CARBOHYDRATES AND DIETARY FIBER

Dietary carbohydrates play a central role in human nutrition because they provide the primary source for the energy we need to fuel bodily functions. Carbohydrates are classified into two basic groups: simple and complex. Most dietary fiber is composed of indigestible carbohydrates, so fiber and related compounds are discussed as well.

Many in the medical and research communities now believe that excessive consumption of carbohydrates, specifically, carbohydrates that have been refined and stripped of their supportive nutrients, is a major contributing factor to a wide variety of diseases and premature aging. Virtually all of the fiber, phytochemical, vitamin, and trace element content have been removed from white sugar, white breads and pastries, and many breakfast cereals. Even the natural simple sugars in fruits and vegetables have an advantage over sucrose (white sugar) and other refined sugars in that they are balanced by fiber and a wide range of nutrients that aid in the utilization of the sugars.

Eating too many carbohydrates, particularly simple sugars, can be harmful to blood sugar control, especially if you are insulin resistant, experience reactive hypoglycemia or are diabetic. Carbohydrate excess, especially consuming too many refined carbohydrates, is also associated with increased risk for obesity, heart disease, and some forms of cancer. Currently, more than half of the carbohydrates being consumed in the U.S. are in the form of simple sugars being added to foods as sweetening agents.

The consumption of sweeteners in the United States increased from about 14 million tons in 1979 to about 22 million tons in 1999. Included in the category of sweeteners are sugar, corn sweeteners, honey, maple syrup, and other edible syrups. The per capita consumption just of added sugars went from 27 teaspoons (108 grams) per person per day in 1970 to 32 teaspoons (128 grams) per person per day in 1996, according to U.S. Food Supply Data. What is staggering to consider is that non-caloric sweeteners are not included in these calculations.

The large increase in the use of corn sweeteners, or high fructose corn syrup (HFCS), in the past 30 years is directly related to the overall increase in sugar consumption in the U.S. In spite of its name, there is no more fructose in high fructose corn syrup than there is sucrose. HFCS is simply sweet and is much less expensive than sucrose.

Many different products can use HFCS as an ingredient. Some of these include beverages, cereal and baked goods, dairy products, candy, and many other processed foods. Production of HFCS in the U.S. increased from 2.2 million tons in 1980 to 9.4 million tons in 1999. The production of HFCS in 2000 consumed about 5.3% of the total American corn crop. The consumption of sugar-sweetened beverages has played the largest role in the increase of added sweeteners in the American diet. Food consumption studies have found that recent increases in energy intake coincide with increased consumption of soft drinks.

SIMPLE CARBOHYDRATES

Simple sugars are either monosaccharides composed of one sugar molecule, or disaccharides composed of two sugar molecules. The principle monosaccharides that occur in foods are glucose and fructose. The major disaccharides are: sucrose also known as white sugar, which is composed of one molecule of glucose and one molecule of fructose; maltose, which is composed of two molecules of glucose; and lactose, which is composed of one molecule of glucose and one molecule of galactose.

Glucose is not particularly sweet tasting compared to fructose and sucrose. It is found in abundant amounts in fruits, honey, sweet corn, and most root vegetables. Glucose is also the primary repeating sugar unit of most complex carbohydrates (starches).

Fructose or fruit sugar is the primary carbohydrate in many fruits, maple syrup, and honey. Fructose, which is very sweet, is roughly 1-½ times sweeter than sucrose (white sugar). Although fructose has the same chemical formula as glucose, its structure is quite different. In order to be utilized by the body, fructose must first be converted to glucose within the liver.

Sucrose, which is common table sugar, is found in a large number of processed foods and some fruits.

Maltose is found in malted grain products and syrups derived from grains such as barley and sorghum.

Lactose is the sugar found in milk. Humans have the enzyme, called lactase, to digest lactose as infants, but start to lose this enzyme. By age four most of our lactase production is absent. In some people, particularly those of African American descent, lactase production is completely absent, causing lactose intolerance with symptoms of gas, bloating and diarrhea when dairy products are consumed. Lactase enzyme can be supplemented for the occasional consumption of dairy foods in people who are lactose intolerant.

