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Dietary, Functional, and Total Fiber

SUMMARY

Dietary Fiber consists of nondigestible carbohydrates and lignin that are intrinsic and intact in plants. *Functional Fiber* consists of isolated, nondigestible carbohydrates that have beneficial physiological effects in humans. *Total Fiber* is the sum of *Dietary Fiber* and *Functional Fiber*. Fibers have different properties that result in different physiological effects. For example, viscous fibers may delay the gastric emptying of ingested foods into the small intestine, resulting in a sensation of fullness, which may contribute to weight control. Delayed gastric emptying may also reduce postprandial blood glucose concentrations and potentially have a beneficial effect on insulin sensitivity. Viscous fibers can interfere with the absorption of dietary fat and cholesterol, as well as with the enterohepatic recirculation of cholesterol and bile acids, which may result in reduced blood cholesterol concentrations. Consumption of *Dietary* and certain *Functional Fibers*, particularly those that are poorly fermented, is known to improve fecal bulk and laxation and ameliorate constipation. The relationship of fiber intake to colon cancer is the subject of ongoing investigation and is currently unresolved. An Adequate Intake (AI) for *Total Fiber* in foods is set at 38 and 25 g/d for young men and women, respectively, based on the intake level observed to protect against coronary heart disease. Median intakes of *Dietary Fiber* ranged from 16.5 to 17.9 g/d for men and 12.1 to 13.8 g/d for women (Appendix Table E-4). There was insufficient evidence to set a Tolerable Upper Intake Level (UL) for *Dietary Fiber* or *Functional Fiber*.

BACKGROUND INFORMATION

Overview

Definitions of Fiber

A variety of definitions of fiber exist worldwide (IOM, 2001). Some are based solely on one or more analytical methods for isolating fiber, while others are physiologically based. For instance, in the United States fiber is defined by a number of analytical methods that are accepted by the Association of Official Analytical Chemists International (AOAC); these methods isolate nondigestible animal and plant carbohydrates. In Canada, however, a formal definition has been in place that recognizes nondigestible food of plant origin—but not of animal origin—as fiber. As nutrition labeling becomes uniform throughout the world, it is recognized that a single definition of fiber may be needed. Furthermore, new products are being developed or isolated that behave like fiber, yet do not meet the traditional definitions of fiber, either analytically or physiologically.

Without an accurate definition of fiber, compounds can be designed or isolated and concentrated using available methods without necessarily providing beneficial health effects, which most people consider to be an important attribute of fiber. Other compounds can be developed that are nondigestible and provide beneficial health effects, yet do not meet the current U.S. definition based on analytical methods. For these reasons, the Food and Nutrition Board, under the oversight of the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, assembled a Panel on the Definition of Dietary Fiber to develop a proposed definition of fiber (IOM, 2001). Based on the panel's deliberations, consideration of public comments, and subsequent modifications, the following definitions have been developed:

Dietary Fiber consists of nondigestible carbohydrates and lignin that are intrinsic and intact in plants.
Functional Fiber consists of isolated, nondigestible carbohydrates that have beneficial physiological effects in humans.
Total Fiber is the sum of *Dietary Fiber* and *Functional Fiber*.

This two-pronged approach to define edible, nondigestible carbohydrates recognizes the diversity of carbohydrates in the human food supply that are not digested: plant cell wall and storage carbohydrates that predominate in foods, carbohydrates contributed by animal foods, and isolated and low molecular weight carbohydrates that occur naturally or have been synthesized or otherwise manufactured. These definitions recognize a continuum of carbohydrates and allow for flexibility to incorporate new fiber

sources developed in the future (after demonstration of beneficial physiological effects in humans). While it is not anticipated that the new definitions will significantly impact recommended levels of intake, information on both *Dietary Fiber* and *Functional Fiber* will more clearly delineate the source of fiber and the potential health benefits. Although sugars and sugar alcohols could potentially be categorized as *Functional Fibers,* for labeling purposes they are not considered to be *Functional Fibers* because they fall under "sugars" and "sugar alcohols" on the food label.

Distinguishing Features of Dietary Fiber Compared with Functional Fiber

Dietary Fiber consists of nondigestible food plant carbohydrates and lignin in which the plant matrix is largely intact. Specific examples are provided in Table 7-1. Nondigestible means that the material is not digested and absorbed in the human small intestine. Nondigestible plant carbohydrates in foods are usually a mixture of polysaccharides that are integral components of the plant cell wall or intercellular structure. This definition recognizes that the three-dimensional plant matrix is responsible for some of the physicochemical properties attributed to *Dietary Fiber.* Fractions of plant foods are considered *Dietary Fiber* if the plant cells and their three-dimensional interrelationships remain largely intact. Thus, mechanical treatment would still result in intact fiber. Another distinguishing feature of *Dietary Fiber* sources is that they contain other macronutrients (e.g., digestible carbohydrate and protein) normally found in foods. For example, cereal brans, which are obtained by grinding, are anatomical layers of the grain consisting of intact cells and substantial amounts of starch and protein; they would be categorized as *Dietary Fiber* sources.

TABLE 7-1 Characteristics of *Dietary Fiber*

Characteristic	Dietary Fiber
Nondigestible animal carbohydrate	No
Carbohydrates not recovered by alcohol precipitation[a]	Yes
Nondigestible mono- and disaccharides and polyols	No
Lignin	Yes
Resistant starch	Some
Intact, naturally occurring food source only	Yes
Resistant to human enzymes	Yes
Specifies physiological effect	No

[a] Includes inulin, oligosaccharides (3–10 degrees of polymerization), fructans, polydextrose, methylcellulose, resistant maltodextrins, and other related compounds.

Resistant starch that is naturally occurring and inherent in a food or created during normal processing of a food, as is the case for flaked corn cereal, would be categorized as *Dietary Fiber*. Examples of oligosaccharides that fall under the category of *Dietary Fiber* are those that are normally constituents of a *Dietary Fiber* source, such as raffinose, stachyose, and verbacose in legumes, and the low molecular weight fructans in foods, such as Jerusalem artichoke and onions.

Functional Fiber consists of isolated or extracted nondigestible carbohydrates that have beneficial physiological effects in humans. *Functional Fibers* may be isolated or extracted using chemical, enzymatic, or aqueous steps. Synthetically manufactured or naturally occurring isolated oligosaccharides and manufactured resistant starch are included in this definition. Also included are those naturally occurring polysaccharides or oligosaccharides usually extracted from their plant source that have been modified (e.g., to a shorter polymer length or to a different molecular arrangement). Although they have been inadequately studied, animal-derived carbohydrates such as connective tissue are generally regarded as nondigestible. The fact that animal-derived carbohydrates are not of plant origin forms the basis for including animal-derived, nondigestible carbohydrates in the *Functional Fiber* category. Isolated, manufactured, or synthetic oligosaccharides of three or more degrees of polymerization are considered to be *Functional Fiber*. Nondigestible monosaccharides, disaccharides, and sugar alcohols are not considered to be *Functional Fibers* because they fall under "sugars" or "sugar alcohols" on the food label. Also, rapidly changing lumenal fluid balance resulting from large amounts of nondigestible mono- and disaccharides or low molecular weight oligosaccharides, such as that which occurs when sugar alcohols are consumed, is not considered a mechanism of laxation for *Functional Fibers*.

Rationale for Definitions

Nondigestible carbohydrates are frequently isolated to concentrate a desirable attribute of the mixture from which it was extracted. Distinguishing a category of *Functional Fiber* allows for the desirable characteristics of such components to be highlighted. In the relatively near future, plant and animal synthetic enzymes may be produced as recombinant proteins, which in turn may be used in the manufacture of fiber-like materials. The definition will allow for the inclusion of these materials and will provide a viable avenue to synthesize specific oligosaccharides and polysaccharides that are part of plant and animal tissues.

In summary, one definition has been proposed for *Dietary Fiber* because many other substances in high fiber foods, including a variety of vitamins and minerals, often have made it difficult to demonstrate a significant

health benefit specifically attributable to the fiber in foods. Thus, it is difficult to separate out the effect of fiber per se from the high fiber food. Attempts have been made to do this, particularly in epidemiological studies, by controlling for other substances in those foods, but these attempts were not always successful. The advantage, then, of adding isolated nondigestible carbohydrates as a fiber source to a food is that one may be able to draw conclusions about *Functional Fiber* itself with regard to its physiological role rather than that of the vehicle in which it is found. The proposed definitions do not preclude research directed towards the health benefits of *Dietary Fiber* in foods, but it is not necessary to demonstrate a physiological effect in order for a food fiber to be listed as *Dietary Fiber*.

An important aspect of the recommended definitions is that a substance is required to demonstrate a beneficial physiological effect to be classified as *Functional Fiber*. Research has shown that extraction or isolation of a polysaccharide, usually through chemical, enzymatic, or aqueous means, can either enhance its health benefit (usually because it is a more concentrated source) or diminish the beneficial effect. These recommendations should be helpful in evaluating diet and disease relationship studies as it will be possible to classify fiber-like components as *Functional Fibers* due to their documented health benefits. Although databases are not currently constructed to delineate potential beneficial effects of specific fibers, there is no reason that this could not be accomplished in the future.

Examples of Dietary and Functional Fibers

As described in the report, *Dietary Reference Intakes: Proposed Definition of Dietary Fiber* (IOM, 2001), *Dietary Fiber* includes plant nonstarch polysaccharides (e.g., cellulose, pectin, gums, hemicellulose, β-glucans, and fibers contained in oat and wheat bran), plant carbohydrates that are not recovered by alcohol precipitation (e.g., inulin, oligosaccharides, and fructans), lignin, and some resistant starch. Potential *Functional Fibers* for food labeling include isolated, nondigestible plant (e.g., resistant starch, pectin, and gums), animal (e.g., chitin and chitosan), or commercially produced (e.g., resistant starch, polydextrose, inulin, and indigestible dextrins) carbohydrates.

How the Definitions Affect the Interpretation of This Report

The reason that a definition of fiber is so important is that what *is* or *is not* considered to be dietary fiber in, for example, a major epidemiological study on fiber and heart disease or fiber and colon cancer, could determine the results and interpretation of that study. In turn, that would affect recommendations regarding fiber intake. Clearly, the definitions described

above were developed after the studies cited in this report, which form the basis for fiber intake recommendations. However, that should not detract from the relevance of the recommendations, as the database used to measure fiber for these studies will be noted.

For example, most epidemiological studies use the U.S. Department of Agriculture (USDA) database for fiber, along with other databases and data added by the investigators for missing values (Hallfrisch et al., 1988; Heilbrun et al., 1989; Miller et al., 1983; Platz et al., 1997). Such a database represents *Dietary Fiber*, since *Functional Fibers* that serve as food ingredients contribute a minor amount to the *Total Fiber* content of foods. In 1987, the U.S. Food and Drug Administration (FDA) adopted AOAC method 985.29 for regulatory purposes to identify fiber as a mixture of nonstarch polysaccharides, lignin, and some resistant starch (FDA, 1987). Related methods that isolated the same components as AOAC method 985.29 were developed independently and accepted by AOAC and FDA in subsequent years. These methods exclude all oligosaccharides (3 to 9 degrees of polymerization) from the definition and include all polysaccharides, lignin, and some of the resistant starch that is resistant to the enzymes (protease, amylase, and amyloglucosidase) used in the AOAC methods. It is these methods that are used to measure the fiber content of foods that is entered into the USDA database.

Other epidemiological studies have assessed intake of specific high fiber foods, such as legumes, breakfast cereals, fruits, and vegetables (Hill, 1997; Thun et al., 1992). Intervention studies often use specific fiber supplements such as pectin, psyllium, and guar gum, which would, by the above definition, be considered *Functional Fibers* if their role in human health is documented. For the above reasons, the type of fiber (*Dietary*, *Functional*, or *Total Fiber*) used in the studies discussed later in this chapter is identified.

Description of the Common Dietary and Functional Fibers

Below is a description of the *Dietary Fibers* that are most abundant in foods and the *Functional Fibers* that are commonly added to foods or provided as supplements. To be classified as a *Functional Fiber* for food labeling purposes, a certain level of information on the beneficial physiological effects in humans will be needed. For some of the known beneficial effects of *Dietary* and potential *Functional Fibers*, see "Physiological Effects of Isolated and Synthetic Fibers" and "Evidence Considered for Estimating the Requirement for *Dietary Fiber* and *Functional Fiber*."

Cellulose. Cellulose, a polysaccharide consisting of linear β-(1,4)–linked glucopyranoside units, is the main structural component of plant cell walls.

Humans lack digestive enzymes to cleave β-(1,4) linkages and thus cannot absorb glucose from cellulose. Powdered cellulose is a purified, mechanically disintegrated cellulose obtained as a pulp from wood or cotton and is added to food as an anticaking, thickening, and texturizing agent. Dietary cellulose can be classified as *Dietary Fiber* or *Functional Fiber,* depending on whether it is naturally occurring in food (*Dietary Fiber*) or added to foods (*Functional Fiber*).

    Chitin and Chitosan. Chitin is an amino-polysaccharide containing β-(1,4) linkages as is present in cellulose. Chitosan is the deacetylated product of chitin. Both chitin and chitosan are found in the exoskeletons of arthropods (e.g., crabs and lobsters) and in the cell walls of most fungi. Neither chitin nor chitosan is digested by mammalian digestive enzymes. Chitin and chitosan are primarily consumed as a supplement and potentially can be classified as *Functional Fibers* if sufficient data on physiological benefits in humans are documented.

    β-*Glucans.* β-glucans are homopolysaccharides of branched glucose resides. These β-linked D-glucopyranose polymers are constituents of fungi, algae, and higher plants (e.g., barley and oats). Naturally occurring β-glucans can be classified as *Dietary Fibers*, whereas added or isolated β-glucans are potential *Functional Fibers*.

    Gums. Gums consist of a diverse group of polysaccharides usually isolated from seeds and have a viscous feature. Guar gum is produced by the milling of the endosperm of the guar seed. The major polysaccharide in guar gum is galactomannan. Galactomannans are highly viscous and are therefore used as food ingredients for their thickening, gelling, and stabilizing properties. Gums in the diet can be classified as *Dietary* or *Functional Fibers.*

    Hemicelluloses. Hemicelluloses are a group of polysaccharides found in plant cell walls that surround cellulose. These polymers can be linear or branched and consist of glucose, arabinose, mannose, xylose, and galacturonic acid. Dietary hemicelluoses are classified as *Dietary Fibers.*

    Inulin, Oligofructose, and Fructooligosaccharides. Inulin and oligofructose are naturally occurring in a variety of plants. Most of the commercially available inulin and oligofructose is either synthesized from sucrose or extracted and purified from chicory roots. Oligofructose is also formed by partial hydrolysis of inulin. Inulin is a polydisperse β-(2,1)-linked fructan with a glucose molecule at the end of each fructose chain. The chain length is usually 2 to 60 units, with an average degree of polymerization of

ten. The β-(2,1) linkage is resistant to enzymatic digestion. Synthetic oligofructose contains β-(2,1) fructose chains with and without terminal glucose units. The chain ranges from two to eight monosaccharide residues. Synthetic fructooligosaccharides have the same chemical and structural composition as oligofructose, except that the degree of polymerization ranges from two to four. Because many current definitions of dietary fiber are based on methods involving ethanol precipitation, oligosaccharides and fructans that are endogenous in foods, but soluble in ethanol, are not analyzed as dietary fiber. Thus, the USDA database does not currently include these fiber sources. With respect to the definitions outlined in this chapter, the naturally occurring fructans that are found in plants, such as chicory, onions, and Jerusalem artichoke, would be classified as *Dietary Fibers*; the synthesized or extracted fructans could be classified as *Functional Fibers* when there are sufficient data to show positive physiological effects in humans.

Lignin. Lignin is a highly branched polymer comprised of phenyl-propanoid units and is found within "woody" plant cell walls, covalently bound to fibrous polysaccharides (*Dietary Fibers*). Although not a carbohydrate, because of its association with *Dietary Fiber*, and because it affects the physiological effects of *Dietary Fiber*, lignin is classified as a *Dietary Fiber* if it is relatively intact in the plant. Lignin isolated and added to foods could be classified as *Functional Fiber* given sufficient data on positive physiological effects in humans.

Pectins. Pectins, which are found in the cell wall and intracellular tissues of many fruits and berries, consist of galacturonic acid units with rhamnose interspersed in a linear chain. Pectins frequently have side chains of neutral sugars, and the galactose units may be esterified with a methyl group, a feature that allows for its viscosity. While fruits and vegetables contain 5 to 10 percent naturally occurring pectin, pectins are industrially extracted from citrus peels and apple pomace. Isolated, high methoxylated pectins are mainly added to jams due to their gelling properties with high amounts of sugar. Low methoxylated pectins are added to low-calorie gelled products, such as sugar-free jams and yogurts. Thus, pectins in the diet are classified as *Dietary* and/or *Functional Fiber*.

Polydextrose. Polydextrose is a polysaccharide that is synthesized by random polymerization of glucose and sorbitol. Polydextrose serves as a bulking agent in foods and sometimes as a sugar substitute. Polydextrose is not digested or absorbed in the small intestine and is partially fermented in the large intestine, with the remaining excreted in the feces. Polydextrose

can potentially be classified as a *Functional Fiber* when sufficient data on physiological benefits in humans are documented.

Psyllium. Psyllium refers to the husk of psyllium seeds and is a very viscous mucilage in aqueous solution. The psyllium seed, also known as plantago or flea seed, is small, dark, reddish-brown, odorless, and nearly tasteless. *P. ovata*, known as blond or Indian plantago seed, is the species from which husk is usually derived. *P. ramosa* is known as Spanish or French psyllium seed. Psyllium, also known as ispaghula husk, may be classified as a *Functional Fiber.*

Resistant Dextrins. Indigestible components of starch hydrolysates, as a result of heat and enzymatic treatment, yield indigestible dextrins that are also called resistant maltodextrins. Unlike gums, which have a high viscosity that can lead to problems in food processing and unpleasant organoleptic properties, resistant maltodextrins are easily added to foods and have a good mouth feel. Resistant maltodextrins are produced by heat/acid treatment of cornstarch, followed by enzymatic (amylase) treatment. The average molecular weight of resistant maltodextrins is 2,000 daltons and consists of polymers of glucose containing α-(1-4) and α-(1-6) glucosidic bonds, as well as 1-2 and 1-3 linkages. Resistant dextrins can potentially be classified as *Functional Fibers* when sufficient data on physiological benefits in humans are documented.

Resistant Starch. Resistant starch is naturally occurring, but can also be produced by the modification of starch during the processing of foods. Starch that is included in a plant cell wall and thus physically inaccessible to α-amylase is called RS_1. Native starch that can be made accessible to the enzyme by gelatinization is called RS_2. Resistant starch that is formed during processing is called RS_3 or RS_4 and is considered to be fiber that is isolated rather than intact and naturally occurring. RS_3 (retrograded starch) is formed from the cooking and cooling or extrusion of starchy foods (e.g., potato chips and cereals). RS_4 (chemically modified starch) includes starch esters, starch ethers, and cross-bonded starches that have been produced by the chemical modification of starch. RS_3 and RS_4 are not digested by mammalian intestinal enzymes and are partly fermented in the colon (Cummings et al., 1996; Englyst et al., 1992). Resistant starch is estimated to be approximately 10 percent (2 to 20 percent) of the amount of starch consumed in the Western diet (Stephen et al., 1983). Thus, RS_1 and RS_2 are classified as *Dietary Fibers*, and RS_3 and RS_4 may be classified as *Functional Fibers.*

Physiology of Absorption, Metabolism, and Excretion

By definition, *Dietary Fiber* and *Functional Fiber* are not digested by mammalian enzymes. Therefore, they pass into the large intestine relatively intact. Along the gastrointestinal tract, properties of fiber result in different physiological effects.

Effect on Gastric Emptying and Satiety

Consumption of viscous fibers delays gastric emptying (Low, 1990; Roberfroid, 1993) and expands the effective unstirred layer, thus slowing the process of absorption once in the small intestine (Blackburn et al., 1984). This in turn can cause an extended feeling of fullness (Bergmann et al., 1992). A slower emptying rate means delayed digestion and absorption of nutrients (Jenkins et al., 1978; Ritz et al., 1991; Roberfroid, 1993; Truswell, 1992), resulting in decreased absorption of energy (Heaton, 1973). For example, Stevens and coworkers (1987) showed an 11 percent reduction in energy intake with psyllium gum intake. Postprandial glucose concentration in the blood is thus lower after the consumption of viscous fiber than after consumption of digestible carbohydrate alone (Benini et al., 1995; Holt et al., 1992; Leathwood and Pollet, 1988). The extended presence of nutrients in the upper small intestine may promote satiety (Sepple and Read, 1989).

Fermentation

Fibers may be fermented by the colonic microflora to carbon dioxide, methane, hydrogen, and short-chain fatty acids (primarily acetate, propionate, and butyrate). Foods rich in hemicelluloses and pectins, such as fruits and vegetables, contain *Dietary Fiber* that is more completely fermentable than foods rich in celluloses, such as cereals (Cummings, 1984; Cummings and Englyst, 1987; McBurney and Thompson, 1990). There appears to be no relationship between the level of *Dietary Fiber* intake and fermentability up to very high levels (Livesey, 1990). Resistant starch is highly fermentable (van Munster et al., 1994). Butyrate, a four-carbon, short-chain fatty acid, is the preferred energy source for colon cells (Roediger, 1982), and lack of butyrate production, absorption, or metabolism is thought by some to contribute to ulcerative colitis (Roediger, 1980; Roediger et al., 1993). Others have suggested that butyrate may be protective against colon cancer (see "*Dietary Fiber* and the Prevention of Colon Cancer"). However, the relationship between butyrate and colon cancer is controversial and the subject of ongoing investigation (Lupton, 1995).

Contribution of Fiber to Energy

When a metabolizable carbohydrate is absorbed in the small intestine, its energy value is 16.7 kJ/g (4 kcal/g); when fiber is anaerobically fermented by colonic microflora in the large intestine, short-chain fatty acids (e.g., butyrate, acetate, and propionate) are produced and absorbed as an energy source. Once absorbed into the colon cells, butyrate can be used as an energy source by colonocytes (Roediger, 1982); acetate and propionate travel through the portal vein to the liver, where propionate is then utilized by the liver. Acetate can be metabolized peripherally. A small proportion of energy from fermented fiber is used for bacterial growth and maintenance, and bacteria are excreted in feces, which also contain short-chain fatty acids (Cummings and Branch, 1986). Differences in food composition, patterns of food consumption, the administered dose of fiber, the metabolic status of the individual (e.g., obese, lean, malnourished), and the digestive capability of the individual influence the digestible energy consumed and the metabolizable energy available from various dietary fibers. Because the process of fermentation is anaerobic, less energy is recovered from fiber than the 4 kcal/g that is recovered from carbohydrate. While it is still unclear as to the energy yield of fibers in humans, current data indicate that the yield is in the range of 1.5 to 2.5 kcal/g (Livesey, 1990; Smith et al., 1998).

Physiological Effects of Isolated and Synthetic Fibers

This section summarizes the fibers for which there is a sufficient database that documents their beneficial physiological human effects, which is the rationale for categorizing them as *Functional Fibers*. It is important to note that discussions on the potential benefits of what might eventually be classified as *Functional Fibers* should not be construed as endorsements of those fibers. While plant-based foods are a good source of *Dietary Fiber*, isolated or synthetic fibers have been developed for their use as food ingredients and because of their beneficial role in human health. In 1988 Health Canada published guidelines for what they considered to be "novel fiber sources" and food products containing them that could be labeled as a source of fiber in addition to those included in their 1985 definition (Health Canada, 1988). The rationale for these guidelines was that there were safety issues unique to novel sources of fiber, and if a product was represented as containing fiber, it should have the beneficial physiological effects associated with dietary fiber that the public expects. The guidelines indicated that both safety and efficacy of the fiber source had to be established in order for the product to be identified as a source of dietary fiber in Canada, and this had to be done through experiments using humans.

Three measures of efficacy were identified: (1) laxation, (2) normalization of blood lipid concentrations, and (3) attenuation of blood glucose responses. Detailed guidelines were later produced for the clinical studies required to assess laxation effects, as this was the physiological function most often used by industry when seeking approval for a novel fiber source (Health Canada, 1997). For each of the fiber sources discussed below, studies will be summarized that relate to one of the three measures of efficacy identified by Health Canada, as these are the three most commonly accepted beneficial effects of fibers. A more complete discussion of these three measures of efficacy may be found later in this chapter. In addition, other potentially efficacious effects will be noted where studies are available.

As interest has increased in fiber, manufacturers have isolated various types of fiber from a wide range of carbohydrate sources added to foods. Many of these isolated materials are used as food additives based on functional properties such as thickening or fat reduction. As enzymatic and other technologies evolve, many types of polysaccharides will continue to be designed and manufactured using plant and animal synthetic enzymes. Examples in this category include modified cellulose, in which the hydroxyl groups on the glucose residues have been substituted to varying degrees with alkyl groups such as methyl and propyl; fructooligosaccharides manufactured from sucrose; and polydextrose synthesized from glucose. In some instances, fibers isolated from plants or manufactured chemically or synthetically have demonstrated more powerful beneficial physiological effects than a food source of the fiber polysaccharide.

Cellulose

Laxation. From a meta-analysis of about 100 studies of changes in stool weight with various fiber sources, investigators have calculated the increase in fecal weight due to fiber ingestion (Cummings, 1993). As noted later in this chapter, an increase in fecal weight does not necessarily equate with enhanced laxation, so this needs to be considered in interpreting the results of fecal bulking studies. Cellulose was shown to increase fecal bulk by 3 g/g of cellulose fed. This is lower than that achieved by bran (5.7 g/g of bran), but higher than that of isolated, fermentable fibers such as pectin (1.3 g/g of pectin) (Cummings, 1993). In a randomized, crossover study designed to compare the effects of supplemental pectin (12 g/d), cellulose (15 g/d), and lignin (12 g/d) on stool characteristics of healthy volunteers, cellulose was the only fiber that significantly decreased (–27 percent) mean stool transit time and increased mean wet stool weight (+57 percent) (Hillman et al., 1983).

Normalization of Blood Lipid Concentrations. Cellulose is often used as the placebo in studies designed to test the efficacy of fibers on decreasing serum cholesterol concentrations. Cellulose is either neutral with respect to blood cholesterol concentrations (Hillman et al., 1985; Niemi et al., 1988) or, in some studies, it actually shows a slight increase (Anderson et al., 1999).

Attenuation of Blood Glucose Responses. Similar to the relationship between cellulose and serum cholesterol concentrations, cellulose is also often used as a placebo in studies that evaluate the effect of fiber on blood glucose and insulin concentrations. Cellulose is ineffective in decreasing the postprandial glucose response (Librenti et al., 1992; Niemi et al., 1988).

Chitin and Chitosan

Laxation. There is no evidence that chitin or chitosan function as laxatives in humans.

Normalization of Blood Lipid Concentrations. There are a number of animal studies that have suggested that chitin and chitosan may decrease lipid absorption and thus the amount of fat entering the blood (Gallaher et al., 2000; Razdan and Pettersson, 1994; Sugano et al., 1980; Zacour et al., 1992). Therefore, blood cholesterol and triacylglycerol concentrations have been shown to be reduced with chitosan intake in animals (Chiang et al., 2000; Jennings et al., 1988; Razdan and Pettersson, 1994, 1996; Razdan et al., 1997).

These results, however, have not always been observed in controlled intervention trials with humans. When adult volunteers were given 2.7 g of chitosan for 7 days, there was no effect on fecal fat excretion (Guerciolini et al., 2001). When 2.4 g of chitosan was consumed daily by women, a significant reduction in low density lipoprotein (LDL) cholesterol concentration was observed (Wuolijoki et al., 1999). More intervention studies are needed to further understand the role of chitin and chitosan in the attenuation of blood lipid concentration in humans.

