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Review article

Dietary fiber and body weight

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Abstract

Objective: This review provides an update of recent studies of dietary fiber and weight and includes a discussion of potential mechanisms of how dietary fiber can aid weight loss and weight maintenance.

Methods: Human studies published on dietary fiber and body weight were reviewed and summarized. Dietary fiber content of popular low-carbohydrate diets were calculated and are presented.

Results: Epidemiologic support that dietary fiber intake prevents obesity is strong. Fiber intake is inversely associated with body weight and body fat. In addition, fiber intake is inversely associated with body mass index at all levels of fat intake after adjusting for confounding factors. Results from intervention studies are more mixed, although the addition of dietary fiber generally decreases food intake and, hence, body weight. Many mechanisms have been suggested for how dietary fiber aids in weight management, including promoting satiation, decreasing absorption of macronutrients, and altering secretion of gut hormones.

Conclusion: The average fiber intake of adults in the United States is less than half recommended levels and is lower still among those who follow currently popular low-carbohydrate diets, such as Atkins and South Beach. Increasing consumption of dietary fiber with fruits, vegetables, whole grains, and legumes across the life cycle is a critical step in stemming the epidemic of obesity found in developed countries. The addition of functional fiber to weight-loss diets should also be considered as a tool to improve success.

Keywords: Dietary fiber; Weight maintenance; Weight loss

Introduction

The increasing prevalence of obesity in the United States population and associated morbidity compels us to develop dietary strategies to combat the problem. Although it is well known that excess calorie intake is the primary dietary cause, alterations in food patterns or nutrients must be considered. Dietary guidance universally recommends diets higher in fiber for health promotion and disease prevention, but there are inconsistencies in the literature on the relation of dietary fiber to body weight. The first goal of this review is to describe the challenges in measuring dietary fiber intake in studies and describe recent developments in dietary fiber definitions and recommendations. Second, epidemiologic studies on the role of fiber in weight maintenance will be summarized. Third, intervention studies on dietary fiber and weight loss will be presented. Fourth, potential mechanisms for how dietary fiber may aid weight loss will be described. The current obesity epidemic in developed countries demands that we design diets to improve weight loss and maintenance. In addition, the popularity of low-carbohydrate diets that are low in dietary fiber must be considered in this discussion.

What is dietary fiber?

Examining the relation between dietary fiber intake and body weight is difficult because we struggle to define dietary fiber and agree on recommended intake levels. New definitions for dietary fiber and recommendations for fiber intake were published as dietary reference intakes [1]. Dietary fiber consists of non-digestible carbohydrates and lignin that are intrinsic and intact in plants. Functional fiber

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consists of isolated, non-digestible carbohydrates that have beneficial physiologic effects in humans. Total fiber is the sum of dietary fiber and functional fiber.

The Panel on Dietary Reference Intakes for Macronutrients was responsible for reviewing the research on dietary fiber and disease prevention and deciding whether to set a recommended intake level for dietary fiber. Before this report, there was no recommended dietary allowance for dietary fiber. The panel also found in its deliberations that there was no official definition of dietary fiber. Thus, a National Academy of Sciences Panel on the Definition of Dietary Fiber was formed to review existing literature on dietary fiber and determine the best scientific definition of dietary fiber [2].

All fiber is not created equal. Previously, dietary fiber was divided into soluble and insoluble fiber in an attempt to assign physiologic effects to chemical types of fiber. Scientific support for the belief that soluble fibers decrease serum cholesterol but that insoluble fibers increase stool size is inconsistent at best. A meta-analysis testing the effects of pectin, oat bran, guar gum, and psyllium on blood lipid concentrations associated 2 to 10 g/d of viscous fiber with small but significant decreases in total and low-density lipoprotein cholesterol concentrations [3]. Oat bran decreases serum lipids but wheat bran does not [4]. Resistant starch, generally a soluble fiber, does not affect serum lipids [5]. Thus, not all soluble fibers are hypocholesterolemic agents and other traits, such as viscosity of fiber, play a role and must be considered.