Sucrose maltose and lactose get broken down into their constituent sugars in the small intestine. Glucose is the primary form of sugar that enters the bloodstream. In fact, most of the content of other sugars are converted to glucose at the surface of the intestine or in the liver.

COMPLEX CARBOHYDRATES

Complex carbohydrates, or starches, are composed of many simple sugars joined together by chemical bonds. These bonds can be linked in a serial chain, one after the other, as well as side to side, creating branches. Basically, the more chains and branches, the more complex the carbohydrate. The more complex a carbohydrate is, the slower it is broken down. Some carbohydrates are complex in a way that the body cannot digest them. These carbohydrates are a major component of fiber, discussed below, and generally pass through the digestive tract unabsorbed. In general, as long as complex carbohydrates are present in high fiber foods, the body breaks down complex carbohydrates into simple sugars more gradually, which leads to better blood sugar control. More and more research on heart disease, various forms of cancer, and diabetes indicates that complex carbohydrates, including high fiber, should form a major part of the diet. For example, the Dietary Approach to Stop Hypertension or DASH diet focuses on a whole foods diet comprised of vegetables, legumes and whole grains, which are excellent sources of complex carbohydrates, high in fiber.

GLYCEMIC INDEX AND GLYCEMIC LOAD

More important than labeling a carbohydrate simple or complex is to consider its "glycemic index" and “glycemic load.” As described in Chapter 1, the glycemic index (GI) provides a numerical value that expresses the rise of blood glucose after eating a particular food. The GI is computed in two ways due to the fact that there are two standards of comparison. The first standard to be developed was based on the rise in blood sugar seen with the ingestion of glucose, which was given a value of 100. Today, this glucose standard has largely been abandoned by the scientific community in favor of the more accurate starch standard. In the starch standard, a 50 gram portion of white bread made using refined flour (the bread most commonly eaten in the U.S.) is given the value of 100. White bread was selected as the new standard because the glycemic response to white bread is more reliable than the response to glucose. This is because glucose attracts water, an effect, called osmolarity that can delay gastric emptying and misrepresent the insulin response. In addition, white bread stimulates more insulin activity than glucose. Using either standard, the glycemic index ranges from about 20 for fructose and whole barley to about 98 for a baked potato. The insulin response to carbohydrate-containing foods is similar to the rise in blood sugar.

The glycemic load (GL) takes the glycemic index into account, but gives a more complete picture of the effect that a food has on blood sugar levels because it also takes into consideration the amount of carbohydrate in the food.

Glycemic Index of Some Common Foods

Sugars	
Fructose	20
Glucose	100
Honey	75
Maltose	105
Sucrose	60
Fruits	
Apples	39
Bananas	62
Oranges	40
Orange juice	46
Raisins	64
Vegetables	
Beets	64
Carrot, raw	31
Carrot, cooked	36
Potato, baked	98
Potato (new), boiled	70
Grains	
Bran cereal	51
Bread, white	69
Bread, wholegrain	72
Corn	59
Cornflakes	80
Oatmeal	49
Pasta	45
Rice	70
Rice, puffed	95
Wheat cereal	67
Legumes	
Beans	31
Lentils	29

Peas	39
Other foods	
Ice cream	36
Milk	34
Nuts	13

DIETARY FIBER

Originally, the definition of dietary fiber was restricted to the sum of plant compounds that are not digestible by the secretions of the human digestive tract. But, this definition is vague since it depends on an exact understanding of what exactly is not digestible. For our purposes, the term "dietary fiber" will be used to refer to the components of the plant cell wall as well as the indigestible residues.

The composition of the plant cell wall varies according to the species of plant. In general, most plant cell walls contain 35% insoluble fiber, 45% soluble fiber, 15% lignans, 3% protein, and 2% ash. It is important to recognize that dietary fiber is a complex of these constituents, so supplementation of a single component cannot substitute for a diet rich in high-fiber foods. Some of these components, including inositol hexaphosphate and fructoologsaccharides, are discussed below.

