Dietary fiber

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Abstract Dietary fiber is plant-derived material that is resistant to digestion by human alimentary enzymes. Fiber may be divided into two broad chemical classes: *1*) non-α-glucan polysaccharides (cellulose, hemicelluloses, and pectins) and *2*) lignins. Dietary fiber behaves within the gastrointestinal tract as a polymer matrix with variable physicochemical properties including susceptibility to bacterial fermentation, water-holding capacity, cation-exchange, and adsorptive functions. These properties determine physiological actions of fiber and are dependent on the physical and chemical composition of the fiber. Fiber undergoes compositional changes as a consequence of bacterial enzymatic action in the colon. Dietary fiber is of clinical significance in certain disorders of colonic function and in glucose and lipid metabolism. Dietary fiber increases stool bulk by acting as a vehicle for fecal water and by increasing fecal bacterial volume. Use of fiber in the treatment of constipation and uncomplicated diverticular disease is well established. By increasing stool bulk, fiber also reduces the fecal concentration of bile acids and other substances. Certain types of fiber decrease the rate of glucose absorption and attenuate postprandial rises in blood glucose and insulin. Plasma cholesterol levels are reduced by mucilaginous forms of fiber. This effect appears to be mediated in part by an increase in fecal acidic sterol excretion.—**Kay, R. M.** Dietary fiber. *J. Lipid Res.* 1982. **23:** 221–242.

Supplementary key words cell wall • cholesterol • diet • colon • gastrointestinal tract

INTRODUCTION

Dietary fiber is a ubiquitous component of plant foods and includes materials of diverse chemical and morphological structure, resistant to the action of human alimentary enzymes. Within the gastrointestinal tracts, fiber forms a matrix with both fibrous and amorphous characteristics. The physicochemical properties of this matrix determine the homeostatic and therapeutic functions of dietary fiber in human nutrition.

Fiber swells within the aqueous medium of the intestinal lumen taking up water and small molecules (1). The swelling pressure determines the diffusion rate as well as intestinal smooth muscle responses with ultimate

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effects on bulk flow. Multiple linkages form between fiber and surrounding molecules. These interactions include ionic bonds, hydrogen bonds, and weaker hydro-

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Abbreviations: SCFA, short chain fatty acids; NCP, noncellulosic polysaccharides.

phobic and dispersion forces (2), and may affect both mineral and steroid absorption. There is also continuous alteration in matrix structure and function contingent on changes in the surrounding pH and osmolality and in the fiber matrix itself as it is selectively degraded by colonic bacterial enzymes. Thus, the effects of fiber in the upper and lower intestine may differ considerably.

In the following pages, the botanical origin and chemical structure of dietary fiber are outlined. Analytical methods for fiber quantification are reviewed briefly. Based on a general overview of the physicochemical properties of fiber, the various actions of dietary fiber along the gastrointestinal tract are discussed with particular reference to the role of fiber in human disease.

BOTANICAL FUNCTION OF FIBER

The major components of dietary fiber are cellulose, noncellulosic polysaccharides such as hemicelluloses and pectic substances, and a non-carbohydrate component, lignin. These are mainly structural components of the plant cell wall (3). Most of the detailed studies on the morphological development and ultrastructure of plant cell walls have been made on woody cells rather than on food plant cells and information on the bonding and distribution of polymers throughout the cell wall is still incomplete. Development of the cell wall begins with the appearance of the middle lamella which is derived from a dense plate between divided nuclei; this layer is rich in pectic substances. The primary wall is formed on the inner surface of the middle lamella and contains cellulose fibrils embedded in a ground substance of pectic substances and hemicellulose and is formed by layering on the interior of the middle lamella. The secondary cell wall forms later and consists of several layers containing little pectin but rich in cellulose fibrils; these are arranged in parallel fashion in a matrix of hemicellulose (3–5). In the later stages of maturation, lignin infiltration proceeds from the exterior to the interior of the cell wall imparting hydrophobicity and extra rigidity to the plant structure (6–8). Lignification reduces the digestibility by bacterial enzymes of other types of dietary fiber in the cell wall.

Maturation of the plant cell is thus associated with a gradual shift in fiber composition in favor of increasing proportions of cellulose and lignin.

Some types of plant fiber are not cell wall components but are formed in specialized secretory plant cells (8). Included are plant gums and mucilages. The former are sticky exudations formed in response to trauma (i.e., gum arabic). Mucilages are secreted into the endosperm of plant seeds where they act to prevent excessive dehydra-

tion and include materials with widespread industrial applications such as guar gum.

OVERVIEW OF FIBER CHEMISTRY

Clearly the composition of fiber in the diet will depend on the age, species, and anatomical source of the plant material.

Polysaccharides

The two major classes of dietary fiber are polysaccharides and lignin. These include cellulose and a diffuse group of substances collectively termed noncellulosic polysaccharides (NCP).

Cellulose, the most abundant molecule in nature, is the beta isomer of starch; it is a long (up to 10,000 sugar residues) linear polymer of $1,4\beta$-linked glucose units. Hydrogen bonding between sugar residues in adjacent chains imparts a crystalline microfibril structure. Cellulose is insoluble in strong alkali (9).

Noncellulosic polysaccharides include a large number of heteroglycans which contain a mixture of pentoses, hexoses, and uronic acids (**Table 1**). Among the more important NCPs are hemicellulose and pectic substances (10).

Hemicelluloses are those cell wall polysaccharides solubilized by aqueous alkali after removal of water soluble and pectic polysaccharides. They contain backbones of β-1,4-linked pyranoside sugars, but differ from cellulose in that they are smaller in size (often less than 200 sugar residues), contain a variety of sugars, and are usually branched (Table 1). The hemicelluloses are subclassified on the basis of the principal monomeric sugar residue. Acidic or neutral forms differ in the content of glucuronic and galacturonic acids (11). Uronic acid formation involves the oxidation of the terminal $-CH_2OH$ to $-COOH$ and is of biological importance since the sugar residues become available for methylation, amidation, and the formation of cation complexes (12). Hemicelluloses, especially the hexose and uronic acid components, are somewhat more accessible to bacterial enzymes than is cellulose (13).

Pectic substances are a complex group of polysaccharides in which D-galacturonic acid is a principal constituent. They are structural components of plant cell walls and also act as intercellular cementing substances. Included are a water-insoluble parent compound, protopectin, as well as pectinic acids, pectic acids, and pectin. The backbone structure of pectin is an unbranched chain of axial-axialα-(1→4)-linked D-galacturonic acid units. Long chains of galacturonan are interrupted by blocks of L-rhamnose-rich units that result in bends in the molecule. Many pectins have neutral sugars covalently

TABLE 1. Chemical classification of dietary fiber

Fiber	Chemical Components		Description
	Main Chain	Side Chain	
Polysaccharides			
Cellulose	Glucose	None	Main structural component of plant cell wall. Insoluble in concentrated alkali; soluble in concentrated acid.
Noncellulose			
Hemicellulose	Xylose Mannose Galactose Glucose	Arabinose Galactose Glucuronic acid	Cell wall polysaccharides which contain backbone of 1–4 linked pyranoside sugars. Vary in degree of branching and uronic acid content. Soluble in dilute alkali.
Pectic substances	Galacturonic acid	Rhamnose Arabinose Xylose Fucose	Components of primary cell wall and middle lamella vary in methyl ester content. Generally water soluble and gel-forming.
Mucilages	Galactose-mannose Glucose-mannose Arabinose-xylose Galacturonic acid rhamnose	Galactose	Synthesized by plant secretory cells; prevent desiccation of seed endosperm. Food industry use, hydrophilic, stabilizer, e.g., guar.
Gums	Galactose Glucuronic acid-mannose Galacturonic acid-rhamnose	Xylose Fucose Galactose	Secreted at site of plant injury by specialized secretory cells. Food and pharmaceutical use, e.g., Karaya gum.
Algal polysaccharides	Mannose Xylose Guluronic acid Glucose	Galactose	Derived from algae and seaweed. Vary in uronic acid content and presence of sulfate groups. Food and pharmaceutical use, e.g., carrageenan, agar.
Lignin	Sinapyl alcohol Coniferyl alcohol p-Coumaryl alcohol	3-dimensional structure	Non-carbohydrate cell wall component. Complex cross-linked phenyl propane polymer. Insoluble in 72% H_2SO_4. Resists bacterial degradation.