The association between insoluble fiber and laxation also is inconsistent. Fecal weight increases to 5.4 g/g of wheat bran fiber (mostly insoluble), 4.9 g/g of fruits and vegetables (soluble and insoluble), 3 g/g of isolated cellulose (insoluble), and 1.3 g/g of isolated pectin (soluble) [6]. Many fiber sources are mostly soluble but increase stool weight, such as oat bran and psyllium. Not all insoluble fibers are particularly good at relieving constipation, e.g., isolated cellulose. The disparities between the amounts of soluble and insoluble fiber measured chemically and the magnitude of their physiologic effects led the National Academy of Sciences Panel on the Definition of Dietary Fiber to recommend that the terms *soluble fiber* and *insoluble fiber* gradually be eliminated and be replaced by specific beneficial physiologic effects of a fiber, perhaps *viscosity* and *fermentability*.

The dietary reference intake committee used the new definitions for dietary, functional, and total fiber in their report. In addition, they set an adequate intake for total fiber in foods of 38 g and 25 g/d for young men and women, respectively, based on intake levels observed to protect against coronary heart disease (Table 1). Adequate intake is the recommended average daily intake level based on observed or experimentally determined approximations or estimates of nutrient intake by a group (or groups) of apparently healthy people that are assumed to be adequate and is used when an recommended dietary allowance cannot be determined. There was insufficient evidence to set a tolerable upper intake level for dietary fiber or functional fibers.

Table 1
Dietary reference intake values for total fiber by life stage

Life stage	Adequate intake (g/d)	
	Male	Female
1–3 y	19	19
4–8 y	25	25
9–13 y	31	26
14–18 y	38	26
19–30 y	38	25
31–50 y	38	25
51–70 y	30	21
>70 y	30	21
Pregnancy		28
Lactation		29

Median intake of dietary fiber ranged from 16.5 to 17.9 g/d for men and from 12.1 to 13.8 g/d for women in the Continuing Survey of Food Intakes by Individuals (1994 to 1996, and 1998). Thus, there is a large fiber gap to fill between usual intake of dietary fiber and recommended intakes. Because fiber intake is directly related to total food intake, consumers of low-calorie diets are particularly susceptible to low fiber intakes. In addition, the trend toward high-protein, low-carbohydrate diets for weight loss has further limited dietary fiber intakes.

Fiber levels of popular weight-loss diets

In general, dietary fiber intakes are linked to total food intake and thus calorie intake. Fiber recommendations published in the dietary reference intakes are related to calorie intake and explain why the recommendation for men, 38 g/d, is higher than the recommendation for women, 25 g/d. Previous recommendations suggested that Americans consume 10 to 13 g of fiber per 1000 kcal consumed [7].

The fiber levels of popular diets have been reported by Anderson et al. [8]. When the dietary fiber content of weight-loss diets at 1600 kcal was determined, dietary fiber intakes ranged from 4 g/d for the Atkins diet to 49 g/d for the Ornish diet. The Zone diet at 1600 kcal/d provided 18.1 g of dietary fiber, whereas Protein Power provided 10.6 g of dietary fiber.

Novartis Consumer Health (summit, NJ, USA) recently sponsored a Harris Interactive QuickQuery Survey (August 21 to 25, 2003) to determine the most popular weight-loss diets. The survey was weighted to the U.S. adult general population and its findings were included in a press release on September 16, 2003. Not surprisingly, high-protein, low-carbohydrate diets were the most popular diets, including the Atkins diet and the South Beach diet. We examined the dietary fiber content of these currently popular diets, based on representative menus shown on their Web sites. Because

Table 2
Caloric and dietary fiber content of popular weight-loss diets

Diet	kcal/d	Dietary fiber (g/d)
South Beach Diet		
Phase 1	1043	4.4
Phase 2	1088	7.6
Phase 3	1026	3.0
Atkins Diet		
Induction	1015	1.6
Ongoing weight loss	1297	7.2
Premaintenance	1027	9.3
Lifetime maintenance	1681	5.0

these diets are designed with different phases, we analyzed all phases of the diets (Table 2).

Despite some efforts to expand inclusion of fruits, vegetables, and whole grains in these diets, fiber intakes were well below recommended levels. In the induction phase of the Atkins diet, dietary fiber intakes were extremely low, only 1.6 g/d. Intakes increased with later phases of the diet but were always woefully inadequate. The South Beach diet as described on its Web site was also extremely low in dietary fiber, i.e., always less than 10 g/d.

Epidemiologic studies on dietary fiber and weight

The "fiber hypothesis" suggests that consumption of unrefined, high-fiber carbohydrate-based foods protects against industrialized diseases such as diabetes, cancer, heart disease, and obesity. These traditional diets are high in dietary fiber and low in dietary fat, making it difficult to separate out these effects. Roberts and Heyman [9] suggested that that too often there is an overemphasis on dietary fat. Dietary factors less frequently examined for their role in obesity include fiber, glycemic index, and dietary variety.