Classification of Dietary Fiber

Fiber Class	Chemical Structure	Plant Part	Food Sources	Physiological Effect
I. Cellulose	Unbranched 1-4-beta-D-glucose polymer	Principal plant wall component	Wheat bran	Increases fecal weight and size
II. Soluble Fibers				
A. Hemicelluloses	Mixture of pentose and hexose molecules in branching chains	Plant cell walls	Oat bran (β-glucan), guar gum	Increases fecal weight and size, binds bile acids
B. Gums	Branched-chain uronic acid containing polymers	Endosperm of plant seeds, plant exudates	Karaya, locust bean, tragacanth, gum Arabic, guar	Bulk laxative, binds metals
C. Mucilages	Similar to hemicelluloses	Endosperm of plant seeds	Legumes, psyllium, konjac root, slippery elm bark, marshmallow root	Hydrocolloids that bind cholesterol and delay gastric emptying; chelate out heavy metals
D. Pectins	Mixture of methyl esterified galacturan, galactan, and arabinose in varying proportions	Plant cell walls	Citrus rind, apple and onion skin	As above
E. Algal polysaccharides	Polymerized D-mannuronic acid and L-glucuronic acid	Algin, agar, carrageenan	Seaweeds	As above
III. Lignans	Non-carbohydrate polymeric phenylpropene	Woody part of plant	Wheat (25%), apple (25%), cabbage (6%), flaxseeds, other nuts and seeds	Antioxidants, anti-carcinogenic

Cellulose and Insoluble Fibers:

The best example of an insoluble fiber is wheat bran. Wheat bran is rich in cellulose. Although wheat bran is relatively insoluble in water, it has an ability to bind water. This ability accounts for its effect of increasing fecal size and weight, thus promoting regular bowel movements. Although cellulose cannot be digested by humans, it is partially digested by beneficial microflora in the gut, for which it is the primary food source. The natural fermentation process, which occurs in the colon, results in the degradation of about 50% of the cellulose, and is an important source of the short-chain fatty acids that nourish our intestinal cells.

Soluble Fibers:

The majority of fibers in most plant cell walls are water-soluble compounds. Included in this class are hemicelluloses, gums, mucilages, pectin and algal polysaccharides. It is this group of fiber compounds that exert the most beneficial effects.

Hemicelluloses

Hemicelluloses, like those found in oat bran, also promote regular bowel movements by increasing hydration of the stool. Hemicelluloses also directly bind cholesterol in the gut, preventing cholesterol absorption. Bacteria in the gut digest hemicelluloses increasing the number of beneficial bacteria in the gut and creating short-chain fatty acids (discussed below), which colon cells use as fuel and decrease cholesterol.

Gums and Mucilages

Structurally, gums and mucilages resemble the hemicelluloses, but they are not classed as such due to their unique location in the seed portion of the plant. They are generally found within the inner layer (endosperm) of grains, legumes, nuts, and seeds. Also, some gums are exuded on the surface of plants, such as gum Arabic, gum karaya and gum tragacanth. Guar gum, which is technically a mucilage and not a gum, is found in most legumes (beans), and is the most widely studied plant mucilage. Commercially, guar gum is used as a stabilizing, thickening and film-forming agent in the production of cheese, salad dressings, ice cream, soups, toothpaste, pharmaceutical jelly, skin cream, and tablets. Guar gum is also used as a laxative.

Gums and other mucilages, including psyllium seed husk and konjac root glucomannan, are perhaps the most potent cholesterol-lowering agents of the gel-forming fibers. In addition, mucilage fibers have been shown to reduce fasting and after-meal glucose and insulin levels in both healthy and diabetic subjects; and mucilage has decreased body weight and hunger ratings when taken with meals by obese subjects.

Pectins

Pectins are found in all plant cell walls as well as in the outer skin and rind of fruits and vegetables. For example, the rind of an orange contains 30% pectin, an apple peel 15%. and onion skins 12%. The gel-forming properties of pectin are well known to anyone who has made jelly or jam. These same gel-forming qualities are responsible for the cholesterol-lowering effects of pectin. Pectin lowers cholesterol by binding the cholesterol and bile acids in the gut and promoting their excretion.