linked to them as side chains, mainly arabinose and galactose, and to a lesser extent, xylose, rhamnose, and glucose. It has also been shown that small quantities of glucuronic acid may be linked to pectin in a side chain (14–16). The carboxyl groups of the galacturonic acids are partially methylated and the secondary hydroxyls may be acetylated. Pectin is highly water-soluble and is almost completely metabolized by colonic bacteria (17). Other NCPs including gums, mucilages, and algal polysaccharides (18, 19) are described in Table 1. The major chemical features of the polysaccharide fibers are illustrated in **Fig. 1.**

Lignin

Lignin is not a polysaccharide but a complex random polymer containing about 40 oxygenated phenylpropane units including coniferyl, sinapyl, and p-coumaryl alcohols that have undergone a complex dehydrogenative polymerization process (6, 7, 11). Lignins vary in molecular weight and methoxyl content. The structure of an aspen wood lignin which has been shown to bind bile acids in vitro and in vivo is illustrated in **Fig. 2.** Due to strong intramolecular bonding which includes carbon to carbon linkages, lignin is very inert. Chemically, it is usually measured as Klason lignin, the cell wall residue insoluble in 72% sulfuric acid (10). Lignin demonstrates greater resistance to digestion than any other naturally occurring polymer.

Fiber-related materials

The human diet contains, in addition to polysaccharides and lignin, a number of plant-derived materials that are similar to fiber in that they resist digestion in the upper intestine. Included are cutin and suberin, polymeric esters of fatty acids. The former is a water-impermeable substance secreted onto the plant surface, whereas suberin is deposited in the later stages of cell wall development. These are enzyme- and acid-resistant materials recoverable in the lignin fraction (10). Other dietary components which associate with the lignin residue are the products of the Maillard reaction. These result from the formation of enzyme-resistant linkages between the amino groups of proteins and the carbonyl groups of reducing sugars during heat treatment (10).

Certain fiber-rich foodstuffs contain significant amount of plant sterols. Also in close physical and chemical association with fiber in the plant cell wall are proteins, inositol hexaphosphate, silica, saponins and other gly-
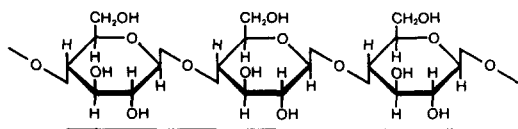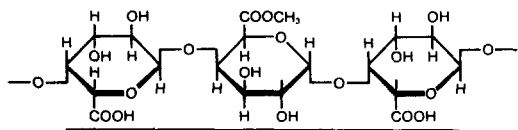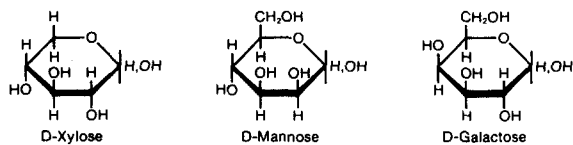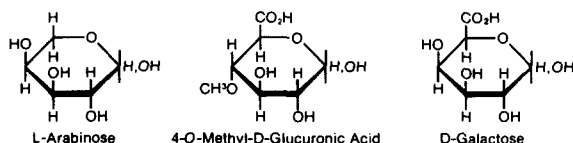
Fig. 1. Major polysaccharide components of dietary fiber. Cellulose is a linear chain of from one to four linked glucose units. Pectic substances contain D-galacturonic acid as the major component; the extent of methylation of carboxyl groups is variable. Hemicelluloses are a heterogeneous group of polysaccharides which are usually branched. The major component sugars of the backbone and sidechains are illustrated.

cosides, and polyhydroxyphenolic materials such as tannins. It is often difficult to dissociate the physiological effects of these materials from those of true dietary fiber components (10).

DETERMINATION OF FIBER IN FOODS

Reliable analytical data on the fiber composition of common foodstuffs has only recently become available (20). There is still not complete consensus regarding specific analytical procedures (21). Although rapid quantitative methodologies are acceptable for routine use such as industry quality control, the more rigorous qualitative methods are essential in defining the chemical characteristics of specified fibers with known physiological effects (22).

Until recently, many nutritionists have relied on "crude fiber" figures as an index of true dietary fiber. The "crude fiber" analysis is a highly empirical chemical procedure that defines fiber as the residue remaining after extraction with dilute acid and alkali (10). Crude fiber bears no consistent or quantitative relationship to dietary fiber.

Other methods differ in the amount of qualitative information given and applicability to different classes of fiber. A neutral detergent extraction procedure developed by Van Soest and McQueen is acceptable for routine determination of insoluble fiber (23). In foods containing starch, it must be preceded by hydrolysis of the amylose fraction. If this method is used, water-soluble fiber components (pectin, gums, mucilages) must be determined in a separate procedure. Dialysis or organic solvent precipitation methods are acceptable. Methods involving enzymatic removal of starch and protein are gradually assuming greater importance in fiber analysis (24–26).

It is becoming increasingly clear that the physiological effects of a given fiber are dependent on its particular chemical composition. Hence there is a growing requirement for the detailed analytical information such as that provided by the Southgate analysis. By this procedure, the fiber residue is subjected to a series of hydrolysis and extraction steps resulting in the determination of water-soluble and water-insoluble polysaccharides as their component hexoses, pentoses, and uronic acids by gas–liquid or liquid chromatography (27).

FIBER CONTENT OF HUMAN DIETS

The hypothesis that dietary fiber may be a protective factor in human disease was proposed on the basis of very approximate data on the distribution of fiber consumption in different populations. There is still a paucity of reliable information and available figures will likely be modified as methods for the determination of food intake and fiber composition of food evolve.

Recent data are available on average fiber intake in Western countries. In a survey of 200 Canadian males, Kay, Sabry, and Csima (28) reported mean dietary fiber consumption was 19 g/d, about half of which was cereal-derived fiber. In separate studies in England, Bingham, Cummings, and McNeil (29) and Southgate, Bingham, and Robertson (30) also determined average dietary fiber consumption to be in the order of 20 g/d for both men and women. American figures based on foods available for consumption gave similar results and indicated a general decline in available dietary fiber, especially cereal-derived fiber (31). Among British vegetarians, dietary fiber intake was increased twofold in comparison to persons eating a mixed diet (32).