Attenuation of Blood Glucose Responses. There are no known reports in humans on chitin or chitosan intake and the attenuation of blood glucose responses.

Other Potential Physiological Effects. Because chitosan has been shown in some animal studies to reduce fat absorption, it has been proposed that chitosan intake can aid in weight reduction. When rats were fed up to

5 percent of their diet as chitosan, there was no effect on weight gain (Jennings et al., 1988; Sugano et al., 1980). Significantly reduced body weights were observed when chickens were fed 30 g/kg of chitosan (Razdan et al., 1997). There was no change in body weight in women consuming 2.4 g/d of chitosan for 8 weeks (Wuolijoki et al., 1999). Furthermore, no change in body weight was observed in women who consumed 2 g/d of chitosan for 28 days (Pittler et al., 1999). Similarly, in a study of 88 obese Asians, Ho and colleagues (2001) found no effect of chitosan supplementation (3 g/d) on weight, body mass index, or lean body mass compared to placebo.

Guar Gum

Laxation. As a viscous, highly fermentable fiber, guar gum has little effect on fecal bulk or laxation (Slavin, 1987).

Normalization of Blood Lipid Concentrations. Jenkins and coworkers (1975) reported the hypocholesterolemic effect of guar gum, which is often added to foods. Since 1975 there have been a number of studies with guar gum supplementation and findings of an 11 to 16 percent reduction in serum cholesterol concentration (Anderson and Tietyen-Clark, 1986; Penagini et al., 1986). For example, when type 2 diabetics were provided guar gum (21 g/d) for 3 months, the mean serum total and LDL cholesterol concentrations were significantly lower than controls (Aro et al., 1981). Furthermore, hypercholesterolemic men who received 15 g/d of guar gum had significantly lower serum total cholesterol and LDL cholesterol concentrations compared to the placebo controls after 6 weeks (Aro et al., 1984). Blake and coworkers (1997) evaluated the effect of depolymerized guar galactomannan on fasting plasma lipid concentrations in volunteers with moderately raised plasma cholesterol. There were significant reductions in plasma total cholesterol (9.7 percent) and LDL cholesterol (11 percent) concentrations after the guar treatment ($p < 0.001$). In addition to decreasing blood cholesterol concentrations, guar gum has also been shown to decrease concentrations of triacylglycerols (Bosello et al., 1984), as well as systolic and diastolic blood pressure (Krotkiewski, 1987).

Attenuation of Blood Glucose Responses. Viscous fibers, such as pectin and guar gum and those present in oat products and beans, produced significant reductions in glycemic response in 33 of 50 studies (66 percent) as reviewed in Wolever and Jenkins (1993). This is in contrast to only 3 of 14 studies conducted with insoluble fiber (21 percent). For example, when individuals with type 2 diabetes were given 21 g/d of guar gum,

there was a significant reduction in both basal and postprandial hyperglycemia compared to the placebo controls (Aro et al., 1981). In addition, the provision of 30 g/d of guar gum decreased fasting blood glucose concentration and increased insulin sensitivity (Landin et al., 1992).

In a dose–response study to determine the amount of guar gum needed to decrease postprandial glycemia and insulinemia, guar gum was supplied at 0, 2.9, 6.0, and 9.1 g/d in the form of biscuits to eight nondiabetics (Ellis et al., 1988). A reduction of 209 mU/min/L in the integrated insulin curve was estimated for every 1 g of guar gum incorporated into the biscuit. The addition of 10 g/d of guar gum to a test meal generated an overall decrease in blood glucose concentrations in both normal ($n = 5$) and diabetic ($n = 6$) individuals (Goulder et al., 1978).

Guar gum has also been shown to be effective when sprinkled on food. In a study with 18 type 2-diabetic patients, 5 g of guar gum granules or 5 g of wheat bran were sprinkled over food at each main meal for 4 weeks (Fuessl et al., 1987). There was a 50 percent reduction in the incremental area under the postprandial glycemic curve with the guar gum. Mean fasting plasma glucose and glycosylated hemoglobin concentrations were lower after treatment with guar gum compared with the wheat bran control.

Not all studies, however, have found a glycemic benefit from guar administration. In one study with type 2 diabetics with near-normal fasting plasma glucose concentrations, 15 g/d of guar gum did not reduce the excessive postprandial glycemic response (Holman et al., 1987). Although the mechanism for improved glycemic response seen with guar gum in most studies is not entirely clear, guar gum has been shown to increase C-peptide response over time, thus suggesting enhanced insulin secretion by guar gum (Groop et al., 1993). When the standard glucose test was performed after ingestion of 15 g/d of guar gum, improved glucose tolerance was observed in all but one pregnant women. In addition, guar gum generated significant reductions in mean serum glucose concentrations at 1, 2, and 3 hours after feeding (Gabbe et al., 1982).

Inulin, Oligofructose, and Fructooligosaccharides

Laxation. A few studies have demonstrated an increase in fecal bulk and increased stool frequency upon the ingestion of inulin or oligofructose. Fecal weight was increased after consuming 15 g/d of inulin or oligofructose (Gibson et al., 1995), and inulin (20 to 40 g/d) was shown to reduce constipation (Kleessen et al., 1997). A multicenter trial was conducted to test whether fructooligosaccharides worsen gastrointestinal symptoms in people with irritable bowel syndrome (Olesen and Gudmand-

Høyer, 2000). After 2 to 6 weeks of treatment with 20 g/d of fructo-oligosaccharides or placebo, symptoms of irritable bowel syndrome improved more in the placebo group than in the fructooligosaccharide group; however, there was no difference between the groups after continuous treatment for 12 weeks.

Normalization of Blood Lipid Concentrations. Studies on the effect of inulin or oligofructose ingestion on plasma lipid concentrations have provided mixed results. Significant reductions in plasma triacylglycerol concentrations occurred with the intake of 10 g/d of inulin, particularly in those individuals with a baseline triacylglycerol concentration greater than 1.5 mmol/L (Jackson et al., 1999). The ingestion of 9 g/d of inulin significantly reduced plasma total cholesterol and triacylglycerol concentrations in young men (Brighenti et al., 1999). Nonsignificant changes in plasma total or high density lipoprotein (HDL) cholesterol and triacylglycerol concentrations were reported for individuals consuming 14 g/d of inulin (Pedersen et al., 1997) or 20 g/d of fructooligosaccharide (Luo et al., 1996). In young, healthy males, 15 g/d of nondigestible oligosaccharides (inulin or fructooligosaccharides) did not decrease blood lipids or affect glucose absorption compared to controls (van Dokkum et al., 1999).

Attenuation of Blood Glucose Responses. A placebo-controlled parallel study showed that a daily intake of 10 g of inulin significantly reduced fasting insulin concentrations (Jackson et al., 1999). Fasting blood glucose concentrations were significantly reduced by 15 mg/dL in type 2 diabetics who were fed 8 g/d of fructooligosaccharides (Yamashita et al., 1984). Daily intake of 20 g of fructooligosaccharides significantly decreased basal hepatic glucose production (Luo et al., 1996). No difference, however, was observed in the incremental area under the curve for glucose when individuals were fed 50 g of a rice-based cereal containing 0 or 9 g of inulin (Brighenti et al., 1999).

Other Potential Physiological Effects. An important effect of inulin intake is considered to be the production of *Bifidobacteria*. *Bifidobacteria* contain high amounts of β-fructosidase, which are specific for the β-(1,2) bond present in inulin and oligofructose. A number of studies in humans have shown that the ingestion of fructooligosaccharides leads to an increase in fecal *Bifidobacteria* (Bouhnik et al., 1996, 1999; Buddington et al., 1996; Tuohy et al., 2001; Williams et al., 1994). *Bifidobacteria* have been shown to promote beneficial health effects in animals (Grizard and Barthomeuf, 1999); however, potential beneficial effects in humans are not well understood.

Oat Products and β-Glucans

Laxation. Extracted β-glucans are highly fermentable and therefore their contribution to fecal bulk is minimal (McBurney, 1991). This may contribute, in part, to the lack of an effect in preventing constipation. Oat bran increases stool weight by supplying rapidly fermented viscous fiber to the proximal colon for bacterial growth (Chen et al., 1998).

Normalization of Blood Lipid Concentrations. In one study, oat gum supplementation (9 g/d of β-glucan) did not significantly decrease serum total cholesterol concentration compared to the placebo, leading the authors to conclude that the cholesterol-lowering capacity of oat gum in healthy young men is weak (Beer et al., 1995). In contrast, when hyper-cholesterolemic individuals were fed oat gum providing 5.8 g/d of β-glucan or a maltodextrin placebo for 4 weeks, mean total and LDL cholesterol concentrations decreased throughout the oat gum phase, and both concentrations were reduced 9 percent relative to initial values (Braaten et al., 1994b). In a larger study, adults with multiple risk factors and LDL cholesterol concentrations above 4.14 mmol/L or between 3.37 and 4.14 mmol/L were randomized to one of seven groups to receive either oatmeal or oat bran at various levels or a placebo control (Davidson et al., 1991). There was a dose-dependent reduction in LDL cholesterol concentrations with the oat cereals. However, when a modest level of β-glucan (3 g/d) was provided to 62 healthy adults with mild to moderate hyperlipidemia, there was no significant reduction in plasma total or LDL cholesterol concentrations (Lovegrove et al., 2000).

Oat bran concentrate has been incorporated into bread products. The long-term effects of such products were tested in men with type 2 diabetes (Pick et al., 1996). Total plasma and LDL cholesterol concentrations were lower in the oat bran concentrate period (9 g/d of viscous fiber) than in the white bread period.

Attenuation of Blood Glucose Responses. In one study, individuals with type 2 diabetes were fed meals containing wheat farina, wheat farina with oat gum, or oat bran (Braaten et al., 1994a). Both the oat bran and wheat farina with oat gum meals reduced the postprandial rise in plasma glucose and insulin concentrations compared to the wheat farina meal without the oat gum. This is an example of the extracted form of oat bran (*Functional Fiber*) having a similar effect to the native form (*Dietary Fiber*). Oat gum has also been compared to guar gum with respect to glucose and insulin responses after an oral glucose load in healthy, fasting individuals (Braaten et al., 1991). In this study, the glucose and insulin responses to the oat and guar gum meals were nearly identical. In addition, both gum meals

resulted in increases in plasma glucose and insulin concentrations that were lower than glucose alone ($p < 0.01$). Hallfrisch and colleagues (1995) studied glucose responses in 16 women and 7 men with moderately high cholesterol concentrations who supplemented their normal diets with oat extracts in which either 1 or 10 percent viscous β-glucans were added. Glucose responses were reduced at both the 1 and 10 percent β-glucan supplementation level.

Pectin

Laxation. In a meta-analysis of approximately 100 studies on stool weight changes with various fiber sources, investigators were able to calculate the increase in fecal weight due to fiber ingestion (Cummings, 1993). This meta-analysis concluded that pectin ingestion leads to an increase of about 1.3 g of stool/g of pectin as compared to 5.4 g/g produced from wheat bran, suggesting that pectin is not an important fecal bulking agent (Cummings, 1993). In a randomized crossover study designed to compare the effects of pectin (12 g/d), cellulose (15 g/d), and lignin (12 g/d) on stool characteristics in healthy volunteers, pectin did not alter transit time or increase 24-hour stool wet weight, whereas cellulose decreased mean stool transit time and increased mean wet stool weight (Hillman et al., 1983).

Normalization of Blood Lipid Concentrations. Pectin has been tested in a number of studies for its hypocholesterolemic effect. For example, in a 16-week, double-blind crossover study, grapefruit pectin supplementation decreased plasma cholesterol concentration by 7.6 percent and LDL cholesterol concentration by 10.8 percent in individuals at moderate to high risk of coronary heart disease (Cerda et al., 1988). When 12 g/d of pectin was taken with meals for 3 weeks, there was a mean decrease in total serum cholesterol concentration of 0.48 ± 0.18 mmol/L (Durrington et al., 1976). This decrease was mainly due to a reduction in LDL cholesterol concentration. When 15 g/d of citrus pectin was provided in metabolically controlled diets for 3 weeks, plasma cholesterol concentrations were reduced by 13 percent and fecal fat excretion increased by 44 percent; however, plasma triacylglycerol concentrations did not change (Kay and Truswell, 1977). Gold and coworkers (1980) did not observe reductions in serum cholesterol concentrations following the consumption of 10 g of pectin with 100 g of glucose. The consumption of 7.2 g/d of psyllium that had been added to foods did not result in a significant decrease in LDL cholesterol concentration. However, total cholesterol and triacylglycerol concentrations were significantly decreased (Jenkins et al., 2002).

There is some documentation that the hypocholesterolemic effects of pectin are due to increased excretion of bile acids and cholesterol. Supplementation with 15 g of pectin increased bile acid excretion by 35 percent and net cholesterol excretion by 14 percent in ileostomy patients, whereas 16 g of wheat bran produced no significant changes (Bosaeus et al., 1986).

Attenuation of Blood Glucose Responses. Viscous fibers such as pectin have been found to produce a significant reduction in glycemic response in 33 of 50 studies (66 percent) (Wolever and Jenkins, 1993). This is in contrast to only 3 of 14 studies with insoluble fiber (21 percent).

Polydextrose

Laxation. Polydextrose has been shown to increase fecal mass and sometimes stool frequency. Tomlin and Read (1988) showed that 30 g/d of polydextrose increased fecal mass without affecting transit time and stool frequency. Achour and coworkers (1994) observed no significant changes in fecal weight or transit time when seven men consumed 30 g/d of polydextrose. When 4, 8, or 12 g/d of polydextrose was provided, fecal weight increased and ease and frequency of defecation improved in a dose–response manner (Jie et al., 2000).

Findings on the effect of polydextrose intake on fecal bacterial production are mixed. Achour and colleagues (1994) reported no changes in bacterial mass in the feces of individuals who consumed 30 g/d of polydextrose. This lack of difference may be explained, in part, by the findings of Jie and coworkers (2000). Following the ingestion of 4, 8, or 12 g/d of polydextrose ($n = 30$ treatment), there was a dose-dependent decrease in *Bacteriodes*, whereas the beneficial *Lactobacillus* and *Bifidobacteria* species increased.

Normalization of Blood Lipid Concentrations. Sixty-one healthy volunteers received 15 g/d of polydextrose for 2 months. Serum concentrations of total cholesterol, triacylglycerols, and LDL cholesterol did not change during this period; however, concentrations of HDL cholesterol decreased (Saku et al., 1991).

Psyllium

Laxation. Psyllium is the active ingredient in laxatives, and thus from an over-the-counter drug viewpoint, there is extensive literature on its efficacy in this regard. After 8 weeks of psyllium treatment to patients with

idiopathic constipation, both stool frequency and stool weight increased significantly, stool consistency improved, and pain on defecation was reduced (Ashraf et al., 1995). The authors concluded that the beneficial effects of psyllium with regard to constipation are largely related to a facilitation of the defecatory process (Ashraf et al., 1995). Similarly, psyllium was tested in a multisite study of 170 individuals with chronic idiopathic constipation for 2 weeks (McRorie et al., 1998). Psyllium increased stool water content, stool water weight, total stool output, bowel movement frequency, and a score combining objective measures of constipation. Four months of psyllium treatment significantly improved bowel function and fecal output in 12 elderly patients (Burton and Manninen, 1982). In a multicenter trial with 394 individuals, psyllium improved bowel function better than other laxatives (mainly lactulose), with superior stool consistency and decreased incidence of adverse events (Dettmar and Sykes, 1998). Prior and Whorwell (1987) tested psyllium (ispaghula husk) in 80 patients with irritable bowel syndrome and found that constipation was significantly improved and transit time decreased in patients taking psyllium.

Normalization of Blood Lipid Concentrations. A number of studies have been conducted to ascertain the beneficial effects of psyllium on blood lipid concentrations. Several of these studies provided 10.2 g/d of psyllium for up to 26 weeks and all showed marked reductions in serum total and LDL cholesterol concentrations compared to cellulose (Anderson et al., 1988, 1999, 2000b; Levin et al., 1990). The dose–response effect of psyllium at 0, 3.4, 6.8, or 10.2 g/d was tested in a double-blind controlled study in 286 adults with LDL cholesterol concentrations between 3.36 and 5.68 mmol/L (Davidson et al., 1998). The effects of 10.2 g/d of psyllium seed husk on serum LDL cholesterol concentrations were modest, with levels 5.3 percent below that of the control group at week 24 ($p < 0.05$).

In a 3-week intervention with 21 g/d of psyllium ($n = 7$), plasma total, LDL, and HDL cholesterol concentrations were significantly reduced (Abraham and Mehta, 1988). Psyllium decreased plasma concentrations of total cholesterol by 5.6 percent and LDL cholesterol by 8.6 percent; concentrations were unchanged in the cellulose group. Serum cholesterol concentration was reduced by 20 percent in 12 elderly patients receiving psyllium supplementation (Burton and Manninen, 1982). In a large, multicenter trial conducted in the United Kingdom, 7 or 10.5 g/d of psyllium was provided to 340 patients with mild to moderate hypercholesterolemia over 12 weeks (MacMahon and Carless, 1998). After 12 weeks, LDL cholesterol concentrations decreased by 8.7 percent for the 7-g/d group and 9.7 percent for the 10.5-g/d group. After a 6-month follow-up period, psyllium combined with diet modification was shown to reduce LDL cholesterol concentrations by 10.6 to 13.2 percent and total choles-

terol concentrations by 7.7 to 8.9 percent (MacMahon and Carless, 1998). Danielsson and coworkers (1979) treated 13 patients with essential hyper-lipoproteinemia over 2 to 29 months with psyllium hydrophilic colloid. Serum cholesterol and triacylglycerol concentrations were reduced an average of 16.9 and 52.0 percent, respectively. If blood lipid concentrations were normal at baseline, no reductions were observed when individuals consumed psyllium colloid (Danielsson et al., 1979).

Studies also have been conducted using a ready-to-eat cereal enriched with psyllium. Hypercholesterolemic individuals consuming 114 g/d of a psyllium-flake cereal for 6 weeks showed significantly lower serum total and LDL cholesterol concentrations than those consuming the same amount of wheat-bran flake cereal (Anderson et al., 1992b). Similarly, Bell and coworkers (1990) tested the cholesterol-lowering effects of viscous fiber (psyllium or pectin) cereals as part of a diet in 58 men with mild to moderate hypercholesterolemia. During the cereal-plus-diet phase of the study, total and LDL cholesterol concentrations in the psyllium-enriched cereal group decreased by 5.9 and 5.7 percent, respectively.

A meta-analysis was conducted to determine the effect of consumption of psyllium-enriched cereal products on blood lipid concentrations in 404 adults with mild to moderate hypercholesterolemia consuming a low fat diet (Olson et al., 1997). Compared to the control cereals, individuals who consumed psyllium cereals had lower total and LDL cholesterol concentrations, whereas HDL cholesterol concentrations were not affected. Anderson and coworkers (2000a) conducted a meta-analysis of eight controlled trials to define the hypolipidemic effects of psyllium when used in combination with a low fat diet in hypercholesterolemic men and women. There were a total of 384 individuals receiving psyllium in the eight studies covered by the meta-analysis and these individuals were compared to those consuming cellulose (n = 272). Consumption of 10.2 g/d of psyllium (n = 384) lowered serum total cholesterol by 4 percent and serum LDL cholesterol by 7 percent, relative to the cellulose control (n = 272).

Everson and colleagues (1992) evaluated the mechanisms of the hypocholesterolemic effect of psyllium by measuring intestinal cholesterol absorption, cholesterol synthesis in isolated peripheral blood mononuclear cells, bile acid kinetics, gallbladder motility, and intestinal transit. The researchers concluded that psyllium decreases LDL cholesterol concentrations mainly by the stimulation of bile acid production.

Attenuation of Blood Glucose Responses. In an 8-week intervention study in 34 men with type 2 diabetes and hypercholesterolemia consuming either 10.2 g/d of psyllium or cellulose, daily and postlunch postprandial glucose concentration were 11.0 and 19.2 percent lower, respectively, in the psyllium group (Anderson et al., 1999). Also, psyllium has been shown to

reduce the glycemic index of foods when added to a meal (Frati-Munari et al., 1998). The effect of psyllium or placebo on postprandial serum glucose and insulin concentrations was tested in 18 type 2 diabetic patients in a crossover design (Pastors et al., 1991). Compared to placebo, postprandial glucose elevation was reduced by 14 percent at breakfast and 20 percent at dinner, and postprandial serum insulin concentration was reduced by 12 percent after breakfast. However, this depression of the normal post-prandial increase in serum glucose and insulin concentrations seen with psyllium does not appear to be due to a delay in gastric emptying (Rigaud et al., 1998).

Resistant Dextrins

Laxation. There are no human studies to support a laxative benefit from ingestion of indigestible dextrins.

Normalization of Blood Lipid Concentrations. The intake of 60 g/d of resistant maltodextrin was shown to reduce serum total cholesterol and triacylglycerol concentrations in type 2 diabetics as compared with type 2 diabetics or healthy adults who consumed 30 g/d of resistant maltodextrin (Ohkuma and Wakabayashi, 2001). No difference was observed in the concentration of HDL cholesterol.

Attenuation of Blood Glucose Responses. Reduced blood glucose concentrations and insulin secretion were observed when rats were given resistant maltodextrins after sucrose or maltose loading (Wakabayashi et al., 1993, 1995). Furthermore, an intake of 5 g of resistant maltodextrin reduced the postprandial blood glucose concentrations in healthy men and women (Tokunaga and Matsuoka, 1999). The ingestion of 60 g/d, but not 30 g/d, of resistant maltodextrin resulted in a significant reduction of fasting blood glucose concentrations in type 2 diabetics (Ohkuma and Wakabayashi, 2001).

Resistant Starch

Laxation. Increased fecal bulk due to increased starch intake has been reported (Shetty and Kurpad, 1986). The impact of resistant starch (RS_3) from a corn-based cereal on colonic function was measured in eight male volunteers (Tomlin and Read, 1990). After consuming 10.33 g/d of RS_3 for 1 week, there was no significant difference in fecal output, stool frequency, ease of defecation, whole-gut transit time, or degree of flatulence compared to an intake of 0.86 g/d of RS_3 from a rice-based cereal. A

significant increase in stool weight, however, was observed when men consumed 32 g/d RS_3 for 4 weeks (Heijnen et al., 1998). Jenkins and coworkers (1998) determined the effects of low fiber (control), wheat bran supplements providing an additional 30 g of fiber (high fiber control), or the equivalent amount of resistant starch as RS_2 or RS_3. Compared to the low fiber control, the wheat bran supplement increased fecal bulk by 96 ± 14 g/d ($p < 0.001$) and the mean for both resistant starches was 22 ± 8 g/d greater than controls ($p = 0.013$). This is consistent with the small increase in fecal bulk seen with resistant starch intake in other studies (Behall and Howe, 1996; Cummings et al., 1996; Heijnen et al., 1998; Hylla et al., 1998; Phillips et al., 1995).

Because resistant starch is partly fermented in the colon, intake may lead to increased production of short-chain fatty acids. When 39 g/d of a mixture of naturally occurring and processed resistant starch was consumed, there was a significant increase in fecal butyrate and acetate concentrations, and therefore a significant reduction in fecal pH (Phillips et al., 1995). However, when glucose or 32 g/d of RS_3 was consumed for 4 weeks, there was no difference in fecal pH, fecal short-chain fatty acid concentrations, or fecal secondary bile acid concentrations (Heijnen et al., 1998).

Normalization of Blood Lipid Concentrations. Several animal studies have demonstrated a lowering of blood cholesterol and triacylglycerol concentrations with resistant starch intake (de Deckere et al., 1993; Ranhotra et al., 1997; Younes et al., 1995). When healthy, normolipidemic individuals were given glucose or 30 g/d of RS_3 supplements for 3 weeks, there were no significant differences in fasting serum total, LDL, and HDL cholesterol concentrations or triacylglycerol concentrations (Heijnen et al., 1996). Resistant starch does not appear to provide the cholesterol-lowering effects of viscous fiber, but rather acts more like nonviscous fiber (Jenkins et al., 1998). Neither Jenkins and coworkers (1998) nor Heijnen and coworkers (1996) showed a lowering effect of resistant starch on serum lipids.

Attenuation of Blood Glucose Responses. Adding resistant starch to bread at various levels (0, 5, 10, and 20 percent) was shown to reduce the glycemic index in a dose-dependent manner (100, 96, 74, and 53) (Brown et al., 1995). The consumption of 30 g/d of RS_3 was shown to significantly reduce the urinary excretion of C-peptide, indicating reduced insulin secretion (de Roos et al., 1995).

Clinical Effects of Inadequate Intake

Dietary and *Functional Fibers* are not essential nutrients, so inadequate intakes do not result in biochemical or clinical symptoms of a deficiency. A

lack of these fibers in the diet, however, can result in inadequate fecal bulk and may detract from optimal health in a variety of different ways depending on other factors, such as the rest of the diet and the stage of the life cycle.

EVIDENCE CONSIDERED FOR ESTIMATING THE REQUIREMENT FOR *DIETARY FIBER* AND *FUNCTIONAL FIBER*

There is no biochemical assay that reflects *Dietary Fiber* or *Functional Fiber* nutritional status. Clearly one cannot measure blood fiber concentration since, by definition, fiber is not absorbed. Instead, the potential health benefits of fiber consumption, which may be compromised by a lack of fiber in the diet, have been reviewed. Throughout each section and the discussion of each indicator, a delineation is made between *Dietary Fiber* and *Functional Fiber*. It should be kept in mind that although high *Dietary Fiber* intake is associated with decreased risk or improvements in several chronic diseases, a report of the National Academy of Sciences states "there is no conclusive evidence that it is dietary fiber rather than the other components of vegetables, fruits, and cereal products that reduces the risk of those diseases" (NRC, 1989). The definition of *Dietary Fiber* in this report states that it must be "intrinsic and intact in plants." Thus, the reported benefits are due to the fiber *source*, not necessarily to the fiber per se. In contrast, *Functional Fiber* (which consists of isolated, nondigestible carbohydrates that have beneficial physiological effects in humans), by definition, must show that the beneficial physiological effect in humans is due to the isolated or synthesized fiber itself.

A number of epidemiological studies have been conducted to evaluate the relationship between fiber intake and risk of chronic disease. While *Functional Fibers*, such as pectins and gums, are added to foods as ingredients, these levels are minimal and therefore fiber intakes that are estimated from food composition tables generally represent *Dietary Fiber*.

Dietary Fiber, Functional Fiber, *and the Prevention of Hyperlipidemia, Hypertension, and Coronary Heart Disease*

Epidemiological Studies

There are no epidemiological studies that have evaluated the relationship between *Functional Fiber* and the risk of coronary heart disease (CHD). A number of epidemiological studies, however, have found reduced CHD rates in individuals consuming high amounts of *Dietary Fiber* and fiber-rich foods (Bolton-Smith et al., 1992; Fraser et al., 1992; Humble et al., 1993; Jacobs et al., 1998; Khaw and Barrett-Connor, 1987; Kushi et al., 1985;

Morris et al., 1977; Pietinen et al., 1996; Rimm et al., 1996; Todd et al., 1999; Wolk et al., 1999). For example, Fraser and colleagues (1992) reported that in a cohort of 31,208 California Seventh-day Adventists, there was a 44 percent reduced risk of nonfatal CHD and an 11 percent reduced risk of fatal CHD for those who ate whole wheat bread compared with those who ate white bread. In the Iowa Women's Health Study, Jacobs and coworkers (1998) found that the risk of CHD death was reduced by approximately one-third for women consuming one or more servings of a whole grain product each day compared with those rarely eating any whole grain products. Similarly, Morris and coworkers (1977) followed 337 men in London, England for 10 to 20 years and found that men with a high intake of cereal fiber had a lower rate of CHD than men with a low cereal fiber intake.

