

An Overview of Carbohydrates in Healthful Eating

“Carbohydrates—the sugars, starches and fibers found in fruits, vegetables, grains and milk products—are an important part of a healthy diet.” Leading the section on carbohydrates in the US Dietary Guidelines Advisory Committee 2005 publication, this quote reflects guidelines from all over the world (1). In fact, the statement and the Committee’s resulting recommendations are based on the 1997 FAO/WHO Expert Consultation of Carbohydrates in Human Nutrition and the 2002 report of the US Institute of Medicine, which both recommended that carbohydrates comprise 45% to 65% of daily calories. (Note: Updated *Dietary Guidelines for Americans* will be released in 2010—carbohydrate intake recommendations may or may not be changed at that time.) In 2009, environmental concerns have added an emphasis on carbohydrates and plant foods such as legumes, fruits and vegetables and whole grains, since these foods rank low in greenhouse gas production and use of water, energy and other inputs (2, 3).

Despite the apparent agreement by prestigious health organizations around the importance of carbohydrate foods as a source of energy, whole grains and fiber, they have been a subject of vigorous debate. In recent years, the rise in rates of obesity and diabetes has caused health professionals, as well as popular press writers, to question dietary recommendations that restricted fat and increased carbohydrate. As a result, some popular diet books and websites advocate low carbohydrate diets and blame sugars, white bread and certain other carbohydrates for a host of health problems (4, 5).

This article looks at the current debate in terms of scientific literature on carbohydrates, defines the lexicon of terms describing carbohydrates, reviews data on the potential health benefits of various types of carbohydrates and suggests strategies for selecting healthier carbohydrate foods.

Carbohydrates in Food and MyPyramid

As indicated in USDA’s MyPyramid food groups, carbohydrates are found in many foods, but primarily in breads and cereals, fruits and vegetables, legumes and nuts (6). There is a small amount naturally occurring in dairy; additionally, some foods are sweetened and/or have added fiber. A quick scan of carbohydrate-containing foods shows that they deliver a wide range of nutrients. Yet, there are carbohydrate foods that are considered to be discretionary choices because they yield primarily calories and are associated with higher fat

and salt intakes. Because of these latter associations, some have concluded that sweetened beverages and combinations of foods high in refined carbohydrates are associated with obesity and other diseases (7-8). Thus, despite carbohydrates’ prominence in foods forming the base of the USDA’s MyPyramid, carbohydrates’ role in the diet is both maligned and misunderstood.

Carbohydrate Terminology

Carbohydrate Understanding and Terminology Have Changed

The word *carbohydrate* is derived from the chemical nature of the molecule (hydrate of carbons). The word itself sets up a scenario for confusion, which is exacerbated by the many terms used to describe carbohydrates. Forty years ago, carbohydrates were divided into two major categories. *Simple carbohydrates*, with their one or two sugar units, were the mono and disaccharides. *Complex carbohydrates*, polymers of many sugar units, were in molecules such as starch and cellulose and were the major components in breads, legumes, cereals, pasta and potatoes. While it was known that starch was comprised of two moieties, *amylose* and *amylopectin*, the structural differences of these two starch entities were thought to be important only to the food scientist developing frozen or canned foods and not to the nutritionist counseling clients and patients.

The polymer *cellulose* was known to be a component of crude fiber, but any dietary importance went unrecognized. Nutrition texts of the late 1960s dispatched dietary fiber in a single paragraph by mentioning its role as the “human broom.” The handful of entries in *Medline* in the late 1960s and early 1970s gave only a hint of dietary fiber’s emerging importance.

Simple Carbohydrates

A number of terms and schema have emerged that describe various aspects of carbohydrates. Carbohydrates are still apportioned into two main categories: simple and complex. Simple carbohydrates are the sugars. While the terminology seems straightforward, it too has issues especially as some people like to distinguish between “naturally-occurring” and “added” sugars. Many consumers are unaware of the various names for sugars, which can make reading product ingredient statements and Nutrition Facts panels confusing.