Less reliable figures are available from other countries, although intakes ranging from 38 to 150 g/d have been reported from parts of Africa and the Indian subcontinent. An excellent review has been prepared by Bingham and Cummings (33).
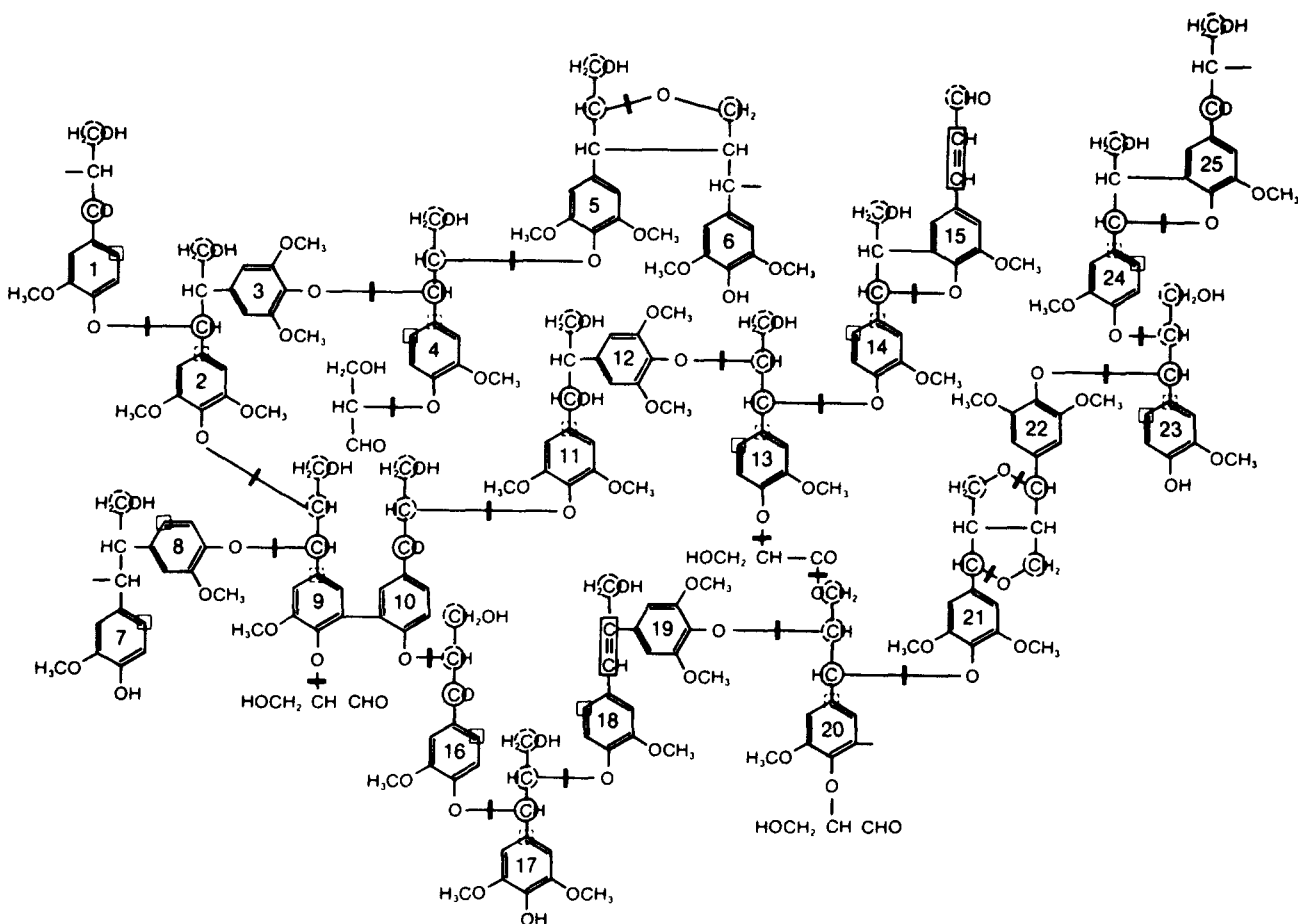
Fig. 2. Chemical structure of a purified lignin from *P. tremuloides* (61).

FUNCTIONAL CAPABILITIES OF PLANT FIBER WITHIN THE GASTROINTESTINAL TRACT

The physiological consequences of fiber ingestion are in part predictable on the basis of certain physicochemical properties (1). Of particular interest are its susceptibility to fermentation by colonic bacterial enzymes, the ability to retain water, and adsorptive and ion exchange capacities.

Susceptibility to bacterial enzyme degradation

Although resistant to the action of human upper intestinal enzymes, passage through the ileocecal valve exposes fiber to bacterial enzymes that selectively degrade many of its components (**Fig. 3**). Colonic fermentation is significant in that it eliminates certain actions of fiber observed in vitro or in the upper intestine. In addition, products of fermentation may themselves exert a physiologic effect or alter the chemical environment of the cecum so as to affect bacterial growth or metabolic activity. The extent of fiber degradation in the colon is dependent on the nature of the colonic bacterial flora,

the transit time through the colon, and the physical and chemical composition of the fiber (34).

Major difficulties are present in the study of colonic bacterial flora. Over 100 species (96–99% anerobes) have been identified and Stephen and Cummings (35) have reported that bacteria may account for 41–57% of the dry weight of feces. The flora are largely saccharolytic and the bacteria that ferment cellulose and hemicellulose display a general specificity. This infers that the microbial spectrum of the lower intestine might be influenced by the fiber composition of the diet (36). Although diet-related population differences in stool flora have been reported (37), efforts to alter this variable by addition of fiber to the diet have not generally been successful (38–40). It must be emphasized that all attempts to relate the intestinal flora to diet have studied the fecal flora. Despite the convenience of this approach, the organisms important in fiber degradation are present in the ascending colon and the cecum and considerable bacterial alteration occurs during passage through the distal portions of the colon (41).

Irrespective of the spectrum of bacterial species present, it is possible that fiber fermentation, through alter-
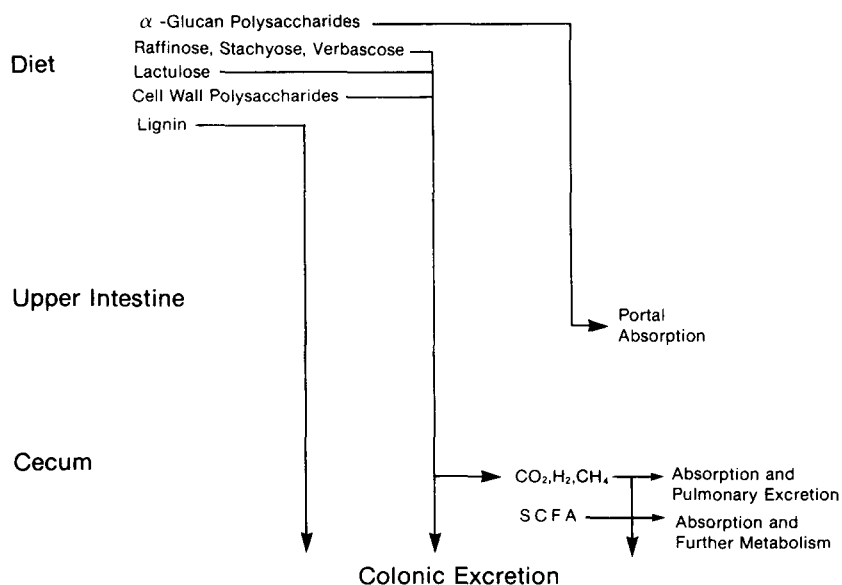
Fig. 3. Fate of dietary fiber within the gastrointestinal tract. Available polysaccharides (α-glucans) are digested and absorbed in the upper intestine. Non-α-glucan polysaccharides and lignin pass to the cecum. Lignin is excreted unaltered in the stool. Cell wall polysaccharides and other sugars are fermented by colonic bacterial enzymes with production of gases and short chain fatty acids (SCFA). These may be absorbed from the cecum to a variable extent.

ation in colonic pH or redox conditions, may affect bacterial enzymatic activity so as to alter the colonic metabolism of steroids and other substances. Ingestion of a fiber-rich diet by normal subjects was associated with a decrease in secondary bile acids in the stool (42). This may have been due in part to accelerated intestinal transit. Furthermore, it has recently been demonstrated that the efficiency of bacterial polysaccharide metabolism in the colon is itself pH-dependent (43). Thus fiber fermentation may be a self-limiting process as production of acidic metabolites alters the cecal H^+ environment. The effect of fiber on colonic transit time will also have a modulating effect on fermentation by determining the duration of contact with microbial enzymes.

