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The Science of Sugars

EXECUTIVE SUMMARY

This paper examines recent research concerning the role of dietary sugars in nutrition and health. The nutrition and policy recommendations of the scientific community are summarized and their conclusions are related to supporting research. As carbohydrates, sugars play many important roles in our food supply. They are a source of calories and, in addition to sweetening, perform many essential technical functions both in processed foods and in foods prepared in the home. Available data show no direct link between moderate consumption of sugars and serious diseases or obesity. Sugars and all fermentable carbohydrates contribute to the multi-factorial etiology of tooth decay. Recent research has focused on indirect sugars/health relationships, such as the possibility that excessive intake of sugars contributes to obesity and/or nutritionally inadequate diets. These concerns are about over-consumption of sugars, and over-consumption can be a problem with any food or nutrient. High fructose corn syrup and sucrose (table sugar) have minimal differences in composition, and no discernable differences in how they are metabolized or in their overall effects on the body. For dietary guidance purposes, researchers recommend focusing on managing discretionary calories and energy balance, without singling out specific sweeteners or specific foods. Experts generally agree that consumers can enjoy modest intakes of calorically sweetened foods and beverages as part of a balanced diet and a physically active lifestyle as long as the total caloric contribution of these foods are within the individual's discretionary calorie limit.

The Science of Sugars

Sugars are carbohydrates that play many roles in our food supply and in our diets. They are a natural part of many foods and are a functional ingredient in others. Sugars bring sweet pleasure to eating but they also have more to offer than just sweetness and calories.

Almost everyone enjoys sugars and sweets, but many consumers wonder whether consumption of sugars affects health. This review examines recent science concerning the nutrition and health aspects of sugars consumption and explains how sugars fit into a healthful eating plan.

Sugars are Carbohydrates

As the main energy source for the body, carbohydrates are an important part of a healthful diet. Carbohydrates are found in a wide range of foods that bring a variety of other important nutrients to the diet, such as vitamins and minerals, phytochemicals, antioxidants and dietary fiber. Fruits, vegetables, grain foods and many dairy products contain carbohydrates in varying amounts. Sugars are carbohydrates that add or provide taste appeal to a nutritious diet and play other important functional or organoleptic roles in foods.

Carbohydrates get their name from the fact that they contain carbon, hydrogen, and oxygen atoms. Carbohydrates have approximately a 1:2:1 molecular ratio of these elements, which is represented by the general chemical formula CxH2xOx. The ratio of hydrogen to oxygen is always 2:1. General types of carbohydrates include sugars, starches, saccharides, and polysaccharides. The simplest carbohydrates are monosaccharides (single sugar units). The primary monosaccharides are glucose, fructose and galactose. Disaccharides are composed of two simple sugars that are joined together by chemical bonds.

Carbohydrate Classification

Dietary Carbohydrate	Sub-group	Components
Sugars (1-2 monosaccharides)	Monosaccharides (1 monosaccharide)	Glucose, fructose, xylose, galactose, ribose
	Disaccharides (2 monosaccharides)	Sucrose, lactose, maltose
Polyols (Sugar Alcohols)		sorbitol, mannitol, malitol, erythritol, xylitol
Oligosaccharides (3-9 monosaccharides)		maltodextrins, raffinose, fructo-oligosaccharides
Polysaccharides (>9 monosaccharides)	Starch	Amylose, amylopectin, glycogen
	Non-starch	Cellulose, pectins, inulin, fructans, dextrins, dextrans, gums

Other carbohydrates are composed of several monosaccharide units. Sucrose (table sugar) is a disaccharide made up of equal amounts of the simple sugars glucose and fructose. The Food and Agriculture Organization and the World Health Organization recommend classifying dietary carbohydrates by their degree of saccharide units, which is called polymerization (*see table above*) (1). The Institute of Medicine's *Dietary Reference Intakes (DRI) Report* subdivides carbohydrates into monosaccharides (one sugar unit), disaccharides (two sugar units), oligosaccharides (3 to 10 sugar units), and polysaccharides (more than 10 sugar units) (2). The IOM/DRI classification system differs slightly from the FAO/SHO with regard to number of units of monosaccharides for oligosaccharides and polysaccharides.