In the Health Professionals Follow-up Study, the relative risk for fatal coronary disease and total myocardial infarction were 0.45 and 0.59, respectively, for men in the highest quintile of *Dietary Fiber* intake (28.9 g/d) compared with the lowest quintile (12.4 g/d) (Rimm et al., 1996) (Table 7-2). Cereal fiber was more strongly associated with the reduced risk of CHD than were fiber from fruits and vegetables. Wolk and coworkers (1999) examined the relationship between intake of *Dietary Fiber* and risk of CHD in the Nurses' Health Study and found a significant inverse association, which was confined to *Dietary Fiber* from cereal sources (Table 7-2). Compared with the lowest quintile of cereal fiber intake (2.2 g/d), women in the highest quintile (7.7 g/d) had a 34 percent lower risk of total CHD. In a large cohort of 21,930 Finnish men, there was a significant inverse association between *Dietary Fiber* intake and CHD, with a multivariate relative risk of 0.84 for men in the highest quintile of intake (34.8 g/d) compared with the lowest quintile of intake (16.1 g/d) (Pietinen et al., 1996) (Table 7-2).

In summary, the large-scale, adequately powered, prospective studies all show a substantial protective effect of *Dietary Fiber* for CHD. Specifically, these three studies—which used multivariate models to control for energy, saturated fat, alcohol, body mass index, and various vitamins—showed a strong relationship between cereal fibers and a weak or no relationship between vegetable and fruit fibers. In terms of setting intake recommendations and actual numbers as a primary determinant of fiber requirements, these studies are most useful as they are adequately powered, divide *Dietary Fiber* into quintiles of intake, and provide data on energy intake (Pietinen et al., 1996; Rimm et al., 1996; Wolk et al., 1999). Using these studies, it is also possible to relate the number of grams of *Dietary Fiber* per day to the decrease in CHD incidence.

Although not reporting quintiles of intake, a fourth study by Khaw and Barrett-Connor (1987) can be considered because it showed that an

TABLE 7-2 Prospective Cohort Studies on *Dietary Fiber* Intake and Risk of Coronary Heart Disease (CHD)

Reference	Study Design	Quintile	Relative Risk for CHD
Pietinen et al., 1996	21,930 Finnish men, 50–69 y 6-y follow-up	1	1.00
		2	0.91
		3	0.88
		4	0.86
		5	0.84
			p for trend = 0.03
Rimm et al., 1996	43,757 U.S. men, 40–75 y 6-y follow-up	1	1.00
		2	0.97
		3	0.91
		4	0.87
		5	0.59
			p for trend < 0.001
Wolk et al., 1999	68,782 U.S. women, 37–64 y 10-y follow-up	1	1.00
		2	0.98
		3	0.92
		4	0.87
		5	0.77
			p for trend = 0.07

[a] *Dietary Fiber* intake is energy-adjusted to 2,000 kcals.
[b] *Dietary Fiber* intake is energy-adjusted to 1,600 kcals.

increased intake of 6 g/d of *Dietary Fiber* was associated with a 33 percent risk reduction for CHD in women and 24 percent in men, and the reduction in CHD mortality was independent of other dietary variables. The Health Professionals Follow-up Study reported a 19 percent decrease in risk for total myocardial infarction per 10-g/d increase of *Dietary Fiber* and a 29 percent decrease per 10-g/d increase of cereal fiber (Rimm et al., 1996). A similar result for women was reported by Wolk and coworkers (1999) with a 19 percent decrease in risk for total CHD events per 10-g/d increase of *Dietary Fiber*, but a stronger relationship was reported for cereal fiber (37 percent decrease per 5-g/d increase).

Dietary Fiber Intake (g/d)	Energy Intake (kcal/d)	Grams of Dietary Fiber/ 1,000 kcal
16.1	2,722	5.9
20.7	2,787	7.4
24.3	2,781	8.7
28.3	2,754	10.3
34.8	2,705	12.9
12.4	2,000[a]	6.2
16.6	2,000	8.3
19.6	2,000	9.8
23.0	2,000	11.5
28.9	2,000	14.45
11.5	1,600[b]	7.2
14.3	1,600	8.9
16.4	1,600	10.25
18.8	1,600	11.75
22.9	1,600	14.31

Intervention Trials

There have been a large number of intervention trials to ascertain whether fiber supplementation can alter blood lipid concentrations and therefore alter the risk of CHD. These trials are briefly summarized below. All but one are small trials; often these interventions are performed in people with high initial serum cholesterol concentrations. The strongest data are for oat products and beans (*Dietary Fiber*). In addition, viscous *Functional Fibers* such as guar, pectin, and psyllium, have been tested in intervention trials and found to decrease serum total and low density lipo-protein (LDL) cholesterol concentration in most studies. For example,

Anderson and coworkers (1984b) compared the effects of oat bran or bean supplementation on 20 hypercholesterolemic adult males, providing approximately 47 g/d of plant *Dietary Fiber* and 17 g/d of viscous *Dietary Fiber*. Both the oat bran and bean diets significantly decreased serum total cholesterol concentrations by 19 percent. In a similar metabolic ward study of 10 hypercholesterolemic men, oat bran and bean diets decreased both serum total and LDL cholesterol concentrations by 23 percent after 3 weeks on the test diets (Anderson et al., 1984a). A review of the oat bran and bean fiber intervention trials where *Dietary Fiber* supplementation was combined with a low fat diet shows that reductions in serum total cholesterol concentrations ranged from 8 to 26 percent (Anderson and Gustafson, 1988; Anderson et al., 1984a, 1984b; Judd and Truswell, 1981; Kirby et al., 1981). Smaller portions of oat bran or oat meal (60 g, dry measure) have been shown to decrease serum total cholesterol concentrations by approximately 8 to 11 percent (Bartram et al., 1992; Van Horn et al., 1986).

Other viscous fibers, in addition to those from oats and beans, have also been shown to decrease serum cholesterol concentrations. For example, Jenkins and coworkers (1975) reported the hypocholesterolemic effect of guar gum (*Functional Fiber*), which is often added to foods. Since that time, there have been a number of studies with guar gum supplementation that resulted in a reduction in serum cholesterol concentrations of between 11 and 15 percent (Anderson and Tietyen-Clark, 1986). In a 3-week intervention that provided 21 g/d of psyllium, total, LDL, and high density lipoprotein cholesterol concentrations were all significantly reduced (Abraham and Mehta, 1988). A meta-analysis testing the effects of pectin, oat bran, guar gum, and psyllium on blood lipid concentrations showed that 2 to 10 g/d of viscous fiber were associated with small but significant decreases in total and LDL cholesterol concentrations (Brown et al., 1999). The different viscous fibers reduced serum total and LDL cholesterol concentrations by similar amounts. Resistant starch does not appear to provide the cholesterol-lowering effects of viscous fibers, but rather acts more like nonviscous fibers (Jenkins et al., 1998). Neither Heijnen and coworkers (1996) nor Jenkins and coworkers (1998) showed a lipid-lowering effect of resistant starch on serum lipid concentrations.

It should also be noted that the effect of fiber on decreasing serum cholesterol concentration is not due to its replacement of fat in the diet. In a prospective, randomized, controlled trial with a low fat and a low fat plus high *Dietary Fiber* groups, the group consuming high *Dietary Fiber* exhibited a greater average reduction (13 percent) in serum total cholesterol concentration than the low fat (9 percent) and the usual diet (7 percent) groups (Anderson et al., 1992a). Mathur and coworkers (1968) conducted a study in 20 men supplemented with Bengal gram. Serum

total cholesterol concentrations averaged 23 percent lower on the high fat, Bengal gram diet than on the high fat diet alone.

Not all fibers decrease serum cholesterol concentration. For example, Anderson and coworkers (1991) randomly allocated 20 hypercholesterolemic men to either a wheat bran or oat bran diet. After 21 days, oat bran significantly decreased serum total cholesterol concentration by 12.8 percent; however, there was no effect with wheat bran. Behall (1990) compared a low fiber diet with a diet containing an average of 19.5 g/d of added cellulose (a nonviscous fiber) or the viscous fibers carboxymethylcellulose gum, karaya gum, or locust bean gum. The diets containing the viscous fibers led to significantly lower plasma cholesterol concentrations. Although these relatively small-scale intervention trials using viscous *Functional Fibers* have reported substantial cholesterol-lowering effects and therefore should be protective against CHD, no protective effect against CHD was seen in a large-scale clinical trial with individuals who had a previous myocardial infarction (Burr et al., 1989). These individuals were encouraged to increase grain fiber intake by increasing consumption of whole meal bread, high fiber breakfast cereals, and wheat bran, which resulted in an increased grain fiber intake from 9 to 17 g/d in the intervention group. Wheat bran and other poorly fermented fibers (e.g., cellulose) have also failed to decrease serum lipids in animal studies. Increasing the intake of *Dietary Fiber* by increasing the consumption of fruits and vegetables can attenuate plasma triacylglycerol concentrations. Obarzanek and coworkers (2001) showed that increasing *Dietary Fiber* intake from 11 to 30 g/d as a result of increased consumption of fruits, vegetables, and whole grains prevented a rise in plasma triacylglycerol concentrations in those fed a low fat diet, especially in those individuals with initially high concentrations. Plasma triacylglycerol concentrations were significantly reduced (Chandalia et al., 2000) or unchanged (Lichtenstein et al., 2002) by increasing *Dietary Fiber* intake when consuming a low fat diet. These studies suggest that *Dietary Fiber* prevents the rise in plasma triacylglycerol concentrations that occurs when consuming a low fat, high carbohydrate diet (see Chapter 11).

Summary of the Intervention Trials

Viscous *Functional Fibers* and foods sources of viscous *Dietary Fiber* reduce both total and LDL cholesterol concentrations, and may also reduce serum triglycerides. The amount of cholesterol reduction appears to be related to the amount of fiber consumed, although only a few studies report dose–response data. A meta-analysis of 20 trials that used high doses of oat bran, which is rich in viscous *Dietary Fiber*, showed that the reductions in serum cholesterol concentrations ranged from 0.1 to 2.5 percent/g of intake (Ripsin et al., 1992). If one accepts the proposed 2 percent risk reduction

for CHD for every 1 percent reduction in serum cholesterol (Lipid Research Clinics Program, 1984), these results suggest substantial benefits from consumption of high amounts of viscous *Dietary* and *Functional Fibers* and support the epidemiological findings regarding fiber and CHD. It is of interest to compare the hypothetical risk reduction for CHD per gram of oat bran consumed (in the clinical intervention trials) to that for total dietary fiber intake in the epidemiological studies. For example, in the oat bran meta-analysis, using a 1.2 percent reduction in serum cholesterol per gram of oat bran (the midpoint of the range of 0.1 to 2.5 percent) and multiplying by 2 (proposed 2 percent reduction for risk of CHD for every 1 percent reduction in serum cholesterol) would suggest a reduced risk of CHD of 2.4 percent/g of oat bran consumed. This can then be compared with the data on total fiber consumption and risk for CHD in the three primary epidemiological studies shown in Table 7-2.

In the Health Professionals Follow-Up Study (Rimm et al., 1996), there is a difference of 16.5 g of fiber intake between the highest and lowest intake groups (28.9–12.4), and a reported relative risk of 0.45 for fatal coronary disease and 0.59 for total myocardial infarction for men in the highest compared to the lowest quintile for fiber intake. This equates to a risk reduction of 3.3 percent/g of fiber for fatal coronary disease and 2.5 percent/g of fiber for total myocardial infarction. In the Nurses' Health Study (Wolk et al., 1999) there is a difference of 11.4 g of fiber between the highest and lowest intake groups (22.9–11.5) and a relative risk of 0.77 for total CHD. This equates to a risk reduction of 2.02 percent/g of fiber. Finally, in a study of Finnish men (Pietinen et al., 1996), there is a difference of 18.7 g of fiber between the highest and lowest intake groups (34.8–16.1) and a relative risk of 0.68 for coronary death. This equates to a risk reduction of 1.71 percent/g of fiber.

Although the calculations above are hypothetical and are based on a number of assumptions, (including the linearity of response of fiber consumption to risk reduction), the finding that the degree of risk reductions per gram of fiber consumed are within a reasonable range of each other are suggestive that the results of the clinical trials for viscous fibers are supportive of the epidemiological finding. It is also clear that the effect of viscous fibers on decreasing blood cholesterol concentrations cannot explain the multitude of studies cited above that generally show *Dietary Fiber* to be protective against CHD, even though a mixed fiber diet is only approximately one-third viscous fiber. This suggests that mechanisms in addition to cholesterol-lowering may be involved.

Mechanisms by Which Dietary Fibers May Protect Against CHD

While not explicit, several hypotheses exist to explain the mechanisms by which *Dietary Fiber* may protect against CHD. The lowering of serum cholesterol concentration by viscous *Dietary* or *Functional Fibers* is thought to involve changes in cholesterol or bile acid absorption, hepatic production of lipoproteins, or peripheral clearance of lipoproteins (Chen and Anderson, 1986). Viscous fibers may interfere with the absorption and enterohepatic recirculation of bile acids and cholesterol in the intestine, forcing the liver to synthesize more cholesterol to meet the need for bile acid synthesis, and thus decreasing circulating cholesterol. This cannot be the sole explanation, however, since not all viscous fibers increase fecal bile acid excretion, and the magnitude of the increase, when present, is often small. In addition to delaying or interfering with the absorption of cholesterol and bile acids, viscous fibers may delay the absorption of macronutrients, including fat and carbohydrate. Delayed carbohydrate absorption, in turn, could lead to increased insulin sensitivity (Hallfrisch et al., 1995) and decreased triacylglycerol concentrations (Rivellese et al., 1980), also considered risk factors for CHD. Ascherio and coworkers (1992) have shown a strong inverse association between *Dietary Fiber* intake and risk of hypertension in men, with hypertension being an important risk factor for CHD.

Diets high in *Dietary Fiber* also may favorably affect plasminogen activator inhibitor type 1 and factor VII activity (Djoussé et al., 1998; Mennen et al., 1997; Sundell and Ranby, 1993). In addition, a large number of studies (described above) show whole-grain cereal products as being protective against CHD. Whole grain cereals are also sources of phytochemicals, such as phytate and phytoestrogens, which may independently impact CHD.

Summary

On the basis of the evidence provided on fiber intake and CHD, certain sources of *Dietary Fiber* (cereal foods) and certain *Functional Fibers* (viscous) are associated with reduced risk of CHD. In prospective population studies, there is a strong relationship between *Total Fiber* intake from foods and CHD. Therefore, a recommended intake level can be set for *Total Fiber* based on prevention of CHD and recognizing that the greatest benefit comes from the ingestion of cereal fibers and viscous *Functional Fibers*, including gums and pectins. Further discussion is provided in the later section, "Findings by Life Stage and Gender Group."

Fiber Intake and Gastrointestinal Health

Fiber Intake and Duodenal Ulcer

In a prospective cohort of 47,806 men with 138 newly diagnosed cases of duodenal ulcer, *Dietary Fibers*, and particularly the viscous fibers, were strongly associated with a decreased risk of duodenal ulcer (relative risk of 0.40 for the highest quintile of viscous fiber intake) (Aldoori et al., 1997). In this study, fiber from fruit, vegetable, and leguminous sources, but not cereal fiber, was associated with a reduced risk of duodenal ulcer. Although the mechanism behind this proposed positive effect of viscous fibers on duodenal ulcer is not known, one hypothesis is that the delay in gastric emptying, known to result from the ingestion of viscous fibers, may play a role.

Dietary Fiber, Functional Fiber, and Colon Health

Constipation, Laxation, and the Contribution of Fiber to Fecal Weight. Consumption of certain *Dietary* and *Functional Fibers* is known to improve laxation and ameliorate constipation (Burkitt et al., 1972; Cummings et al., 1978; Kelsay et al., 1978; Lupton et al., 1993). In most reports there is a strong positive correlation between intake of *Dietary Fiber* and daily fecal weight (Birkett et al., 1997). Also, *Dietary Fiber* intake is usually negatively correlated with transit time (Birkett et al., 1997). Although what constitutes "constipation" is variously defined, diets that increase the number of bowel movements per day, improve the ease with which a stool is passed, or increase fecal bulk are considered to be of benefit. For example, in a weight-loss study, obese individuals were put on a very low energy diet with or without 30 g/d of isolated plant fiber (Astrup et al., 1990). Those receiving the fiber supplement had a higher number of bowel movements per day (1.0) compared to those not receiving the fiber supplement (0.7/d). Not all reports, however, support the concept that fiber serves as a laxative (Cameron et al., 1996; Kochen et al., 1985). Because water is also important for laxation, some have suggested that increasing fiber intake alone is not sufficient, and that more water should be consumed as well (Anti et al., 1998). Determining a stool weight that might promote laxation and ameliorate constipation is very difficult. In one study, although fecal weight ranged from 41 to 340 g and transit time ranged from 22 to 123 hours, no subject reported suffering either constipation or diarrhea (Birkett et al., 1997). At the same time, a number of studies have shown that low fiber intake is associated with constipation. For example, Morais and coworkers (1999) reported that children with chronic constipation had lower *Dietary*

Fiber intake than the control group. The authors concluded that a low intake of fiber is a risk factor for chronic constipation in children.

In a meta-analysis of about 100 studies of stool-weight changes with various fiber sources, investigators were able to calculate the increase in fecal weight due to *Dietary* or *Functional Fiber* ingestion (Cummings, 1993). Such calculations yielded the following increases in fecal weight: 5.4 g of stool/g of wheat-bran fiber, 4.9 g/g of fruits and vegetables, 3 g/g of isolated cellulose, and 1.3 g/g of isolated pectin (Cummings, 1993). The contribution of resistant starch to fecal bulk has also been assessed. For example, Jenkins and colleagues (1998) determined the bulking effects of wheat bran supplements (30 g) or the equivalent amount as resistant starch (RS_2 or RS_3). Compared to the low fiber control, the wheat bran supplement increased fecal bulk by 96 ± 14 g/d ($p < 0.001$) and the mean for both resistant starches was 22 ± 8 g/d greater ($p = 0.013$). This is consistent with the small increase in fecal bulk seen with resistant starch intake in other studies (Behall and Howe, 1996; Cummings et al., 1996; Heijnen et al., 1998; Hylla et al., 1998; Phillips et al., 1995). Additional discussion of the effects of *Functional Fibers*, such as psyllium, is included in the earlier section, "Physiological Effects of Isolated and Synthetic Fibers."

Fiber Fermentation Products as an Energy Source for the Colon. Butyrate is the primary energy source for the colonocyte (Roediger, 1982). One study showed high acetate and low butyrate ratios of short-chain fatty acids in patients with adenomatous polyps and colon cancer (Weaver et al., 1988). Increased fecal butyrate outputs have been demonstrated using both whole food and commercial sources of resistant starch in some studies (Jenkins et al., 1998; Macfarlane and Englyst, 1986; Phillips et al., 1995; Silvester et al., 1995), but not in others (Heijnen et al., 1998; Hylla et al., 1998). It has been proposed that colonic diseases, including ulcerative colitis, are disorders of energy utilization (Roediger, 1980), although this remains an unresolved issue.

Fiber and the Prevention of Diverticular Disease. Diverticular disease is characterized by saccular herniations of the colonic wall and is highly prevalent in elderly populations in Western societies (Watters and Smith, 1990). Although usually asymptomatic, when diverticula become inflamed, the condition is known as diverticulitis. Current estimates for the North American population indicate that one-third of those older than 45 years and two-thirds of those older than 85 years have diverticular disease (Roberts and Veidenheimer, 1990).

Several types of studies have shown a relationship between fiber intake and diverticular disease. In the prospective Health Professionals Follow-Up Study, there was a strong negative association between *Dietary Fiber*

intake and the incidence of symptomatic diverticular disease (Aldoori et al., 1994, 1995), which persisted after adjustment for several other risk factors. The data showed that the inverse relationship was particularly strong for the nonviscous *Dietary Fiber,* particularly cellulose (Aldoori et al., 1998). Case-control studies have consistently found that patients with diverticula consumed less *Dietary Fiber* than did nonpatients. For example, Gear and coworkers (1979) reported on the prevalence of symptomless diverticular disease in vegetarians and nonvegetarians in England. Twelve percent of the vegetarians had diverticular disease compared with 33 percent of the nonvegetarians. In addition, the vegetarians had a mean daily *Dietary Fiber* intake of 41.5 g/d in comparison to 21.4 g/d for the nonvegetarians. Similarly, Manousos and coworkers (1985) reported a lower prevalence of diverticular disease in rural Greece compared with that found in urban areas. In addition, those individuals with diverticular disease consumed fewer vegetables, brown bread, potatoes, and fruit. In an intervention trial, Findlay and coworkers (1974) showed a protective effect of unprocessed bran. In another study, Brodribb (1977) treated 18 patients with diverticular disease by providing either a high fiber, bran-containing bread (6.7 g) or ordinary wheat bread (0.6 g). Relief of symptoms was significantly greater in the high fiber group compared with the low fiber control group.

Although the mechanism by which fiber may be protective against diverticular disease is unknown, several hypotheses have been proposed. For example, some scientists report that it is due to decreased transit time, increased stool weight, and decreased intracolonic pressure with fiber supplementation (Cummings, 2000).

Summary and Conclusions. The majority of the studies cited above show a relationship between *Dietary Fiber* and gastrointestinal health. There are data that show the benefits of certain *Dietary* and *Functional Fibers* on gastrointestinal health, including the effect of fiber on duodenal ulcers, constipation, laxation, fecal weight, energy source for the colon, and prevention of diverticular disease. For duodenal ulcer and diverticular disease, the data are promising for a protective effect, but insufficient data exist at this time upon which to base a recommended intake level. It is clear that fiber fermentation products provide energy for colonocytes and other cells of the body, but again this is not sufficient to use as a basis for a recommendation for fiber intake. With regard to the known fecal bulking and laxative effects of certain fibers, these are very well documented in numerous studies. A recommended intake level for *Total Fiber* based on prevention of CHD should be sufficient to reduce constipation in most normal people given adequacy of hydration of the large bowel.

Dietary Fiber *and the Prevention of Colon Cancer*

Marked international differences in rates of colon cancer (Boyle et al., 1985), coupled with findings from migratory studies showing that individuals take on the cancer demographics of the population to which they move (Haenszel and Kurihara, 1968), have suggested a strong role for environmental factors in colon cancer incidence.

Epidemiological Studies

Thun and coworkers (1992) found a significant inverse relation between the intake of citrus fruits, vegetables, and high fiber grains and colon cancer, although *Dietary Fiber* intake was not specifically analyzed. Fuchs and colleagues (1999) prospectively examined the relationship between *Dietary Fiber* intake and the risk of colon cancer in a large cohort of women. The same study group found a minimal nonsignificant inverse association in an earlier report that was based on 150 cases of colon cancer reported during 6 years of follow-up (Willett et al., 1990). In addition, the follow-up study revealed no relationship (Fuchs et al., 1999). Likewise, in six large, prospective studies, inverse associations between *Dietary Fiber* intake and the risk of colon cancer were weak or nonexistent (Giovannucci et al., 1994; Heilbrun et al., 1989; Kato et al., 1997; Key et al., 1996; Pietinen et al., 1999; Steinmetz et al., 1994).

Inverse relationships have been reported between *Dietary Fiber* intake and risk of colon cancer in some case-control studies (Bidoli et al., 1992; Dales et al., 1979; Freudenheim et al., 1990; Gerhardsson de Verdier et al., 1990; Iscovich et al., 1992; Lyon et al., 1987; Modan et al., 1975; Tuyns et al., 1987; West et al., 1989), but not all (Berta et al., 1985; Jain et al., 1980; Macquart-Moulin et al., 1986). A critical review of 37 observational epidemiological studies and a meta-analysis of 23 case-control studies showed that the majority suggest that *Dietary Fiber* is protective against colon cancer, with an odds ratio of 0.57 for the highest fiber group compared with the lowest (Trock et al., 1990). Furthermore, a meta-analysis of case-control studies demonstrated a combined relative risk of 0.53 for colon cancer in the highest as compared with the lowest quintile of fiber intake (Howe et al., 1992).

Lanza (1990) reviewed 48 epidemiological studies on the relationship between diets containing *Total Fiber* and colon cancer and found that 38 reported an inverse relationship, 7 reported no association, and 3 reported a direct association. In the Netherlands, *Dietary Fiber* intake was reported to be inversely related to total cancer deaths, as the 10-year cancer death rate was approximately threefold higher in individuals with low fiber intake compared with high fiber intake (Kromhout et al., 1982). Despite these

and other positive findings, a number of important studies (Fuchs et al., 1999; Giovannucci and Willett, 1994) and three recent clinical intervention trials (Alberts et al., 2000; Bonithon-Kopp et al., 2000; Schatzkin et al., 2000) do not support a protective effect of *Dietary Fiber* intake against colon cancer. This issue remains to be resolved.

Intervention Studies

There have been a number of small clinical interventions addressing various surrogate markers for colon cancer, primarily changes in rectal cell proliferation and polyp recurrence. Generally, the small intervention trials have shown either no effect of fiber on the marker of choice or a very small effect. For example, Alberts and coworkers (1990) supplemented individuals with 13.5 g/d of wheat-bran fiber (*Dietary Fiber*) for 8 weeks and analyzed rectal mucosa cell biopsies for changes in cell proliferation. There was no overall decrease in rectal cell proliferation as a result of fiber supplementation unless the groups were divided into those with initially high and those with initially normal labeling indices. With this statistical division, there was a significant decrease in cell proliferation as a result of the fiber supplementation in six of the eight patients with initially high labeling indices and three of the eight patients with initially low indices, which suggests that wheat-bran fiber is protective against colon cancer. In a separate trial from the same group, supplemental dietary wheat-bran fiber (2.0 or 13.5 g/d) was provided to participants with a history of colon adenoma resection (Alberts et al., 1997). Wheat-bran fiber did not reduce the labeling index at either 3 or 9 months. Additionally, two randomized, placebo-controlled trials found no significant reduction in the incidence of colon tumor indicators among subjects who supplemented their diet with wheat bran or consumed high fiber diets (MacLennan et al., 1995; McKeown-Eyssen et al., 1994).

Recently, findings from three major trials on fiber and colonic polyp recurrence were reported (Alberts et al., 2000; Bonithon-Kopp et al., 2000; Schatzkin et al., 2000). All were well-designed, well-executed trials in individuals who previously had polyps removed. The Polyp Prevention Trial, which incorporated eight clinical centers, included an intervention that consisted of a diet that was low in fat, high in fiber, and high in fruits and vegetables (*Dietary Fiber*) (Schatzkin et al., 2000). There was no difference in polyp recurrence between the intervention and control groups. The Arizona Wheat-bran Fiber Trial provided 13.5 g/d versus 2 g/d of wheat-bran fiber (*Dietary Fiber*) (Alberts et al., 2000). Again, there was no difference between the control group and the intervention group in terms of polyp recurrence. The third trial used 3.5 g/d of psyllium (ispaghula husk) as the intervention (a potential *Functional Fiber*) (Bonithon-Kopp et al.,

2000). The adjusted odds ratio for the psyllium fiber intervention on polyp recurrence was 1.67 ($p = 0.042$).

Potential Mechanisms

Many hypotheses have been proposed as to how fiber might protect against colon cancer development; these hypotheses have been tested primarily in animal models. The hypotheses include the dilution of carcinogens, procarcinogens, and tumor promoters in a bulky stool; a more rapid rate of transit through the colon with high fiber diets; a reduction in the ratio of secondary bile acids to primary bile acids by acidifying colonic contents; the production of butyrate from the fermentation of dietary fiber by the colonic microflora; and the reduction of ammonia, which is known to be toxic to cells (Harris and Ferguson, 1993; Jacobs, 1986; Klurfeld, 1992; Van Munster and Nagengast, 1993; Visek, 1978). Unfortunately, most of the epidemiological and even the clinical intervention trials did not measure functional aspects of potential mechanisms by which fiber may be protective, and they did not attempt to relate aspects of colon physiology such as fecal weight or transit time to a protective effect against tumor development. Cummings and colleagues (1992) suggest that a daily fecal weight greater than 150 g is protective against colon cancer. In a study by Birkett and coworkers (1997), it was necessary to achieve a stool weight of 150 g to improve fecal markers for colon cancer, including fecal bulk, primary to secondary bile acid ratios, fecal pH, ammonia, and transit time. *Dietary Fiber* intake was 18 ± 8 g in the less than 150-g fecal-weight group and 28 ± 9 g in the greater than 150-g group ($p < 0.01$).

