Total kcal)	49	51	55	52	55
Protein (% Total kcal)	16	18	18	18	14
Total fat (% Total kcal)	33	33	27	32	34
Saturated fat (% Total kcal)	11	8	6	8	8
Unsat. Fat(%Total kcal)	22	25	21	24	26
Fiber (g)	16	31	31	31	35+
Potassium (mg)	2,800	3,350	4,400	3,350	3,300
Sodium (mg)	3,600	1,790	1,100	1,690	1,400
Added sugar (g)	79 (20 tsp)	32 (8 tsp)	12 (3 tsp)	32 (8 tsp)	32 (8 tsp)

Mediterranean diets

The weight management effects of the MedDiet has been extensively studied in both prospective studies and randomized trials. Prospective studies consistently find that a high adherence to the MedDiet is inversely associated weight gain, BMI, waist size, and waist-to-hip ratio compared to lower adherence.[64–76] A meta-analysis of 16 randomized MedDiet trials including 3,436 participants over a duration ranging from 28days to 2years reported a significant pooled mean reduction in weight by 1.75kg and BMI by 0.6kg/m^2 compared to the control diet.[77] The effect of the MedDiet on body weight reduction was even greater when part of an energy restriction diet (3.9kg), with increased physical activity (4.0kg), and at a follow-up longer than 6months (2.7kg). No study reported significant weight gain with a MedDiet, which addresses any concerns regarding the liberal use of olive oil in the MedDiet and weight control. Further, a meta-analysis of 9 randomized MedDiet trials, including 1,178 people with type 2 diabetes found small but significant pooled mean loss of weight by 0.3kg and BMI by 0.3kg/m^2 compared to control diets along with significant improvements in glycemic control and reductions in cardiovascular disease risk factors.[78] Two randomized MedDiet weight loss trials lasting for 2years found that the higher fiber MedDiet significantly reduced weight compared to a lower fiber diet for both men and women.[79,80]

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DASH diets

The DASH (Dietary approaches to stop hypertension) diet has been evaluated in human studies for its effects on weight control and loss but less extensively than the MedDiet. In a prospective study in adolescent girls, a higher adherence to the DASH diet was associated with a lower BMI by 1.9kg/m^2 over 10years than those with low adherence.[81] In randomized trials, the DASH diet supports weight loss and maintenance in overweight and obese individuals unless diet adherence is low as indicated by a total fiber intake of less than 22g/day.[82–86] In the PREMIER trial, overweight and obese participants consuming DASH diets with the lowest energy density and higher fiber intake had significantly greater weight loss.[84] In another study, a DASH diet plus 30-45minutes of exercise 3daysweek and weight control coaching achieved significant weight loss by 8.7kg compared to weight loss of 0.3kg with the DASH diet without exercise or weight control coaching and an increase in weight by 0.9kg in the usual western diet control group (16g fiber/day) after 4months.[85] Additionally, in a randomized trial of 200 men and women, the intent-to treat analysis showed that participants in the DASH diet lost 4.4kg more weight after 6months and 2.6kg after 12months compared to the usual western diet.[86]

Vegetarian diets

Observational studies indicate that vegetarians have 3 to 20% lower weight and BMI than omnivores, which is primarily related to the higher fiber density and lower energy density of the vegetarian diets.[87–90] The Adventist Health Study-2 prospective study comprised of about 60,000 men and women found that vegetarian diet strictness was inversely associated with BMI with vegans having a 5-unit lower BMI than nonvegetarians.[91] A meta-analysis of 15 randomized trials including 755 adults reported that the vegetarian diets (vegan and ovo-lacto) were associated with a significantly greater mean weight reduction by 4.6kg in those who completed the study compared to those on the control diets.[92] High adherence to ovo-lacto-vegetarian and vegan diets were consistently associated with weight loss in intervention trials, despite the absence of specific guidance on energy intake or exercise. Vegan and ovo-lacto-vegetarian diets have similar and greater effects on weight loss compared to omnivorous, semi- and pesco-vegetarian diets.[93] More weight loss was observed in those participants who were heavier at baseline, older in age, and on diets for longer intervention duration.