Terminology -

The terminology used to describe sugars can be confusing and imprecise (3, 4, 5). Researchers use a variety of terms to describe nutritive or caloric sweeteners. "Sugar" generally refers to sucrose, which is primarily manufactured from sugarcane or sugar beets. However, in order to be consistent with some investigators' designations, this review uses the term "sugar-sweetened" to refer to those products that may be sweetened with sucrose, invert sugar (sucrose where the disaccharide bond has been cleaved), high fructose corn syrup (HFCS), crystalline fructose, glucose, or a combination of these. The Department of Agriculture uses "added sugars" to refer to sugars and syrups that are added to foods at the table or during processing or preparation, including sugars and syrups, such as flavor-stripped apple and grape juice concentrates, agave juice and honey, as opposed to those sugars that are naturally occurring in foods such as the lactose naturally found in milk (6). Others have defined added sugars in a slightly different manner at times omitting sugars from fruit juices or other small differences. This review also uses the terms "nutritive sweeteners" and "caloric sweeteners" to describe these products. Commonly accepted definitions would facilitate communication among regulators, scientists, manufacturers, health professionals and consumers (3).

A Closer Look at Sugars

Sugars occur naturally in a wide variety of fruits, vegetables and dairy foods. Also, they are produced commercially and added to foods as caloric sweeteners and for the many technical functions they perform. Sugars have approximately 4 calories per gram, the same as complex carbohydrates and protein. Some common sugars found in foods are:

- **Glucose:** The main source of energy for the body and is the only fuel normally used by brain cells. Glucose is a major component of polysaccharides and the sugar produced when you digest polysaccharides. Glucose is sometimes referred to as dextrose.
- **Fructose:** A simple sugar found in fruits, honey, and root vegetables. When it occurs naturally, fructose is always found in combination with other sugars such as glucose. Fructose makes up about half of the sugars in sucrose and in the most common form of high fructose corn syrup. Pure fructose is also a caloric sweetener added to foods and beverages in crystalline or liquid form (made from corn syrup in a process similar to making HFCS)
- **Galactose:** A simple sugar that is unique to milk and dairy foods.

- **Sucrose:** Found naturally in fruits and vegetables, but in the highest quantities in sugar beets and sugar cane. Sucrose is a disaccharide that is composed of one glucose unit and one fructose unit joined together by a chemical bond. When sucrose is digested or placed in an acidic environment (such as in many ready to drink beverages), it yields 50% glucose and 50% fructose.
- **Lactose:** The natural sugar found in milk, it is composed of one galactose unit and one glucose unit; sometimes called milk sugar.
- **Maltose:** A disaccharide composed of two glucose units. It is found in molasses and is also used for fermentation.
- **Corn Syrup:** Corn syrup can refer to several products according to the FDA. All corn syrups are made from corn. They can contain primarily the sugar glucose, the sugar fructose, or any combination of these. Some commercial products called corn syrup are found in the baking section of the supermarket. There is occasionally some confusion as corn syrup is sometimes used to describe liquid pure fructose derived from corn.
- **High-Fructose Corn Syrup:** A mixture of glucose and fructose produced from corn. The most common form of high fructose corn syrup (HFCS-55) is similar in composition to sucrose, having 55 percent fructose and 45 percent glucose. The other commonly used form of HFCS is HFCS-42 which has about 42% fructose which is less fructose than found in sucrose (table sugar). HFCS is only used commercially and is not sold in the supermarket.

Sugars are part of the makeup of fruit juice concentrates, honey, molasses, hydrolyzed lactose syrup and whey. Other sources of sugars seen increasingly in ingredient lists include evaporated cane sugar, brown rice syrup, maltodextrins and date syrup—all comprised of the same basic sugars described above. In addition to sweetening, sugars perform many functions in foods. They contribute to food safety by binding water in products such as jams, jellies and cured hams, thereby making them less available for microbial growth.

Functions of Sugars in Foods -

- Add texture, flavor, and color to baked foods
- Provide a source of nourishment for the growth of yeast, which enables the leavening or fermentation process (e.g. enables breads to rise).
- Contribute “bulk,” or volume, in ice cream, baked goods, and preserves and jams.
- Enhance the creamy texture of frozen desserts.
- Control crystallization in confectionary products.
- Provide body and texture in foods and beverages.
- Enhance flavor and balance acidity in non-sweet foods, such as salad dressings, sauces, and condiments.
- Preserve the flavor, aroma, and color of the fruits used in jellies, jams, and preserves (and preventing spoilage after the jar is opened).
- Improve flavor and texture and help preserve the natural color and shape of the fruits used for canning and freezing.