In epidemiologic studies, usual intake of dietary fiber, soluble fiber, and insoluble fiber can be measured and then linked to body weight. Epidemiologic studies can also determine intake of foods that are high in dietary fiber, such as whole grains, fruits, and vegetables, and measure if intake of these foods is related to body weight. For intervention studies, subjects who are overweight or lean can be given low- or high-fiber diets and changes in weight can be monitored.

A multidisciplinary study of more than 5000 individuals associated obesity with increased energy intakes and decreased consumption of fiber rich foods such as fruits and vegetables [10]. Populations that report higher fiber consumption also demonstrate lower obesity rates [11]. Thus, increasing dietary fiber in the diet, as a part of a health promotion plan of action, may be an important public health strategy in preventing obesity.

Fiber and body mass index

In cross-sectional observational studies, fiber intake is inversely associated with body weight [12,13] and body fat [14]. In the Seven Countries Study, dietary fiber was significantly inversely associated with subscapular skinfold thickness [15]. Few studies have compared different fiber types and their association with body weight. In a longitudinal study, fiber intake was inversely associated with body mass index at all levels of fat intake after adjustment for lifestyle factors and other confounding factors among young adults [16]. Obese men and women have significantly lower dietary fiber intakes than do lean mean and women [17]. In the Nurses' Health Study, weight gain was inversely associated with intake of high fiber, whole grain foods but positively associated with intake of refined grain foods [18].

Intervention studies

Fiber and weight loss

Many intervention studies have investigated whether dietary fiber intake assists in weight loss and results have been inconsistent. Birketvedt et al. [19] found that the addition of dietary fiber to a low-calorie diet significantly improved weight loss, with the placebo group losing 5.8 kg and the fiber-supplemented group losing 8.0 kg. When postmenopausal women consumed higher-fiber diets as part of a study of very low-fat diets and weight loss, the higher-fiber diets were associated with significant weight loss [20]. The addition of fermentable and non-fermentable fiber supplements did not alter hunger, satiety, or body weight in a pilot study of men and women who consumed self-selected diets [21]. A randomized, controlled small study of 34 individual for 12 wk found that a high-carbohydrate diet consumed ad libitum, without energy restriction or change in energy intake, caused significant body weight and body fat losses in older men and women [22]. High-carbohydrate diets consistently have been associated with lower body weight. Rolls et al. [23] recently concluded that fruit and vegetable consumption does play a role in weight management, probably because their consumption decreases energy density, promotes satiety, and decreases energy intake. As summarized by Howarth et al. [24], increased dietary fiber intakes have been associated with a body weight loss of 1.9 kg over 3.8 mo, with greater weight loss in more obese subjects. These studies were conducted with whole foods high in dietary fiber and with supplemental fiber.

Theoretical reasons that dietary fiber helps in weight management

Heaton [25] proposed that fiber acts as a physiologic obstacle to energy intake by at least three mechanisms: 1) fiber displaces available calories and nutrients from the diet;