The susceptibility of a given fiber to bacterial digestion is dependent on physical and chemical structure. Digestion of polysaccharides varies between 30 to over 90%. Pectin and hemicellulose are almost completely lost during passage through the stool; cellulose is somewhat less well digested (44–46). Lignin, by virtue of its polymeric cross-linked structure, is resistant to bacterial degradation and is almost completely recovered in the stool (13). The physical structure of plant fiber also determines access to bacterial enzymes. Polysaccharides from older, highly lignified plant tissues are less well digested since physical encrustation and chemical bonding to lignin occur. In general, the fiber constituents of fruit and vegetables are much more fermentable than are cereal brans since the latter display thicker cell walls (lower surface to volume ratio) and a high degree of lignification. Bac-

terial degradation of dietary fiber in the colon occurs in two stages. Extracellular hydrolysis of polysaccharides into component mono- and disaccharides is followed by intracellular anerobic glycolysis (47). The products of fermentation of dietary fiber include the short chain fatty acids, acetate, proprionate, and butyrate. Other products are lactic and formic acids, ethanol, and CO_2. Excess H^+ released in the regeneration of NAD is partially disposed of by the formation of H_2 (48). Methane production from H_2 by colonic organisms has also been documented (43) but is less common (49).

The partially degraded metabolites of anerobic glycolysis must be disposed of. Most of the hydrogen and methane are absorbed into the circulation and excreted via the pulmonary route (50). Clinical studies have indicated that addition of fiber or lactulose to the diet may initially cause severe flatulence but the symptoms subside within a few weeks of treatment. It is possible that organisms yielding gases as the main products of fermentation (i.e., coliforms) are replaced during continued therapy by those producing little gas (i.e., lactobacilli and streptococci) (48). In addition, creation of an acidic environment specifically inhibits H_2 production (43).

The short chain fatty acids (SCFA) produced during fiber fermentation have pKs of less than 5 and at colonic pH are almost completely ionized. It has been suggested that high concentrations of SCFA may elicit an osmotic catharsis (51). However, the absorption of SCFA from the colon has been documented in animals (52) and, indirectly, in man (53). It is possible therefore that fer-

mentation products of dietary fiber may make a minor contribution to the energy value of the diet.

Water-holding capacity of dietary fiber

The water-holding capacity of dietary fiber has important physiological effects in both the upper and lower intestine. Hydration of fiber occurs by adsorption to the surface of the macromolecules and by entrapment within the interstices of the fibrous or gel matrix. The fiber saturation capacity or upper limit of water held is determined by the chemistry and morphology of the macromolecules and by the pH and electrolyte concentration of the surrounding medium.

The initial event upon exposure of fiber to an aqueous medium is surface adsorption of water molecules. The presence of sugar residues with free polar groups confers a significant hydrophilic capacity to polysaccharides whereas intermolecular bonding, such as the ether cross-linkages between chains of cellulose molecules, has the opposite effect (3). Aqueous swelling of cellulose fibers does not alter the x-ray diffraction pattern, suggesting that water adsorption is limited to monocrystalline regions occupied by other sugars or uronic acids (10). Lignin is relatively apolar and much less hygroscopic than are other fiber components.

Particle size may also influence the water-holding capacity of fiber, since it determines the volume of the interstitial space within the fiber matrix available for water entrapment (54–56). Robertson and Eastwood (56) have demonstrated that the method of fiber preparation alters water-holding capacity profoundly although the chemical composition is unchanged. This suggests that the physical structure of fiber is the most important determinant of hydratability.

Water-holding capacity has been assessed by using centrifugation to separate free or unadsorbed water from bound and interstitial water. Dependent on the fiber source, variable degrees of fibrous matrix collapse may occur (2). A second method involves equilibration of a fiber suspension with a solution of a "probe" substance such as dextran blue. This method assumes that the concentration in the interstitial volume is identical to the external solution, hence adsorption of the probe to fiber could yield erroneous results (2). A reliable method is not yet available for the separate determination of bound and interstitial water (56). In the upper intestine, the water-holding capacity of fiber may affect the pattern of nutrient absorption, postprandial satiety, and intestinal motility. Viscous fibers such as guar and pectin reduce the rate of glucose absorption (57) presumably due to partitioning of water-soluble nutrients into the gel structure, thus reducing their rate of diffusion towards the absorptive mucosal surface. In vitro studies are, however, of limited usefulness in predicting the effect of fiber on stool bulk and water content, since fermentation by colonic bacteria profoundly alters the capacity of the fiber for water adsorption (58).

Adsorption of organic materials

A number of organic materials such as bile acids, other steroids, various toxic compounds, and bacteria may be reversibly bound to fiber as it passes along the gastrointestinal tract.

In vitro studies. Adsorption of bile acids has been best documented and is dependent on the composition of the fiber, the chemistry of the sterol, and the pH and osmolality of the surrounding medium (59, 60). Lignin is the most potent bile acid adsorbent and binding is apparently influenced by molecular weight, pH, and the presence of methoxyl and β-carbonyl groups on the lignin molecule (61). Kay et al. (61) reported that autohydrolyzed lignin bound bile acids half as effectively as DEAE-Sephadex. Adsorption was maximum for the less polar, unconjugated dihydroxy bile acids and reduction of environmental pH enhanced binding especially of trihydroxy bile acids. Eastwood and Hamilton (62) demonstrated that methylation of lignin increased bile acid adsorption. These authors also reported that adsorption was greatest at low pH. Both conditions would block or suppress ionization of carboxyl groups and hydroxyl groups on lignin's phenyl propane units suggesting a hydrophobic bonding mechanism. These studies predict that interaction with lignin is likely to be greatest for bacterially modified bile acids formed in the colon. Saponins also bind bile acids in vitro (63) and in vivo (64) and it has been suggested that they may be responsible for sterol adsorption associated with fiber. However, bran and alfalfa showed no diminution of adsorptive capacity following removal of associated saponins (65).

Other mechanisms may be responsible for organic anion binding to acidic polysaccharides such as alginates and pectins. These are the gel-forming fibers with notable hypocholesterolemic effects. Polyuronic acids with free carboxyl groups are known to form coordination complexes with di- and trivalent metal anions. Nagyvary and Bradbury (66) proposed that since for steric reasons the positive charge of trivalent cations such as Al^{3+} is not fully neutralized by the carboxyl anion, free valences would be available to bind external anions, particularly large structures such as bile acid micelles. In support of this hypothesis, dietary aluminum was found to enhance the hypocholesterolemic effect of alginates and pectin (66). Furda (67) tested this proposal in vitro by preparing cationic forms of pectin with H^+, Ca^{2+}, Fe^{2+}, Fe^{3+}, and Al^{3+}. These were stirred into an oleic acid emulsion. The Fe^{3+} form of pectin resulted in complete phase separation of the emulsion; Al^{3+}, partial separation; and the other cationic forms were without effect. Acidic polysaccha-

rides tend to be degraded by colonic bacteria but formation of cationic bridges could provide a mechanism for bile acid and fatty acid adsorption in the upper intestine. Micelle adsorption to pectin has been observed in vitro (68). These and other (69–74) in vitro studies on steroid adsorption to fiber are summarized in **Table 2.**

Effects of dietary fiber on fecal bile acid and lipid excretion. As indicated by the in vitro studies, the chemical form of bile acid and the fiber type are both important determinants of the site of interaction (upper or lower intestine) and binding mechanism.

Lignin and various particulate fibers which do not form gels or cationic complexes probably act via hydrophobic and other weak bonding mechanisms in the colon. Consistent with in vitro adsorption studies, Rotstein et al. (75, 76) reported that autohydrolyzed lignin significantly enhanced fecal bile acid excretion in hamsters. Cellulose has been reported to increase acid sterol output when included in the diet in large amounts (77, 78). In a long-term study in man, legumes enhanced fecal bile acid output (79) in agreement with bile acid adsorption observed in vitro (69). Various other sources of food-derived fiber also increased bile acid loss (80, 81). Vegetarians, on the other hand, were reported to have reduced rates of bile acid turnover (82) but vegetarian diets also differ in lipid and sterol content.

Although wheat bran demonstrated moderate bile acid affinity in vitro, few human studies have indicated an increase in fecal bile acid excretion (83–87). Tarpila, Miettinen, and Metasaranta (88) actually observed a decrease in acid sterol output during bran feeding in subjects with diverticular disease. There was a commensurate decrease in cholesterol synthesis. Oat bran, however, did significantly increase fecal bile acid loss (80, 89).