Metabolism -

Once ingested, carbohydrates (polysaccharides and simple sugars) are broken down into their component simple sugars. In the digestion of sucrose, both glucose and fructose are released into the bloodstream, and further metabolic processes are required to utilize fructose. It should be noted that fructose metabolism is altered depending upon the levels of glucose present and that the body can change glucose to fructose and fructose to glucose depending upon metabolic needs. Under normal circumstances, glucose is the only fuel utilized by the brain and the primary fuel used by working muscles. To protect the brain from a potential fuel shortage, the body maintains a fairly constant glucose level in the blood. Dietary glucose can be stored in the liver and muscle cells in units called glycogen. When the level of glucose in the blood starts to drop, glycogen can be converted to glucose to maintain blood glucose levels. Several hormones, including insulin, work rapidly to regulate the flow of glucose to and from the blood to keep it at a steady level. Insulin also allows the muscles to utilize the glucose they need from the blood supply. Human metabolism does not distinguish between sugars that are added to foods and sugars that occur naturally in foods, since they are chemically the same (3).

Fructose is predominantly metabolized in the liver, and unlike glucose it does not require insulin to be utilized by the body.

The Sugar Alcohols

Sugar alcohols, or polyols as they are also called, are neither sucrose nor ethyl alcohol. They are carbohydrate derivatives of sugars with a chemical structure that partially resembles sugars and partially resembles chemical alcohols, but they do not contain ethanol as alcoholic beverages do. They occur naturally in a wide variety of fruits and vegetables, but are made from other carbohydrates such as sucrose, glucose, and starch when produced commercially. Common sugar alcohols used in foods include sorbitol, mannitol, xylitol, maltitol, maltitol syrup, lactitol, erythritol, isomalt and hydrogenated starch hydrolysates. Their calorie content ranges from 0 to 3 calories per gram compared to about 4 calories per gram for sucrose and most other sugars. Most sugar alcohols are approximately half as sweet as sucrose; maltitol and xylitol are about as sweet as sucrose.

Sugar alcohols are slowly and incompletely absorbed from the small intestine into the blood. Once absorbed they are converted to energy by processes that require little or no insulin. Depending on the specific sugar alcohol, some of the sugar alcohol may not be absorbed into the blood but passes through the small intestine and is fermented by bacteria in the large intestine. Thus, overconsumption of some sugar alcohols may result in abdominal gas and gastrointestinal discomfort in some individuals. However, other sugar alcohols are much less likely to have this effect (7).

Reviewing the health aspects of polyols, Livesy found that they have a role in reducing constipation and promoting health (8).

Sugar alcohols are not completely metabolized by the body. Due to their incomplete absorption, sugar alcohols contribute fewer calories than other sugars and, as a result, may be useful in weight management. Since absorption does not require insulin, polyol sweeteners may be useful for people with diabetes. The American Diabetes Association notes that "the total amount of carbohydrate in meals or snacks will be more important than the source or type" (9). In essence, all types of carbohydrates, including sugars and sugar alcohols, can be included in the diet. For people with diabetes, all types of carbohydrates including sugars and sugar alcohols need to be accounted for in their daily carbohydrate intake.

Sugar alcohols are not acted upon by bacteria in the mouth, and therefore do not contribute to dental caries (7, 8). Xylitol has been found to inhibit oral bacteria, and is often used in sugarless mints and chewing gums to have this effect. The Food and Drug Administration authorizes the use of a health claim in food labeling stating that sugar alcohols do not promote tooth decay (10).

Consumption of Sugars

Nutrition researchers, economists and statisticians use different methods to measure consumption of sugars –namely, disappearance data and food consumption surveys. Each method has advantages and drawbacks. For many years the U.S. Department of Agriculture's Economic Research Service (ERS) has measured the "disappearance" of sugar (sucrose) and other sweeteners from the food supply. These data report the amounts of sugars that are manufactured or the deliveries of sugars to manufacturers and consumers. This disappearance data does not measure actual consumption, but it can be useful for indicating trends in sugar usage. The data do not account for loss or waste during shipping, storage, manufacturing, or at the table. Also, expressing the data as sugars availability per capita, this method assumes equal usage across population groups and does not allow for investigating the use of sugars by different ages, genders, socioeconomic or ethnic groups (5).

The ERS data show that from 1966 to 1999 the amount of per capita sugars disappearance increased from approximately 113 pounds to approximately 151 pounds. Sugars deliveries have decreased and stabilized at about 137 pounds per capita in 2008 (11).

Recently, ERS began adjusting its food availability data for losses such as waste and converting the resulting data into daily per capita servings as defined by the 2005 Dietary Guidelines for Americans and its supporting guidance document *MyPyramid* Plan. These data show that when losses (nonedible food parts and food lost through spoilage, plate waste, and other losses in the home and marketing system) are subtracted, daily per capita consumption of caloric sweeteners decreased from approximately 134.6 pounds in 1999 to 121.3 pounds in 2007 adjusted for losses (12). ERS notes that its disappearance calculations are "first estimates" intended to serve as starting points for discussion and further research.