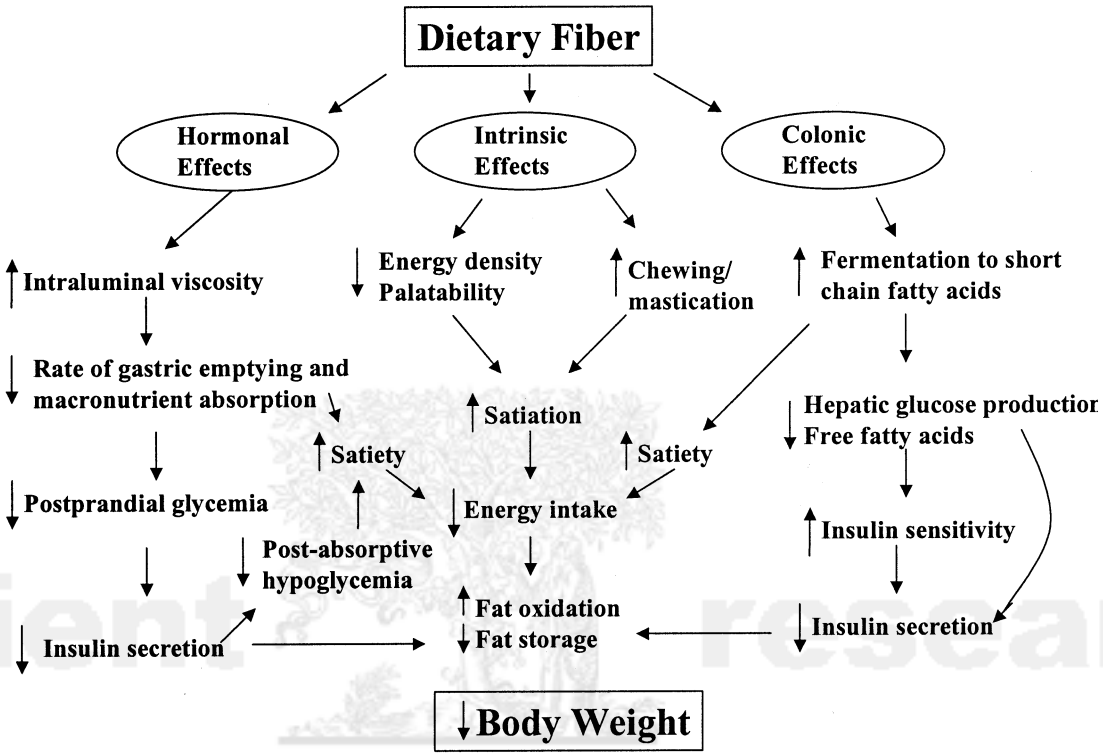

Fig. 1. How dietary fiber affects physiologic measurements. Adapted with permission from Pereira and Ludwig[28]

2) fiber increases chewing, which limits intake by promoting the secretion of saliva and gastric juice, resulting in an expansion of the stomach and increased satiety; and 3) fiber decreases the absorption efficiency of the small intestine.

Diets high in energy density increase food consumption when compared with diets lower in energy density. Rolls [26] suggested that humans may consume a constant weight of food and, hence, a constant weight of lower energy (i.e., high fiber) food per unit weight may promote a decrease in weight. High-fiber foods have much less energy density compared with high-fat foods. Thus, high-fiber foods can displace energy or calories. Eating equal weight of a lowered energy or high-fiber food increases satiety. The bulking and viscosity properties of dietary fiber are predominantly responsible for influencing satiation and satiety [27]. Fiber-rich foods usually are accompanied by increased efforts and/or time of mastication, which leads to increased satiety through a decreased rate of ingestion [24].

Fig. 1 summarizes physiologic mechanisms by which dietary fiber affects body weight regulation [28]. Intrinsic, hormonal, and colonic effects of dietary fiber decrease food intake by promoting satiation and/or satiety. *Satiation* is defined as the satisfaction of appetite that develops during the course of eating and eventually results in the cessation of eating. *Satiety* refers to the state in which further eating is inhibited and occurs as a consequence of having eaten. Dietary fiber also decreases gastric emptying and/or slows energy and nutrient absorption, leading to lower postprandial glucose and lipid levels. Dietary fiber may also influence fat oxidation and fat storage.

Howarth et al. [24] summarized the effects of dietary fiber on hunger, satiety, energy intake, and body weight. Most studies with controlled energy intake have reported an increase in satiety after meals and a decrease in subsequent hunger with increased dietary fiber. With ad libitum energy intake, the average effect of increasing dietary fiber across all these studies indicated that an additional 14 g/d of fiber resulted in a 10% decrease in energy intake and a weight loss greater than 1.9 kg through approximately 3.8 mo of intervention. The effects of increasing dietary fiber were reported to be even more impressive in obese individuals. The results of increased dietary fiber from high-fiber foods or from fiber supplements on weight regulation were similar. In addition, the beneficial effect of dietary fiber on weight regulation was seen for soluble and insoluble dietary fibers.

Pereira and Ludwig [28] reviewed 27 experimental human studies published between 1984 and 2000 that measured dietary fiber effects on objective or subjective measurements of satiety. Seventeen studies showed a beneficial effect of dietary fiber on energy intake. Seven studies reported mixed effects, whereas only three studies reported no effects of dietary fiber on satiety.