Dietary Fiber Intake and Colonic Adenomas

People with colonic adenomas are at elevated risk of developing colon cancer (Lev, 1990). Several epidemiological studies have reported that high *Dietary Fiber* and low fat intakes are associated with a lower incidence of colonic adenomas (Giovannucci et al., 1992; Hoff et al., 1986; Little et al., 1993; Macquart-Moulin et al., 1987; Neugut et al., 1993). For example, Giovannucci and coworkers (1992) studied a population of 7,284 men from the Health Professionals Follow-up Study and found a significant negative relationship between *Dietary Fiber* intake and colonic adenomas. The inverse relationship with *Dietary Fiber* persisted when they adjusted for other nutrients commonly found in fruits and vegetables. The overall median dietary intake of *Dietary Fiber* in this population was 21 g/d, with a median intake of 13 g/d for the lowest quintile and 34 g/d for the highest quintile. A reanalysis of 16,448 men from the Health Professionals Follow-Up Study that controlled for folate intake did not find a significant associa-

tion between intake of *Dietary Fiber* and colon adenomas, although a slight reduction in risk was observed with increasing intake of fruit fiber (Platz et al., 1997).

Possible Reasons for the Lack of a Protective Effect of Dietary Fiber in Some Trials

There is considerable debate and speculation as to why clinical intervention trials on the relationship between fiber intake and colon cancer have not shown the expected beneficial effect of fiber. Some of the possible reasons for these results are discussed below.

Timing of the Intervention. Some of the recent prospective studies, such as the Nurses' Health Study (Fuchs et al., 1999) and the Health Professionals Follow-Up Study (Giovannucci et al., 1994), have failed to show a protective effect of *Dietary Fiber* intake against colon cancer when early indications from these same cohorts suggested that they would. As noted above, the Health Professionals Follow-up Study showed a protective effect of *Dietary Fiber* from the diet against colonic adenomas (Giovannucci et al., 1992). However, when the same cohort was later investigated for the relationship between intake of *Dietary Fiber* and colon carcinoma, no relationship was found (Giovannucci et al., 1994). A partial explanation for the difference is due to differences in ways that the data were analyzed based on information that was known at the time of analysis.

A similar situation was found in the Nurses' Health Study cohort, which initially found that the combination of high *Dietary Fiber* and low saturated or animal fat intake was associated with a reduced risk of adenomas (Willett et al., 1990), whereas a low intake of fiber alone did not contribute to the risk of colon cancer. Again, at follow-up in the same cohort, no relationship was found between *Dietary Fiber* intake and colon cancer incidence (Fuchs et al., 1999). This may also account for the lack of a protective effect of *Dietary Fiber* in the three recently reported clinical intervention trials (Alberts et al., 2000; Bonithon-Kopp et al., 2000; Schatzkin et al., 2000) since the participants already had colonic adenomas. Perhaps, as Giovannucci and colleagues (1992) suggest, intake of *Dietary Fiber* may influence the early stages of carcinogenesis, whereas dietary fat may have a greater influence on the progression of initiated cells into cancer.

The Confounding Role of Other Dietary Factors. Another possible explanation for the lack of a positive effect of fiber on colon cancer involves the potential confounding role of starch. As discussed in Chapter 6, starch may be divided into glycemic and nonglycemic starch, with nonglycemic starch being resistant to digestion by mammalian enzymes and thus reach-

ing the colon. Resistant starch intake has been associated with increased concentrations of fecal ammonia (Birkett et al., 1997). This association was reversed when nonstarch polysaccharides were added. Ammonia is toxic to normal colonic cells and stimulates the growth of malignant cells (Visek, 1978). Thus, diets that are high in resistant starch, but low in fiber, may have adverse effects (Birkett et al., 1997).

Individuals May Not Consume Sufficient Amounts of Fiber or the Right Type of Fiber. Neither the prospective studies nor the three large intervention trials reported aspects of colonic function (Alberts et al., 2000; Bonithon-Kopp et al., 2000; Schatzkin et al., 2000). It is possible that bulkier stools or faster transit through the colon reduce the risk of bowel cancer (Cummings et al., 1992), but that the amounts or types of *Dietary Fibers* consumed did not result in these physiological effects. In addition, positive benefits of fiber with respect to colon cancer may not occur until *Dietary Fiber* intake is sufficiently high; for example, greater than the median 32 g/d for the highest quintile in The Health Professionals Follow-Up Study of men (Giovannucci et al., 1994; Platz et al., 1997) and 25 g/d in the Nurses' Health Study (Fuchs et al., 1999).

Summary

All but one of the studies (Bonithon-Kopp et al., 2000) cited in this section examined the relationship of *Dietary Fiber* to colon cancer. Information is lacking on the role of *Functional Fibers* in the incidence of colon cancer because of the lack of intake data on specific *Functional Fibers* collected in epidemiological studies. Most animal studies on fiber and colon cancer, however, have used what could be termed *Functional Fibers* (Jacobs, 1986). Because evidence available is either too conflicting or inadequately understood, a recommended intake level based on the prevention of colon cancer cannot be set.

Dietary Fiber *and Protection Against Breast Cancer*

A growing number of studies have reported on the relationship of *Dietary Fiber* intake and breast cancer incidence, and the strongest case can be made for cereal consumption rather than consumption of *Dietary Fiber* per se (for an excellent review see Gerber [1998]). Between-country studies, such as England versus Wales (Ingram, 1981), southern Italy versus northern Italy versus the United States (Taioli et al., 1991), and China versus the United States (Yu et al., 1991), and one study within Spain (Morales and Llopis, 1992), all showed an inverse correlation between bread and cereal consumption and breast cancer risk. The findings of

Caygill and coworkers (1998) showed an inverse correlation between breast cancer incidence and both the current diet ($p < 0.001$) and the diet 20 years previously ($p < 0.001$). However, starchy root, vegetable, and fruit intakes were not related to breast cancer risk for either diet.

Prospective Studies

There have been at least two prospective studies relating *Dietary Fiber* intake to breast cancer incidence in the United States and both found no significant association (Graham et al., 1992; Willett et al., 1992). A Canadian study showed a significant protective trend for the intake of cereals, with borderline significance for *Dietary Fiber* (Rohan et al., 1993). Verhoeven and coworkers (1997) investigated the relationship between *Dietary Fiber* intake and breast cancer risk in The Netherlands Cohort Study. This prospective cohort study showed no evidence that a high intake of *Dietary Fiber* decreased the risk of breast cancer.

Case-Control Studies

Eight of eleven reported case-control studies showed a protective effect of *Dietary Fiber* against breast cancer (Baghurst and Rohan, 1994; De Stefani et al., 1997; Franceschi et al., 1996; Freudenheim et al., 1996; Graham et al., 1991; Lubin et al., 1986; Rohan et al., 1988; Ronco et al., 1999; van't Veer et al., 1990; Witte et al., 1997; Yuan et al., 1995). For studies that showed this protection, the range of the odds ratio or relative risk was 0.40 to 0.74.

Intervention Studies

Most intervention studies on fiber and breast cancer have examined fiber intake and plasma or urinary indicators of estrogen (e.g., estrone, estradiol). Since certain breast cancers are hormone dependent, the concept is that fiber may be protective by decreasing estrogen concentrations. Rose and coworkers (1991) provided three groups of premenopausal women with a minimum of 30 g/d of *Dietary Fiber* from wheat, oats, or corn. After 2 months, wheat bran was shown to decrease plasma estrone and estradiol concentrations, but oats and corn were not effective. Bagga and coworkers (1995) provided 12 premenopausal women a very low fat diet (10 percent of energy) that provided 25 to 35 g/d of *Dietary Fiber*. After 2 months there were significant decreases in serum estradiol and estrone concentrations, with no effects on ovulation. Woods and colleagues (1989) found that a low fat (25 percent of energy), high fiber (40 g of *Dietary Fiber*) diet significantly reduced serum estrone sulfate concentra-

tions in healthy premenopausal women compared with consumption of a typical Western diet (40 percent of energy from fat, 12 g of *Dietary Fiber*). In a separate study, the same researchers again provided a low fat (20 percent of energy), high fiber (40 g of *Dietary Fiber*) diet to premenopausal African-American women and observed reduced concentrations of serum estradiol and estrone sulfate when compared with a typical Western diet (Woods et al., 1996).

Mechanisms

A variety of different mechanisms have been proposed as to how fiber might protect against breast cancer, but the primary hypothesis is through decreasing serum estrogen concentrations. Fiber can reduce the entero-hepatic circulation of estrogen by binding unconjugated estrogens in the gastrointestinal tract (Shultz and Howie, 1986), making them unavailable for absorption (Gorbach and Goldin, 1987). Goldin and coworkers (1982) reported decreased plasma concentrations of estrone and increased fecal excretion of estrogens with increasing fecal weight. Alternatively, certain fibers can modify the colonic microflora to produce bacteria with low deconjugating activity (Rose, 1990), and deconjugated estrogens are reabsorbed. With less reabsorption of estrogens, plasma concentrations decrease. Another related hypothesis is that fiber speeds up transit through the colon, thus allowing less time for bacterial deconjugation. In fact, Petrakis and King (1981) noted abnormal cells in the mammary fluid of severely constipated women. Also, fiber sources contain phytoestrogens, which may compete with endogenous estrogens and act as antagonists (Lee et al., 1991; Rose, 1992). Finally, one report showed that *Dietary Fiber* intake was negatively correlated with total body fat mass, intra-abdominal adipose tissue, and subcutaneous abdominal adipose tissue in 135 men and 214 women (Larson et al., 1996). Since estrogen synthesis can occur in lipid stores, a decreased lipid mass should result in decreased synthesis. In addition to decreasing serum estrogen concentrations, fiber may be protective by adsorbing carcinogens or speeding their transit through the colon and providing less opportunity for their absorption. Carcinogens known to be related to breast cancer that may be affected include hetero-cyclic amines (Ito et al., 1991; Knekt et al., 1994), which have been shown to adsorb to fiber (Harris et al., 1996).

Summary

There are no reports on the role of *Functional Fibers* in the risk of breast cancer. Clearly, fiber has the potential capacity to decrease blood

estrogen concentrations by a variety of different mechanisms, but whether or not this is sufficient to decrease the risk of breast cancer has not been thoroughly investigated. Because of the lack of evidence to support a role of *Dietary Fiber* in preventing breast cancer, this clinical endpoint cannot be used to set a recommended intake level.

Dietary Fiber *and Other Cancers*

Although the preponderance of the literature on fiber intake and cancer involves colon cancer and breast cancer, several studies have shown decreased risk for other types of cancer. Because *Dietary Fiber* has been shown to decrease serum estrogen concentrations, some researchers have hypothesized a protective effect against hormone-related cancers such as endometrial, ovarian, and prostate. Studies on *Dietary Fiber* intake and endometrial cancer have shown both significant and nonsignificant decreases in risk (Barbone et al., 1993; Goodman et al., 1997; McCann et al., 2000). In addition, studies have shown a decreased risk in ovarian cancer with a high intake of *Dietary Fiber* (McCann et al., 2001; Risch et al., 1994; Tzonou et al., 1993). However, no significant associations have been observed between *Dietary Fiber* intake and risk of prostate cancer (Andersson et al., 1996; Ohno et al., 1988; Rohan et al., 1995). Although interesting to note, this literature is in its infancy and cannot be used to set a recommended intake level for *Dietary Fiber.*

Dietary Fiber *and* Functional Fiber *and Glucose Tolerance, Insulin Response, and Amelioration of Diabetes*

Epidemiological Studies

Epidemiological evidence suggests that intake of certain fibers may delay glucose uptake and attenuate the insulin response, thus providing a protective effect against diabetes. Evidence for the protective effect of *Dietary Fiber* intake against type 2 diabetes comes from several prospective studies that have reported on the relationship between food intake and type 2 diabetes (Colditz et al., 1992; Meyer et al., 2000; Salmerón et al., 1997a, 1977b). One study examined the relationship between specific dietary patterns and risk of type 2 diabetes in a cohort of 42,759 men, while controlling for major known risk factors (Salmerón et al., 1997a). The results suggest that diets with a high glycemic load and low cereal fiber content are positively associated with risk of type 2 diabetes, independent of other currently known risk factors (Figure 7-1). In a second study, diet and risk of type 2 diabetes in a cohort of 65,173 women were evaluated (Salmerón et al., 1997b). Again, diets with a high glycemic load and
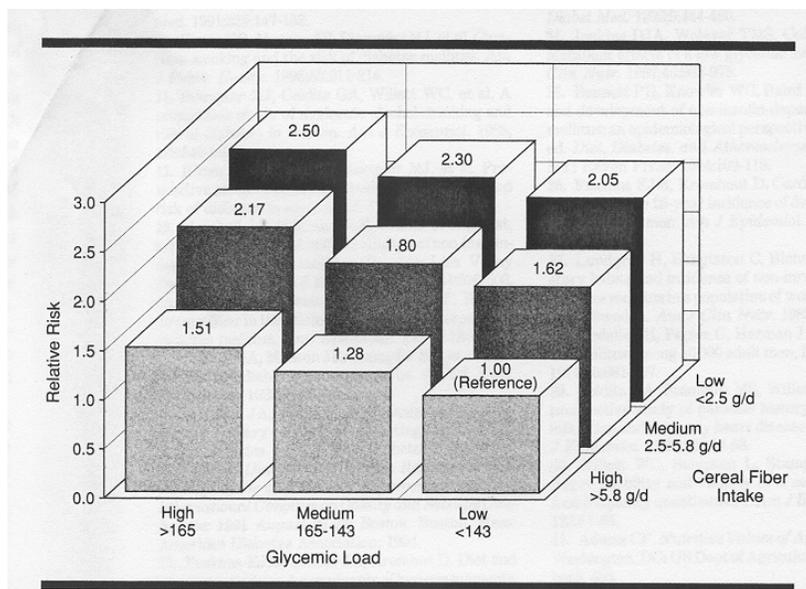
FIGURE 7-1 Relative risk of type 2 diabetes by different levels of cereal fiber intake and glycemic load. Reprinted, with permission, from Salmerón et al. (1997b). Copyright 1997 by the American Medical Association.

low cereal fiber content were positively associated with risk of type 2 diabetes, independent of other dietary factors and currently known risk factors. Of particular importance is that this combination resulted in a relative risk of 2.17 for men (Salmerón et al., 1997a) and 2.5 for women (Salmerón et al., 1997b), which is more than twofold greater relative to consumption of a diet high in cereal fiber and low in glycemic load (Figure 7-1).

In theory, the hypothesis as to how *Dietary Fiber* may be protective against type 2 diabetes is that it attenuates the glucose response and decreases insulin concentrations. This theory is supported by results from the Zutphen Elderly Study, where a negative relationship was observed between *Dietary Fiber* intake and insulin concentrations (Feskens et al., 1994).

Intervention Studies

In some clinical intervention trials ranging from 2 to 17 weeks, consumption of *Dietary Fiber* was shown to decrease insulin requirements in type 2 diabetics (Anderson et al., 1987; Rivellese et al., 1980; HCR Simpson

et al., 1981). However, Behall (1990) compared the addition of 19.5 g of one of four different *Functional Fibers* (cellulose, carboxymethycellulose gum, karaya gum, and locust bean gum) to a low fiber diet with respect to glucose and insulin response curves from a standard glucose tolerance test and found no significant differences between the diets after 4 weeks. In addition, resistant starch has not been shown to have an effect on glycemic index. This is in contrast to the differences in "slow release" versus "fast release" starches, which have differential effects on postprandial glycemic and insulinemic profiles (Golay et al., 1992; Jenkins et al., 1987).

Viscous *Dietary* and *Functional Fibers*, such as are found in oat products, beans, isolated pectin, and isolated guar gum, have been found to produce significant reductions in glycemic response in 33 of 50 studies (66 percent) reviewed by Wolever and Jenkins (1993), which is in contrast to only 3 of 14 studies with nonviscous fiber (21 percent). Mechanistic data and hypotheses support this effect of viscous fibers as they delay gastric emptying and delay the absorption of glucose and other nutrients (Jenkins et al., 1978; Wood et al., 1994). However, a seeming anomaly is that the blood glucose response of foods is more closely related to their nonviscous fiber content than to their viscous fiber content (Wolever, 1995). It is not clear as to how significant the viscosity of fiber is to its contribution to the reduction in glycemic response in the overall observation of a lower incidence of type 2 diabetes with high fiber diets. Therefore, viscosity should not be considered the most important attribute of fiber with respect to this endpoint.

Summary

There is evidence that *Total Fiber* reduces the risk of diabetes; this can be used as a secondary endpoint to support a recommended intake level for *Total Fiber* that is primarily based on prevention of CHD. Further discussion is provided in the later section, "Findings by Life Stage and Gender Group."

Fiber Intake, Satiety, and Weight Maintenance

Epidemiological Studies

Since foods rich in fiber tend to be low in energy, researchers have hypothesized that fiber consumption may help with weight maintenance. This is an important consideration since obesity is such a prevalent problem and contributes to the risk of many diseases. Support for the concept that fiber consumption helps with weight maintenance is provided by studies showing that daily *Dietary Fiber* intake is lower for obese men (20.9 ± 1.8 g)

and women (15.7 ± 1.1 g) than for lean men (26.9 ± 1.8 g) and women (22.7 ± 2.1 g) (Miller et al., 1994). Furthermore, in a study of 1,914 men and 3,378 women, mean body mass index (BMI) was significantly lower in the high *Dietary Fiber* group for both men and women (Appleby et al., 1998).

Intervention Studies

Several intervention studies suggest that diets high in fiber may assist in weight loss (Birketvedt et al., 2000; Eliasson et al., 1992; Rigaud et al., 1990; Rössner et al., 1987; Ryttig et al., 1989), although other studies have not found this effect (Astrup et al., 1990; Baron et al., 1986). For example, Birketvedt and coworkers (2000) conducted a study in which 53 moderately overweight females consumed a reduced energy diet (1,200 kcal/d) with or without a fiber supplement, which was 6 g/d for 8 weeks and then 4 g/d thereafter. The women on the fiber-supplemented diets lost 8.0 kg versus 5.8 kg for the placebo group ($p < 0.05$). High fiber diets are characterized by a very low energy density compared to diets high in fat, and a greater volume must be consumed in order to reach a certain energy level (Duncan et al., 1983; Tremblay et al., 1991), which again could result in cessation of eating. The issue of whether fiber has implications in the modulation of appetite has been reviewed (Blundell and Burley, 1987; Levine and Billington, 1994). Consumption of viscous fibers delays gastric emptying (Roberfroid, 1993), which in turn can cause an extended feeling of fullness (Bergmann et al., 1992) and delayed absorption of glucose and other nutrients (Jenkins et al., 1978; Ritz et al., 1991; Roberfroid, 1993; Truswell, 1992). Some investigators suggest that the delayed absorption of nutrients is associated with an extended feeling of satiety and delayed return of appetite (Grossman, 1986; Holt et al., 1992; Leathwood and Pollet, 1988), but not all investigators have found this effect (de Roos et al., 1995; Krishnamachar and Mickelsen, 1987; Sepple and Read, 1989).

A number of studies investigated the effect of consumption of a high fiber meal and food intake at a later eating occasion. For example, eating a breakfast supplemented with 29 g of sugar beet fiber resulted in 14 percent less energy consumption at the subsequent lunch (Burley et al., 1993). In contrast, other investigators have failed to demonstrate any postingestive effect of fiber on food intake (Delargy et al., 1995; Levine and Billington, 1994). One study found that there was no difference between a high fiber and a low fiber diet on later food intake if the energy content of the initial diets was similar (Delargy et al., 1995). These authors used 20 g of *Dietary Fiber* for their test breakfast meal, which is much lower than the 29 g used by Burley and coworkers (1993). The authors concluded that for *Dietary Fiber* to have an effect, there has to be greater than 20 g in the test meal

(Delargy et al., 1995). Similar findings of no effect of a test meal on appetite throughout the day have been found for substituting resistant starch for digestible starch (Raben et al., 1994). In addition, much of the data on chitin and chitosan in promoting weight loss have been negative (see earlier section, "Physiological Effects of Isolated and Synthetic Fibers").

Summary

The strongest data supporting a relationship between fiber and weight maintenance come from the few epidemiological studies showing that *Dietary Fiber* intake is lower for obese men and women than for lean men and women and that BMI is lower with higher fiber consumption for both men and women. Efforts to show that eating specific fibers increases satiety and thus results in a decreased food intake have been inconclusive. In terms of the attribute of fiber that may result in decreased food intake, some have suggested that viscosity is important as it delays gastric emptying and may lead to feeling more full for a longer period of time. However, this hypothesis has not been validated in clinical trials.

Although the finding that the overall data on *Dietary Fiber* intake are negatively correlated with BMI is suggestive of a role for fiber in weight control, the studies designed to determine how fiber intake might impact overall energy intake have not shown a major effect. In fact, it appears that very high amounts of fiber (e.g., 30 g/meal) are required to diminish subsequent energy intake after that meal. For humans, there is no overwhelming evidence that *Dietary Fiber* has an effect on satiety or weight maintenance, therefore this endpoint is not used to set a recommended intake level.

FINDINGS BY LIFE STAGE AND GENDER GROUP

Expression of the Total Fiber Requirement

Total Fiber requirements (the sum of *Dietary Fiber* and *Functional Fiber*) may be expressed in a variety of different ways, including age plus number of grams per day (Williams et al., 1995), grams per kilogram of body weight (AAP, 1993), grams per day (Health and Welfare Canada, 1985; LSRO, 1987), and grams per 1,000 kcal (LSRO, 1987). Each of these methods has its advantages and disadvantages. Because the available evidence suggests that the beneficial effects of fiber in humans are most likely related to the amount of food consumed—not to the individual's age or body weight— the best approach is to set an Adequate Intake (AI) based on grams per 1,000 kcal. However, since many people do not know how many kilocalories they consume in a day, the AI is based on the usual daily intake of

energy (Appendix Table E-1) for each age group and is expressed in grams per day. Those with energy intakes significantly above or below the reference intakes for their age and gender may want to consider adjusting their total fiber intake accordingly.

Infants Ages 0 Through 12 Months

There are no functional criteria for fiber status that reflect response to dietary intake in infants. Since human milk is recognized as the optimal source of nourishment for infants throughout at least the first year of life and as a sole nutritional source for infants during the first 4 to 6 months of life (IOM, 1991), and because human milk contains no *Dietary Fiber*, there is no AI for infants 0 through 6 months of age. During the 7- through 12-month age period, the intake of solid foods becomes more significant, and *Dietary Fiber* intake may increase. However, there are no data on *Dietary Fiber* intake in this age group and no theoretical reason to establish an AI for infants 7 through 12 months of age.

Children and Adolescents Ages 1 Through 18 Years

Method Used to Set the AI

Although guidelines have been endorsed for recommended dietary intakes of total fat and fatty acids, protein, carbohydrate, and cholesterol in children 2 years of age and older by a variety of different organizations (AHA, 1983; Dwyer, 1980; USDA/HHS, 2000), none of these guidelines recommend a specific level of fiber intake during childhood. Data suggest that North American children, like adults, consume inadequate amounts of fiber for optimal health, and that consumption of fiber should be increased to promote normal laxation, to help prevent diet-related cancer, to help reduce serum cholesterol concentrations and therefore the risk of coronary heart disease (CHD), and to help prevent obesity and the risk of adult-onset diabetes (AHA, 1983; AMA Council on Scientific Affairs, 1989; Wynder and Berenson, 1984). National pediatric dietary goals are targeted for children older than 2 years of age, with a suggestion that age 2 to 3 years be a transition year (National Cholesterol Education Program, 1991).

Constipation is a common problem during childhood, as it is in adults, and accounts for 25 percent of visits to pediatric gastroenterology clinics (Loening-Baucke, 1993). As discussed in the earlier section, "*Dietary Fiber, Functional Fiber*, and Colon Health," there are strong data showing the contribution of high fiber diets, along with adequate fluid intake, to laxation in adults. However, fiber intake and constipation data in children are limited. Studies correlate low *Dietary Fiber* intake with constipation

(Hunt et al., 1993; Roma et al., 1999). Two studies by the same research group addressed fiber intake in American children and found that children with constipation consumed, on average, about half as much fiber as the healthy control group (McClung et al., 1993, 1995). Morais and coworkers (1999) reported that children with chronic constipation ingested less *Dietary Fiber* than age-matched controls.

The AI for *Total Fiber* for children and adolescents is based on the data cited for adults, which showed that 14 g/1,000 kcal reduced the risk of CHD (see "Adults Ages 19 Years and Older"). The AI (14 g/1,000 kcal × median energy intake [kcal/1,000 kcal/d]) is then set for each age and gender group. The median energy intake for 1- to 3-year-old children is 1,372 kcal/d (Appendix Table E-1). Thus, 19 g/d (14 × 1.37) of total fiber would be recommended for this age group. It should be kept in mind that recommendations for fiber intake are based on a certain amount of total fiber as a function of energy intake. This means that those who consume less than the median energy intake of a particular category need less fiber than the recommendation (which is based on the mean energy intake). For example, the median energy intake for 1- to 3-year-old children is 1,372 kcal/d and the recommendation for total fiber is 19 g/d. However, 1-year-old children not meeting this energy consumption level will not require 19 g/d and their intake should be scaled back accordingly.

The median energy intake for 4- to 8-year-old children is 1,759 kcal/d (Appendix Table E-1). Thus, 25 g/d (14 × 1.76) of *Total Fiber* would be recommended for these children. The AIs for *Total Fiber* for boys and girls 9 to 18 years of age have been calculated in a similar manner using the energy intake values in Appendix Table E-1.

Total Fiber *AI Summary, Ages 1 Through 18 Years*

AI for Children
>   1–3 years   **19 g/d of *Total Fiber***
>   4–8 years   **25 g/d of *Total Fiber***

AI for Boys
>   9–13 years   **31 g/d of *Total Fiber***
>   14–18 years   **38 g/d of *Total Fiber***

AI for Girls
>   9–13 years   **26 g/d of *Total Fiber***
>   14–18 years   **26 g/d of *Total Fiber***

Adults Ages 19 Years and Older

Methods Used to Set the AI

Fiber Intake and Risk of CHD. Although the preponderance of the data shows a protective effect of consumption of high fiber and high fiber-containing foods against CHD (see earlier section, "*Dietary Fiber, Functional Fiber,* and the Prevention of Hyperlipidemia, Hypertension, and Coronary Heart Disease"), there are exceptions to these findings. A more important consideration for establishing a requirement for fiber is the fact that the dietary intake data from epidemiological studies are on fiber-containing foods, which are considered *Dietary Fiber.* Certain investigators specifically analyzed diets for *Dietary Fiber* (Burr and Sweetnam, 1982; Hallfrisch et al., 1988; Khaw and Barrett-Connor, 1987; Kromhout et al., 1982; Kushi et al., 1985; Morris et al., 1977; Pietinen et al., 1996; Rimm et al., 1996), but others used indicators of *Dietary Fiber* intake such as cereals, vegetables, fruits, whole grains, or legumes. There are many constituents of whole grains, in addition to *Dietary Fiber,* that may reduce the risk of CHD (Slavin et al., 1997; Thompson, 1994). Despite these cautions, the data on the relationship between *Dietary Fiber* intake and risk of CHD based on epidemiological, clinical, and mechanistic data are strong enough to warrant using this relationship as a basis for setting a recommended level of intake. Both men and women appear to benefit from increasing their intake of foods rich in fibers, particularly cereal fibers, with women appearing to benefit more from increasing fiber consumption than men.