Oat bran differs from wheat bran in being more mucilaginous in nature due to a high content of β-glucans. Other mucilaginous fibers such as pectin, guar, and psyllium seed colloid have consistently been shown to increase bile acid excretion in man by 33 to 300% (77, 90–93). Unlike lignin and various particulate fibers, the gel-forming fibers probably act in the upper intestine either by direct sequestration or by impeding micelle transport through the unstirred water layer. These fibers do not survive passage through the colon and no selectivity with regard to bile acid chemistry has been demonstrated. The effect of dietary fiber on fecal bile acid excretion in man (79–95) is summarized in Fig. 3. Methodology used for bile acid measurement has also been indicated since titration methods are highly inaccurate and enzymatic methods do not detect 3β- or 3-keto isomers of fecal bile acids. Hence small changes in bile acid output may not be detected.

TABLE 2. Adsorption of bile acids to fiber: in vitro studies

Fiber	Effects
A. Bile acid solutions	
Corn-barley (62)	Adsorption directly related to bile acid polarity and enhanced by methylation suggesting hydrophobic interaction.
Vegetable fibers (69)	Preferential adsorption of unconjugated dihydroxy bile acids, string beans, celery, corn, lettuce, and potato 20–60% as effective as cholestyramine.
Isolates and native fibers (59)	Lignin 36%, alfalfa 20%, bran 11%, and cellulose 2% as effective as cholestyramine.
Vegetable fibers (70)	Bile acid affinity varied with fiber source: carrot > pea > celery > bran.
Alfalfa, bran (65)	Deoxycholate adsorption increased after removal of saponins and decreased 70% after removal of lignins.
Oats, wood shavings (71)	Adsorption greater for oats; bile acid adsorption to wood shavings increased with decreasing particle size.
Lignin (61)	Autohydrolyzed lignin of small molecular weight with intact carbonyl groups bound bile acids 50% as effectively as DEAE Sephadex. Binding maximal for more polar bile acids. Relative affinity for trihydroxy bile acids increased with reduction in pH.
B. Micellar suspensions	
Mixed fibers (72)	Taurocholate adsorption: lignin, 22%, alfalfa, 10%, wheat, 10%, oats, 7%, cellulose, 0. Cholesterol adsorption: lignin, 28%, alfalfa, 23%, wheat, 23%, oats, 21%, cellulose, 0.
Corn-barley (60)	Incorporation of bile acid into mixed micelle reduced adsorption to fiber especially in the presence of unsaturated short chain fatty acids.
Bran, alfalfa (73)	Alfalfa adsorbed 10% of micellar cholesterol and small amounts of unconjugated bile acids. Bran adsorbed 38% of micellar cholesterol.
C. Ileal transport	
Pectin (74)	Addition of pectin to perfusate reduced in vitro rat ileal transport of bile acids by 50%.

Through alteration in sterol concentration, bacterial flora, or cecal pH, fiber may also influence the bacterial modification of bile acids. Wheat bran reduced the deoxycholate fraction of gallbladder bile suggesting reduced formation or absorption of secondary bile acids in the colon (96).

Dietary fiber has, in general, less effect on neutral steroid excretion. Lymphatic cholesterol absorption was reduced in rats fed pectin, cellulose, or alfalfa. Bran was without effect (97, 98). Balmer and Zilversmit (72) reported decreased absorption of cholesterol in animals in response to a mixture of fibers. There are varying reports on the effect of pectin on neutral steroid excretion in man (90, 91). Mucilaginous fibers tend to increase fecal fat excretion but the effect is not quantitatively significant (2–4 g/d) (91, 92). Other fibers that enhanced bile acid output, i.e., psyllium (77), lignin (75), and oat bran (89), had no effect on neutral steroid excretion.

Adsorption of other organic substances by fiber. Less information is available on the adsorption of the other materials by fiber. Rubio et al. (99) demonstrated in vitro that the thermodynamic activity, and hence the bioavailability, of N-nitrosodiethylamine was lowered in the presence of lignin. Rotstein et al. (76) reported that lignin increased the fecal excretion of estrogen in animals given intraperitoneal injections of ethinyl estradiol. Fiber may interact with a number of organic substances within the enterohepatic circulation but there is not yet complete information on the physiological significance of such processes.

Cation exchange properties

The functional capacity of dietary fiber for cation exchange is well established. The effect is related to the number of free carboxyl groups on the sugar residues (100, 101). Calcium binding can be predicted on the basis of uronic acid content of fiber residues (102). Formation of cation complexes with acidic polysaccharides is reflected in their effects on mineral balance, electrolyte absorption, and heavy metal toxicity.

DIETARY FIBER IN THE ETIOLOGY AND TREATMENT OF HUMAN DISEASE

Colon and rectum

Constipation. Dietary fiber has established effects on stool bulk and consistency, and lower intestinal motility. Average stool weights in Western countries are in the order of 100 g/d in comparison to over 300 g/d in populations ingesting high carbohydrate, high fiber diets (103). For relief of constipation, a suggested therapeutic goal is 150 g/d (104).

The effect of fiber on stool bulk is likely to be related not only to the hydration capacity of the surviving residue and production of osmotically active metabolites but also to induction of bacterial growth, since bacterial cells are normally 80% water and represent an important fraction of total stool volume (35). Thus the mechanism by which stool bulk and laxation is promoted will vary for different fibers. Stephen and Cummings (35) demonstrated that 48% of the increase in stool bulk and water content in subjects fed wheat fiber could be accounted for by the water-holding capacity of the hydrated fiber. Only 36% of the wheat fiber fed was bacterially degraded. By contrast, when an almost completely digestible (92%) fiber (cabbage) was fed, stool bulk and water content also increased but much of this increase (35%) was due to enhanced bacterial output. Similarly the reported relationship of fecal weight to intake of pentose-containing polysaccharides may be mediated by their tendency to increase bacterial growth and output (105).

Although large amounts of fermentable fibers enhance fecal bulk and water content, they are somewhat less effective than less fermentable types. Stasse-Wolthuis and colleagues (106) demonstrated in a carefully controlled study that the mean increase in stool weight was 4.1 g/g of added fiber for coarse wheat bran (fermentation resistant) as compared to 1.9 g/g of added fiber when fruit and vegetables (highly fermentable) were used as a fiber source. The influence of various unprocessed wheat brans on fecal weight is partially dependent on particle size (107) which affects the water-holding capacity of the fiber matrix. Cooked wheat bran has a reduced stool-bulking capacity probably due to structural alterations leading to greater bacterial degradation (108).

Addition of fiber to the diet also increases the frequency and urgency of defecation (109, 110). Whole gut transit times tend to decrease especially when transit is initially prolonged (111–116). There is a negative and exponential relationship between transit time and stool weight. However, studies on the effect of dietary fiber on transit time are complicated by large intra-individual variation, the effect of other endogenous and environmental variables, and by methodological difficulties in measurement (116–118). Use of a continuous marker technique that permits calculation of a 5-day moving average of transit time is recommended (116).

Diverticular disease. Diverticular disease of the sigmoid colon is characterized by thickening of the circular muscle and contraction of the teniae coli, resulting in the formation of redundant folds of mucosal membrane which may partially obstruct the lumen. The diverticula are acquired mucosal hernias, usually formed where the bowel wall is weakened by penetrating vasculature (117, 119).

Painter and Burkitt (120) proposed that a diet which

provides little colonic residue results in a small hard stool that requires vigorous segmentation for propulsion along the colon, eventually culminating in circular muscle hypertrophy, high colonic pressures, and production of diverticula. In contrast, populations ingesting much fiber have bulky stools and low colonic pressure and the disease incidence is low.

Clinical studies have demonstrated that abnormally high intraluminal pressures occur within the sigmoid colon in diverticular disease particularly in response to cholinergic stimuli (121, 122). Cine-radiographic techniques showed that this was due to segmental occlusion of the bowel as the circular muscle contracted (123). However, circular, muscle hypertrophy is not a consistent accompaniment of diverticular disease and many asymptomatic patients do not have abnormally increased intraluminal pressures, suggesting that the pathogenesis of the disease may be more complex (124, 125).