Complex Carbohydrates

Complex carbohydrates are classified in a number of ways,

including by their size. Traditionally, *oligosaccharides* are chains of 3-9 sugar units (e.g., fructooligosaccharides), while *polysaccharides* contain 10 or more sugar units (e.g., inulin). In foods, this category includes starches and dietary fibers such as pectin, guar gum and cellulose.

Carbohydrates also are categorized by their absorbability, and their effect on blood glucose. Thus they are classed as *fully* digested and absorbed in the small intestine (starch and most sugars); *partially* digested and absorbed (resistant starch and most sugar alcohols); or *not* digested and absorbed (some dietary fibers). Sugar alcohols typically yield only about half of their carbohydrate grams, as the rest are not absorbed (9). (One sugar alcohol, *erythritol*, is absorbed but not metabolized. It is excreted unchanged in the urine.) If carbohydrates are absorbed, they are termed *available*. (Some companies label these as *net* carbohydrate, but this term has no regulatory or scientific definition.)

Dietary Fiber

Unabsorbed (unavailable) carbohydrate moves into the large intestine and is termed *dietary fiber*. The term dietary fiber evolved from crude fiber, which is currently used only to determine the proximate composition of foods. Dietary fiber also has many categories including soluble, insoluble and viscous. Fibers in the large intestine are fermented to various degrees by resident microorganisms. Most prebiotic fibers, such as inulin and fructooligosaccharides, and viscous fibers, such as guar gum, are *highly* fermentable. Other fibers are *partially* fermentable. Some, such as cellulose, are *slightly* fermented. Thus, fibers may be classed by their fermentability.

When fibers are fermented, they produce short-chain fatty acids. These are taken up by the bloodstream, carried to the liver and metabolized by the body to yield energy. Thus, different types of fiber yield differing amounts of energy—usually 1-2 calories per gram, not the 4 calories per gram of other carbohydrate foods. Therefore, fibers do not directly impact blood glucose.

Amylose, Amylopectin and Starch Digestion

Starches can be fully digested, but may also only be partially digested (e.g., resistant starch). The extent and rate of digestion depends not only on the starch's positioning in the food matrix and the starch granule and its degree of gelatinization, but also on the particular starch moiety. While both starch moieties are polymers of glucose, the glucose in amylose is a long, linear chain, while that in amylopectin is a highly-branched, tree-like structure. Breakdown of starches is caused by the enzyme

amylase. Amylase acts by attaching to a single end of a starch chain and splicing off two sugar units at a time. Therefore, in amylose, sugar units slowly peel off from the one available end of the long chain polymer, steadily releasing glucose into the bloodstream. In contrast, amylopectin's branches offer many ends for amylase attachment, releasing a number of sugar units at once and a correspondingly rapid entry into the bloodstream. Amylase activity speeds up markedly if the starch is cooked with liquid (i.e., it becomes gelatinized).

Starches and foods that rapidly release their glucose may be referred to as *rapidly available glucose* (RAG). Ungelatinized starches—for example, those in raw potatoes, unripe bananas or raw oatmeal used in making foods such as muesli—are less glycemic and are referred to as *slowly available glucose* (SAG).

Measures of Glycemic Response

In terms of blood glucose, carbohydrates are classified as *glycemic* and *non-glycemic*. A carbohydrate that raises blood glucose dramatically and/or quickly has a high glycemic response and is sometimes simply called high glycemic. The glycemic response is typically measured through the glycemic index or the glycemic load. Simply stated, the *glycemic index* (GI) measures how quickly a carbohydrate enters the bloodstream and raises blood sugar. The actual measurement compares the blood glucose-raising effects of ingesting 50 grams of a standard, usually glucose, to ingesting 50 grams of *available* carbohydrate from a particular food. The blood glucose test follows the rise and fall in blood glucose, which is measured as the area-under-the-curve (AUC) for a 2-hour time period after ingestion of the test food or standard glucose. For each subject, the AUC for glucose is arbitrarily assigned the value of 100. The GI is a ratio calculated by comparing the AUC observed with the test food to the AUC with glucose. It must be emphasized that GI compares amounts of available carbohydrate in the test food equal to 50 grams of glucose, which often means that the quantities of foods compared are dramatically different. These measures have generated much debate for a number of reasons, especially because of their variability, even under meticulously controlled conditions (10, 11). The other way to measure the glycemic response is through *glycemic load* (GL), which is the GI multiplied by the amount (grams) of carbohydrate in a food.