Because the prospective studies of Pietinen and coworkers (1996), Rimm and coworkers (1996), and Wolk and coworkers (1999) are adequately powered, divide fiber intake into quintiles, and provide data on energy intake (Table 7-2), it is possible to set a recommended intake level. Data from 21,930 Finnish men showed that at the highest quintile of *Dietary Fiber* intake (34.8 g/d), median energy intake was 2,705 kcal/d, which equates to 12.9 g of *Dietary Fiber*/1,000 kcal (Pietinen et al., 1996). The Health Professionals Follow-up Study of men reported a *Dietary Fiber* intake of 28.9 g/d in the highest quintile, with a normalized energy intake of 2,000 kcal/d, which equates to 14.45 g of *Dietary Fiber*/1,000 kcal (Rimm et al., 1996). In the Nurses' Health Study of women, the median *Dietary Fiber* intake at the highest quintile was 22.9 g/d, with a normalized energy intake of 1,600 kcal/d (Wolk et al., 1999), which equates to 14.3 g of *Dietary Fiber*/1,000 kcal. In these three studies, there was a significant negative trend in *Dietary Fiber* intake and risk of CHD. Specifically, there was a strong nega-

tive correlation between cereal fiber intake and risk of CHD, whereas the correlation was weak or nonexistent for fruit and vegetable fibers. Taken collectively and averaging to the nearest gram, these data suggest an intake of 14 g of *Dietary Fiber*/1,000 kcal, particularly from cereals, to promote heart health. Data from the intervention trials are in line with these recommendations, as are data from epidemiological studies.

Fiber Intake and Risk of Type 2 Diabetes. The literature on *Dietary Fiber* intake and glucose tolerance, insulin response, and amelioration of diabetes alone is insufficient at this time to use as a basis for a recommendation (see "Evidence Considered for Estimating the Requirement for *Dietary Fiber* and *Functional Fiber*"). However, it should be noted that the positive effects seen in two large prospective studies (Salmerón et al., 1997a, 1997b) were achieved with the same levels of fiber that have previously been reported as being protective against CHD (Pietinen et al., 1996; Rimm et al., 1996; Wolk et al., 1999). Therefore, the recommendations made using the effect of *Dietary Fiber* intake on CHD are supported by the data on *Dietary Fiber* intake and type 2 diabetes.

Summary. Prospective studies have shown that the impact of *Dietary Fiber* on the advent of CHD occurs continuously across a range of intakes. Therefore, an Estimated Average Requirement (EAR) cannot be set.

Based on the average intake of *Dietary Fiber* and its effect on CHD, as well as the beneficial role of *Functional Fibers* (such as gums, pectin and psyllium), an AI for *Total Fiber* is set for each age and gender group by multiplying 14 g/1,000 kcal × median energy intake (kcal/1,000 kcal/d). The highest median intake level for each gender-specific age group (from Appendix Table E-1) was used in the equation to set the AI for young adults (19 to 50 years of age) and older adults (51 years of age and older). There is no information to indicate that fiber intake as a function of energy intake differs during the life cycle.

By definition, the AI is expected to meet or exceed the EAR or the average amount needed to maintain a defined nutritional state or criterion of adequacy in essentially all members of a specific healthy population. Thus, where data are insufficient to be used as the basis of an AI, *Total Fiber* at the recommended levels may also help to ameliorate constipation and diverticular disease, provide fuel for colonic cells, attenuate blood glucose and lipid concentrations, and provide a source of nutrient-rich, low energy-dense foods that could contribute to satiety.

Total Fiber AI Summary, Ages 19 Years and Older

AI for Men
    19–30 years   **38 g/d of *Total Fiber***
    31–50 years   **38 g/d of *Total Fiber***
    51–70 years   **30 g/d of *Total Fiber***
    > 70 years   **30 g/d of *Total Fiber***

AI for Women
    19–30 years   **25 g/d of *Total Fiber***
    31–50 years   **25 g/d of *Total Fiber***
    51–70 years   **21 g/d of *Total Fiber***
    > 70 years   **21 g/d of *Total Fiber***

Pregnancy

Method Used to Set the AI

There is no evidence to suggest the beneficial effects of fiber in reducing the risk of CHD for pregnant adolescent girls and women is different from nonpregnant adolescent girls and women. Therefore, the AI for *Total Fiber* is 28 g/d (14 g/1,000 kcal × 1,978 kcal/1,000 kcal/d).

Total Fiber *AI Summary, Pregnancy*

AI for Pregnant Women
    14–18 years   **28 g/d of *Total Fiber***
    19–30 years   **28 g/d of *Total Fiber***
    31–50 years   **28 g/d of *Total Fiber***

Lactation

Method Used to Set the AI

There is no evidence to suggest the beneficial effects of fiber in reducing the risk of CHD for lactating adolescent girls and women are different from nonpregnant adolescent girls and women. Therefore, the AI for *Total Fiber* is 29 g/d (14 g/1,000 kcal × 2,066 kcal/1,000 kcal/d).

Total Fiber *AI Summary, Lactation*

AI for Lactating Women
   14–18 years   **29 g/d of *Total Fiber***
   19–30 years   **29 g/d of *Total Fiber***
   31–50 years   **29 g/d of *Total Fiber***

INTAKE OF *DIETARY FIBER*

Food Sources

Marlett (1992) reported on the *Dietary Fiber* content of 117 frequently consumed foods. *Dietary Fiber* was present in the majority of fruits, vegetables, refined grains, and miscellaneous foods such as ketchup, olives, and soups, at concentrations of 1 to 3 percent, or 1 to 3 g/100 g of fresh weight. Nuts, legumes, and high fiber grains typically contained more than 3 percent *Dietary Fiber*. About one-third of the fiber in legumes, nuts, fruits, and vegetables was present as hemicelluloses. Approximately one-fourth of the fiber in grains and fruit and one-third in nuts and vegetables consisted of cellulose. Although fruits contained the greatest amount of pectin, 15 to 20 percent of the fiber content in legumes, nuts, and vegetables was pectin.

The major sources of naturally occurring inulin and oligofructose are wheat and onions, which provide about 70 and 25 percent of these components, respectively (Moshfegh et al., 1999). Isolated inulin provides a creamy texture and is added to replace fat in table spreads, dairy products, frozen desserts, baked goods, fillings, and dressings. Oligofructose is most commonly added to cereals, fruit preparations for yogurt, cookies, dairy products, and frozen desserts.

Depending on one's chosen diet, naturally occurring and manufactured resistant starch, as well as that produced during normal processing of foods for human consumption, could make a significant contribution to daily *Total Fiber* intake. Legumes are the largest source of naturally occurring resistant starch (Marlett and Longacre, 1996). In addition, green bananas (Englyst and Cummings, 1986) and cooled, cooked potatoes (Englyst and Cummings, 1987) can provide a significant amount of resistant starch. Resistant starch resulting from normal processing of a foodstuff is a more modest contributor to a typical daily intake. Starches specifically manufactured to be resistant to endogenous human digestion are a rapidly growing segment of commercially available resistant starches.

Dietary Intake

National nutrition surveys use the U.S. Department of Agriculture (USDA) food composition database to estimate the intake of various nutrients. This database primarily measures *Dietary Fiber* intake because isolated *Functional Fibers*, such as pectins and gums, that are used as ingredients represent a very minor amount of the fiber present in foods. For instance, the fiber content of fat-free ice creams and yogurts, which contain *Functional Fibers* as additives, is much less than 1 g/serving and therefore is often labeled as having 0 g of fiber. Based on intake data from the Continuing Survey of Food Intakes by Individuals (CSFII) (1994–1996, 1998), median *Dietary Fiber* intakes ranged from 16.5 to 17.9 g/d for men and 12.1 to 13.8 g/d for women (Appendix Table E-4). Based on the Adequate Intakes (AI) set for the various age and gender groups, 10 percent or less of a particular group consumed greater than the AI.

Based on additional intake data from CSFII, American diets provided on average 2.6 g/d of inulin and 2.5 g/d of oligofructose (Moshfegh et al., 1999). Since inulin and oligofructose have not been analyzed as fiber previously, they would not be in the USDA database. This would mean that people are actually consuming approximately 5.1 g/d more fiber than reported in the CSFII database (Appendix Table E-4). Although there is a seemingly large gap between current fiber intake and the recommended intake, it is not difficult to consume recommended levels of *Total Fiber* by choosing foods recommended by the Food Guide Pyramid. Two sample menus are provided that meet the Estimated Energy Requirement (EER) and AI for *Total Fiber* for men (Table 7-3) and women (Table 7-4).

These menus show that a 19-year-old active male and a 19-year-old active female can meet their AI for *Total Fiber* without exceeding their EER. These diets also meet the Recommended Dietary Allowances and AIs for all of the micronutrients.

ADVERSE EFFECTS OF OVERCONSUMPTION

Adverse Effects of Dietary Fiber

Mineral Bioavailability

Within the last 20 years, several animal and human studies have shown that foods or diets rich in fibers may alter mineral metabolism, especially when phytate is present (Sandstead, 1992). Fibers may reduce the bioavailability of minerals such as iron, calcium, and zinc (AAP, 1981; Williams and Bollella, 1995). However, levels of 10 to 12 g of *Dietary Fiber*/1,000 kcal have been suggested as safe even for Japanese adolescents, who tradition-

TABLE 7-3 Fiber Intake from an Omnivorous Diet Adequate in Essential Micronutrients to Meet the Estimated Energy Requirement for a Male 19 Years of Age (3,078 kcal/d)

Meal	Foods Eaten	Energy (kcal)	Total Fiber (g)
Breakfast	Grapefruit, pink or red ($1/_2$ medium)	38	1.4
	Banana (1 medium)	109	2.8
	Cereal, ready-to-eat shredded oats (1 cup)	112	3.0
	English muffin (white, 1 whole)	134	1.5
	Margarine (2 tsp)	68	0
	Milk, 1% (1 cup)	102	0
	Total for meal	563	8.7
Snack	Crackers, whole wheat (6 each)	109	0.9
	Cheddar cheese (1.5 oz)	171	0
	Juice ($3/_4$ cup)	78	0.4
	Total for snack	358	1.3
Lunch	Tossed salad (1 cup)	16	1.5
	Salad dressing (1 tbs)	66	0
	Chili with beans and beef (1 cup)	273	6.5
	Cornbread (1 piece)	173	1.3
	Margarine (1 tsp)	34	0
	Grapes ($1/_2$ cup)	57	0.8
	Fig bar cookies (2)	111	1.5
	Milk, 1% (1 cup)	102	0
	Total for meal	832	11.6
Dinner	Salmon in soy sauce (3.5 oz)	169	0.2
	Rice with vegetables ($3/_4$ cup)	167	1.4
	Broccoli (1-$1/_2$ cup)	40	4.4
	Roll, whole wheat (2 medium)	177	5.0
	Margarine (2 tsp)	68	0
	Ice cream ($1/_2$ cup)	98	0.3
	Total for meal	719	11.3
Snack	Carrots, raw (12 medium baby)	51	3.6
	Spinach dip (2 tbs)	58	0.4
	Turkey sandwich	344	1.2
	Cola (1 can)	153	0
	Total for snack	606	5.2
Daily total		3,078	38.1

NOTE: Source of food composition data: NDS-R Food and Nutrient Data Base, Version 4.04_32, 2001, Nutrition Coordinating Center, University of Minnesota.

TABLE 7-4 Fiber Intake from an Omnivorous Diet Adequate in Essential Micronutrients to Meet the Estimated Energy Requirement for a Female 19 Years of Age (2,393 kcal/d)

Meal	Foods Eaten	Energy (kcal)	Total Fiber (g)
Breakfast	Banana ($^1/_2$ medium)	54	1.4
	Cereal, ready-to-eat shredded oats ($^3/_4$ cup)	84	2.3
	English muffin (white, 1 whole)	134	1.5
	Margarine (2 tsp)	68	0
	Milk, skim (1 cup)	86	0
	Total for meal	426	5.2
Snack	Crackers, whole wheat (5 each)	90	0.7
	Cheddar cheese (1.5 oz)	171	0
	Juice ($^3/_4$ cup)	78	0.4
	Total for snack	339	1.1
Lunch	Tossed salad ($^3/_4$ cup)	12	1.1
	Salad dressing (1 tbs)	66	0
	Chili with beans and beef ($^3/_4$ cup)	205	4.9
	Cornbread (1 piece)	173	1.3
	Margarine (1 tsp)	34	0
	Grapes ($^1/_2$ cup)	57	0.8
	Milk, skim (1 cup)	86	0
	Total for meal	633	8.1
Dinner	Salmon in soy sauce (3.5 oz)	169	0.2
	Rice with vegetables ($^1/_2$ cup)	111	1.0
	Broccoli ($^1/_2$ cup)	14	1.5
	Roll, whole wheat (1 medium)	89	2.5
	Margarine (1 tsp)	34	0
	Ice cream ($^1/_2$ cup)	98	0.3
	Total for meal	515	5.5
Snack	Apple (1 medium)	81	3.7
	Pretzels (1 oz)	108	0.9
	Peanut butter sandwich	138	1.3
	Cola (1 can)	153	0
	Total for snack	480	5.9
Daily total		2,393	25.8

NOTE: Source of food composition data: NDS-R Food and Nutrient Data Base, Version 4.04_32, 2001, Nutrition Coordinating Center, University of Minnesota.

ally have low levels of calcium intake (Nishimune et al., 1993). Most studies that assess the effect of fiber intake on mineral status have looked at calcium, magnesium, iron, or zinc.

Calcium. Most studies investigating the effects of cereal, vegetable, and fruit fibers on the absorption of calcium in animals and humans have reported no effect on calcium absorption or balance (Spencer et al., 1991; Wisker et al., 1991). However, some studies described a decrease in calcium absorption with ingestion of *Dietary Fiber* under certain conditions (Knox et al., 1991; O'Brien et al., 1993). Slavin and Marlett (1980) found that supplementing the diet with 16 g/d of cellulose resulted in significantly greater fecal excretion of calcium resulting in an average loss of approximately 200 mg/d. There was no effect on the apparent absorption of calcium after the provision of 15 g/d of citrus pectin (Sandberg et al., 1983).

Magnesium. Studies report no differences in magnesium balance with intake of certain *Dietary Fibers* (Behall et al., 1987; Hallfrisch et al., 1987; Spencer et al., 1991). Astrup and coworkers (1990) showed no effect of the addition of 30 g/d of plant fiber to a very low energy diet on plasma concentrations of magnesium. There was no effect on the apparent absorption of magnesium after the provision of 15 g/d of citrus pectin (Sandberg et al., 1983). Magnesium balance was not significantly altered with the consumption of 16 g/d of cellulose (Slavin and Marlett, 1980).

Iron and Zinc. A number of studies have looked at the impact of fiber-containing foods, such as cereal fibers, on iron and zinc absorption. These cereals typically contain levels of phytate that are known to impair iron and zinc absorption. Coudray and colleagues (1997) showed no effect of isolated viscous inulin or partly viscous sugar beet fibers on either iron or zinc absorption when compared to a control diet. Metabolic balance studies conducted in adult males who consumed four oat bran muffins daily showed no changes in zinc balance due to the supplementation (Spencer et al., 1991). Brune and coworkers (1992) have suggested that the inhibitory effect of bran on iron absorption is due to its phytate content rather than its *Dietary Fiber* content. However, the addition of 12 g/d of bran to a meal decreased iron absorption by 51 to 74 percent, and the inhibition was not explained by the presence of phytate (KM Simpson et al., 1981).

Gastrointestinal Distress. There are limited studies to suggest that chronic high intakes of *Dietary Fibers* can cause gastrointestinal distress. The consumption of wheat bran at levels up to 40 g/d did not result in significant increases in gastrointestinal distress compared to a placebo (McRorie et al., 2000). However, flatulence did increase with increased intake of *Dietary*

Fiber (Bolin and Stanton, 1998; Tomlin et al., 1991). Adverse effects have been observed under certain special circumstances. For instance, 75 to 80 g/d of *Dietary Fiber* has been associated with sensations of excessive abdominal fullness and increased flatulence in individuals with pancreatic disease (Dutta and Hlasko, 1985). Furthermore, the consumption of 160 to 200 g/d of unprocessed bran resulted in intestinal obstruction in a woman who was taking an antidepressant (Kang and Doe, 1979).

Summary

Dietary Fiber can have variable compositions and therefore it is difficult to link a specific fiber with a particular adverse effect, especially when phytate is also often present. It is concluded that as part of an overall healthy diet, a high intake of *Dietary Fiber* will not produce significant deleterious effects in healthy people. Therefore, a Tolerable Upper Intake Level (UL) is not set for *Dietary Fiber*.

Special Considerations

Dietary Fiber is a cause of gastrointestinal distress in people with irritable bowel syndrome. Those who suffer from excess gas production can consume a low gas-producing diet, which is low in dietary fiber (Cummings, 2000).

Hazard Identification for Isolated and Synthetic Fibers

Unlike *Dietary Fiber*, it may be possible to concentrate large amounts of *Functional Fiber* in foods, beverages, and supplements. Since the potential adverse health effects of *Functional Fiber* are not completely known, they should be evaluated on a case-by-case basis. In addition, projections regarding the potential contribution of *Functional Fiber* to daily *Total Fiber* intake at anticipated patterns of food consumption would be informative. *Functional Fiber*, like *Dietary Fiber*, is not digested by mammalian enzymes and passes into the colon. Thus, like *Dietary Fiber*, most potentially deleterious effects of *Functional Fiber* ingestion will be on the interaction with other nutrients in the gastrointestinal tract. Data from human studies on adverse effects of consuming what may be considered as *Functional Fibers* (if sufficient data exist to show a potential health benefit) are summarized below under the particular fiber.

Chitin and Chitosan

Studies on the adverse effects of chitin and chitosan are limited. A study in rats fed up to 5 percent chitin for 13 weeks showed no adverse

effects based on clinical signs, hematology, serum biochemistry, and histopathology analysis (Niho et al., 1999).

Gums

Gastrointestinal Distress. While the adverse gastrointestinal effects of gums are limited, incidences of moderate to severe degrees of flatulence were reported from a trial in which 4 to 12 g/d of a hydrolyzed guar gum were provided to 16 elderly patients (Patrick et al., 1998).

Allergic Reactions. Gums such as the exudate gums, gum arabic, and gum tragacanth have been shown to elicit an immune response in mice (Strobel et al., 1982). Occupational asthma caused by guar gum has been reported (Lagier et al., 1990).

Inulin, Oligofructose, and Fructooligosaccharide

Cancer. When F-344 rats, known to have a high incidence of neoplastic lesions, were given 0, 8,000, 20,000, or 50,000 ppm doses of fructooligosaccharide, the incidence of pituitary adenomas was 20, 26, 38, and 44 percent, respectively (Haseman et al., 1990). The incidence was significantly higher for intakes at 20,000 and 50,000 ppm. Clevenger and coworkers (1988) reported no difference in the onset of cancer in F-344 rats fed 0, 8,000 (341 to 419 mg/kg/d), 20,000 (854 to 1,045 mg/kg/d), or 50,000 ppm (2,170 to 2,664 mg/kg/d) doses of fructooligosaccharide compared with the controls.

Development and Reproduction. Henquin (1988) observed a lack of developmental toxicity when female rats were fed a diet containing 20 percent fructooligosaccharide during gestation. When pregnant rats were fed diets containing 5, 10, or 20 percent fructooligosaccharide during gestation, no adverse developmental effects were observed (Sleet and Brightwell, 1990).

Genotoxicity. Fructooligosaccharide has been tested for genotoxicity using a wide range of test doses (0 to 50,000 ppm); the results indicated no genotoxic potential from use of fructooligosaccharide (Clevenger et al., 1988).

Gastrointestinal Distress. A number of studies have observed gastrointestinal distress (e.g., diarrhea, flatulence, bloating, and cramping) with

inulin, oligofructose, or fructooligosaccharide intake. Cramping, bloating, flatulence, and diarrhea was observed at intakes ranging from 14 to 18 g/d of inulin (Davidson and Maki, 1999; Pedersen et al., 1997). Consumption of 5 or 15 g/d of fructooligosaccharide produced a gaseous response in healthy men (Alles et al., 1996). Briet and coworkers (1995) reported increased flatulence as a result of consuming more than 30 g/d of fructo-oligosaccharide, increased bloating at greater than 40 g/d, and cramps and diarrhea at 50 g/d. Increased flatulence and bloating were observed when 10 g/d of fructooligosaccharide was consumed (Stone-Dorshow and Levitt, 1987).

The role carbohydrate malabsorption plays in the onset of diarrhea most likely depends upon the balance between the osmotic force of the carbohydrate and the capacity of the colon to remove the carbohydrate via bacterial fermentation. In order to evaluate the significance of osmolarity, Clausen and coworkers (1998) compared the severity of diarrhea after consumption of fructooligosaccharide and lactulose, both of which are nonabsorbable carbohydrates. Although both carbohydrates are fermented by colonic microflora, they differ in osmolarity. The osmotic force is twice as high for lactulose as for frutooligosaccharide. In a crossover design, 12 individuals were given fructooligosaccharide or lactulose in increasing doses of 0, 20, 40, 80, and 160 g/d. The increase in fecal volume measured as a function of the dose administered was twice as high for lactulose as for fructooligosaccharide; however, there was substantial interindividual variation in the response. The researchers concluded that fecal volume in carbohydrate-induced diarrhea is proportional to the osmotic force of the malabsorbed saccharide, even though most is degraded by colonic bacteria (Clausen et al., 1998).

Allergic Reactions. Data on the allergenicity of inulin and oligofructose is very limited. Anaphylaxis was observed following the intravenous administration of inulin for determining the glomerular filtration rate (Chandra and Barron, 2002). Separate episodes of anaphylaxis were observed following the ingestion of artichoke leaves, a margarine containing inulin extracted from chicory (Raftiline HP), and a candy containing inulin (Raftiline HP) or oligofructose (Raftilose P95) (Gay-Crosier et al., 2000). A skin-pricking test revealed hypersensitivity to each of the above foods or ingredients (Gay-Crosier et al., 2000).

Pectin

Pectin has been shown to have a negligible effect on zinc retention in humans (Lei et al., 1980). Also, Behall and coworkers (1987) found that refined fibers had no effect on mineral balance as long as people were

consuming recommended dietary allowance levels of iron and zinc when fed as part of their control diet.

Polydextrose

Polydextrose has showed no reproductive toxicity, teratology, mutagenicity, genotoxicity, or carcinogenesis in experimental animals (Burdock and Flamm, 1999). In humans, no reports of abdominal cramping or diarrhea were reported in men and women who were given up to 12 g/d of polydextrose (Jie et al., 2000). Furthermore, there were no complaints of abdominal distress with the consumption of 30 g/d of polydextrose (Achour et al., 1994). However, flatulence and gas-related problems were reported following the intake of 30 g/d of polydextrose (Tomlin and Read, 1988). Diarrhea was reported with the consumption of 15 g/d of polydextrose; however, this symptom ceased after 1 month of intake (Saku et al., 1991).

Psyllium

Gastrointestinal Distress. In a meta-analysis of eight studies regarding psyllium intake, the authors found that psyllium was well tolerated and safe (Anderson et al., 2000a). There have been certain situations in which adverse effects have been observed. Esophageal obstruction was noted in an elderly man who regularly took a "heaping" teaspoon with some water (Noble and Grannis, 1984). Furthermore, an elderly woman who was given 2 tbs of a psyllium-based laxative three times daily suffered from small-bowel obstruction (Berman and Schultz, 1980). It was determined that her water intake was insufficient for this dose. Thus, psyllium generally does not cause gastrointestinal distress provided adequate amounts of water are consumed.

Cancer. In the European Center Prevention Organization Study, psyllium (*Functional Fiber*) was provided at a level of 3.5 g/d (Bonithon-Kopp et al., 2000). Patients ($n = 655$) with a history of colon adenomas were randomly assigned to one of three treatment groups: 2 g/d of calcium, 3.5 g/d of psyllium, or placebo. Participants in the study also had a colonoscopy after 3 years of follow-up. The adjusted odds ratio for colon adenoma recurrence for the psyllium fiber intervention was 1.67 ($p = 0.042$). The authors concluded that supplementation with psyllium may have adverse effects on colon adenoma recurrence.

Allergic Reactions. Several reports of anaphylaxis have been reported following the ingestion of psyllium-containing cereals (Drake et al., 1991; James et al., 1991; Lantner et al., 1990). Subsequent IgE antibodies to psyllium were confirmed in these reports. Symptoms of asthma have also been reported in individuals exposed to psyllium powder (Busse and Schoenwetter, 1975).

Resistant Starch

Ninety-one percent of individuals who consumed 32 g/d of RS_3 (retrograded starch; formed from the cooking and cooling or extrusion of starchy foods) experienced flatulence and 41 percent reported bloated feelings (Heijnen et al., 1998). Other gastrointestinal discomforts were reported by 14 percent of those consuming 32 g/d of RS_3, whereas only 5 percent of individuals consuming an equal amount of glucose reported such discomforts.

Summary

While occasional adverse gastrointestinal symptoms are observed when consuming some of the isolated or synthetic fibers, serious chronic adverse effects have not been observed. Furthermore, due to the bulky nature of fibers, excess consumption is likely to be self-limiting. Therefore, a UL was not set for these individual fibers.

RESEARCH RECOMMENDATIONS

The relationship of fiber to health is of great importance, particularly since novel fiber sources are appearing on the market, and these fiber sources may or may not produce the same physiological effects as fiber from traditional foods. Research that provides human data and does the following is assigned the highest priority:

- Evaluate the protective effect of fiber against colon cancer in subsets of the population by applying genotyping and phenotyping to those participating in fiber and colon cancer trials. There also needs to be increased validation of intermediate markers, such as polyp recurrence, and assessment of functional markers (e.g., fecal bulk) and its relationship to these endpoints.
- Conduct a dose–response study to determine the amount of fiber that needs to be ingested to promote optimum laxation so that this could form the basis for a recommendation for fiber intake and provide a basis for determining functional fibers.

• Attempt to relate changes in the colonic microflora due to fiber ingestion to functional endpoints (e.g., decreased irritable bowel syndrome, increased laxation).

• Conduct longer-term studies on low energy-dense food sources (high in dietary fiber) and satiety and weight control to see if a higher fiber diet will help with weight maintenance or promote adherence to reduced calorie diets for weight reduction.

• Examine the relation between *Dietary Fiber* intake, energy intake, and long-term body weight in existing prospective epidemiological studies in addition to intervention studies.

• Conduct long-term studies on the effects of both viscous and whole-grain cereal fibers on coronary heart disease and diabetes risk factors.

REFERENCES

AAP (American Academy of Pediatrics). 1981. Plant fiber intake in the pediatric diet. *Pediatrics* 67:572–575.

AAP. 1993. Carbohydrate and dietary fiber. In: Barness LA, ed. *Pediatric Nutrition Handbook*, 3rd ed. Elk Grove Village, IL: AAP. Pp. 100–106.

Abraham ZD, Mehta T. 1988. Three-week psyllium-husk supplementation: Effect on plasma cholesterol concentrations, fecal steroid excretion, and carbohydrate absorption in men. *Am J Clin Nutr* 47:67–74.

Achour L, Flourié B, Briet F, Pellier P, Marteau P, Rambaud J-C. 1994. Gastrointestinal effects and energy value of polydextrose in healthy nonobese men. *Am J Clin Nutr* 59:1362–1368.

AHA (American Heart Association). 1983. AHA committee report. Diet in the healthy child. Task Force Committee of the Nutrition Committee and the Cardiovascular Disease in the Young Council of the American Heart Association. *Circulation* 67:1411A–1414A.