Total Sugars

The other way estimates of intakes of sugars can be obtained is from food consumption surveys, although calculating accurate estimates for sugars intake for individual populations has proved challenging. One persistent problem is that consumption study participants may not be aware of some of their sugar consumption. Also people are known to underreport their intake, and may particularly underestimate intakes of sugars or sugars-containing foods. In addition, overweight and obese populations show a greater disparity between actual intake and reported intake (13, 14).

Another drawback is that consumption surveys rely on food composition databases to calculate the amount of sugars in each individual food reported as consumed. These calculations frequently overestimate sugars content as they are based on recipe data or food label values rather than chemical analyses. The excess results from not accounting for sugars that are unavailable (not consumed), and due to such processes as the Maillard reaction, caramelization or fermentation (leavening) that occurs during typical cooking or baking (5).

Food intake survey information is primarily obtained from two nationwide monitoring surveys: the Department of Agriculture's *Continuing Survey of Food Intakes by Individuals (CSFII)* and the National Health and Nutrition Examination Survey (NHANES) conducted by the Department of Health and Human Service. In 2002 these two studies were combined into a single, population-based national nutrition survey known as "What We Eat in America—NHANES." An analysis of the recent 2-day NHANES 2003-04 data estimates total sugars intake at 128 g/day, which is close to the ERS loss-adjusted availability data discussed above. This is approximately 24.1% of energy intake but it should be noted that this percentage reflects total sugars from all sources, not just added sugars (15).

Sigman-Grant recommends that accurate and precise measures are essential for scientists, educators, regulators and the public to communicate about the health aspects of sugars consumption (5). To obtain a more accurate picture of intakes of sugars, methods for obtaining both individual intake data and economic availability estimates should be improved and reconciled. This could be accomplished: by 1) improving methods for determining intakes to reduce underreporting, 2) accounting for manufacturing losses and other nonfood and nonalcoholic beverage uses of sugars to reduce overestimation, and 3) measuring the exact sugars content of foods rather than obtaining data from calculations from recipes (5).

Added Sugars

Whether naturally occurring or added to foods, sugars are found in all kinds of food. Once ingested, the body metabolizes naturally occurring and "added" sugars in exactly the same way. The term "added sugars" refers to sugars added to foods in the home kitchen or during commercial food preparation. The 1994-1996 Continuing Survey of Food Intake (CSFII) by Individuals reported that the mean intake of added sugars and sweeteners for Americans two years and older is approximately 82g per day (equivalent to approximately 66 pounds per person per year) or about 16% of energy. Children and adolescents consumed 19% and 20% of energy respectively. Intakes decreased in adulthood, ranging from about 12% to about 18% depending on age and gender (4). According to data from NHANES III (1988 -1994) intakes of energy from added sugars declines with age. The median daily intake of added sugars varies across population groups, ranging from 10 to 30 teaspoons (40 to 120 g/day) (2). Published calculations show the significant difference between disappearance and actual intakes.

Guthrie and Morton analyzed the CSFII data to determine the most prominent food sources of added sweeteners (16). They found that regular soft drinks contributed one-third of the intake of added sweeteners. Sugars/sweets contributed approximately 16% of added sweeteners, followed by sweetened grains (≈13%). Regular fruitades/drinks contributed about 10% of total intake. These four food categories account for approximately 72% of the intake of added sweeteners. It should be noted, however, that recent data from the National Cancer Institute found that all of this consumption combined accounted for only 5.5% of average total caloric intake (NCI data presented to Dietary Guideline Panel 2009).

High Fructose Corn Syrup

Increasing interest in the effects of fructose on nutrition and health has led researchers to examine existing data for consumption trends of fructose. This includes fructose from table sugar as well as from high fructose corn syrup. Utilizing data from the CSFII and NHANES, Duffey and Popkin reported that by 2004, HFCS provided roughly 8% of total energy intake, while total added sugars accounted for 17% of total energy intake (17). Sweetened beverages (soda, fruit drinks) account for the largest proportion of energy from HFCS, but other beverages (sports drinks) and foods (desserts, bread, ready-to-eat-cereals) also contribute to HFCS intake. The researchers conclude that most HFCS-containing foods are consumed as snacks rather than meals. The question of whether substitution of HFCS for sucrose led to an increase in fructose intake has been examined and most researchers now believe that the effect of this change on total fructose intake is minimal (46).