Algal Polysaccharides

Algal polysaccharides, or seaweed gums, are dervived from brown seaweeds, such as alginates, and red seaweeds, such as agar and carrageenan, which is also known as Irish moss. Alginates form insoluble gells that are used as emulsifiers, thickeners and binders in food production. Agar forms a gel that is soluble in hot water, but not cold water. Agar is used as a culture medium for microbes as well as a stabilizer in many foods. Carrageenan can be broken into compoents that do and do not form gels. Carrageenan is used in many foods to thicken and create a smooth texture. Excessive carrageenan may cause irritation to the gastrointestinal tract and liver.

Lignans

Lignans are compounds found in high-fiber foods that show important properties, such as anticancer, antibacterial, antifungal, and antiviral activity. Plant lignans are changed by the gut flora into enterolactone and enterodiol, two compounds protective against cancer, particularly breast cancer. Lignans bind to estrogen receptors and interfere with the cancer-promoting effects of estrogen on breast tissue. Lignans also increase the production of a compound known as sex hormone binding globulin, or SHBG. This protein regulates estrogen levels by escorting excess estrogen from the body.

Flaxseeds are the most abundant source of lignans. Additional good sources of lignans are other seeds, grains, and legumes.

Inositol and Inositol Hexaphosphate (Ip6 or Phytic Acid)

Inositol is an "unofficial" member of the B vitamins that functions as a primary component of cell membranes and, with phosphate groups attached, it acts as an important regulator of cell division. Although inositol has not been shown to be essential in the human diet, supplementation has been shown to exert some beneficial effects in cases of depression, panic attacks, and diabetes.

Inositol is required for the proper action of several brain neurotransmitters, including serotonin and acetylcholine. It is currently thought that a reduction of brain inositol levels may induce depression as inositol levels in the cerebrospinal fluid have been shown to be low in patients with depression. In double-blind studies, inositol at a dosage of 12 grams per day has demonstrated therapeutic results, such as reduction in the Hamilton Depression Scale. The results are similar to tricyclic antidepressant drugs, but without their side effects.

The major source of inositol in nature is found in the form of inositol hexaphosphate (Ip6), which is a component of fiber from whole grains and legumes and not a fiber class on its own. In the plant, Ip6 is responsible for storing minerals, such as calcium, phosphorus, magnesium, and potassium, as phytates. There is some concern that Ip6 can adversely affect the uptake and utilization of many minerals in the body, including calcium, iron, and zinc, however this does not seem to be the case. Phytates are destroyed by heat and by the enzyme phytase during the leavening of bread.

Although naturally occurring Ip6 exerts impressive antioxidant and antitumor effects, it may be better to take supplements containing purified Ip6 plus inositol. The supplement form offers several advantages. In grains and beans, Ip6 binds to molecules of protein and minerals, such as calcium, magnesium, or potassium to form phytate. The body has trouble absorbing this complex. Studies have shown that pure Ip6 is significantly more bioavailable than the Ip6 found in foods as phytates. Supplemental Ip6 should be taken on an empty stomach away from other mineral containing substances to avoid phytates forming in the digestive tract as we do not produce our own phytase to break these down.

Fructooligosaccahride (FOS)

Fructooligosaccharides (FOS) which are another fiber component found in many vegetables, consist of short chains of fructose molecules. The term "oligosaccharide" refers to a short chain of sugar molecules ("oligo" means "few", "saccharide" means "sugar.") Galactooligosaccharides (GOS), which also occur naturally, consist of short chains of galactose molecules. Inulin is one of the more researched FOS molecules that is derived from Elecampagne root or *Inula helenium* as well as the roots of other plants. These compounds can be only partially digested by humans. When oligosaccharides are consumed, the undigested portion serves as food for "friendly" bacteria, such as *Bifidobacteria* and

Lactobacillus species. Clinical studies have shown that administering FOS, GOS, and inulin can increase the number of these friendly bacteria in the colon while simultaneously reducing the population of harmful bacteria. Other benefits noted with FOS, GOS, or inulin supplementation include increased production of beneficial short-chain fatty acids like butyrate, increased absorption of calcium and magnesium, and improved elimination of toxic compounds.

