Supplement

DIETARY FIBER AND ENERGY REGULATION [1]

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ABSTRACT

Dietary fiber has many functions in diet, one of which may be to aid in energy intake control and reduced risk for development of obesity. The role of dietary fiber in energy intake regulation and obesity development is related to its unique physical and chemical properties that aid in early signals of satiation and enhanced or prolonged signals of satiety. Early signals of satiation may be induced through cephalic- and gastric-phase responses related to the bulking effects of dietary fiber on energy density and palatability, whereas the viscosity-producing effects of certain fibers may enhance satiety through intestinal-phase events related to modified gastrointestinal function and subsequent delay in fat absorption. The goal of this paper is to provide a brief overview of the role of dietary fiber in energy intake regulation, highlighting the relationship between fiber properties and physiologic action.

KEY WORDS: • *fiber* • *food intake* • *satiety* • *obesity* • *viscosity* • *cholecystokinin*

INTRODUCTION

The prevalence of obesity has increased dramatically over the past few decades. Obesity is associated with a number of adverse health outcomes and enormous economic costs, causing it to rank as one of the leading public health issues in the U.S. and Westernized countries (Kuczmarski et al. 1994♣ , Pi-Sunyer 1993♣). Consequently, research efforts have focused on identifying the key factors contributing to the development of obesity with the goal of devising reasonable strategies that will successfully prevent further weight gain and perhaps induce weight loss.

Among the many areas in obesity research, one area has focused on the possible ways in which the composition of the diet may affect food intake regulation and energy balance. Numerous studies have examined the role of dietary fat, protein and carbohydrate on energy intake control, whereas fewer studies have focused on the role of dietary fiber (Barkeling et al. 1990 , Burton-Freeman et al. 1997 and 1998 , Foltin et al. 1992 , Hill and Blundell 1986 , Rolls 1995a). The purpose of this paper is to discuss the importance of fiber in the diet as it relates to energy regulation in humans.

Fiber: background

Dietary fiber is a term used to describe a variety of plant substances that are resistant to digestion by alimentary enzymes in humans and most animals. Dietary fiber includes a number of nonstarch polysaccharide substances including cellulose, hemicellulose, ß-glucans, pectins, mucilages and gums plus the nonpolysaccharide lignin. These fiber components have unique chemical structures and characteristic physical properties (e.g., bulk/volume, viscosity, water-holding capacity, adsorption/binding or fermentability) that determine their subsequent physiologic behavior (Schneeman and Tietyen 1994). In the diets of humans, fiber sources include fruits, vegetables, grain products, legumes, nuts and concentrated plant sources such as oat and wheat bran. The benefits of consuming foods rich in fiber are numerous, ranging from improved large bowel function to slowed digestion and absorption of carbohydrate and fat and reduced risk for certain diseases (Ali et al. 1982 , Schneeman and Tietyen 1994). The recommended daily intake of fiber for healthy adults is between 20 and 35 g/d; however, much lower intakes of fiber have been reported (Pilch 1987). The significance of this lower intake of fiber to obesity development is suggested by epidemiologic and cross-sectional studies, indicating that diets low in dietary fiber are associated with increased risk for obesity (Alfieri et al. 1995 , Burkitt and Trowell 1975 , Van Itallie 1978).

Fiber and obesity development: food intake control

There are several ways in which dietary fiber may affect obesity development (Ali et al. 1982). Because obesity represents the long-term result of an imbalance between energy intake and energy expenditure, the most obvious link between dietary fiber and obesity development is through its effects on energy intake control mechanisms. The ingestion of fiber has been hypothesized to suppress energy intake by inducing satiation and satiety (Blundell and Burley 1987). Satiation is defined as the satisfaction of appetite that develops during the course of eating and eventually results in the cessation of eating. Satiation can be quantified by the duration of a meal and/or the size of the meal. In contrast, satiety is the state in which further eating is inhibited and occurs as a consequence of having eaten. The intensity of the satiety response to a meal/food(s) is measured by the duration of time between meals/eating occasions and/or the amount of food consumed at the next meal (Blundell et al. 1996). Together, satiation and satiety are integral processes controlling food intake and feeding behavior. The means by which dietary fibers influence satiation and satiety are related to their inherent chemical and physical properties, particularly their bulking and viscosity-producing capabilities. Adding fiber to the diet adds bulk, which in turn alters energy density and palatability. The addition of fibers that form viscous colloidal dispersions when hydrated affects multiple aspects of gastrointestinal (GI) function, such as gastric emptying, small bowel transit time, and the digestion and absorption of nutrients, particularly fat and carbohydrate (Schneeman and Tietyen 1994 , Vahouny et al. 1988). Hence, dietary fiber has the ability to modify cephalic-, gastric- and intestinal-phase processes of ingestion, digestion and absorption, providing it numerous opportunities to influence satiation and satiety.