Alberts DS, Einspahr J, Rees-McGee S, Ramanujam P, Buller MK, Clark L, Ritenbaugh C, Atwood J, Pethigal P, Earnest D, Villar H, Phelps J, Lipkin M, Wargovich M, Meyskens FL. 1990. Effects of dietary wheat-bran fiber on rectal epithelial cell proliferation in patients with resection for colorectal cancers. *J Natl Cancer Inst* 82:1280–1285.

Alberts DS, Einspahr J, Ritenbaugh C, Aickin M, Rees-McGee S, Atwood J, Emerson S, Mason-Liddil N, Bettinger L, Patel J, Bellapravalu S, Ramanujam PS, Phelps J, Clark L. 1997. The effect of wheat-bran fiber and calcium supplementation on rectal mucosal proliferation rates in patients with resected adenomatous colorectal polyps. *Cancer Epidemiol Biomarkers Prev* 6:161–169.

Alberts DS, Martínez ME, Roe DJ, Guillén-Rodríguez JM, Marshall JR, van Leeuwen JB, Reid ME, Ritenbaugh C, Vargas PA, Bhatacharyya AB, Earnest DL, Sampliner RE. 2000. Lack of effect of a high-fiber cereal supplement on the recurrence of colorectal adenomas. *N Engl J Med* 342:1156–1162.

Aldoori WH, Giovannucci EL, Rimm EB, Wing AL, Trichopoulos DV, Willett WC. 1994. A prospective study of diet and the risk of symptomatic diverticular disease in men. *Am J Clin Nutr* 60:757–764.

Aldoori WH, Giovannucci EL, Rimm EB, Ascherio A, Stampfer MJ, Colditz GA, Wing AL, Trichopoulos DV, Willett WC. 1995. Prospective study of physical activity and the risk of symptomatic diverticular disease in men. *Gut* 36:276–282.

Aldoori WH, Giovannucci EL, Stampfer MJ, Rimm EB, Wing AL, Willett WC. 1997. Prospective study of diet and the risk of duodenal ulcer in men. *Am J Epidemiol* 145:42–50.

Aldoori WH, Giovannucci EL, Rockett HRH, Sampson L, Rimm EB, Willett WC. 1998. A prospective study of dietary fiber types and symptomatic diverticular disease in men. *J Nutr* 128:714–719.

Alles MS, Hautvast JG, Nagengast FM, Hartemink R, Van Laere KM, Jansen JB. 1996. Fate of fructo-oligosaccharides in the human intestine. *Br J Nutr* 76:211–221.

AMA (American Medical Association) Council on Scientific Affairs. 1989. Dietary fiber and health. *J Am Med Assoc* 262:542–546.

Anderson JW, Gustafson NJ. 1988. Hypocholesterolemic effects of oat and bean products. *Am J Clin Nutr* 48:749–753.

Anderson JW, Tietyen-Clark J. 1986. Dietary fiber: Hyperlipidemia, hypertension, and coronary heart disease. *Am J Gastroenterol* 81:907–919.

Anderson JW, Story L, Sieling B, Chen W-JL. 1984a. Hypocholesterolemic effects of high-fibre diets rich in water-soluble plant fibres. *J Can Diet Assoc* 45:140–148.

Anderson JW, Story L, Sieling B, Chen W-JL, Petro MS, Story J. 1984b. Hypocholesterolemic effects of oat-bran or bean intake for hypercholesterolemic men. *Am J Clin Nutr* 40:1146–1155.

Anderson JW, Gustafson NJ, Bryant CA, Tietyen-Clark J. 1987. Dietary fiber and diabetes: A comprehensive review and practical application. *J Am Diet Assoc* 87:1189–1197.

Anderson JW, Zettwoch N, Feldman T, Tietyen-Clark J, Oeltgen P, Bishop CW. 1988. Cholesterol-lowering effects of psyllium hydrophilic mucilloid for hypercholesterolemic men. *Arch Intern Med* 148:292–296.

Anderson JW, Gilinsky NH, Deakins DA, Smith SF, O'Neal DS, Dillon DW, Oeltgen PR. 1991. Lipid responses of hypercholesterolemic men to oat-bran and wheat-bran intake. *Am J Clin Nutr* 54:678–683.

Anderson JW, Garrity TF, Wood CL, Whitis SE, Smith BM, Oeltgen PR. 1992a. Prospective, randomized, controlled comparison of the effects of low-fat and low-fat plus high-fiber diets on serum lipid concentrations. *Am J Clin Nutr* 56:887–894.

Anderson JW, Riddell-Mason S, Gustafson NJ, Smith SF, Mackey M. 1992b. Cholesterol-lowering effects of psyllium-enriched cereal as an adjunct to a prudent diet in the treatment of mild to moderate hypercholesterolemia. *Am J Clin Nutr* 56:93–98.

Anderson JW, Allgood LD, Turner J, Oeltgen PR, Daggy BP. 1999. Effects of psyllium on glucose and serum lipid responses in men with type 2 diabetes and hypercholesterolemia. *Am J Clin Nutr* 70:466–473.

Anderson JW, Allgood LD, Lawrence A, Altringer LA, Jerdack GR, Hengehold DA, Morel JG. 2000a. Cholesterol-lowering effects of psyllium intake adjunctive to diet therapy in men and women with hypercholesterolemia: Meta-analysis of 8 controlled trials. *Am J Clin Nutr* 71:472–479.

Anderson JW, Davidson MH, Blonde L, Brown WV, Howard JW, Ginsberg H, Allgood LD, Weingand KW. 2000b. Long-term cholesterol-lowering effects of psyllium as an adjunct to diet therapy in the treatment of hypercholesterolemia. *Am J Clin Nutr* 71:1433–1438.

Andersson S-O, Wolk A, Bergström R, Giovannucci E, Lindgren C, Baron J, Adami H-O. 1996. Energy, nutrient intake and prostate cancer risk: A population-based case-control study in Sweden. *Int J Cancer* 68:716–722.

Anti M, Pignataro G, Armuzzi A, Valenti A, Iascone E, Marmo R, Lamazza A, Pretaroli AR, Pace V, Leo P, Castelli A, Gasbarrini G. 1998. Water supplementation enhances the effect of high-fiber diet on stool frequency and laxative consumption in adult patients with functional constipation. *Hepatogastroenterology* 45:727–732.

Appleby PN, Thorogood M, Mann JI, Key TJ. 1998. Low body mass index in non-meat eaters: The possible roles of animal fat, dietary fibre and alcohol. *Int J Obes Relat Metab Disord* 22:454–460.

Aro A, Uusitupa M, Voutilainen E, Hersio K, Korhonen T, Siitonen O. 1981. Improved diabetic control and hypocholesterolaemic effect induced by long-term dietary supplementation with guar gum in type-2 (insulin-independent) diabetes. *Diabetologia* 21:29–33.

Aro A, Uusitupa M, Voutilainen E, Korhonen T. 1984. Effects of guar gum in male subjects with hypercholesterolemia. *Am J Clin Nutr* 39:911–916.

Ascherio A, Rimm EB, Giovannucci EL, Colditz GA, Rosner B, Willett WC, Sacks F, Stampfer MJ. 1992. A prospective study of nutritional factors and hypertension among US men. *Circulation* 86:1475–1484.

Ashraf W, Park F, Lof J, Quigley EM. 1995. Effects of psyllium therapy on stool characteristics, colon transit and anorectal function in chronic idiopathic constipation. *Aliment Pharmacol Ther* 9:639–647.

Astrup A, Vrist E, Quaade F. 1990. Dietary fibre added to very low calorie diet reduces hunger and alleviates constipation. *Int J Obes* 14:105–112.

Bagga D, Ashley JM, Geffrey SP, Wang HJ, Barnard RJ, Korenman S, Heber D. 1995. Effects of a very low fat, high fiber diet on serum hormones and menstrual function. Implications for breast cancer prevention. *Cancer* 76:2491–2496.

Baghurst PA, Rohan TE. 1994. High-fiber diets and reduced risk of breast cancer. *Int J Cancer* 56:173–176.

Barbone F, Austin H, Partridge EE. 1993. Diet and endometrial cancer: A case-control study. *Am J Epidemiol* 137:393–403.

Baron JA, Schori A, Crow B, Carter R, Mann JI. 1986. A randomized controlled trial of low carbohydrate and low fat/high fiber diets for weight loss. *Am J Public Health* 76:1293–1296.

Bartram P, Gerlach S, Scheppach W, Keller F, Kasper H. 1992. Effect of a single oat bran cereal breakfast on serum cholesterol, lipoproteins, and apolipoproteins in patients with hyperlipoproteinemia type IIa. *J Parenter Enteral Nutr* 16:533–537.

Beer MU, Arrigoni E, Amado R. 1995. Effects of oat gum on blood cholesterol levels in healthy young men. *Eur J Clin Nutr* 49:517–522.

Behall KM. 1990. Effect of soluble fibers on plasma lipids, glucose tolerance and mineral balance. *Adv Exp Med Biol* 270:7–16.

Behall KM, Howe JC. 1996. Resistant starch as energy. *J Am Coll Nutr* 15:248–254.

Behall KM, Scholfield DJ, Lee K, Powell AS, Moser PB. 1987. Mineral balance in adult men: Effect of four refined fibers. *Am J Clin Nutr* 46:307–314.

Bell LP, Hectorn KJ, Reynolds H, Hunninghake DB. 1990. Cholesterol-lowering effects of soluble-fiber cereals as part of a prudent diet for patients with mild to moderate hypercholesterolemia. *Am J Clin Nutr* 52:1020–1026.

Benini L, Castellani G, Brighenti F, Heaton KW, Brentegani MT, Casiraghi MC, Sembenini C, Pellegrini N, Fioretta A, Minniti G. 1995. Gastric emptying of a solid meal is accelerated by the removal of dietary fibre naturally present in food. *Gut* 36:825–830.

Bergmann JF, Chassany O, Petit A, Triki R, Caulin C, Segrestaa JM. 1992. Correlation between echographic gastric emptying and appetite: Influence of psyllium. *Gut* 33:1042–1043.

Berman JI, Schultz MJ. 1980. Bulk laxative ileus. *J Am Geriatr Soc* 28:224–226.

Berta JL, Coste T, Rautureau J, Guilloud-Bataille M, Pequignot G. 1985. Diet and rectocolonic cancers. Results of a case-control study. *Gastroenterol Clin Biol* 9:348–353.

Bidoli E, Franceschi S, Talamini R, Barra S, La Vecchia C. 1992. Food consumption and cancer of the colon and rectum in north-eastern Italy. *Int J Cancer* 50:223–229.

Birkett AM, Jones GP, de Silva AM, Young GP, Muir JG. 1997. Dietary intake and faecal excretion of carbohydrate by Australians: Importance of achieving stool weights greater than 150 g to improve faecal markers relevant to colon cancer risk. *Eur J Clin Nutr* 51:625–632.

Birketvedt GS, Aaseth J, Florholmen JR, Ryttig K. 2000. Long term effect of fibre supplement and reduced energy intake on body weight and blood lipids in overweight subjects. *Acta Medica (Hradec Králové)* 43:129–132.

Blackburn NA, Holgate AM, Read NW. 1984. Does guar gum improve post-prandial hyperglycaemia in humans by reducing small intestinal contact area? *Br J Nutr* 52:197–204.

Blake DE, Hamblett CJ, Frost PG, Judd PA, Ellis PR. 1997. Wheat bread supplemented with depolymerized guar gum reduces the plasma cholesterol concentration in hypercholesterolemic human subjects. *Am J Clin Nutr* 65:107–113.

Blundell JE, Burley VJ. 1987. Satiation, satiety and the action of fibre on food intake. *Int J Obesity* 11:9–25.

Bolin TD, Stanton RA. 1998. Flatus emission patterns and fibre intake. *Eur J Surg* 582:115–118.

Bolton-Smith C, Woodward M, Tunstall-Pedoe H. 1992. The Scottish Heart Health Study. Dietary intake by food frequency questionnaire and odds ratios for coronary heart disease risk. II. The antioxidant vitamins and fibre. *Eur J Clin Nutr* 46:85–93.

Bonithon-Kopp C, Kronborg O, Giacosa A, Räth U, Faivre J. 2000. Calcium and fibre supplementation in prevention of colorectal adenoma recurrance: A randomised intervention trial. *Lancet* 356:1300–1306.

Bosaeus I, Carlsson NG, Sandberg AS, Andersson H. 1986. Effect of wheat bran and pectin on bile acid and cholesterol excretion in ileostomy patients. *Hum Nutr Clin Nutr* 40:429–440.

Bosello O, Cominacini L, Zocca I, Garbin U, Ferrari F, Davoli A. 1984. Effects of guar gum on plasma lipoproteins and apolipoproteins C-II and C-III in patients affected with familial combined hyperlipoproteinemia. *Am J Clin Nutr* 40:1165–1174.

Bouhnik Y, Flourié B, Riottot M, Bisetti N, Gailing M-F, Guibert A, Bornet F, Rambaud J-C. 1996. Effects of fructo-oligosaccharides ingestion on fecal bifidobacteria and selected metabolic indexes of colon carcinogenesis in healthy humans. *Nutr Cancer* 26:21–29.

Bouhnik Y, Vahedi K, Achour L, Attar A, Salfati J, Pochart P, Marteau P, Flourié B, Bornet F, Rambaud J-C. 1999. Short-chain fructo-oligosaccharide administration dose-dependently increases fecal bifidobacteria in healthy humans. *J Nutr* 129:113–116.

Boyle P, Zaridze DG, Smans M. 1985. Descriptive epidemiology of colorectal cancer. *Int J Cancer* 36:9–18.

Braaten JT, Wood PJ, Scott FW, Riedel KD, Poste LM, Collins MW. 1991. Oat gum lowers glucose and insulin after an oral glucose load. *Am J Clin Nutr* 53:1425–1430.

Braaten JT, Scott FW, Wood PJ, Riedel KD, Wolynetz MS, Brulé D, Collins MW. 1994a. High β-glucan oat bran and oat gum reduce postprandial blood glucose and insulin in subjects with and without type 2 diabetes. *Diabetic Med* 11:312–318.

Braaten JT, Wood PJ, Scott FW, Wolynetz MS, Lowe MK, Bradley-White P, Collins MW. 1994b. Oat beta-glucan reduces blood cholesterol concentration in hypercholesterolemic subjects. *Eur J Clin Nutr* 48:465–474.

Briet F, Achour L, Flourié B, Beaugerie L, Pellier P, Franchisseur C, Bornet F, Rambaud JC. 1995. Symptomatic response to varying levels of fructo-oligosaccharides consumed occasionally or regularly. *Eur J Clin Nutr* 49:501–507.

Brighenti F, Casiraghi MC, Canzi E, Ferrari A. 1999. Effect of consumption of a ready-to-eat breakfast cereal containing inulin on the intestinal milieu and blood lipids in healthy male volunteers. *Eur J Clin Nutr* 53:726–733.

Brodribb AJM. 1977. Treatment of symptomatic diverticular disease with a high-fibre diet. *Lancet* 1:664–666.

Brown IL, McNaught KJ, Moloney E. 1995. Hi-maize: New directions in starch technology and nutrition. *Food Aust* 47:273–279.

Brown L, Rosner B, Willett W, Sacks FM. 1999. Cholesterol-lowering effects of dietary fiber: A meta-analysis. *Am J Clin Nutr* 69:30–42.

Brune M, Rossander-Hulten L, Hallberg L, Gleerup A, Sandberg AS. 1992. Iron absorption from bread in humans: Inhibiting effects of cereal fiber, phytate and inositol phosphates with different numbers of phosphate groups. *J Nutr* 122:442–449.

Buddington RK, Williams CH, Chen S-C, Witherly SA. 1996. Dietary supplementation of neosugar alters the fecal flora and decreases activities of some reductive enzymes in human subjects. *Am J Clin Nutr* 63:709–716.

Burdock GA, Flamm WG. 1999. A review of the studies of the safety of polydextrose in food. *Food Chem Toxicol* 37:233–264.

Burkitt DP, Walker ARP, Painter NS. 1972. Effect of dietary fibre on stools and transit-times, and its role in the causation of disease. *Lancet* 2:1408–1412.

Burley VJ, Paul AW, Blundell JE. 1993. Sustained post-ingestive action of dietary fibre: Effects of a sugar-beet-fibre-supplemented breakfast on satiety. *J Hum Nutr Diet* 6:43–50.

Burr ML, Sweetnam PM. 1982. Vegetarianism, dietary fiber, and mortality. *Am J Clin Nutr* 36:873–877.

Burr ML, Fehily AM, Gilbert JF, Rogers S, Holliday RM, Sweetnam PM, Elwood PC, Deadman NM. 1989. Effects of changes in fat, fish, and fibre intakes on death and myocardial reinfarction: Diet and Reinfarction Trial (DART). *Lancet* 2:757–761.

Burton R, Manninen V. 1982. Influence of psyllium-based fibre preparation on faecal and serum parameters. *Acta Med Scand Suppl* 668:91–94.

Busse WW, Schoenwetter WF. 1975. Asthma from psyllium in laxative manufacture. *Ann Intern Med* 83:361–362.

Cameron KJ, Nyulasi IB, Collier GR, Brown DJ. 1996. Assessment of the effect of increased dietary fibre intake on bowel function in patients with spinal cord injury. *Spinal Cord* 34:277–283.

Caygill CPJ, Charlett A, Hill MJ. 1998. Relationship between the intake of high-fibre foods and energy and the risk of cancer of the large bowel and breast. *Eur J Cancer Prev* 7:S11–S17.

Cerda JJ, Robbins FL, Burgin CW, Baumgartner TG, Rice RW. 1988. The effects of grapefruit pectin on patients at risk for coronary heart disease without altering diet or lifestyle. *Clin Cardiol* 11:589–594.

Chandalia M, Garg A, Lutjohann D, von Bergmann K, Grundy SM, Brinkley LJ. 2000. Beneficial effects of high dietary fiber intake in patients with type 2 diabetes mellitus. *N Engl J Med* 342:1392–1398.

Chandra R, Barron JL. 2002. Anaphylactic reaction to intravenous sinistrin (Inutest). *Ann Clin Biochem* 39:76.

Chen H-L, Haack VS, Janecky CW, Vollendorf NW, Marlett JA. 1998. Mechanisms by which wheat bran and oat bran increase stool weight in humans. *Am J Clin Nutr* 68:711–719.

Chen WJL, Anderson JW. 1986. Hypocholesterolemic effects of soluble fibers. In: Vahouny GV, Kritchevsky D, eds. *Dietary Fiber: Basic and Clinical Aspects*. New York: Plenum Press. Pp. 275–286.

Chiang MT, Yao HT, Chen HC. 2000. Effect of dietary chitosans with different viscosity on plasma lipids and lipid peroxidation in rats fed on a diet enriched with cholesterol. *Biosci Biotechnol Biochem* 64:965–971.

Clausen MR, Jorgensen J, Mortensen PB. 1998. Comparison of diarrhea induced by ingestion of fructooligosaccharide Idolax and disaccharide lactulose (role of osmolarity versus fermentation of malabsorbed carbohydrate). *Dig Dis Sci* 43:2696–2707.

Clevenger MA, Turnbill D, Inoue H, Enomoto M, Allen JA, Henderson LM, Jones E. 1988. Toxicological evaluation of neosugar: Genotoxicity, carcinogenicity, and chronic toxicity. *J Am Coll Toxicol* 7:643–662.

Colditz GA, Manson JE, Stampfer MJ, Rosner B, Willett WC, Speizer FE. 1992. Diet and risk of clinical diabetes in women. *Am J Clin Nutr* 55:1018–1023.

Coudray C, Bellanger J, Castiglia-Delavaud C, Remesy C, Vermorel M, Rayssignuier Y. 1997. Effect of soluble or partly soluble dietary fibres supplementation on absorption and balance of calcium, magnesium, iron and zinc in healthy young men. *Eur J Clin Nutr* 51:375–380.

Cummings JH. 1984. Microbial digestion of complex carbohydrates in man. *Proc Nutr Soc* 43:35–44.

Cummings JH. 1993. The effect of dietary fiber on fecal weight and composition. In: Spiller GA, ed. *CRC Handbook of Dietary Fiber in Human Nutrition*, 2nd ed. Boca Raton, FL: CRC Press. Pp. 263–349.

Cummings JH. 2000. Nutritional management of diseases of the gut. In: Garrow JS, James WPT, Ralph A, eds. *Human Nutrition and Dietetics*, 10th ed. Edinburgh: Churchill Livingston. Pp. 547–573.

Cummings JH, Branch WJ. 1986. Fermentation and the production of short-chain fatty acids in the human large intestine. In: Vahouny GV, Kritchevsky D, eds. *Dietary Fiber: Basic and Clinical Aspects*. New York: Plenum Press. Pp. 131–149.

Cummings JH, Englyst HN. 1987. Fermentation in the human large intestine and the available substrates. *Am J Clin Nutr* 45:1243–1255.

Cummings JH, Southgate DAT, Branch W, Houston H, Jenkins DJA, James WPT. 1978. Colonic responses to dietary fibre from carrot, cabbage, apple, bran, and guar gum. *Lancet* 1:5–9.

Cummings JH, Bingham SA, Heaton KW, Eastwood MA. 1992. Fecal weight, colon cancer risk, and dietary intake of nonstarch polysaccharides (dietary fiber). *Gastroenterology* 103:1783–1789.

Cummings JH, Beatty ER, Kingman SM, Bingham SA, Englyst HN. 1996. Digestion and physiological properties of resistant starch in the human large bowel. *Br J Nutr* 75:733–747.

Dales LG, Friedman GD, Ury HK, Grossman S, Williams SR. 1979. A case-control study of relationships of diet and other traits to colorectal cancer in American blacks. *Am J Epidemiol* 109:132–144.

Danielsson A, Ek B, Nyhlin H, Steen L. 1979. Effect of long term treatment with hydrophilic colloid on serum lipids. *Acta Hepatogastroenterol (Stuttg)* 26:148–153.

Davidson MH, Maki KC. 1999. Effects of dietary inulin on serum lipids. *J Nutr* 129:1474S–1477S.

Davidson MH, Dugan LD, Burns JH, Bova J, Story K, Drennan KB. 1991. The hypocholesterolemic effects of β-glucan in oatmeal and oat bran. A dose-controlled study. *J Am Med Assoc* 265:1833–1839.

Davidson MH, Maki KC, Kong JC, Dugan LD, Torri SA, Hall HA, Drennan KB, Anderson SM, Fulgoni VL, Saldanha LG, Olson BH. 1998. Long-term effects of consuming foods containing psyllium seed husk on serum lipids in subjects with hypercholesterolemia. *Am J Clin Nutr* 67:367–376.

de Deckere EA, Kloots WJ, van Amelsvoort JM. 1993. Resistant starch decreases serum total cholesterol and triacylglycerol concentrations in rats. *J Nutr* 123:2142–2151.

Delargy HJ, Burley VJ, O'Sullivan KR, Fletcher RJ, Blundell JE. 1995. Effects of different soluble:insoluble fibre ratios at breakfast on 24-h pattern of dietary intake and satiety. *Eur J Clin Nutr* 49:754–766.

de Roos N, Heijnen M-L, de Graaf C, Woestenenk G, Hobbel E. 1995. Resistant starch has little effect on appetite, food intake and insulin secretion of healthy young men. *Eur J Clin Nutr* 49:532–541.

De Stefani E, Correa P, Ronco A, Mendilaharsu M, Guidobono M, Deneo-Pellegrini H. 1997. Dietary fiber and risk of breast cancer: A case-control study in Uruguay. *Nutr Cancer* 28:14–19.

Dettmar PW, Sykes J. 1998. A multi-centre, general practice comparison of ispaghula husk with lactulose and other laxatives in the treatment of simple constipation. *Curr Med Res Opin* 14:227–233.

Djoussé L, Ellison RC, Zhang Y, Arnett DK, Sholinsky P, Borecki I. 1998. Relation between dietary fiber consumption and fibrinogen and plasminogen activator inhibitor type 1: The National Heart, Lung, and Blood Institute Family Heart Study. *Am J Clin Nutr* 68:568–575.

Drake CL, Moses ES, Tandberg D. 1991. Systemic anaphylaxis after ingestion of a psyllium-containing breakfast cereal. *Am J Emerg Med* 9:449–451.

Duncan KH, Bacon JA, Weinsier RL. 1983. The effects of high and low energy density diets on satiety, energy intake, and eating time of obese and nonobese subjects. *Am J Clin Nutr* 37:763–767.

Durrington PN, Manning AP, Bolton CH, Hartog M. 1976. Effect of pectin on serum lipids and lipoproteins, whole-gut transit-time, and stool weight. *Lancet* 2:394–396.

Dutta SK, Hlasko J. 1985. Dietary fiber in pancreatic disease: Effect of high fiber diet on fat malabsorption in pancreatic insufficiency and in vitro study of the interaction of dietary fiber with pancreatic enzymes. *Am J Clin Nutr* 41:517–525.

Dwyer J. 1980. Diets for children and adolescents that meet the dietary goals. *Am J Dis Child* 134:1073–1080.

Eliasson K, Ryttig KR, Hylander B, Rossner S. 1992. A dietary fibre supplement in the treatment of mild hypertension. A randomized, double-blind, placebo-controlled trial. *J Hypertens* 10:195–199.

Ellis PR, Kamalanathan T, Dawoud FM, Strange RN, Coultate TP. 1988. Evaluation of guar biscuits for use in the management of diabetes: Tests of physiological effects and palatability in non-diabetic volunteers. *Eur J Clin Nutr* 42:425–435.

Englyst HN, Cummings JH. 1986. Digestion of the carbohydrates of banana (*Musa paradisiaca sapientum*) in the human small intestine. *Am J Clin Nutr* 44:42–50.

Englyst HN, Cummings JH. 1987. Digestion of polysaccharides of potato in the small intestine of man. *Am J Clin Nutr* 45:423–431.

Englyst HN, Kingman SM, Cummings JH. 1992. Classification and measurement of nutritionally important starch fractions. *Eur J Clin Nutr* 46:S33–S50.

Everson GT, Daggy BP, McKinley C, Story JA. 1992. Effects of psyllium hydrophilic muccilloid on LDL-cholesterol and bile acid synthesis in hypercholesterolemic men. *J Lipid Res* 33:1183–1192.

FDA (U.S. Food and Drug Administration). 1987. Nutrition labeling of food; calorie content. *Fed Regis* 52:28590–28691.

Feskens EJM, Loeber JG, Kromhout D. 1994. Diet and physical activity as determinants of hyperinsulinemia: The Zutphen Elderly Study. *Am J Epidemiol* 140:350–360.

Findlay JM, Smith AN, Mitchell WD, Anderson AJB, Eastwood MA. 1974. Effects of unprocessed bran on colon function in normal subjects and in diverticular disease. *Lancet* 1:146–149.

Franceschi S, Favero A, Decarli A, Negri E, La Vecchia C, Ferraroni M, Russo A, Salvini S, Amadori D, Conti E, Montella M, Giacosa A. 1996. Intake of macronutrients and risk of breast cancer. *Lancet* 347:1351–1356.

Fraser GE, Sabaté J, Beeson WL, Strahan TM. 1992. A possible protective effect of nut consumption on risk of coronary heart disease. The Adventist Health Study. *Arch Intern Med* 152:1416–1424.

Frati-Munari AC, Benitez-Pinto W, Raul Ariza-Andraca C, Casarrubias M. 1998. Lowering glycemic index of food by acarbose and Plantago psyllium mucilage. *Arch Med Res* 29:137–141.

Freudenheim JL, Graham S, Horvath PJ, Marshall JR, Haughey BP, Wilkinson G. 1990. Risks associated with source of fiber and fiber components in cancer of the colon and rectum. *Cancer Res* 50:3295–3300.

Freudenheim JL, Marshall JR, Vena JE, Laughlin R, Brasure JR, Swanson MK, Nemoto T, Graham S. 1996. Premenopausal breast cancer risk and intake of vegetables, fruits, and related nutrients. *J Natl Cancer Inst* 88:340–348.