Potential fiber biological mechanisms

The potential fiber biological mechanisms associated with enhanced body weight regulation and weight loss are summarized in Table 5.

Energy density

Lower energy dense fiber-rich diets, as a replacement for higher energy dense diets, help to promote energy balance to prevent weight gain.[94] This is because: (1) fiber is generally considered to be 2kcals/g or less as compared to 4kcals/g for digestible carbohydrates such as sugar and starch because fiber is not digested in the small bowel and (2) lower energy dense fiber-rich foods displace higher density foods.[94–97] The lower fiber energy density results from about 70% of fiber in mixed diets being fermented by colonic anaerobic bacteria to short chain fatty acids (SCFAs) and gases (carbon dioxide, hydrogen, and methane) and the excretion of undigested fiber in the stool.[94–96] New studies using breath hydrogen measurement indicate that more fiber sources than previously reported have an energy value in the range of 1kcal/g.[98]

Table 5 Potential mechanisms for fiber and fiber-rich diets on body weight regulation and weight loss

Target	Increase	Decrease
Food Intake	Food volume/bulk Chewing time	Diet energy density (fiber = 2 kcal /g vs refined carbohydrate = 4 kcal/g) Dietary fat intake Hunger
Stomach	Satiety signals (e.g., ghrelin)	Gastric emptying Lipid emulsification Hunger
Small Intestine	Satiety signals (cholecystokinin (CCK), glucagon-like peptide-1 and peptide YY)	Hunger
Circulation	Insulin sensitivity Short chain fatty acids (SCFAs) Satiety signals	Postprandial glucose and insulin
Large Intestine	Fiber fermentation SCFAs Prebiotic microbiotia Unabsorbed macronutrients (e.g. dietary fat) and bile acids	Metabolizable energy
Body Weight	Negative energy balance	Weight gain Total body fat gain Abdominal and visceral fat gain

Eating and digestion rates

Fiber-rich meals are more mouth filling and harder to swallow because of their higher bulk, physical density, volume, or viscosity compared with energy-matched, low-fiber meals, and more rapidly reduce hunger after ingestion.[94,99] Fiber-rich foods or clinically proven fiber supplements, especially bulky, viscous soluble fibers, increase intraluminal concentration or viscosity, slow gastric emptying, and create a mechanical barrier to enzymatic digestion of macronutrients such as starch in the small intestine.

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Postprandial satiety signaling

There are a number of hormonal satiety inducing activities associated with increased fiber intake.[99,100] High fiber meals or β-glucan and psyllium supplements compared to energy matched low fiber control diets can: (1) decrease plasma ghrelin, a stomach hunger promoting hormone, and slow the rate of postprandial increases in glucose and insulin blood levels to prevent reactive hypoglycemia known to promote hunger;[94,99–104] (2) trigger the increased secretion of the hormone cholecystokinin (CCK), a brain neuropeptide known to decrease food intake, from the proximal small intestine to slow gastric emptying and increase satiety;[100,105,106] and/or (3) delay the absorption of nutrients long enough to deliver a portion of them to the distal ileum, where they are not normally present, to stimulate the release of a cascade of metabolic responses called the "ileal brake" phenomenon including the release of satiety hormones glucagon-like peptide-1 (GLP-1), known to control appetite, which slows gastric emptying and small bowel transit, decreases glucagon secretion, increases pancreatic β-cell growth, and improves insulin sensitivity[107–108] and peptide YY (PYY) known to reduce appetite by further slowing gastric emptying.[100] However, several systematic reviews show a wide variability in the ability of different fiber sources to promote satiety and reduce energy intake.[109,110]

Colonic effects

Microbiota: Many fibers can stimulate beneficial bacterial microbiota.[111] Increasing research is now focused on how the gut microbiota differs in composition between lean and obese individuals and the effect of a low-fiber Western-style diet vs healthy fiber-rich dietary patterns on gut microbiota.[111,112] One randomized trial found that the consumption of 21g polydextrose or soluble corn fiber in the form of 3 cereal bars/day for 3weeks changed the gut microbiota of overweight subjects by shifting the colonic Bacteroidetes to Firmicutes ratio to one that was more typical of lean individuals, independent of caloric restriction.[112]