The literature is mixed, reporting that GI and GL are related to risk of a variety of chronic diseases in some studies, but not in others. Inconsistency may be due partly to differences in subjects and partly to differences in diets. Low GI/GL diets could be linked to reduced disease risk because the diets may

be largely comprised of fruits, vegetables, nuts, legumes and whole grains. All these nutritious, phytochemical-rich, high fiber foods contain components that have the capacity to lower disease risk regardless of their GI/GL. On the other hand, foods and diets containing low GI sweeteners, such as fructose, and high in meat and fat can also have a low GI/GL. Thus, the recommendation to use GI/GL in dietary guidance is not widely accepted in the US, but is recognized in certain countries, such as Australia and Canada. Nonetheless, GI and GL may be useful in refining carbohydrate choices among certain individuals. It is also important to remember that GI, in particular, can be affected by a number of variables. For example, its effect on blood glucose changes when it is eaten in combination with other foods, such as those containing protein, fat or fiber (12-14).

Carbohydrate Foods and Dietary Fiber

Dietary fiber was listed by the 2005 Dietary Guidelines Advisory Committee as a “nutrient of concern” because of its low intake in the US (14). The average American gets 12-15 g of dietary fiber per day, significantly less than the 25 g per day recommended for adult women 19-50 years of age, and the 38 g for men in that age category. Dietary fiber has long been associated with improved gut health, prevention of diverticular disease and normal laxation (15). More recently, the gut health benefits and prebiotic functions of “newer” fibers, such as inulin, have been recognized, not only for their roles in promoting a beneficial balance of gut bacteria, but also for numerous other functional effects that promote health (16).

Systematic reviews suggest that dietary fiber of all types, but particularly cereal fiber, may protect against the development of obesity, diabetes, hypertension, metabolic syndrome and coronary heart disease, possibly through anti-inflammatory and immune-enhancing actions, improved insulin sensitivity and blood glucose concentrations, and control of arterial blood pressure and blood lipids (17-21). Fiber in the diet is satiating and may help with weight control (22). A number of viscous fibers including psyllium, beta-glucan, pectin and guar gum, and foods containing them, such as oats, barley and legumes, have been shown in well-controlled intervention studies to decrease cholesterol, specifically LDL cholesterol (23-25).

Dietary fiber's role in decreasing cancer risk is uncertain. Animal and case-control studies have long suggested that dietary fiber is important in reducing tumors. Recent studies have shown that fiber in the colon produces butyrate and other short chain fatty acids, which can help reduce colon cancer

risk in at least four ways. They acidify the colon, promote the growth of healthy colonic cells, affect cell signaling, and reduce the formation of DNA adducts (26-28). A large-scale, multi-country investigation in Europe (European Prospective Investigations into Cancer and Nutrition) with over 519,000 subjects showed that high fiber intakes were associated with reduced risk of colon cancer by as much as 25% (29). However, not all studies show that fiber protects against cancer (30, 31). In the US National Institutes of Health-AARP Diet and Health Study of 291,988 men and 197,623 women aged 50-71 years, total dietary fiber was not related to colon cancer (32). Perhaps some inconsistency is due to differences in intakes. In the quintile with the most fiber intake in some northern European countries, participants meet the recommended fiber intakes (>35 g/d). This is not the case in US cohorts. What the data may imply is that fiber intake levels in the US cohorts were not high enough to affect cancer risk.