Fuchs CS, Giovannucci EL, Colditz GA, Hunter DJ, Stampfer MJ, Rosner B, Speizer FE, Willett WC. 1999. Dietary fiber and the risk of colorectal cancer and adenoma in women. *N Engl J Med* 340:169–176.

Fuessl HS, Williams G, Adrian TE, Bloom SR. 1987. Guar sprinkled on food: Effect on glycaemic control, plasma lipids and gut hormones in non-insulin dependent diabetic patients. *Diabetic Med* 4:463–468.

Gabbe SG, Cohen AW, Herman GO, Schwartz S. 1982. Effect of dietary fiber on the oral glucose tolerance test in pregnancy. *Am J Obstet Gynecol* 143:514–517.

Gallaher CM, Munion J, Hesslink R, Wise J, Gallaher DD. 2000. Cholesterol reduction by glucomannan and chitosan is mediated by changes in cholesterol absorption and bile acid and fat excretion in rats. *J Nutr* 130:2753–2759.

Gay-Crosier F, Schreiber G, Hauser C. 2000. Anaphylaxis from inulin in vegetables and processed food. *N Engl J Med* 342:1372.

Gear JSS, Ware A, Fursdon P, Mann JI, Nolan DJ, Brodribb AJM, Vessey MP. 1979. Symptomless diverticular disease and intake of dietary fibre. *Lancet* 1:511–514.

Gerber M. 1998. Fibre and breast cancer. *Eur J Cancer Prev* 7:S63–S67.

Gerhardsson de Verdier M, Hagman U, Steineck G, Rieger Å, Norell SE. 1990. Diet, body mass and colorectal cancer: A case-referent study in Stockholm. *Int J Cancer* 46:832–838.

Gibson GR, Beatty ER, Wang X, Cummings JH. 1995. Selective stimulation of bifidobacteria in the human colon by oligofructose and inulin. *Gastroenterology* 108:975–982.

Giovannucci E, Willett WC. 1994. Dietary factors and risk of colon cancer. *Ann Med* 26:443–452.

Giovannucci E, Stampfer MJ, Colditz G, Rimm EB, Willett WC. 1992. Relationship of diet to risk of colorectal adenoma in men. *J Natl Cancer Inst* 84:91–98.

Giovannucci E, Rimm EB, Stampfer MJ, Colditz GA, Ascherio A, Willett WC. 1994. Intake of fat, meat, and fiber in relation to risk of colon cancer in men. *Cancer Res* 54:2390–2397.

Golay A, Koellreutter B, Bloise D, Assal JP, Wursch P. 1992. The effect of muesli or cornflakes at breakfast on carbohydrate metabolism in type 2 diabetic patients. *Diabetes Res Clin Pract* 15:135–141.

Gold LA, McCourt JP, Merimee TJ. 1980. Pectin: An examination in normal subjects. *Diabetes Care* 3:50–52.

Goldin BR, Adlercreutz H, Gorbach SL, Warram JH, Dwyer JT, Swenson L, Woods MN. 1982. Estrogen excretion patterns and plasma levels in vegetarian and omnivorous women. *N Engl J Med* 307:1542–1547.

Goodman MT, Wilkens LR, Hankin JH, Lyu L-C, Wu AH, Kolonel LN. 1997. Association of soy and fiber consumption with the risk of endometrial cancer. *Am J Epidemiol* 146:294–306.

Gorbach SL, Goldin BR. 1987. Diet and the excretion and enterohepatic cycling of estrogens. *Prev Med* 16:525–529.

Goulder TJ, Alberti KGMM, Jenkins DA. 1978. Effect of added fiber on the glucose and metabolic response to a mixed meal in normal and diabetic subjects. *Diabetes Care* 1:351–355.

Graham S, Hellmann R, Marshall J, Freudenheim J, Vena J, Swanson M, Zielezny M, Nemoto T, Stubbe N, Raimondo T. 1991. Nutritional epidemiology of postmenopausal breast cancer in western New York. *Am J Epidemiol* 134:552–566.

Graham S, Zielezny M, Marshall J, Priore R, Freudenheim J, Brasure J, Haughey B, Nasca P, Zdeb M. 1992. Diet in the epidemiology of postmenopausal breast cancer in the New York State Cohort. *Am J Epidemiol* 136:1327–1337.

Grizard D, Barthomeuf C. 1999. Non-digestible oligosaccharides used as prebiotic agents: Mode of production and beneficial effects on animal and human health. *Reprod Nutr Dev* 39:563–588.

Groop P-H, Aro A, Stenman S, Groop L. 1993. Long-term effects of guar gum in subjects with non-insulin-dependent diabetes mellitus. *Am J Clin Nutr* 58:513–518.

Grossman SP. 1986. The role of glucose, insulin and glucagon in the regulation of food intake and body weight. *Neurosci Biobehav Rev* 10:295–315.

Guerciolini R, Radu-Radulescu L, Boldrin M, Dallas J, Moore R. 2001. Comparative evaluation of fecal fat excretion induced by orlistat and chitosan. *Obes Res* 9:364–367.

Haenszel W, Kurihara M. 1968. Studies of Japanese migrants. I. Mortality from cancer and other diseases among Japanese in the United States. *J Natl Cancer Inst* 40:43–68.

Hallfrisch J, Powell A, Carafelli C, Reiser S, Prather ES. 1987. Mineral balances of men and women consuming high fiber diets with complex or simple carbohydrate. *J Nutr* 117:48–55.

Hallfrisch J, Tobin JD, Muller DC, Andres R. 1988. Fiber intake, age, and other coronary risk factors in men of the Baltimore Longitudinal Study (1959–1975). *J Gerontol Med Sci* 43:M64–M68.

Hallfrisch J, Scholfield DJ, Behall KM. 1995. Diets containing soluble oat extracts improve glucose and insulin responses of moderately hypercholesterolemic men and women. *Am J Clin Nutr* 61:379–384.

Harris PJ, Ferguson LR. 1993. Dietary fibre: Its composition and role in protection against colorectal cancer. *Mutat Res* 290:97–110.

Harris PJ, Triggs CM, Roberton AM, Watson ME, Ferguson LR. 1996. The adsorption of heterocyclic aromatic amines by model dietary fibres with contrasting compositions. *Chem Biol Interact* 100:13–25.

Haseman JK, Arnold J, Eustis SL. 1990. Tumor incidences in Fischer 344 rats: NTP historical data. In: GA Boorman, ed. *Pathology of the Fischer Rat.* San Diego, CA: Academic Press. Pp. 557–564.

Health and Welfare Canada. 1985. *Report of the Expert Advisory Committee on Dietary Fibre.* Ottawa: Supply and Services Canada.

Health Canada. 1988. *Guideline Concerning the Safety and Physiological Effects of Novel Fibre Sources and Food Products Containing Them.* Ottawa: Food Directorate, Health Protection Branch, Health Canada.

Health Canada. 1997. Appendix 2. Guideline for planning and statistical review of clinical laxation studies for dietary fibre. In: *Guideline Concerning the Safety and Physiological Effects of Novel Fibre Sources and Food Products Containing Them.* Ottawa: Food Directorate, Health Protection Branch, Health Canada.

Heaton KW. 1973. Food fibre as an obstacle to energy intake. *Lancet* 2:1418–1421.

Heijnen M-LA, van Amelsvoort JMM, Deurenberg P, Beynen AC. 1996. Neither raw nor retrograded resistant starch lowers fasting serum cholesterol concentrations in healthy normolipidemic subjects. *Am J Clin Nutr* 64:312–318.

Heijnen M-LA, van Amelsvoort JMM, Deurenberg P, Beynen AC. 1998. Limited effect of consumption of uncooked (RS_2) or retrograded (RS_3) resistant starch on putative risk factors for colon cancer in healthy men. *Am J Clin Nutr* 67:322–331.

Heilbrun LK, Nomura A, Hankin JH, Stemmermann GN. 1989. Diet and colorectal cancer with special reference to fiber intake. *Int J Cancer* 44:1–6.

Henquin JC. 1988. *Reproduction Toxicity: Study on the Influence of Fructooligosaccharides on the Development of Foetal and Postnatal Rat.* Raffinerie Tirlemontoise Internal Report. Photocopy.

Hill MJ. 1997. Cereals, cereal fibre and colorectal cancer risk: A review of the epidemiological literature. *Eur J Cancer Prev* 6:219–225.

Hillman LC, Peters SG, Fisher CA, Pomare EW. 1983. Differing effects of pectin, cellulose and lignin on stool pH, transit time and weight. *Br J Nutr* 50:189–195.

Hillman LC, Peters SG, Fisher CA, Pomare EW. 1985. The effects of the fiber components pectin, cellulose and lignin on serum cholesterol levels. *Am J Clin Nutr* 42:207–213.

Ho SC, Tai ES, Eng PHK, Tan CE, Fok ACK. 2001. In the absence of dietary surveillance, chitosan does not reduce plasma lipids or obesity in hyper-cholesterolaemic obese Asian subjects. *Singapore Med J* 42:6–10.

Hoff G, Moen IE, Trygg K, Frølich W, Sauar J, Vatn M, Gjone E, Larsen S. 1986. Epidemiology of polyps in the rectum and sigmoid colon. Evaluation of nutritional factors. *Scand J Gastroenterol* 21:199–204.

Holman RR, Steemson J, Darling P, Turner RC. 1987. No glycemic benefit from guar administration in NIDDM. *Diabetes Care* 10:68–71.

Holt S, Brand J, Soveny C, Hansky J. 1992. Relationship of satiety to postprandial glycaemic, insulin and cholecystokinin responses. *Appetite* 18:129–141.

Howe GR, Benito E, Castelleto R, Cornée J, Estéve J, Gallagher RP, Iscovich JM, Deng-ao J, Kaaks R, Kune GA, Kune S, L'Abbé KA, Lee HP, Lee M, Miller AB, Peters RK, Potter JD, Riboli E, Slattery ML, Trichopoulos D, Tuyns A, Tzonou A, Whittemore AS, Wu-Williams AH, Shu Z. 1992. Dietary intake of fiber and decreased risk of cancers of the colon and rectum: Evidence from the combined analysis of 13 case-control studies. *J Natl Cancer Inst* 84:1887–1896.

Humble CG, Malarcher AM, Tyroler HA. 1993. Dietary fiber and coronary heart disease in middle-aged hypercholesterolemic men. *Am J Prev Med* 9:197–202.

Hunt R, Fedorak R, Frohlich J, McLennan C, Pavilanis A. 1993. Therapeutic role of dietary fibre. *Can Fam Physician* 39:897–910.

Hylla S, Gostner A, Dusel G, Anger H, Bartram H-P, Christl SU, Kasper H, Scheppach W. 1998. Effects of resistant starch on the colon in healthy volunteers: Possible implications for cancer prevention. *Am J Clin Nutr* 67:136–142.

Ingram DM. 1981. Trends in diet and breast cancer mortality in England and Wales 1928–1977. *Nutr Cancer* 3:75–80.

IOM (Institute of Medicine). 1991. *Nutrition During Lactation.* Washington, DC: National Academy Press.

IOM. 2001. *Dietary Reference Intakes: Proposed Definition of Dietary Fiber.* Washington, DC: National Academy Press.

Iscovich JM, L'Abbé KA, Castelleto R, Calzona A, Bernedo A, Chopita NA, Jmelnitzky AC, Kaldor J, Howe GR. 1992. Colon cancer in Argentina. II: Risk from fibre, fat and nutrients. *Int J Cancer* 51:858–861.

Ito N, Hasegawa R, Sano M, Tamano S, Esumi H, Takayama S, Sugimura T. 1991. A new colon and mammary carcinogen in cooked food, 2-amino-1-methyl-6-phenylimidazo[4,5-b]pyridine (PhIP). *Carcinogenesis* 12:1503–1506.

Jackson KG, Taylor GRJ, Clohessy AM, Williams CM. 1999. The effect of the daily intake of inulin fasting lipid, insulin and glucose concentrations in middle-aged men and women. *Br J Nutr* 82:23–30.

Jacobs DR, Meyer KA, Kushi LH, Folsom AR. 1998. Whole-grain intake may reduce the risk of ischemic heart disease death in postmenopausal women: The Iowa Women's Health Study. *Am J Clin Nutr* 68:248–257.

Jacobs LR. 1986. Relationship between dietary fiber and cancer: Metabolic, physiologic, and cellular mechanisms. *Proc Soc Exp Biol Med* 183:299–310.

Jain M, Cook GM, Davis FG, Grace MG, Howe GR, Miller AB. 1980. A case-control study of diet and colo-rectal cancer. *Int J Cancer* 26:757–768.

James JM, Cooke SK, Barnett A, Sampson HA. 1991. Anaphylactic reactions to a psyllium-containing cereal. *J Allergy Clin Immunol* 88:402–408.

Jenkins DJA, Newton C, Leeds AR, Cummings JH. 1975. Effect of pectin, guar gum, and wheat fibre on serum cholesterol. *Lancet* 1:1116–1117.

Jenkins DJA, Wolever TMS, Leeds AR, Gassull MA, Haisman P, Dilawari J, Goff DV, Metz GL, Alberti KGMM. 1978. Dietary fibres, fibre analogues, and glucose tolerance: Importance of viscosity. *Br Med J* 1:1392–1394.

Jenkins DJA, Wolever TMS, Collier GR, Ocana A, Rao AV, Buckley G, Lam Y, Mayer A, Thompson LU. 1987. Metabolic effects of a low-glycemic-index diet. *Am J Clin Nutr* 46:968–975.

Jenkins DJA, Vuksan V, Kendall CWC, Würsch P, Jeffcoat R, Waring S, Mehling CC, Vidgen E, Augustin LSA, Wong E. 1998. Physiological effects of resistant starches on fecal bulk, short chain fatty acids, blood lipids and glycemic index. *J Am Coll Nutr* 17:609–616.

Jenkins DJA, Kendall CWC, Vuksan V, Vidgen E, Parler T, Faulkner D, Mehling CC, Garsetti M, Testolin G, Cunnane SC, Ryan MA, Corey PN. 2002. Soluble fiber intake at a dose approved by the US Food and Drug Administration for a health claim of health benefits: Serum lipid risk factors for cardiovascular disease assessed in a randomized controlled crossover trial. *Am J Clin Nutr* 75:834–839.

Jennings CD, Boleyn K, Bridges SR, Wood PJ, Anderson JW. 1988. A comparison of the lipid-lowering and intestinal morphological effects of cholestyramine, chitosan, and oat gum in rats. *Proc Soc Exp Biol Med* 189:13–20.

Jie Z, Bang-Yao L, Ming-Jie X, Hai-Wei L, Zu-Kang Z, Ting-Song W, Craig SAS. 2000. Studies on the effects of polydextrose intake on physiologic function in Chinese people. *Am J Clin Nutr* 72:1503–1509.

Judd PA, Truswell AS. 1981. The effect of rolled oats on blood lipids and fecal steroid excretion in man. *Am J Clin Nutr* 34:2061–2067.

Kang JY, Doe WF. 1979. Unprocessed bran causing intestinal obstruction. *Br Med J* 1:1249–1250.

Kato I, Akhmedkhanov A, Koenig K, Toniolo PG, Shore RE, Riboli E. 1997. Prospective study of diet and female colorectal cancer: The New York University Women's Health Study. *Nutr Cancer* 28:276–281.

Kay RM, Truswell AS. 1977. Effect of citrus pectin on blood lipids and fecal steroid excretion in man. *Am J Clin Nutr* 30:171–175.

Kelsay JL, Behall KM, Prather ES. 1978. Effect of fiber from fruits and vegetables on metabolic responses of human subjects. I. Bowel transit time, number of defecations, fecal weight, urinary excretions of energy and nitrogen and apparent digestibilities of energy, nitrogen, and fat. *Am J Clin Nutr* 31:1149–1153.

Key TJA, Thorogood M, Appleby PN, Burr ML. 1996. Dietary habits and mortality in 11,000 vegetarians and health conscious people: Results of a 17 year follow up. *Br Med J* 313:775–779.

Khaw K, Barrett-Connor E. 1987. Dietary fiber and reduced ischemic heart disease mortality rates in men and women: A 12-year prospective study. *Am J Epidemiol* 126:1093–1102.

Kirby RW, Anderson JW, Sieling B, Rees ED, Chen W-JL, Miller RE, Kay RM. 1981. Oat-bran intake selectively lowers serum low-density lipoprotein cholesterol concentrations of hypercholesterolemic men. *Am J Clin Nutr* 34:824–829.

Kleessen B, Sykura B, Zunft HJ, Blaut M. 1997. Effects of inulin and lactose on fecal microflora, microbial activity, and bowel habit in elderly constipated persons. *Am J Clin Nutr* 65:1397–1402.

Klurfeld DM. 1992. Dietary fiber-mediated mechanisms in carcinogenesis. *Cancer Res* 52:2055S–2059S.

Knekt P, Steineck G, Järvinen R, Hakulinen T, Aromaa A. 1994. Intake of fried meat and risk of cancer: A follow-up study in Finland. *Int J Cancer* 59:756–760.

Knox TA, Kassarjian Z, Dawson-Hughes B, Golner BB, Dallal GE, Arora S, Russell RM. 1991. Calcium absorption in elderly subjects on high- and low-fiber diets: Effect of gastric acidity. *Am J Clin Nutr* 53:1480–1486.

Kochen MM, Wegscheider K, Abholz HH. 1985. Prophylaxis of constipation by wheat bran: A randomized study in hospitalized patients. *Digestion* 31:220–224.

Krishnamachar S, Mickelsen O. 1987. The influence of different carbohydrate sources on blood glucose levels and satiety: Effect of physical activity on blood glucose response. *Hum Nutr Food Sci Nutr* 41F:29–39.

Kromhout D, Bosschieter EB, de Lezenne Coulander C. 1982. Dietary fibre and 10-year mortality from coronary heart disease, cancer, and all causes. The Zutphen Study. *Lancet* 2:518–522.

Krotkiewski M. 1987. Effect of guar gum on the arterial blood pressure. *Acta Med Scand* 222:43–49.

Kushi LH, Lew RA, Stare FJ, Ellison CR, el Lozy M, Bourke G, Daly L, Graham I, Hickey N, Mulcahy R, Kevaney J. 1985. Diet and 20-year mortality from coronary heart disease. The Ireland-Boston Diet-Heart Study. *N Engl J Med* 312:811–818.

Lagier F, Cartier A, Somer J, Dolovich J, Malo JL. 1990. Occupational asthma caused by guar gum. *J Allergy Clin Immunol* 85:785–790.

Landin K, Holm G, Tengborn L, Smith U. 1992. Guar gum improves insulin sensitivity, blood lipids, blood pressure, and fibrinolysis in healthy men. *Am J Clin Nutr* 56:1061–1065.

Lantner RR, Espiritu BR, Zumerchik P, Tobin MC. 1990. Anaphylaxis following ingestion of a psyllium-containing cereal. *J Am Med Assoc* 264:2534–2536.

Lanza E. 1990. National Cancer Institute Satellite Symposium on Fiber and Colon Cancer. In: Kritchevsky D, Bonfield C, Anderson JW, eds. *Dietary Fiber: Chemistry, Physiology, and Health Effects.* New York: Plenum Press. Pp. 383–387.

Larson DE, Hunter GR, Williams MJ, Kekes-Szabo T, Nyikos I, Goran MI. 1996. Dietary fat in relation to body fat and intraabdominal adipose tissue: A cross-sectional analysis. *Am J Clin Nutr* 64:677–684.

Leathwood P, Pollet P. 1988. Effects of slow release carbohydrates in the form of bean flakes on the evolution of hunger and satiety in man. *Appetite* 10:1–11.

Lee HP, Gourley L, Duffy SW, Estève J, Lee J, Day NE. 1991. Dietary effects on breast-cancer risk in Singapore. *Lancet* 337:1197–1200.

Lei KY, Davis MW, Fang MM, Young LC. 1980. Effect of pectin on zinc, copper and iron balances in humans. *Nutr Rep Int* 22:459–466.

Lev R. 1990. Malignant potential of adenomatous polyps. In: *Adenomatous Polyps of the Colon: Pathobiological and Clinical Features.* New York: Springer-Verlag. Pp. 53–89.

Levin EG, Miller VT, Muesing RA, Stoy DB, Balm TK, LaRosa JC. 1990. Comparison of psyllium hydrophilic mucilloid and cellulose as adjuncts to a prudent diet in the treatment of mild to moderate hypercholesterolemia. *Arch Intern Med* 150:1822–1827.

Levine AS, Billington CJ. 1994. Dietary fiber: Does it affect food intake and body weight? In: Fernstrom JD, Miller GD, eds. *Appetite and Body Weight Regulation: Sugar, Fat, and Macronutrient Substitutes.* Boca Raton, FL: CRC Press. Pp. 191–200.

Librenti MC, Cocchi M, Orsi E, Pozza G, Micossi P. 1992. Effect of soya and cellulose fibers on postprandial glycemic response in type II diabetic patients. *Diabetes Care* 15:111–113.

Lichtenstein AH, Ausman LM, Jalbert SM, Vilella-Bach M, Jauhiainen M, McGladdery S, Erkkila AT, Ehnholm C, Frohlich J, Schaefer EJ. 2002. Efficacy of a Therapeutic Lifestyle Change/Step 2 diet in moderately hypercholesterolemic middle-aged and elderly female and male subjects. *J Lipid Res* 43:264–273.

Lipid Research Clinics Program. 1984. The Lipid Research Clinics Coronary Primary Prevention Trial results. II. The relationship of reduction in incidence of coronary heart disease to cholesterol lowering. *J Am Med Assoc* 251:365–374.

Little J, Logan RFA, Hawtin PG, Hardcastle JD, Turner ID. 1993. Colorectal adenomas and diet: A case-control study of subjects participating in the Nottingham Faecal Occult Blood Screening Programme. *Br J Cancer* 67:177–184.

Livesey G. 1990. Energy values of unavailable carbohydrate and diets: An inquiry and analysis. *Am J Clin Nutr* 51:617–637.

Loening-Baucke V. 1993. Chronic constipation in children. *Gastroenterology* 105:1557–1564.

Lovegrove JA, Clohessy A, Milon H, Williams CM. 2000. Modest doses of β-glucan do not reduce concentrations of potentially atherogenic lipoproteins. *Am J Clin Nutr* 72:49–55.

Low AG. 1990. Nutritional regulation of gastric secretion, digestion and emptying. *Nutr Res Rev* 3:229–252.

LSRO (Life Sciences Research Office). 1987. *Physiological Effects and Health Consequences of Dietary Fiber.* Bethesda, MD: LSRO.

Lubin F, Wax Y, Modan B. 1986. Role of fat, animal protein, and dietary fiber in breast cancer etiology: A case-control study. *J Natl Cancer Inst* 77:605–612.

Luo J, Rizkalla SW, Alamowitch C, Boussairi A, Blayo A, Barry J-L, Laffitte A, Guyon F, Bornet FRJ, Slama G. 1996. Chronic consumption of short-chain fructo-oligosaccharides by healthy subjects decreased basal hepatic glucose production but had no effect on insulin-stimulated glucose metabolism. *Am J Clin Nutr* 63:939–945.

Lupton JR. 1995. Butyrate and colonic cytokinetics: Differences between in vitro and in vivo studies. *Eur J Cancer Prev* 4:373–378.

Lupton JR, Morin JL, Robinson MC. 1993. Barley bran flour accelerates gastro-intestinal transit time. *J Am Diet Assoc* 93:881–885.

Lyon JL, Mahoney AW, West DW, Gardner JW, Smith KR, Sorenson AW, Stanish W. 1987. Energy intake: Its relationship to colon cancer risk. *J Natl Cancer Inst* 78:853–861.

Macfarlane GT, Englyst HN. 1986. Starch utilization by the human large intestinal microflora. *J Appl Bacteriol* 60:195–201.

MacLennan R, Macrae F, Bain C, Battistutta D, Chapuis P, Gratten H, Lambert J, Newland RC, Ngu M, Russell A, Ward M, Wahlqvist ML. 1995. Randomized trial of intake of fat, fiber, and beta carotene to prevent colorectal adenomas. *J Natl Cancer Inst* 87:1760–1766.

MacMahon M, Carless J. 1998. Ispaghula husk in the treatment of hypercholesterolemia: A double-blind controlled study. *J Cardiovasc Risk* 5:167–172.

Macquart-Moulin G, Riboli E, Cornée J, Charnay B, Berthezène P, Day N. 1986. Case-control study on colorectal cancer and diet in Marseilles. *Int J Cancer* 38:183–191.

Macquart-Moulin G, Riboli E, Cornée J, Kaaks R, Berthezène P. 1987. Colorectal polyps and diet: A case-control study in Marseilles. *Int J Cancer* 40:179–188.

Manousos O, Day NE, Tzonou A, Papadimitriou C, Kapetanakis A, Polychronopoulou-Trichopoulou A, Trichopoulos D. 1985. Diet and other factors in the aetiology of diverticulosis: An epidemiological study in Greece. *Gut* 26:544–549.

Marlett JA. 1992. Content and composition of dietary fiber in 117 frequently consumed foods. *J Am Diet Assoc* 92:175–186.

Marlett JA, Longacre MJ. 1996. Comparison of in vitro and in vivo measures of resistant starch in selected grain products. *Cereal Chem* 73:63–68.

Mathur KS, Khan MA, Sharma RD. 1968. Hypocholesterolaemic effect of Bengal gram: A long-term study in man. *Br Med J* 1:30–31.

McBurney MI. 1991. Potential water-holding capacity and short-chain fatty acid production from purified fiber sources in a fecal incubation system. *Nutrition* 7:421–424.

McBurney MI, Thompson LU. 1990. Fermentative characteristics of cereal brans and vegetable fibers. *Nutr Cancer* 13:271–280.

McCann SE, Freudenheim JL, Marshall JR, Brasure JR, Swanson MK, Graham S. 2000. Diet in the epidemiology of endometrial cancer in western New York (United States). *Cancer Causes Control* 11:965–974.

McCann SE, Moysich KB, Mettlin C. 2001. Intakes of selected nutrients and food groups and risk of ovarian cancer. *Nutr Cancer* 39:19–28.

McClung HJ, Boyne LJ, Linsheid T, Heitlinger LA, Murray RD, Fyda J, Li BUK. 1993. Is combination therapy for encopresis nutritionally safe? *Pediatrics* 91:591–594.

McClung HJ, Boyne L, Heitlinger L. 1995. Constipation and dietary fiber intake in children. *Pediatrics* 96:999–1001.

McKeown-Eyssen GE, Bright-See E, Bruce WR, Jazmaji V. 1994. A randomized trial of a low fat high fibre diet in the recurrence of colorectal polyps. *J Clin Epidemiol* 47:525–536.

McRorie JW, Daggy BP, Morel JG, Diersing PS, Miner PB, Robinson M. 1998. Psyllium is superior to docusate sodium for treatment of chronic constipation. *Aliment Pharmacol Ther* 12:491–497.

McRorie J, Kesler J, Bishop L, Filloon T, Allgood G, Sutton M, Hunt T, Laurent A, Rudolph C. 2000. Effects of wheat bran and Olestra on objective measures of stool and subjective reports of GI symptoms. *Am J Gastroenterol* 95:1244–1252.

Mennen LI, Witteman JCM, den Breeijen JH, Schouten EG, de Jong PTVM, Hofman A, Grobbee DE. 1997. The association of dietary fat and fiber with coagulation factor VII in the elderly: The Rotterdam Study. *Am J Clin Nutr* 65:732–736.

Meyer KA, Kushi LH, Jacobs DR, Slavin J, Sellers TA, Folsom AR. 2000. Carbohydrates, dietary fiber, and incident type 2 diabetes in older women. *Am J Clin Nutr* 71:921–930.

Miller AB, Howe GR, Jain M, Craib KJP, Harrison L. 1983. Food items and food groups as risk factors in a case-control study of diet and colo-rectal cancer. *Int J Cancer* 32:155–161.