The effects of dietary fiber on weight gain were investi-

gated in the Coronary Artery Risk Development in Young Adults (CARDIA) study [16]. The CARDIA study is an epidemiologic observational study of more than 2900 black and white participants 18 to 30 y of age. There was a linear relation from lowest to highest quintile of dietary fiber intake with body weight. Dietary fiber had an independent association to body weight even after adjustment for carbohydrate, protein, and fat in whites. Correspondingly, in blacks, an independent relation to body weight remained for dietary fiber after adjusting for fat or carbohydrate. The CARDIA researchers also investigated the independent and joint associations of fiber and fat consumption with 10-y weight gain. Regardless of fat intake, participants who consumed the most fiber gained less weight compared with individuals who consumed the least amount of fiber. The results of the CARDIA study provide strong support for a significant role of dietary fiber in weight regulation.

Does dietary fiber promote satiation?

Although emphasis has been placed on specific effects that can be detected as statistically significant when a particular fiber source is consumed, dietary fiber has many subtle, less easily quantifiable effects that are beneficial. A fiber-rich meal is processed more slowly and nutrient absorption occurs over a longer period [29]. Further, a diet of foods that provide adequate fiber is usually less energy dense and larger in volume than a low-fiber diet that may limit spontaneous intake of energy [30]. This larger mass of food takes longer to eat and its presence in the stomach may bring a feeling of satiety sooner, although this feeling of fullness is short term. A diet of different fiber-containing foods also is usually richer in micronutrients.

Pasman et al. [31] studied the effect of 1 wk of fiber supplementation on hunger, satiety rating, and energy intake. With high intakes of guar gum (40 g/d), mean daily energy intake decreased significantly from 6.7 MJ to 5.4 MJ, whereas hunger and satiety scores did not change. Dietary compliance is difficult in these types of studies and there is often a strong order effect of diets [32]. Mattes and Rothacker [33] reported that beverage viscosity is inversely related to postprandial hunger in humans. Holt et al. [34] fed equal-energy portions of seven different breads and measured feelings of fullness and subsequent ad libitum food intake in 10 healthy subjects. A satiety index score was calculated for each test food by comparing the response to regular white bread. The strongest predictor of the breads' satiety index scores was their portion size and thus energy density. Satiety scores of the breads were positively associated with portion size, total carbohydrate, and fiber content of the breads. Warren et al. [35] found that low glycemic breakfasts, which were higher in dietary fiber, decreased food intake in preadolescent children.

Does dietary fiber alter glycemic or insulin response?

When viscous fibers are isolated and thereby concentrated, their effects on digestion are frequently easier to detect; when these types of fibers are added to a diet, the rate of glucose appearance in the blood is slowed, and insulin secretion is subsequently decreased. These beneficial effects on blood glucose and insulin concentrations are most evident in individuals who have diabetes mellitus. In healthy individuals, the rapid insulin secretion that causes rapid removal of glucose from the blood frequently makes it difficult to detect a difference between blood glucose concentrations during a test meal with and without a fiber supplement. Anderson et al. [36] suggested that diabetics should consume diets that provide 25 to 50 g/d of dietary fiber (15 to 25 g/1000 kcal). They recommended that diabetics should achieve and maintain a desirable body weight and consume a high-carbohydrate diet with greater than 55% of kilocalories coming from carbohydrate.

Does dietary fiber decrease absorption of macronutrients and thus energy?

Theoretically, if dietary fiber could block or limit the absorption of macronutrients, it could aid in weight control. Even a small change in absorption could have long-term significance in weight maintenance. Few studies have been conducted in this area because of the need to collect fecal samples and measure fecal energy, fat, protein, or carbohydrate. Gades and Stern [37] measured the ability of a commercially available chitosan supplement on fecal fat excretion in men. Chitosan-based supplements are purported to "trap" dietary fat and thus inhibit intestinal fat absorption. With chitosan supplementation at 10 capsules/d, fecal fat excretion increased by 1.1 g/d. The investigators concluded that the effect of chitosan on fat absorption is clinically negligible.

Does dietary fiber affect gastric emptying?

Dietary fiber affects gastrointestinal physiology and functions including delaying gastric emptying [38]. Consumption of viscous fibers delays gastric emptying, which may cause an extended feeling of fullness [39] and may delay absorption of glucose and other nutrients. Yao and Roberts [40] summarized the effect of an increase in energy density on the rate of gastric emptying in humans and consistently found that high-fiber diets slowed gastric emptying. Although the exact mechanism whereby gastric emptying would affect weight is unknown, they speculated that there is a link between palatability, gastric emptying, and glycemic index.

Does dietary fiber affect secretion of gut hormones, including cholecystokinin, independently of glycemic response?