Another possibility is that fiber is not the only factor (33). While total fiber in the AARP study showed no association with cancer risk, there was an inverse association with whole grain and cereal fiber intake. Antioxidant vitamins and minerals and other micro-constituents of whole grains and fruits and vegetables can impact tumor development. Different fiber types and foods have different structures, functions and micro-constituents (34). This perhaps explains why various studies show an impact of cereal fiber and not vegetable fiber. On the other hand, so few people in North America eat the recommended amounts of vegetables, that perhaps the vegetable fiber intake is too low to have an impact.

Carbohydrates and Whole Grains

The 2005 *Dietary Guidelines for Americans* elevated guidance regarding whole grains by devoting one of the guidelines to it: *Make half your grains whole*. For a person eating a 2000-calorie diet, this translates into making at least three of the six daily grain group servings whole grain. Much of the fiber in the diet comes from whole grains. Whole grains also deliver an entire package of nutrients for which the total may be greater than the sum of the parts.

Fiber and Whole Grain Are Not Synonymous

Whole grains have been associated with reduced risk of all the diseases listed for dietary fiber (35, 36). For most diseases, the ingestion of approximately 48 g of whole grains per day reduces risk about 25% on average and reduces overall mortality about 20% (37). The strength of the evidence varies with the

disease end point, but for most of the diseases, well-designed, randomized clinical trials would strengthen the body of evidence (38). In some studies, the observed risk reduction is greater than that seen with dietary fiber alone (39). For example, a variety of studies have shown whole grains to be associated with a reduced risk of coronary disease of 20% to 40% (40). The β -glucan content of oats reduces serum cholesterol from 5% to 8% when it is part of a cholesterol-lowering diet (41). The theory is that for every decrease in serum cholesterol there is a two-point decrease in heart disease risk (41). So the decrease in coronary disease would be predicted to be 15% rather than the observed 20% to 40%, implying an effect beyond fiber (41).

Functional Components of Whole Grains

Whole grains contain a unique package of micro-constituents and numerous types of dietary fiber. For example, the viscous β -glucans of barley and oats and the arabinoxylans of wheat and rye are associated with blood glucose attenuation and cholesterol lowering. Whole grains also contain some fiber constituents including resistant starch and prebiotic fibers, such as inulin. Folic acid, tocopherols, tocotrienols and magnesium are just a few of the traditional nutrients found in whole grains. Many of these are associated with lower risk of coronary disease and diabetes. In addition, whole grains contain phytochemicals, including sterols and stanols, which lower cholesterol; numerous polyphenolics, which function as antioxidants and anti-inflammatory agents; betaine, which functions as a methyl donor; sphingolipids and long chain waxes such as policosinol, which may lower cholesterol; and alkylresorcinols, which affect mammalian lignans and may, in turn, alter coronary disease and cancer risk. Further, many grains contain unique bioactive compounds, such as the powerful antioxidant oryzanol in brown rice, avenanthramides in oats or matairesinol in rye.

Selecting Whole Grain Foods

It is often difficult for consumers to select whole grain foods because there currently is no mandatory quantitative food label identifier for whole grains. A food that states it contains whole grain may or may not have a nutritionally significant amount. Frequently, advice for selecting whole grain foods is “look for a whole grain as the first ingredient.” While this guarantees that the product has whole grain as its most plentiful ingredient, it does not guarantee that it will deliver a significant amount of whole grain. For instance, a trail mix breakfast granola with the following ingredient statement: Oatmeal, Almonds, Coconut, Raisins, Apricots, Honey, Oil and Salt, could contain 20% oatmeal, 19% almonds, 19% coconut, 19% raisins, 15%