Metabolizable energy: Compared to low fiber foods, fiber-rich foods tend to decrease the efficiency of macronutrient bioavailability, especially that of dietary fat, leading to higher fecal macronutrient excretion.[113] The consumption of >25g fiber/day can lead to the excretion of 3-4% macronutrient energy in the feces, which is equivalent to 80kcals in a 2,000kcal diet.[114–117]

Satiety and energy metabolism: Short chain fatty acids (SCFAs) are involved in the crosstalk existing between microbes and human appetite and energy regulation.[21,118–123] Fiber fermentation produces SCFAs of which 95% consist of acetate, propionate and butyrate in a molar ratio of 60:20:20. It has been estimated that as much as 70% of the fiber from mixed diets is fermentable depending on physical properties.[95,96] SCFAs can contribute to energy homeostasis via effects on multiple cellular metabolic pathways and receptor-mediated mechanisms.[21] In particular, there is a widespread SCFA receptor system including G-protein-coupled receptors, free fatty acid receptors (FFAR) 2 and FFAR3 expressed in numerous tissue sites, such as the gut epithelium and adipose tissue. Increased colonic levels of SCFAs from fiber and their absorption into circulation can stimulate a second wave of satiety hormonal and neural signals such as GLP-1, PYY and/or neuropeptide Y that can reduce appetite, and gastric, intestinal mobility, and regulate energy metabolism.[21,117–121] Acetate has recently been shown to have a direct role in central appetite regulation.[21] Butyrate has improved insulin sensitivity and increased energy expenditure in experimental studies.[122] In obese subjects, propionate significantly increased the release of postprandial plasma PYY and GLP-1 from colonic cells, and reduced energy intake. In cultured human colonic cells, propionate was shown to stimulate the release of GLP-1 and PYY along with reducing energy intake.[123] A 24week study indicated that colonic generated propionate entering the circulatory system helped to reduce body weight gain and significantly reduce intra-abdominal fat accretion and intrahepatocellular lipid content in overweight adults with non-alcoholic fatty liver disease.[123]

Conclusion

Fiber is one of the most under-consumed healthy food components in the western diet with typical intakes about half of the recommended level, which contributes to a daily positive energy balance and increased risk of significant weight gain overtime. To achieve and maintain a healthy body weight, individuals are encouraged to consume dietary patterns that are lower in energy density and contain >30g fiber/day by: (1) high intake of vegetables, fruits, whole grains, legumes and nuts and (2) reduced intake of meats (including red and processed meats), sugar-sweetened foods and beverages, and refined grains. As childhood and adolescence is a critical time period for the prevention of obesity later in life, it is especially important to introduce this type of dietary pattern at a young age. Prospective studies consistently indicate that populations consuming higher fiber dense diets (including whole grains, fruit, vegetables, legumes and nuts) are leaner than those that eat lower fiber dense diets. A number of randomized trials show that intake of lower energy dense, fiber-rich whole-food diets containing ≥30g fiber/day can result in weight loss in overweight or obese individuals. In order to consume ≥30g fiber/day, individuals consuming the usual western diet need to double their fiber intake (or add about 15g fiber/day) and this could be accomplished by the daily substitution of one fiber-rich food for a lower fiber, energy dense food at each meal and one snack. High adherence to a variety of healthy fiber-rich dietary patterns can improve body weight regulation and lead to weight loss in overweight and obese individuals compared to the western diet. Fiber-rich diets are generally more effective at promoting weight loss than fiber supplements largely because they directly displace low fiber, energy dense foods and increase food bulk (volume) and satiety signals. The unique fiber and fiber-rich food potential mechanisms that help to promote weight loss and reduce the rate of weight gain do so by: (1) lowering total dietary energy density, (2) slowing eating and digestion rates, (3) increasing postprandial satiety signaling, and (4) promoting colonic effects including a leaner microbiotia profile, fecal excretion of undigested macronutrients (e.g., dietary fat), and higher satiety signals and energy metabolism.

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Conflict of interest

The author declares no conflict of interest.

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