Miller WC, Niederpruem MG, Wallace JP, Lindeman AK. 1994. Dietary fat, sugar, and fiber predict body fat content. *J Am Diet Assoc* 94:612–615.

Modan B, Barell V, Lubin F, Modan M, Greenberg RA, Graham S. 1975. Low-fiber intake as an etiologic factor in cancer of the colon. *J Natl Cancer Inst* 55:15–18.

Morais MB, Vítolo MR, Aguirre ANC, Fagundes-Neto U. 1999. Measurement of low dietary fiber intake as a risk factor for chronic constipation in children. *J Pediatr Gastroenterol Nutr* 29:132–135.

Morales M, Llopis A. 1992. Breast cancer and diet in Spain. *J Environ Pathol Toxicol Oncol* 11:157–167.

Morris JN, Marr JW, Clayton DG. 1977. Diet and heart: A postscript. *Br Med J* 2:1307–1314.

Moshfegh AJ, Friday JE, Goldman JP, Ahuja JKC. 1999. Presence of inulin and oligofructose in the diets of Americans. *J Nutr* 129:1407S–1411S.

National Cholesterol Education Program. 1991. *Report of the Expert Panel on Blood Cholesterol Levels in Children and Adolescents*. NIH Publication No. 91-2732. Bethesda, MD: National Heart, Lung, and Blood Institute.

Neugut AI, Garbowski GC, Lee WC, Murray T, Nieves JW, Forde KA, Treat MR, Waye JD, Fenoglio-Preiser C. 1993. Dietary risk factors for the incidence and recurrence of colorectal adenomatous polyps. A case-control study. *Ann Intern Med* 11:91–95.

Niemi MK, Keinänen-Kiukaanniemi SM, Salmela PI. 1988. Long-term effects of guar gum and microcrystalline cellulose on glycaemic control and serum lipids in type 2 diabetes. *Eur J Clin Pharmacol* 34:427–429.

Niho N, Tamura T, Toyoda K, Uneyama C, Shibutani M, Hirose M. 1999. A 13-week subchronic toxicity study of chitin in F344 rats. *Kokuritsu Iyakuhin Shokuhin Eisei Kenkyusho Hokoku* 117:129–134.

Nishimune T, Sumimoto T, Konishi Y, Yakushiji T, Komachi Y, Mitsuhashi Y, Nakayama I, Okazaki K, Tsuda T, Ichihashi A, Adachi T, Imanaka M, Kirigaya T, Ushio H, Kasuga Y, Saeki K, Yamamoto Y, Ichikawa T, Nakahara S, Oda S. 1993. Dietary fiber intake of Japanese younger generations and the recommended daily allowance. *J Nutr Sci Vitaminol (Tokyo)* 39:263–278.

Noble JA, Grannis FW. 1984. Acute esophageal obstruction by a psyllium-based bulk laxative. *Chest* 86:800.

NRC (National Research Council). 1989. *Diet and Health: Implications for Reducing Chronic Disease Risk*. Washington, DC: National Academy Press.

Obarzanek E, Sacks FM, Vollmer WM, Bray GA, Miller ER, Lin P-H, Karanja NM, Most-Windhauser MM, Moore TJ, Swain JF, Bales CW, Proschan MA. 2001. Effects on blood lipids of a blood pressure-lowering diet: The Dietary Approaches to Stop Hypertension (DASH) Trial. *Am J Clin Nutr* 74:80–89.

O'Brien KO, Allen LH, Quatromoni P, Siu-Caldera M-L, Vieira NE, Perez A, Holick MF, Yergey AL. 1993. High fiber diets slow bone turnover in young men but have no effect on efficiency of intestinal calcium absorption. *J Nutr* 123:2122–2128.

Ohkuma K, Wakabayashi S. 2001. Fibersol-2: A soluble, non-digestible, starch-derived dietary fibre. In: McCleary BV, Prosky L, eds. *Advanced Dietary Fibre Technology*. Oxford: Blackwell Science. Pp. 510–523.

Ohno Y, Yoshida O, Oishi K, Okada K, Yamabe H, Schroeder FH. 1988. Dietary β-carotene and cancer of the prostate: A case-control study in Kyoto, Japan. *Cancer Res* 48:1331–1336.

Olesen M, Gudmand-Høyer E. 2000. Efficacy, safety, and tolerability of fructo-oligosaccharides in the treatment of irritable bowel syndrome. *Am J Clin Nutr* 72:1570–1575.

Olson BH, Anderson SM, Becker MP, Anderson JW, Hunninghake DB, Jenkins DJA, LaRose JC, Rippe JM, Roberts DCK, Stoy DB, Summerbell CD, Truswell AS, Wolever TMS, Morris DH, Fulgoni VL. 1997. Psyllium-enriched cereals lower blood total cholesterol and LDL cholesterol, but not HDL cholesterol, in hypercholesterolemic adults: Results of a meta-analysis. *J Nutr* 127:1973–1980.

Pastors JG, Blaisdell PW, Balm TK, Asplin CM, Pohl SL. 1991. Psyllium fiber reduces rise in postprandial glucose and insulin concentrations in patients with non-insulin-diabetes mellitus. *Am J Clin Nutr* 53:1431–1435.

Patrick PG, Gohman SM, Marx SC, DeLegge MH, Greenberg NA. 1998. Effect of supplements of partially hydrolyzed guar gum on the occurrence of constipation and use of laxative agents. *J Am Diet Assoc* 98:912–914.

Pedersen A, Sandstrom B, Van Amelsvoort JM. 1997. The effect of ingestion of inulin on blood lipids and gastrointestinal symptoms in healthy females. *Br J Nutr* 78:215–222.

Penagini R, Velio P, Vigorelli R, Bozzani A, Castagnone D, Ranzi T, Bianchi PA. 1986. The effect of dietary guar on serum cholesterol, intestinal transit, and fecal output in man. *Am J Gastroenterol* 81:123–125.

Petrakis NL, King EB. 1981. Cytological abnormalities in nipple aspirates of breast fluid from women with severe constipation. *Lancet* 2:1203–1204.

Phillips J, Muir JG, Birkett A, Lu ZX, Jones GP, O'Dea K, Young GP. 1995. Effect of resistant starch on fecal bulk and fermentation-dependent events in humans. *Am J Clin Nutr* 62:121–130.

Pick ME, Hawrysh ZJ, Gee MI, Toth E, Garg ML, Hardin RT. 1996. Oat bran concentrate bread products improve long-term control of diabetes: A pilot study. *J Am Diet Assoc* 96:1254–1261.

Pietinen P, Rimm EB, Korhonen P, Hartman AM, Willett WC, Albanes D, Virtamo J. 1996. Intake of dietary fiber and risk of coronary heart disease in a cohort of Finnish men. The Alpha-Tocopherol, Beta-Carotene Cancer Prevention Study. *Circulation* 94:2720–2727.

Pietinen P, Malila N, Virtanen M, Hartman TJ, Tangrea JA, Albanes D, Virtamo J. 1999. Diet and risk of colorectal cancer in a cohort of Finnish men. *Cancer Causes Control* 10:387–396.

Pittler MH, Abbot NC, Harkness EF, Ernst E. 1999. Randomized, double-blind trial of chitosan for body weight reduction. *Eur J Clin Nutr* 53:379–381.

Platz EA, Giovannucci E, Rimm EB, Rockett HRH, Stampfer MJ, Colditz GA, Willett WC. 1997. Dietary fiber and distal colorectal adenoma in men. *Cancer Epidemiol Biomarkers Prev* 6:661–670.

Prior A, Whorwell PJ. 1987. Double blind study of ispagula in irritable bowel syndrome. *Gut* 28:1510–1513.

Raben A, Tagliabue A, Christensen NJ, Madsen J, Holst JJ, Astrup A. 1994. Resistant starch: The effect on postprandial glycemia, hormonal response, and satiety. *Am J Clin Nutr* 60:544–551.

Ranhotra GS, Gelroth JA, Leinen SD. 1997. Hypolipidemic effect of resistant starch in hamsters is not dose dependent. *Nutr Res* 17:317–323.

Razdan A, Pettersson D. 1994. Effect of chitin and chitosan on nutrient digestibility and plasma lipid concentrations in broiler chickens. *Br J Nutr* 72:277–288.

Razdan A, Pettersson D. 1996. Hypolipidaemic, gastrointestinal and related responses of broiler chickens to chitosans of different viscosity. *Br J Nutr* 76:387–397.

Razdan A, Pettersson D, Pettersson J. 1997. Broiler chicken body weights, feed intakes, plasma lipid and small-intestinal bile acid concentrations in response to feeding of chitosan and pectin. *Br J Nutr* 78:283–291.

Rigaud D, Ryttig KR, Angel LA, Apfelbaum M. 1990. Overweight treated with energy restriction and a dietary fibre supplement: A 6-month randomized, double-blind, placebo-controlled trial. *Int J Obes* 14:763–769.

Rigaud D, Paycha F, Meulemans A, Merrouche M, Mignon M. 1998. Effect of psyllium on gastric emptying, hunger feeling and food intake in normal volunteers: A double blind study. *Eur J Clin Nutr* 52:239–245.

Rimm EB, Ascherio A, Giovannucci E, Spiegelman D, Stampfer MJ, Willett WC. 1996. Vegetable, fruit, and cereal fiber intake and risk of coronary heart disease among men. *J Am Med Assoc* 275:447–451.

Ripsin CM, Keenan JM, Jacobs DR, Elmer PJ, Welch RR, Van Horn L, Liu K, Turnbull WH, Thye FW, Kestin M, Hegsted M, Davidson DM, Davidson MH, Dugan LD, Demark-Wahnefried W, Beling S. 1992. Oat products and lipid lowering. A meta-analysis. *J Am Med Assoc* 267:3317–3325.

Risch HA, Jain M, Marrett LD, Howe GR. 1994. Dietary fat intake and risk of epithelial ovarian cancer. *J Natl Cancer Inst* 86:1409–1415.

Ritz P, Krempf M, Cloarec D, Champ M, Charbonnel B. 1991. Comparative continuous-indirect-calorimetry study of two carbohydrates with different glycemic indices. *Am J Clin Nutr* 54:855–859.

Rivellese A, Riccardi G, Giacco A, Pacioni D, Genovese S, Mattioli PL, Mancini M. 1980. Effect of dietary fibre on glucose control and serum lipoproteins in diabetic patients. *Lancet* 2:447–450.

Roberfroid M. 1993. Dietary fiber, inulin, and oligofructose: A review comparing their physiological effects. *Crit Rev Food Sci Nutr* 33:103–148.

Roberts PL, Veidenheimer MC. 1990. Diverticular disease of the colon. In: Bayless TM, ed. *Current Therapy in Gastroenterology and Liver Disease—3.* Toronto: Decker Mosby. Pp. 416–419.

Roediger WEW. 1980. The colonic epithelium in ulcerative colitis: An energy-deficiency disease? *Lancet* 2:712–715.

Roediger WEW. 1982. Utilization of nutrients by isolated epithelial cells of the rat colon. *Gastroenterology* 83:424–429.

Roediger WE, Duncan A, Kapaniris O, Millard S. 1993. Reducing sulfur compounds of the colon impair colonocyte nutrition: Implications for ulcerative colitis. *Gastroenterology* 104:802–809.

Rohan TE, McMichael AJ, Baghurst PA. 1988. A population-based case-control study of diet and breast cancer in Australia. *Am J Epidemiol* 128:478–489.

Rohan TE, Howe GR, Friedenreich CM, Jain M, Miller AB. 1993. Dietary fiber, vitamins A, C, and E, and risk of breast cancer: A cohort study. *Cancer Causes Control* 4:29–37.

Rohan TE, Howe GR, Burch JD, Jain M. 1995. Dietary factors and risk of prostate cancer: A case-control study in Ontario, Canada. *Cancer Causes Control* 6:145–154.

Roma E, Adamidis D, Nikolara R, Constantopoulos A, Messaritakis J. 1999. Diet and chronic constipation in children: The role of fiber. *J Pediatr Gastroenterol Nutr* 28:169–174.

Ronco A, De Stefani E, Boffetta P, Deneo-Pellegrini H, Mendilaharsu M, Leborgne F. 1999. Vegetables, fruits, and related nutrients and risk of breast cancer: A case-control study in Uruguay. *Nutr Cancer* 35:111–119.

Rose DP. 1990. Dietary fiber and breast cancer. *Nutr Cancer* 13:1–8.

Rose DP. 1992. Dietary fiber, phytoestrogens, and breast cancer. *Nutrition* 8:47–51.

Rose DP, Goldman M, Connoly JM, Strong LE. 1991. High-fiber diet reduces serum estrogen concentrations in premenopausal women. *Am J Clin Nutr* 54:520–525.

Rössner S, von Zweigbergk D, Öhlin A, Ryttig K. 1987. Weight reduction with dietary fibre supplements. Results of two double-blind randomized studies. *Acta Med Scand* 222:83–88.

Ryttig KR, Tellnes G, Haegh L, Boe E, Fagerthun H. 1989. A dietary fibre supplement and weight maintenance after weight reduction: A randomized, double-blind, placebo-controlled long-term trial. *Int J Obes* 13:165–171.

Saku K, Yoshinaga K, Okura Y, Ying H, Harada R, Arakawa K. 1991. Effects of polydextrose on serum lipids, lipoproteins, and apolipoproteins in healthy subjects. *Clin Ther* 13:254–258.

Salmerón J, Ascherio A, Rimm EB, Colditz GA, Spiegelman D, Jenkins DJ, Stampfer MJ, Wing AL, Willett WC. 1997a. Dietary fiber, glycemic load, and risk of NIDDM in men. *Diabetes Care* 20:545–550.

Salmerón J, Manson JE, Stampfer MJ, Colditz GA, Wing AL, Willett WC. 1997b. Dietary fiber, glycemic load, and risk of non-insulin-dependent diabetes mellitus in women. *J Am Med Assoc* 277:472–477.

Sandberg AS, Ahderinne R, Andersson H, Hallgren B, Hulten L. 1983. The effect of citrus pectin on the absorption of nutrients in the small intestine. *Hum Nutr Clin Nutr* 37:171–183.

Sandstead HH. 1992. Fiber, phytates, and mineral nutrition. *Nutr Rev* 50:30–31.

Schatzkin A, Lanza E, Corle D, Lance P, Iber F, Caan B, Shike M, Weissfeld J, Burt R, Cooper MR, Kikendall JW, Cahill J. 2000. Lack of effect of a low-fat, high-fiber diet on the recurrence of colorectal adenomas. *N Engl J Med* 342:1149–1155.

Sepple CP, Read NW. 1989. Gastrointestinal correlates of the development of hunger in man. *Appetite* 13:183–191.

Shetty PS, Kurpad AV. 1986. Increasing starch intake in the human diet increases fecal bulking. *Am J Clin Nutr* 43:210–212.

Shultz TD, Howie BJ. 1986. In vitro binding of steroid hormones by natural and purified fibers. *Nutr Cancer* 8:141–147.

Silvester KR, Englyst HN, Cummings JH. 1995. Ileal recovery of starch from whole diets containing resistant starch measured in vitro and fermentation of ileal effluent. *Am J Clin Nutr* 62:403–411.

Simpson HCR, Simpson RW, Lousley S, Carter RD, Geekie M, Hockaday TDR, Mann JI. 1981. A high carbohydrate leguminous fibre diet improves all aspects of diabetic control. *Lancet* 1:1–15.

Simpson KM, Morris ER, Cook JD. 1981. The inhibitory effect of bran on iron absorption in man. *Am J Clin Nutr* 34:1469–1478.

Slavin JL. 1987. Dietary fiber: Classification, chemical analyses, and food sources. *J Am Diet Assoc* 87:1164–1171.

Slavin JL, Marlett JA. 1980. Influence of refined cellulose on human bowel function and calcium and magnesium retention. *Am J Clin Nutr* 33:1932–1939.

Slavin J, Jacobs D, Marquart L. 1997. Whole-grain consumption and chronic disease: Protective mechanisms. *Nutr Cancer* 27:14–21.

Sleet R, Brightwell J. 1990. *FS-Teratology Study in Rats*. Raffinerie Tirlemontoise Internal Report. Photocopy.

Smith T, Brown JC, Livesey G. 1998. Energy balance and thermogenesis in rats consuming nonstarch polysaccharides of various fermentabilities. *Am J Clin Nutr* 68:802–819.

Spencer H, Norris C, Derler J, Osis D. 1991. Effect of oat bran muffins on calcium absorption and calcium, phosphorus, magnesium and zinc balance in men. *J Nutr* 121:1976–1983.

Steinmetz KA, Kushi LH, Bostick RM, Folsom AR, Potter JD. 1994. Vegetables, fruit, and colon cancer in the Iowa Women's Health Study. *Am J Epidemiol* 139:1–15.

Stephen AM, Haddad AC, Phillips SF. 1983. Passage of carbohydrate into the colon. Direct measurements in humans. *Gastroenterology* 85:589–595.

Stevens J, Levitsky DA, VanSoest PJ, Robertson JB, Kalkwarf HJ, Roe DA. 1987. Effect of psyllium gum and wheat bran on spontaneous energy intake. *Am J Clin Nutr* 46:812–817.

Stone-Dorshow T, Levitt MD. 1987. Gaseous response to ingestion of a poorly absorbed fructo-oligosaccharide sweetener. *Am J Clin Nutr* 46:61–65.

Strobel S, Ferguson A, Anderson DM. 1982. Immunogenicity of foods and food additives—In vivo testing of gums arabic, karaya, and tragacanth. *Toxicol Lett* 14:247–252.

Sugano M, Fujikawa T, Hiratsuji Y, Nakashima K, Fukuda N, Hasegawa Y. 1980. A novel use of chitosan as a hypocholesterolemic agent in rats. *Am J Clin Nutr* 33:787–793.

Sundell IB, Ranby M. 1993. Oat husk fiber decreases plasminogen activator inhibitor type 1 activity. *Haemostasis* 23:45–50.

Taioli E, Nicolosi A, Wynder EL. 1991. Dietary habits and breast cancer: A comparative study of United States and Italian data. *Nutr Cancer* 16:259–265.

Thompson LU. 1994. Antioxidants and hormone-mediated health benefits of whole grains. *Crit Rev Food Sci Nutr* 34:473–497.

Thun MJ, Calle EE, Namboodiri MM, Flanders WD, Coates RJ, Byers T, Boffetta P, Garfinkel L, Heath CW. 1992. Risk factors for fatal colon cancer in a large prospective study. *J Natl Cancer Inst* 84:1491–1500.

Todd S, Woodward M, Tunstall-Pedoe H, Bolton-Smith C. 1999. Dietary antioxidant vitamins and fiber in the etiology of cardiovascular disease and all-causes mortality: Results from the Scottish Heart Health Study. *Am J Epidemiol* 150:1073–1080.

Tokunaga K, Matsuoka A. 1999. Effects of a Food for Specified Health Use (FOSHU) which contains indigestible dextrin as an effective ingredient on glucose and lipid metabolism. *J Jpn Diabetes Soc* 42:61–65.

Tomlin J, Read NW. 1988. A comparative study of the effects on colon function caused by feeding ispaghula husk and polydextrose. *Aliment Pharmacol Ther* 2:513–519.

Tomlin J, Read NW. 1990. The effect of resistant starch on colon function in humans. *Br J Nutr* 64:589–595.

Tomlin J, Lowis C, Read NW. 1991. Investigation of normal flatus production in healthy volunteers. *Gut* 32:665–669.

Tremblay A, Lavallée N, Alméras N, Allard L, Després J-P, Bouchard C. 1991. Nutritional determinants of the increase in energy intake associated with a high-fat diet. *Am J Clin Nutr* 53:1134–1137.

Trock B, Lanza E, Greenwald P. 1990. Dietary fiber, vegetables, and colon cancer: Critical review and meta-analyses of the epidemiologic evidence. *J Natl Cancer Inst* 82:650–661.

Truswell AS. 1992. Glycaemic index of foods. *Eur J Clin Nutr* 46:S91–S101.

Tuohy KM, Kolida S, Lustenberger AM, Gibson GR. 2001. The prebiotic effects of biscuits containing partially hydrolysed guar gum and fructo-oligosaccharides—A human volunteer study. *Br J Nutr* 86:341–348.

Tuyns AJ, Haelterman M, Kaaks R. 1987. Colorectal cancer and the intake of nutrients: Oligosaccharides are a risk factor, fats are not. A case-control study in Belgium. *Nutr Cancer* 10:181–196.

Tzonou A, Hsieh C-C, Polychronopoulou A, Kaprinis G, Toupadaki N, Trichopoulou A, Karakatsani A, Trichopoulos D. 1993. Diet and ovarian cancer: A case-control study in Greece. *Int J Cancer* 55:411–414.

USDA/HHS (U.S. Department of Agriculture/U.S. Department of Health and Human Services). 2000. *Nutrition and Your Health: Dietary Guidelines for Americans.* Home and Garden Bulletin No. 232. Washington, DC: U.S. Government Printing Office.

van Dokkum W, Wezendonk B, Srikumar TS, van den Heuvel EGHM. 1999. Effect of nondigestible oligosaccharides on large-bowel functions, blood lipid concentrations and glucose absorption in young healthy male subjects. *Eur J Clin Nutr* 53:1–7.

Van Horn LV, Liu K, Parker D, Emidy L, Liao Y, Pan WH, Giumetti D, Hewitt J, Stamler J. 1986. Serum lipid response to oat product intake with a fat-modified diet. *J Am Diet Assoc* 86:759–764.

van Munster IP, Nagengast FM. 1993. The role of carbohydrate fermentation in colon cancer prevention. *Scand J Gastroenterol* 200:80–86.

van Munster IP, de Boer HM, Jansen MC, de Haan AF, Katan MB, van Amelsvoort JM, Nagengast FM. 1994. Effect of resistant starch on breath-hydrogen and methane excretion in healthy volunteers. *Am J Clin Nutr* 59:626–630.

van't Veer P, Kolb CM, Verhoef P, Kok FJ, Schouten EG, Hermus RJ, Sturmans F. 1990. Dietary fiber, beta-carotene and breast cancer: Results from a case-control study. *Int J Cancer* 45:825–828.

Verhoeven DTH, Assen N, Goldbohm RA, Dorant E, van't Veer P, Sturmans F, Hermus RJJ, van den Brandt PA. 1997. Vitamins C and E, retinol, beta-carotene and dietary fibre in relation to breast cancer risk: A prospective cohort study. *Br J Cancer* 75:149–155.

Visek WJ. 1978. Diet and cell growth modulation by ammonia. *Am J Clin Nutr* 31:S216–S220.

Wakabayashi S, Ueda Y, Matsuoka A. 1993. Effects of indigestible dextrin on blood glucose and insulin levels after various sugar loads in rats. *J Jpn Soc Nutr Food Sci* 46:131–137.

Wakabayashi S, Kishimoto Y, Matsuoka A. 1995. Effects of indigestible dextrin on glucose tolerance in rats. *J Endocrinol* 144:533–538.

Watters DAK, Smith AN. 1990. Strength of the colon wall in diverticular disease. *Br J Surg* 77:257–259.

Weaver GA, Krause JA, Miller TL, Wolin MJ. 1988. Short chain fatty acid distributions of enema samples from a sigmoidoscopy population: An association of high acetate and low butyrate ratios with adenomatous polyps and colon cancer. *Gut* 29:1539–1543.

West DW, Slattery ML, Robison LM, Schuman KL, Ford MH, Mahoney AW, Lyon JL, Sorensen AW. 1989. Dietary intake and colon cancer: Sex- and anatomic site-specific associations. *Am J Epidemiol* 130:883–894.

Willett WC, Stampfer MJ, Colditz GA, Rosner BA, Speizer FE. 1990. Relation of meat, fat, and fiber intake to the risk of colon cancer in a prospective study among women. *N Engl J Med* 323:1664–1672.

Willett WC, Hunter DJ, Stampfer MJ, Colditz G, Manson JE, Spiegelman D, Rosner B, Hennekens CH, Speizer FE. 1992. Dietary fat and fiber in relation to risk of breast cancer. An 8-year follow-up. *J Am Med Assoc* 268:2037–2044.

Williams CH, Witherly SA, Buddington RK. 1994. Influence of dietary neosugar on selected bacterial groups of the human faecal microbiota. *Microb Ecol Health Dis* 7:91–97.

Williams CL, Bollella M. 1995. Is a high-fiber diet safe for children? *Pediatrics* 96:1014–1019.

Williams CL, Bollella M, Wynder EL. 1995. A new recommendation for dietary fiber in childhood. *Pediatrics* 96:985–988.

Wisker E, Nagel R, Tanudjaja TK, Feldheim W. 1991. Calcium, magnesium, zinc, and iron balances in young women: Effects of a low-phytate barley-fiber concentrate. *Am J Clin Nutr* 54:553–559.

Witte JS, Ursin G, Siemiatycki J, Thompson WD, Paganini-Hill A, Haile RW. 1997. Diet and premenopausal bilateral breast cancer: A case-control study. *Breast Cancer Res Treat* 42:243–251.

Wolever TMS. 1995. In vitro and in vivo models for predicting the effect of dietary fiber and starchy foods on carbohydrate metabolism. In: Kritchevsky D, Bonfield C, eds. *Dietary Fiber in Health and Disease*. St. Paul, MN: Eagan Press. Pp. 360–377.

Wolever TMS, Jenkins DJA. 1993. Effect of dietary fiber and foods on carbohydrate metabolism. In: Spiller G, ed. *CRC Handbook of Dietary Fiber in Human Nutrition*. Boca Raton, FL: CRC Press. Pp. 111–162.

Wolk A, Manson JE, Stampfer MJ, Colditz GA, Hu FB, Speizer FE, Hennekens CH, Willett WC. 1999. Long-term intake of dietary fiber and decreased risk of coronary heart disease among women. *J Am Med Assoc* 281:1998–2004.

Wood PJ, Braaten JT, Scott FW, Riedel KD, Wolynetz MS, Collins MW. 1994. Effect of dose and modification of viscous properties of oat gum on plasma glucose and insulin following an oral glucose load. *Br J Nutr* 72:731–743.

Woods MN, Gorbach SL, Longcope C, Goldin BR, Dwyer JT, Morrill-LaBrode A. 1989. Low-fat, high-fiber diet and serum estrone sulfate in premenopausal women. *Am J Clin Nutr* 49:1179–1183.

Woods MN, Barnett JB, Spiegelman D, Trail N, Hertzmark E, Longcope C, Gorbach SL. 1996. Hormone levels during dietary changes in premenopausal African-American women. *J Natl Cancer Inst* 88:1369–1374.

Wuolijoki E, Hirvelä T, Ylitalo P. 1999. Decrease in serum LDL cholesterol with microcrystalline chitosan. *Methods Find Exp Clin Pharmacol* 21:357–361.

Wynder EL, Berenson GS. 1984. Preventive strategies for reducing hyperlipidemia in childhood. *Prev Med* 13:327–329.

Yamashita K, Kawai K, Itakura M. 1984. Effects of fructo-oligosaccharides on blood glucose and serum lipids in diabetic subjects. *Nutr Res* 4:961–966.

Younes H, Levrat MA, Demigne C, Remesy C. 1995. Resistant starch is more effective than cholestyramine as a lipid-lowering agent in the rat. *Lipids* 30:847–853.

Yu H, Harris RE, Gao Y-T, Gao R, Wynder RL. 1991. Comparative epidemiology of cancers of the colon, rectum, prostate and breast in Shanghai, China versus the United States. *Int J Epidemiol* 20:76–81.

Yuan J-M, Wang Q-S, Ross RK, Henderson BE, Yu MC. 1995. Diet and breast cancer in Shanghai and Tianjin, China. *Br J Cancer* 71:1353–1358.

Zacour AC, Silva ME, Cecon PR, Bambirra EA, Vieira EC. 1992. Effect of dietary chitin on cholesterol absorption and metabolism in rats. *J Nutr Sci Vitaminol (Tokyo)* 38:609–613.