apricots, 4% honey, 3% oil and 1% salt. Alternatively, it could have 62% oatmeal, 10% almonds, 10% coconut, 6% raisins, 4% apricots, 4% honey, 3% oil and 1% salt. While both may be nutritious products, a consumer can not tell by looking at the ingredient statement which product delivers a nutritionally significant amount of whole grain. Similarly, two hypothetical cereals, both with 3 g of dietary fiber per serving, have the following ingredient statements: Rice Flour, White Whole Wheat Flour, Oatmeal, Cottonseed Fiber, Sugar and Salt. This could be a **low whole grain** option at 60% rice flour, 15% white whole wheat flour, 10% oatmeal, 10% cottonseed fiber, 3% sugar and 1% salt; or a **high whole grain** option at 34% rice flour, 33% white whole wheat flour, 13% oatmeal, 5% cottonseed fiber, 3% sugar, and 1% salt. The latter choice would have a predominance of whole grain, but using the dictum that a whole grain product is one with whole grain as the first ingredient might cause a consumer to overlook this product.

There are several ways to determine the amount of whole grain contained in a serving of a food. The presence of a US Food and Drug Administration-approved whole grain health claim on a package also is a way to tell if a product is whole grain, as 51% of the product must be whole grain to qualify. The Whole Grain Council’s (a private organization) seal denotes foods that are whole grain and tells the amount of whole grain in the product. Some manufacturers voluntarily state the number of grams of whole grain in a serving of a product (e.g., “X grams of whole grain per serving”).

Not surprisingly, many consumers are confused about terms used to describe whole grains. First, look for ingredients that count as whole grains, such as whole wheat flour, graham flour, white whole wheat flour, oatmeal, popcorn, brown rice, whole cornmeal, quinoa and faro. Don’t be confused by terms describing milling processes (e.g., stone-ground), which can produce both whole grain and refined flours. Then, there is the term “multi-grain,” which can describe a product rich in whole grains or a product made with multiple different refined grains. Neither the color of the product nor the number of grain particles on a product are reliable indicators of whole-grain content.

Thus, there is a need to help consumers understand how to determine whether or not they are eating the recommended 48 g of whole grains per day. Dietitians and nutritionists can help consumers by being familiar with whole-grain products commercially available in their geographic area. This requires monitoring, as formulas of current food products may change

and many whole grain products are entering the market. Increased interest in whole grain foods has reduced the cost and improved the quality, taste and availability of whole-grain food choices. Technological advancements and shifts in available whole grain varieties, such as white whole wheat flour, enable consumers who prefer breads that are light in color and very smooth textured to try whole grain foods. Foods with a mix of whole grains and refined grains may allow consumers' palates to gradually adjust to accepting more whole grain foods. Another solution is to offer consumers tips for incorporating whole grain foods into meals and snacks that will satisfy the tastes and preferences of the whole family.

Wise Choices among Carbohydrate Foods

In selecting carbohydrate foods, it is vital to help clients understand that nutritional values may vary greatly. At one end of the carbohydrate spectrum are foods that contribute vitamins A, C and E and a number of B-vitamins, including folic acid; potassium and other minerals; dietary fiber and numerous phytochemicals. At the other end are foods that supply energy, in the form of calories, but not many nutrients.

The secret for consumers in selecting all foods, including carbohydrates, is to make frequent choices of foods with high nutritional value. Fiber-rich and whole-grain foods need special attention. Low average intakes of dietary fiber and whole grains have been listed as a dietary behavior that predicts mortality in both men and women in the US (42). Conversely, regular intake of fiber and whole grains is suggested as a strategy to prevent diabetes and cardiovascular disease (43). Identifying higher fiber options in each of the food groups can help clients select nutritious, fiber-rich vegetables, fruits, whole grain breads and cereals, legumes and seeds. These choices can be rounded out with low fat dairy foods, and judicious choices in the meat and beans group. The other side of balancing the carbohydrate equation is to manage carbohydrate choices that add enjoyment, but should be occasional options. Cakes, pies, cookies and regular soft drinks should be enjoyed in moderation for the treats that they are. Management, not banishment, is the strategy to teach.

In summary, carbohydrates comprise an important part of the diet. As health professionals, we need to help consumers select a healthy eating plan rich in plant foods that contain positive nutrients, as well as great taste.

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