Several double-blind studies have looked at the ability of FOS or inulin to lower blood cholesterol and triglyceride levels. These studies have shown that in individuals with elevated total cholesterol or triglyceride levels, including people with non-insulin-dependent diabetes, FOS or inulin in amounts ranging from 8-to-20 grams daily can produce meaningful reductions in these blood lipids. But, in individuals with normal or low cholesterol or triglyceride levels, FOS or inulin produced little effect.

FOS and inulin are found naturally in Jerusalem artichoke, burdock, chicory, dandelion root, leeks, onions, and asparagus. FOS can be synthesized by enzymes of the fungus *Aspergillus niger* acting on sucrose. GOS is naturally found in soybeans and can be synthesized from lactose (milk sugar). FOS, GOS, and inulin are available as nutritional supplements in capsules, tablets, and as a powder.

PHYSIOLOGICAL EFFECTS OF DIETARY FIBER

It is beyond the scope of this chapter to detail all known effects of dietary fiber on humans. Instead, we will concentrate on the effects of greatest significance: stool weight and transit time, digestion, lipid metabolism, short chain fatty acids (SCFA), and namely intestinal bacterial flora. We will also review a selection of diseases highly correlated with the lack of dietary fiber, namely colon diseases, obesity, and diabetes.

Beneficial Effects of Dietary Fiber

- Decreased intestinal transit time
- Delayed gastric emptying resulting in reduced after-meal blood sugar levels
- Increased satiety
- Increased pancreatic secretion
- Increased stool weight
- More advantageous intestinal microflora
- Increased production of short-chain fatty acids
- Decreased serum lipids
- More soluble bile

Stool Weight and Transit Time

Fiber has long been used in the treatment of constipation. Dietary fiber, particularly the water-insoluble fibers, such as cellulose, increase stool weight as a result of their water-holding properties. Transit time, the time taken for passage of material from the mouth to the anus, is greatly reduced on a high-fiber diet.

Cultures consuming a high-fiber diet (100-to-170 grams/day) usually have a transit time of 30 hours and a fecal weight of 500 grams. In contrast, Europeans and Americans who eat a typical, low-fiber, diet (20 grams/day) have a transit time of greater than 48 hours and a fecal weight of only 100 grams. The increased intestinal transit time associated with the Western Diet allows prolonged exposure to various cancer-causing compounds within the intestines.

Fiber should not only be thought of in the treatment of constipation, but also in the treatment of diarrhea due to irritable bowel syndrome. When fiber is added to the diet of subjects with abnormally rapid transit times of less than 24 hours, it causes slowing of the transit time. Dietary fiber acts to normalize bowel movements.

Dietary fiber's effect on transit time is apparently directly related to its effect on stool weight and size. A larger, bulkier stool passes through the colon more easily, requires less pressure to be produced during defecation, and subsequently less straining. This results in less stress on the colon wall and therefore avoids the ballooning effect that creates diverticuli, which are sacs or pouches in the wall of the intestinal tract. Diverticuli can become lodged with feces causing inflammation, which is called diverticulitis. Dietary fiber also prevents the formation of hemorrhoids and varicose veins.

Digestion:

Although dietary fiber increases the rate of transit through the gastrointestinal tract, it slows gastric emptying. This effect means that the food is released more gradually into the small intestine, and as a result, blood glucose levels will rise more gradually. Pancreatic enzyme secretion and activity also increase in response to dietary fiber.

A number of research studies have examined the effects of fiber on mineral absorption. Although the results have been somewhat contradictory, it now appears that large amounts of dietary fiber may result in impaired absorption and/or negative balance of some minerals and supplemental fiber, especially wheat bran, may result in mineral deficiencies. However, dietary fiber does not appear to interfere with mineral absorption from other foods.

Lipid Metabolism

The water-soluble gels and mucilagenous fibers, such as oat bran, guar gum, and pectin, are capable of lowering serum cholesterol and triglyceride levels by greatly increasing their fecal excretion as well as preventing their manufacture in the liver as discussed above under hemicellulose. The water-insoluble fibers, such as wheat bran, have much less effect in reducing serum lipid levels.