Available information does indicate that the incidence of diverticular disease is low in populations ingesting much fiber (126) and emergence of the disease has been attributed to the acquisition of a Western lifestyle (127). In a recent study, the presence of symptomless diverticular disease was related to the consumption of dietary fiber in vegetarians and non-vegetarians (32).

Despite incomplete information on the etiology of the disease, the work of many investigators has resulted in a dramatic revision in the medical treatment of diverticular disease in the last decade. There is now general clinical consensus that a high fiber diet is the treatment of choice in simple uncomplicated diverticular disease. Although large amounts of fruit and vegetables may elicit an undesirable increase in gas production, coarse wheat bran usually results in a gradual amelioration of disease symptoms (128–133).

Findlay and colleagues (134) have shown that patients with diverticular disease have an aberration in fecal flow with streaming of solid and liquid phases such that the solid fraction is expelled more rapidly. Ritchie, Truelove, and Ardran (135) suggested that this might be due to retropulsion of the liquid phase of the colonic contents in the presence of high distal intraluminal pressure. Coarse bran, by acting as a vehicle for interstitial water, eliminating streaming; at the same time it increased the rate of transit and stool bulk (135). Pressure changes in the colon, as measured by motility indices, decreased significantly (134). These observations are consistent with Painter and Burkitt's (120) hypothesis that colonic filling reduces intraluminal pressure. More recently however, Smith (136) has reported that other agents such as finely ground wheat bran or isphagula which also increase stool bulk and might therefore be expected to decrease intra-colonic pressure, in fact failed to do so or actually increased it. Moreover, in this study of patients with diverticular disease, there was no consistent relationship between symptoms and pressure (136). Since a reduction in intraluminal pressure is likely to be fundamental to successful long term treatment, it is suggested that coarse wheat bran may be the therapy of choice in uncomplicated diverticular disease.

Bran has also been used in the therapy of the irritable bowel syndrome. Although Manning et al. (137) reported a subjective improvement and a reduction in colonic motor activity in subjects treated with fiber, other studies failed to document an ameliorative effect (138–140).

Colonic cancer. Fiber consumption is only one of several dietary variables tentatively implicated in the etiology of large bowel cancer (141). Certain epidemiological and clinical studies are suggestive of a protective effect but other data are complex and contradictory. It has been postulated that fiber may act as a protective factor in cancer of the large bowel by shortening transit time, thus reducing the time for formation and action of carcinogens. In addition, through its stool-bulking effect, fiber may lower the concentration of fecal carcinogens thereby reducing the amount of carcinogen that comes in contact with the gut wall (142, 143). Other changes may occur in the physical and chemical environment of the colon, the bacterial flora, or in the interaction between bacteria and potential carcinogens. Most types of fiber do increase stool bulk and dilute the concentration of specific substances in the colon, and the concentration of bacterially modified bile acids in the colon has been implicated in tumor formation. Bile acids act as promoters of colon cancer, in mutagenesis assay systems (144) as well as in conventional and germ-free rats (145, 146) when given orally or intra-rectally (145, 147). However, the applicability of animal models of chemically induced carcinogenesis to human cancer is unclear (148).

In addition, the extent to which a specific fiber reduces fecal bile acid concentration will be modified by its concomitant effect on total sterol excretion. Whereas wheat bran decreased the concentration of bile acids in the stool (80), pectin did not (91). It is conceivable that fermentable fiber may alter the production of secondary sterols through its effects on colonic pH, since most bacterial enzymes acting on acidic and neutral steroids have pH optima of 6.5 or greater (149). Bacterial modification of fecal steroids is apparently reduced in individuals consuming high fiber diets (150, 151) or a fiber analogue, lactulose (152).

Ammonia has also been linked to colonic tumor formation (153). Cummings et al. (105) reported a decrease in fecal dialysate ammonia in association with a decrease in transit time in subjects given fiber supplements.

Epidemiological studies have attempted to relate colon cancer to nutritional variables. Consumption of dietary

fiber was found to differ in two communities in Denmark and Finland with a fourfold variation in colon cancer; however, the diets also differed in other respects (154). Reddy et al. (155) has compared dietary intakes in a low-prevalence rural community in Finland with a high risk New York population. Fat intakes were similar in the two groups but fiber intake was far greater in the Finnish population resulting in a threefold increase in stool bulk and a proportionate decrease in fecal bile acid concentration. In a study by Modan and colleagues (156), increased fiber intake was associated with a reduced incidence of cancer of the colon. Graham et al. (157) reported that the ingestion of certain fiber-rich vegetables was inversely related to the frequency of large bowel cancer. However, many of the vegetables implicated (Brassica family) contain indole compounds which themselves directly influence the activity of carcinogen-metabolizing enzymes (158). More recently, Bingham et al. (159) reported a significant negative correlation between intake of pentose-containing dietary fiber and colon cancer mortality in England.

There is some evidence that fiber may influence chemically-induced carcinogenesis in animals. Bran has been reported to reduce the incidence of tumors in dimethylhydrazine-treated rats (160, 161). Other studies have failed to confirm a protective effect of bran (162). Inconsistent results may have been due to differences in level and route of administration of the chemical carcinogen. Similarly, pectin has been reported to increase (163) or decrease (164) tumor formation under varying conditions.

In summary, there is preliminary evidence that stool bulk-promoting fibers may modify the action of colonic carcinogens or promotors. Other environmental and genetic factors are undoubtedly operative and the significance of altered fiber intake in tumorigenesis is not yet established.

Glucose absorption and metabolism

Under certain conditions, dietary fiber has a modulating effect on the glucose absorption rate and attendant hormonal responses.

Jenkins and coworkers (57, 165) have suggested that mucilaginous fibers such as guar have the most potent effects on glucose metabolism. In their studies, these fibers reduced the *rate* of glucose absorption and slowed the upper intestinal transit rate. Frank malabsorption did not occur in these acute studies but animal experiments have indicated that chronic pectin or cellulose feeding impairs jejunal glucose absorption (166). Tasman-Jones, Jones, and Owen (167) have demonstrated a reduction in the number of intestinal villi in animals fed pectin. Other reports indicated that guar delayed gastric emptying (168) and lessened the release of gastric in-

hibitory polypeptide (169). The latter effect may be secondary to alteration in the site of glucose absorption. A number of reports indicated that incorporation of guar or pectin into a test meal resulted in a flattening of the postprandial blood glucose and insulin curves (165, 170). Guar was not effective, however, unless intimately mixed with the carbohydrate vehicle (171). When used in the dietary treatment of diabetes, guar has been reported to reduce insulin requirement and urinary glucose excretion (172).

Mucilaginous polysaccharides, although effective modulators of glucose absorption, are of limited palatability. Hence, efforts have been made to treat diabetics with diets containing a predominance of fiber-rich foods. Improvements in diabetic control and reduction in insulin and sulfonylurea requirements have been reported in both mild (173, 174) and moderate (175–181) diabetics on high-fiber diets containing a normal (176, 180, 182) or high (173, 177, 178, 180) proportion of carbohydrate. In certain studies, reversal of lipid abnormalities also occurred (173, 175, 181). Further controlled trials are required but dietary fiber may be a useful adjunct in diabetic therapy.

Atherosclerosis

The low age-specific incidence of atherosclerotic heart disease (AHD) in central Africa and parts of the Indian subcontinent has been attributed in part to a diet characterized by a high intake of complex carbohydrates and dietary fiber (182–184). Plasma cholesterol levels are low in these populations but other dietary and environmental differences are present.