Fiber, energy density and palatability: means for enhanced satiation

The importance of energy density on satiation and satiety has been reviewed recently (Drewnowski 1998). Briefly, energy density is defined as the number of kilojoules per unit weight of food. The energy density of foods can range from 0 to 37 kJ/g of food. Water, fat and fiber are the main food constituents contributing to energy density, whereas sugar and protein take on a lesser role, except in some reduced- or modified-fat food products. In general, fiber-rich diets, whether achieved through fiber supplementation or incorporation of high fiber foods into meals, have a reduced energy density compared with high fat diets. This is related to fiber’s ability to add bulk and weight to the diet. Therefore, for a given weight or volume of food, fiber can displace the energy of other nutrients. If people consume a constant weight of food rather than a constant quantity of energy, as some studies have suggested (Rolls et al. 1998 , Seagle et al. 1997), then addition/incorporation of fiber into the diet is one strategy for inducing fullness or satiation while consuming less energy. The underlying hypothesis is that gastric capacity along with sensitive mechanoreceptors to gastric distention is key in the regulation of food intake.

Fiber's effect on palatability, as well as other sensory qualities of the diet, may affect energy intake (Drewnowski 1998 , Rolls 1995b). Bulky, low energy-dense foods/diets are, for the most part, less appealing than more energy-dense foods or diets because energy density and palatability have been shown to be correlated (Holt et al. 1995 , Meiselman et al. 1974 as shown in Drewnowski 1998). Therefore, the energy-diluting effects of dietary fiber may reduce energy intake by lowering the overall palatability of the diet. The effect of dietary fiber on other qualities of food(s), such as texture may also reduce energy intake. Textural qualities of some fibrous foods may increase the work effort and time required for mastication. This increase in chewing effort and time may result in a variety of cephalic- and gastric-phase responses and signals, leading to early satiation and reduced food intake (Duncan et al. 1983 , Heaton 1980 , Sakata 1995).

Fiber affects gastrointestinal function: means for enhanced satiety

In addition to the effect of dietary fiber on satiation, which appears to be driven primarily by its ability to dilute the energy density of the diet and exploit mechanical threshold and sensory mechanisms of food intake regulation, dietary fiber also has the capacity to affect satiety. Meal-induced signals of satiety are generated both pre- and postabsorptively. However, preabsorptive satiety-related mechanisms, especially those at the level of the small intestine, are essential in the induction and maintenance of satiety (Rolls 1995b). Therefore, prolonging the intestinal phase of nutrient processing and absorption is likely to intensify satiety and aid in food intake control.

Incorporation of viscous fibers into a mixed meal at sufficient levels increases the viscosity of GI contents. Increasing viscosity of intestinal contents slows gastric emptying and small bowel transit, interferes with the mixing of food stuffs and digestive enzymes, disrupts micelle formation, and alters diffusion and interaction of nutrients with mucosal surface (Schneeman and Tietjen 1994 , Vahouny et al. 1988). The combination of these events results in slowed fat and carbohydrate absorption, which prolongs the period in which these nutrients can interact with preabsorptive mechanisms of satiety. Because the small intestine is the primary site for fat-induced satiety, delaying fat absorption and increasing intestinal exposure to fat should intensify its effect on satiety. Indeed, infusing equivalent amounts of fat into the duodenum of rats at a slow rate (extended exposure) compared with a faster rate (time-reduced exposure), resulted in reduced average daily energy intake, altered patterns of feeding and reduced body weight gain (Burton-Freeman and Schneeman 1996). The concept that intraluminal fat exposure is related to satiety and food intake control may illuminate the reason(s) why diets that are low in fat (often those prescribed for the management of diseases such as obesity, cardiovascular and diabetes) are difficult to adhere to long term (Anderson and Gustafson 1989).