Short Chain Fatty Acids (SCFA)

The fermentation of dietary fiber by the intestinal flora produces three main end products: (1) short chain fatty acids, (2) various gases, and (3) energy. Of these, the SCFAs, including acetic, proprionic, and butyric acids, have many important physiological functions.

Proprionate and acetate are transported directly to the liver and utilized for energy production. Proprionate is a natural HMG Co A reductase inhibitor. HMG Co A reductase is the key enzyme for cholesterol synthesis.

Byrate provides an important energy source for the cells that line the colon. In fact, butyrate is the preferred source for energy metabolism in the colon. Butyrate production may also be responsible for the anticancer properties of dietary fiber. Butyrate has been shown to possess impressive anticancer activity and is being used in enemas for ulcerative colitis.

Certain fibers appear to be more effective than others in increasing the levels of SCFAs in the colon. Pectins (both apple and citrus), guar gum, and other legume fibers produce more SCFAs than beet fiber, corn fiber, or oat bran.

Intestinal Bacterial Flora

Dietary fiber improves all aspects of colon function. Of central importance is the role it plays in maintaining a suitable bacterial flora in the colon. A low-fiber intake is associated with both an overgrowth of endotoxin-producing bacteria (bad guys) and a lower percentage of *Lactobacillus* (good guys) and other acid-loving bacteria. A diet high in dietary fiber promotes the increased synthesis of short chain fatty acids, which reduce the colon pH, creating a friendly environment for the growth of acid-loving bacteria.

Although dietary carbohydrates provide the primary source for the energy we need to fuel bodily functions, the type of carbhyodrate we choose to perform this task has consequences, both good and bad, that reverberate throughout the body. Also, we can now see that too much carbohydrate, particularly simple carbohydrate, is is a major contributing factor in a wide variety of diseases and premature aging.

The diet should contain 25 -35 grams of dietary fiber from a variety of sources, every day. The best sources of fiber come from fruits, vegetables, legumes and grains. Many sources contain both soluble and insoluble fiber. Eat all foods in the least processed form for optimal health, e.g. fresh produce, and whole unprocessed grains.

If you have been eating a low fiber diet, you may initially experience some gas if you drastically increase fiber intake, so ease into it gradually and drink plenty of water (aim for 2 quarts daily) to keep things moving through your digestive system.

Fruits	Fiber grams		Fiber grams		Fiber grams
Figs (3)	5.3	Orange	3.1	Applesauce	1.5
Apple w/skin	4.7	Kiwi	2.6	Peach	1.4
Pears	4.3	Strawberries (6)	2.0	Cantaloupe (1/4)	1.1
Dates (5)	3.7	Raisins (1/4 cup)	1.9	Pineapple (1/2 c.)	0.9
Apricots (10)	3.6	Banana	1.8	Grapefruit (1/2)	0.7
Prunes (5)	3.5	Blueberries (25)	1.7	Watermelon (1 c.)	0.6

(serving size is one piece or as noted)

Vegetables	Fiber grams		Fiber grams		Fiber grams
Baked Potato w/skin	4.2	Broccoli	2.0	Green beans	0.9
Sweet Potato	3.4	Spinach (1c.)	2.0	Tomato (1/2)	0.8
Corn	3.1	Turnip	1.6	Celery (1 stalk)	0.6
Peas	2.9	Beets	1.5	Green pepper (1 stalk)	0.6
Winter squash	2.9	Cabbage	1.5	Lettuce (1 c)	0.6
Carrot (1)	2.3	Cauliflower	1.4	Mushrooms	0.5

(serving size is 1/2 cup unless noted)

Legumes	Fiber grams		Fiber grams		Fiber grams
Pinto beans	14.2	Lima beans	10.3	Lentils	5.6
Kidney beans	13.8	Navy beans	9.0	Split peas	4.1
Black-eyed peas	12.3	Chickpeas	7.1	Tofu	1.4

(serving size is 3/4 cup of cooked beans)

Grains	Fiber grams		Fiber grams		Fiber grams
Barley	8.6	Quinoa	4.6	Wheat	3.1
Bulgur	8.1	Brown rice	3.3	White rice	1.3

(serving size is 1 cup)