The possible relationship of fiber intake to CHD incidence has also been investigated in occidental populations. In an international survey of nutrient intake and serum lipids in 1955, Keys, Fidanza, and Keys (185) noted that mean plasma cholesterol for men in Naples was much lower than that for an age-matched group in Minnesota. Part of the difference (ca. 20 mg/dl) was left unaccounted for by a prediction equation based on intake of fatty acids and cholesterol (186). It was suggested that the large amount of fiber from fruit, vegetable, and legumes in Mediterranean-type diets might be partly responsible for the low levels of plasma cholesterol observed (187). Low concentrations of serum lipids and delayed onset of CHD have also been reported for various vegetarian groups including Seventh Day Adventists (188), Trappist monks (189), strict vegetarians, lacto-ovo vegetarians (190), and persons following a Zen macrobiotic diet (191). An inverse relationship between cereal fiber intake and death from coronary disease was reported in a retrospective study by Morris, Marr, and Clayton (192). This apparent relationship could not be explained

by differences in known risk factors such as serum cholesterol.

In a study of 200 healthy men, Kay et al. (28) reported that men in the lower tertile of the plasma cholesterol and triglyceride distributions were consuming significantly more dietary fiber and significantly fewer calories as fat. However, there were also negative relationships between fiber intake and each of fat intake and adiposity. Multivariate analysis indicated that, whereas the percent of calories consumed as fat was independently, positively related to serum cholesterol and triglyceride levels, the relationship of dietary fiber intake to serum lipids was largely mediated by co-existing differences in other environmental variables. This suggests that, in a free-living Western population, dietary fiber may exert an indirect effect on plasma lipids via displacement of more lipid-active nutrients.

A series of animal experiments lends support to the hypothesis that a large amount of fiber may have a protective effect. A variety of fiber-rich foods such as wheat straw (193), chow (194, 71), oats (195), soy bran (71), rice bran (196), fruit and vegetables (197), apples (198), alfalfa (199, 200), legumes (201–206), mucilaginous fiber (207–210) were shown to reduce the atherogenicity of semisynthetic diets with or without added fat and sterol. However, other fiber sources such as wheat bran (211, 212) were without effect on atherosclerosis risk factors.

Purified preparations of dietary fiber including cellulose, hemicellulose, lignin, and pectin have been tested in man. None of these represent a single homogeneous entity and results of experiments have varied depending on the physical and chemical characteristics of the fiber isolate used.

Guar, a galactomannan from the legume, *Cyanopsis tetragonolaba* is hypocholesterolemic in normal man and has been used clinically to reduce plasma cholesterol in patients with Type II hyperlipidemia (213, 214). Psyllium seed colloid (based on arabinose and galacturonic acid) is a component of the stool-bulking agent, Metamucil. Moderate doses (ca. 24 g/d) have been reported to reduce plasma cholesterol by 16% (77, 93, 215). Numerous investigations have reported that pectin lowers plasma cholesterol in man under a variety of conditions (90–92, 216). Cellulose, on the other hand, was not found to have significant hypocholesterolemic activity unless fed in large doses (77, 83, 217) and human studies on the effect of lignin on plasma lipids have given both positive (218) and negative results (219).

Cereal brans are a common fiber-rich food and their effects on plasma total cholesterol have been recorded in over 23 separate reports summarized elsewhere (220, 221). Several of these were carried out under conditions of rigorous dietary control. The majority of these studies have been negative. Information on the effects of wheat bran on HDL-cholesterol is limited and variable (222–224). In only two of the above studies has bran been reported to reduce plasma triglycerides (223, 225).

In contrast to the generally negative effect of wheat bran, oat bran does appear to have significant hypocholesterolemic properties (80, 89, 226). Other fiber concentrates, mainly particulate in nature, have also been tested. Bagasse (sugar beet residue) is apparently without hypocholesterolemic effect in man (81). Corn bran did not alter plasma lipids but soybean hulls reduced plasma cholesterol by 14% in normal males (227). Raymond et al. (94) added 60 g of mixed dietary fiber including wheat bran, soybean hulls, corn hulls, and cellulose to a liquid formula diet and found no change in plasma cholesterol level. Palumbo, Briones, and Nelson (228) reported that a cellulose-soyhull fiber mixture elicited a 5% decrease in serum cholesterol in 14 Type II hyperlipidemic subjects. In general, particulate fibers such as wheat bran are ineffective hypocholesterolemic agents compared with mucilaginous or partly mucilaginous fibers such as guar and oat bran.

Certain fiber-rich foodstuffs have been reported to significantly lower plasma total cholesterol concentration. In controlled experiments by Keys, Anderson, and Grande (229), plasma cholesterol levels were reduced when 17% of calories as sucrose, lactose, and milk protein were replaced by sugars, starch, protein, and 45 g of dietary fiber in the form of fresh fruits, vegetables, and legumes. In a later experiment by the same investigators, the isonutrient substitution of either bread or sucrose by a mixture of vegetables containing 40 g of dietary fiber reduced plasma cholesterol levels by 20 mg/dl (230). Other reports have indicated that apples (231), carrots (232, 233), and other fruit and vegetables (234) have a hypocholesterolemic effect. Fiber-rich legumes including peas, beans, and chickpeas lowered plasma cholesterol in man (235, 236). A number of studies have indicated that the reduction in serum total cholesterol due to certain types of fiber is limited to the low density lipoprotein (LDL) fraction. HDL cholesterol may be increased slightly (234) or unchanged (226).

A decrease in circulating cholesterol during increased fiber consumption may be due to a number of interacting events resulting in increased fecal steroid excretion not fully compensated for by de novo cholesterol synthesis.

There is a widespread conviction that the effect of dietary fiber on plasma cholesterol concentration may be largely mediated by enhanced fecal excretion of bile acids. Virtually all types of dietary fiber shown to be hypocholesterolemic in man also increase fecal bile acid output (**Table 3**). Miettinen and Tarpila (90) reported at least partial compensation for enhanced sterol loss in subjects fed pectin, since cholesterol synthesis as assessed by

TABLE 3.   Effect of dietary fiber on fecal steroid excretion and plasma cholesterol in man

Fiber	Amount of Supplement	Duration	Subjects	Plasma Cholesterol	Fecal Bile Acids	Fecal Neutral Steroids	Reference
	g/d	days					
Pectin	45	14	9 N + 1 HLD	−13%	+75%[c]	0	(90)
	15	21	9 N	−13%	+33%[c]	+17%	(91)
	36	14	7 N	−15%	+34%[d]		(92)
Guar	36	14	7 N	−16%	+84%[d]		(92)
Psyllium	15	16	22 N		+70%[e]		(77)
	10	42	2 N	−10%	+302%[f]	0	(93)
Cellulose	15	16	22 N		+25%[e]		(77)
	100	10	10 N	−25%	+45%		(78)
Bagasse	11	84	9 N	0	+50%[d]	0	(81)
Legumes		385	10 N	−22%	+55%[g]	0	(79)
Oat bran	40	15	6 N	0	+111%[c]		(80)
	100	10	8 HLD	−13%	+51%[c]	0	(89)
Wheat bran[a]	16	21	8 N	0	0[c]		(83)
	39	21	8 N	0	0[d]	0	(81)
	64	21	6 N		+90%[d]		(84)
	36	21	6 N	0	0[d]	+40%	(85)
	54	21	6 N	0	0[c]	0	(86)
	70	365	22 DD	0	−49%[c]	0	(88)
	35	28–56	7 N		0[c]	0	(87)
Mixed	60	28	8 N + 1 HLD	0	0[c]	0	(94)
	93[b]	15	6 N	0	+111%[c]		(80)
	33[b]	21	46 N	−7%	0[c]	+40%	(95)

[a] Given as wheat bran or derived from whole wheat foods.
[b] g/d of dietary fiber in mixed food sources.
   Methods of total fecal bile acid determination: [c], gas-liquid chromatography; [d], enzymatic; [e], turnover of radiolabeled bile acids; [f], fluorimetry; [g], titration with alkali.
   N, normal; HLD, hyperlipidemic; DD, diverticular disease.

serum concentrations of methyl sterols increases. It is of interest that increased fecal bile acid output due to fiber was not always accompanied by a reduction in plasma cholesterol (39, 81). Similarly, simulation of fiber-inducible increases in fecal bile acid excretion achieved by administration of low doses of cholestyramine failed to alter blood lipids in normolipidemic volunteers (237). This suggests that additional mechanisms may be operative.