Diets low in fat and energy are associated with chronic sensations of hunger, which may be due in part to less fat in the intestine available for stimulation of mechanisms of satiety. Therefore, slowing dietary fat absorption to enhance satiety, especially when fat levels are low, may have a significant effect on the overall therapeutic benefit of low fat diets because adherence may be maintained long term. If inclusion of viscous type fibers in low fat diets will effectively slow fat absorption and impart a greater sense of satiety, this would be a reasonable dietary approach to aid in successful adoption of low fat diets. We recently investigated this potential interaction of fat and fiber in meals to influence postmeal satiety. The data indicated that in women, incorporation of foods rich in viscous fibers into mixed low fat meals (20% energy from fat) resulted in suppressed sensations of hunger and enhanced postmeal satiety compared with an equally energetic and palatable low fat, low fiber meal. Moreover, the satiety response to the low fat, high fiber meal was similar to that of a high fat (38% energy from fat), low fiber meal with similar energy content. Analysis of plasma cholecystokinin (CCK) concentrations in response to these meals showed a similar pattern, in that elevated and sustained CCK concentrations were observed with both the low fat, high fiber meal and the high fat, low fiber meal. Others have shown a similar sustained CCK response above baseline CCK concentrations when viscous fibers were included in a low fat meal (Bourden et al. 1999). Because CCK release is sensitive to fat in the small intestine and is a proposed mediator of fat-induced satiety, the results from these studies are consistent with the idea that delaying fat absorption from the intestine can improve satiety of meals lower in fat.

Fiber, satiation, satiety and energy intake: a look at the data

There is sufficient evidence to suggest that through the action of fiber at different levels of the GI tract, the inclusion of fiber in the diet should promote food intake control. Numerous studies have investigated the effect of fiber on satiation and satiety as well as subsequent food/energy intake. For the most part, these studies have been short-term feeding trials using a preload-type design to investigate effects of fiber isolates, fibersupplemented foods or mixed meals containing fiber-rich foods. The results from these trials vary, depending on the population being studied, the type, dose and mode of fiber administered as well as the timing of food intake assessment relative to treatment. Despite the differences in approach, a significant number of studies have demonstrated suppressed hunger and greater satiety with fibers that have the viscous-producing property, whereas satiation and gastric fullness may be more closely related to the bulking effects of fiber

(Burley et al. 1987 and 1993 , Burton-Freeman, personal communication, Cybulski et al. 1992 , Di Lorenzo et al. 1988 , French and Read 1994 , Gustafsson et al. 1995 , Leathwood and Pollet 1988 , Rigaud et al. 1997 , Tomlin 1995).

The subsequent effect on food intake has been more variable because in some cases, food intake at a test meal was reduced, in other cases, it was not. Although much of the discrepancy in results may be ascribed to differences among studies, different responses related to gender and body weight status (i.e., obese vs. normal weight) may also be responsible. With regard to gender, work in our laboratory indicates that women may be more sensitive to dietary manipulation with fiber than men, which is consistent with a previous report by Burley et al. (1993) . Moreover, we have found that the subjective satiety response to dietary manipulation in men and women is supported by differences in the CCK response, suggesting that signals for satiety differ between genders (Burton-Freeman et al. 1998 and personal communication). The relationship of body weight status and fiber effect on energy intake suggests that obese individuals may be more likely to reduce food intake (Evans and Miller 1975 , Porikos and Hagamen 1986) with dietary fiber inclusion. However, many more studies will be required to establish this relationship firmly by comparing directly the effects of fiber between normal weight and obese subjects. Nonetheless, the data highlight the importance of understanding how fiber or the different types of fiber may influence food consumption behavior in different groups of people. This information is valuable for developing and successfully implementing dietary strategies aimed at food intake and body weight control.

Fiber and weight loss

Few long-term studies have been conducted to determine the effect of fiber on body weight loss. Most have examined the usefulness of fiber in enhancing compliance with diets designed for weight loss by reducing hunger (i.e., low or very low calorie diets) (Astrup et al. 1990 , Heini et al. 1998 , Mickelson et al. 1979 , Pasman et al. 1997 , Ryttig et al. 1985). With the exception of Heini et al. (1998) , the major conclusion drawn from these trials was that subjects found it easier to adhere to the weight loss diets when fiber was part of the dietary regimen. The lack of effect reported in the study by

Heini and co-workers may have resulted from the use of hydrolyzed guar gum, which would have removed the viscosity effect of the fiber, an important component of fiber-related satiety. The usefulness of long-term fiber supplementation to induce or maintain weight loss under unrestricted conditions is not clear (Evans and Miller 1975 , Hylander and Rossner 1983).

SUMMARY

There are many well-established benefits of consuming a diet rich in fiber. One of these benefits is the associated lower risk for certain diseases such as obesity. The relevance of fiber in obesity development is centered around fiber's role in food intake control. Inclusion of fiber in the diet promotes satiation and prolongs satiety, aids in long-term compliance to low energy diets, and encourages "healthy" food choices and eating habits. Dietary strategies aimed at promoting health and encouraging weight maintenance or loss should consider the benefits of dietary fiber and its related properties.

FOOTNOTES

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