Beyond the effects of dietary fiber on postprandial glucose, insulin, and satiety discussed above, dietary fibers alter responses and actions of the gut hormones gastric inhibitory peptide [41], glucagon-like peptide-1 [42], and cholecystokinin (CCK). CCK is a peptide hormone and a neurotransmitter secreted by cells in the upper part of the small intestine after ingestion of food. CCK regulates gut motility, gallbladder contraction, and pancreatic enzyme secretion. CCK may mediate postprandial glycemic and insulinemic responses to viscous fibers [43]. Holt et al. [44] reported a direct correlation between postprandial CCK and subjective satiety scores after ingestion of foods that differed in the amount of fiber. A study with female subjects also associated plasma CCK with subjective measurements of satiety in women [45]. Bean intake, as a source of dietary fiber, also increased CCK in male subjects [46].

A soluble, viscous fiber made from cellulose was tested as part of a liquid meal in hypercholesterolemic subjects [47]. In this acute study, there was a lower peak CCK concentration after consumption of the soluble fiber test meal than after a fiber-free test meal. The researchers concluded that their findings support the hypothesis that CCK may mediate the effect of viscous fibers on glucose metabolism. In addition, they reported significant gender differences in glucose and CCK that they suggested may explain some of the discrepancies in similar experiments in this area. Many other gut hormones affect energy homeostasis [48], and few of these hormones have been studied in relation to changes in dietary fiber intake. A small dose of psyllium (1.7 g) did not alter postprandial glucagon-like-peptide-1 (GLP-1) or gastric emptying in 10 subjects [49]. Gut hormone fragment peptide YY3–36 decreases appetite and food intake in lean and obese subjects, and whether dietary fiber intake alters peptide YY3–36 levels is unknown [50].

Does dietary fiber decrease food intake at a later eating occasion?

Fiber may have the added benefit of helping consumers decrease food intake throughout the day. However, results of trials examining this possibility have been conflicting. In general, large intakes of dietary fiber at breakfast are associated with less food intake at a lunch. Burley et al. [51] found that 29 g of sugar beet fiber resulted in 14% less energy consumption at lunch. Levine et al. [52] also found less food intake at lunch when a high-fiber breakfast cereal was consumed earlier in the day. A higher-fiber breakfast was associated with less food intake at lunch for normal and overweight children in a study of breakfasts with a low glycemic index [35]. Other investigators [53] found no effect of fiber consumption on subsequent food intake and suggested that there is no difference between a low- and a high-fiber breakfast if caloric intake at breakfast is controlled.

Summary

Long-term insufficient intake of dietary fiber represents a challenge for the dietetics professional that can be met with enthusiastic recommendations for a healthy dietary pattern. Modest increases in intakes of fruits, vegetables, legumes, and whole and high-fiber grain products would bring the majority of the North American adult population close to the recommended ranges of dietary fiber intake of 25 g/d for women and 38 g/d for men. In addition, a higher-fiber intake provided by foods is likely to be less calorically dense and lower in fat and added sugar. Many of the diseases of public health significance such as obesity, cardiovascular disease, and type 2 diabetes and the less prevalent, but no less significant diseases of colonic diverticulosis and constipation can be prevented or controlled by increasing the amounts and varieties of fiber-containing foods. Promotion of such a food plan by the dietetics professional and implementation by the adult population should increase fiber intakes across the life cycle [54].

Whether dietary fiber supplements will aid in the prevention and control of obesity is less clear. Clinical studies have found changes in gastric emptying, gut hormones, glycemic index, and satiation indices with fiber supplements. Typically, large amounts of dietary fiber are needed to alter energy balance in studies. In addition, low-calorie, high-protein diets that are often used as a tool in weight loss are alarmingly low in dietary fiber. Thus, supplemental fibers show promise as aids to weight loss. Moreover, consumers who choose low-carbohydrate, high-protein diets to aid in weight loss should consider supplemental dietary fiber to help close the fiber gap.

Not all fiber supplements are effective in clinical studies, and different types of fiber alter energy balance by different mechanisms. Epidemiologic studies have clearly shown that dietary fiber is an important tool in the prevention of obesity. Clinical studies are needed with different eating patterns and fiber supplements that answer important research questions about the types of dietary fiber that are most effective, the dose of fiber needed for effectiveness, differences in response between lean and obese subjects, and the mechanisms by which dietary fiber is involved in energy homeostasis.

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