Experiments demonstrating that the hypocholesterolemic effect of pectin is greatest when the diet contains cholesterol (238) suggested that reduced absorption may be a factor in the cholesterol-lowering response. Fecal neutral steroid excretion in man was variably increased by pectin (91), however other hypocholesterolemic fibers did not appear to alter fecal output of cholesterol and its degradation products (77, 89, 93). Many types of dietary fiber modulate glucose absorption resulting in a reduction in postprandial levels of glucose and insulin. Albrink, Newman, and Davidson (175) demonstrated that a reduction in plasma triglycerides and cholesterol in subjects ingesting high-fiber diets was associated with a markedly lower insulin response to a representative high-fiber meal than to a low-fiber meal.

Insulin has been reported to increase cholesterol synthesis (239) and hepatic synthesis and secretion of very low density lipoprotein (240). Inclusion of dietary fiber in a high carbohydrate diet markedly reduces carbohydrate-associated lipemia (175, 241). Mucilaginous fibers appear to have the greatest effect on plasma total cholesterol concentrations and are of similar importance in their effects on glucose metabolism (241, 242), suggesting that fiber-induced changes in the ambient insulin concentration may influence lipid metabolism.

Cholelithiasis

A series of reports have recently become available on the effects of dietary fiber on gallbladder bile composition (**Table 4**). Most studies have used wheat bran. The tendency of biliary cholesterol to precipitate and form gallstones is dependent on the lithogenic index which is based on the molar ratios of cholesterol, bile acid, and phospholipid. In general, when the bile was initially lithogenic, improvement followed; but in patients with normal

TABLE 4. Effect of wheat bran on gallbladder bile[a] composition

Reference	Subjects	Lithogenic Index	Bile Acid Composition
Pomare et al. (243)	6 Cholelithiasis	↓	↓ DC ↑ CDC
Wicks et al. (96)	12 Normal	0	↓ DC ↑ CDC
Watts et al. (244)	5 Supersaturated	↓	↓ DC[b]
	6 Normal	0	0
McDougall et al. (224)	8 Cholelithiasis	↓	↓ DC
	9 Normal	0	0
Tarpila et al. (88)	22 Diverticular disease	0	↓ DC ↑ CA
Meyer et al. (245)	4 Obese	0	0
Van Berge Henegouwen et al. (223)	7 Normal	0	
Huijbregts et al. (246)	7 Normal	0	0

[a] Obtained by duodenal aspiration.
[b] If initially elevated.
DC, deoxycholic acid; CDC, chenodeoxycholic acid; CA, cholic acid.

bile composition, bran did not further reduce the lithogenic index (96, 223, 224, 243–246). Pomare and coworkers (243) reported that a dose of 30 g/day significantly improved bile composition in patients with cholesterol gallstones and Watts, Jablonski, and Toouli (244) noted improvement in bile composition in all five patients whose lithogenic index was initially greater than unity. A somewhat larger daily amount of bran (50 g) reduced the lithogenic index from 1.35 to 0.71 in patients with stones, but did not affect a control population (224). A mixture of dietary fibers did not improve bile composition in four morbidly obese subjects; however this group does not respond well to other forms of therapy such as chenodeoxycholic acid (245).

Less information is available on the effect of other fibers on bile composition. Miettinen and Tarpila (90) reported that bile composition was not affected in normals receiving citrus pectin, but one individual who initially had supersaturated bile developed normal composition on therapy. Rotstein and coworkers (75, 76) demonstrated that lignin significantly reduced biliary lithogenicity and cholesterol gallstone formation in hamsters. This effect was augmented by inclusion of a synthetic fermentable fiber analogue, lactulose, in the diet. Protection against cholesterol gallstones has been demonstrated in squirrel monkeys fed a diet rich in fiber (247).

The mechanism by which certain fibers improve bile composition is not firmly established. Strasberg, Petrunka, and Ilson (248) demonstrated that controlled stimulation of bile acid synthesis reduced the biliary cholesterol secretion in rhesus monkeys. In accord with this observation, low doses of a bile acid-binding resin improved bile composition in subjects with cholelithiasis (237, 249). Pectin and lignin increase fecal bile acid ex-

cretion and may act in a similar manner. Wheat bran apparently causes other changes in colonic bile acid metabolism as indicated by a reduction in the deoxycholic acid fraction of bile (243).

A reduction in pool size is another abnormality reported in subjects with cholesterol gallstones (250). Since the bile acid pool size is inversely related to the enterohepatic cycling frequency, fibers such as bran, which decrease upper intestinal transit (166, 251) time, might actually decrease pool size. More information is required on the effects and mechanism of action of various fibers on bile composition and bile acid pool size in subjects with cholelithiasis.

Mineral deficiencies

The affinity of acidic polysaccharides for mono- and divalent cations is reflected under certain dietary conditions by an increase in the fecal excretion of various minerals and electrolytes. Wheat fiber lowered blood levels of calcium and iron in subjects on a Western diet (252, 253). These findings were supported by Reinhold and colleagues (254, 255) who also demonstrated reduced bioavailability of zinc and magnesium in volunteers consuming a high fiber Iranian bread. This effect could be only partially ascribed to the associated phytate content (256, 257). Purified fibers such as cellulose lowered calcium and zinc absorption (258, 259). In other recent reports, cellulose, hemicellulose (260), and a diet rich in fruit and vegetables (261, 262) increased calcium, magnesium, zinc, and copper excretion in the stool. However, not in all studies has a detrimental effect of fiber on mineral balance been confirmed. Guthrie and Robinson (263) demonstrated that 150 g per day of wheat bran did not alter zinc, copper, or manganese balance in young women. These balance studies were performed after 21

days of bran consumption in contrast to those carried out immediately after initiation of a high fiber regimen and may indicate adaptive changes to lower concentrations of micronutrients. In careful metabolic studies, Sandstead et al. (264) demonstrated that adult males ingesting a normal Western diet could sustain zinc, copper, and iron balance when 26 g of wheat bran or other fiber was added to their diet; calcium requirements increased slightly. The highly fermentable fiber, pectin, did not affect calcium balance probably because fiber degradation can lead to release and absorption of bound minerals in the colon (265).

Due to the deposition of minerals in the plant cell wall, high fiber diets are often enriched in various minerals including iron, magnesium, chromium, potassium, and calcium. The nutritional significance of fiber-induced changes in mineral balance must be considered in the context of overall dietary adequacy and individual ability to adapt to a reduction in micronutrient availability (265). A low intake of iron, zinc, and calcium has been documented in certain population subgroups; adequate supplementation of these minerals may be indicated if fiber intake is increased.

CONCLUSIONS

Dietary fiber has certain established homeostatic and therapeutic functions in human nutrition. However, despite the enormous surge of interest in this field, the relative etiological importance of fiber in many Western diseases remains unclear. Progress is impeded by the nature of the material under study. Plant fiber consists of a diverse group of substances of chemical and morphological complexity. In both in vitro and in vivo studies of purified fibers, careful characterization of the fiber used is necessary, since the age and species of the plant source and the extraction method all influence the nature of the derived material. The isolation and study of individual fibers represents the most systematic approach to defining the effects of different chemical types of fiber. However, chemical extraction from the plant cell wall undoubtably alters both physical and chemical properties of the native fiber. Although it may appear more physiological to study the effects in man of consuming intact fiber-rich foods, concomitant alterations in the intake of other dietary components is often inevitable.

These problems will continue to evade simple solutions. We have developed the concept that dietary fiber is a polymer matrix with definable physicochemical properties (1). Determination of the physical and chemical characteristics of fiber and the evolution of these properties during passage along the gastrointestinal tract is likely to be fundamental to the prediction of the role of various types of dietary fiber in human physiology.▉▉

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