Fructose

Marriott et al. compared fructose intakes from the 1977-1978 Nationwide Food Consumption Survey (NFCS) with data from NHANES 1999-2004 survey (18). Mean daily intakes of both added and total fructose increased in all gender and age groups. However, this increase "was dwarfed by greater increases in total daily energy and carbohydrate intakes." They conclude that "sweetener consumption is only one part of the complex dietary component of trends in overweight." Nonetheless, the metabolic effects of excess fructose consumption continue to be of concern and further research in this area is needed.

Sugars and a Healthful Diet

Dietary Quality and Sugars Intake –

Sugars are a form of the macronutrients that provide calories but are not usually sources of micronutrients. This fact has led to one of the most commonly heard questions about sugars: Does sugars intake negatively affect the nutritional quality of the diet? Current research indicates that the percentage of sugars in the diet does not accurately predict micronutrient intake. This is probably due to the fact that some sugars are components of or used in foods that are good sources of micronutrients. Also, many naturally occurring sugars are found in foods with high nutrient density.

Gibney et al. analyzed data from the 1987-88 USDA Nationwide Food Consumption Survey (CSFII) and found that high consumption of sugars was not associated with a poorer quality diet (19). Further, eating "low" levels of sugars did not necessarily guarantee that an individual's diet met dietary guidelines, nor did "high" sugars consumption mean a diet of poorer quality.

However, in an analysis of the Continuing Survey of Food Intakes by Individuals (1994-96), Bowman found that individuals consuming greater than 18 percent of their total energy from added sugars did not meet the Recommended Daily Allowance (RDA) for many micronutrients (20). Analyzing the same data (CSFII) Forshee and Storey used a different research design that controlled for all possible sources of energy and reached a different conclusion (21). They examined micronutrient nutrient intake in relation to the other macronutrient components of the diet, and found that in many cases the associations between the other components and micronutrient levels were stronger than those observed with added sugars. They also found that the correlation between added sugars and micronutrients was sometimes negative and sometimes positive. For 6-to-11-year-old children, for example, added sugars were negatively correlated with dairy intake, but positively correlated with grains, vitamin C, iron and folate intake. Added sugars were not linked to vegetable, fruit, lean meat, vitamin A or calcium intake among children. Among adolescents, added sugars were negatively correlated with fruit consumption and positively correlated with grains, vitamin C and iron intake.

Using a similar approach to analyze data from the National Health and Nutrition Examination Survey III (NHANES III), Forshee and Storey again reached the conclusion that the association of energy from added sugars with micronutrient intake was inconsistent and small (22). "We conclude that consumption of added sugars has little or no association with diet quality," they wrote.

Using the most recent NHANES data (2003-2006), Marriott, et al. found that intake of added sugars in g/day has not changed substantially and was comparable to CSFII data from the mid-1990s (23). Over 87 percent of the U.S. population had intakes of added sugars between 0 and 25% of total energy intake, which falls within the Institute of Medicine's suggested maximum intake (see below). They also report that intake of nutrients falls with progressive increases in percent of energy from added sugars. However, regardless of added sugars intake, few individuals met recommended nutrient intake.

Some research has found that the effect of sugars on micronutrient intake can depend on the nutritional quality of the sugars-containing foods consumed. Johnson et al. examined the nutritional consequences of sugar-sweetened flavored-milk consumption by school-aged children and adolescents in the United States (24). Flavored milk intake was positively associated with calcium and phosphorus intakes, and children who consumed flavored milk drank more milk and fewer soft drinks and fruit drinks. The researchers concluded that consuming added sugars in nutritious foods such as dairy products may increase intakes of at-risk nutrients such as calcium.

Other studies have reported that individuals who are high consumers of sugar-sweetened beverages have lower intakes of some micronutrients such as calcium and magnesium (25, 26). Frary et al., examined the relationships among nutrient intakes and the major sugars-containing foods and beverages for U.S. children using data from the 1994-1996 CSFII (26). They found that as intakes of sugar-sweetened beverages, sugars and sweets, and sweetened grains (baked goods) increased, the percentage intakes of the Daily Recommended Intake (DRI) for calcium and iron decreased, and saturated fat intakes increased. As the consumption of sweetened dairy products and presweetened cereals increased, the percentage of the DRI for calcium increased. Among adolescents, as intakes of presweetened cereals increased, the percentage intakes of the DRIs for iron and folate increased. The investigators concluded that consumption of sweetened dairy products and presweetened cereals have a positive effect on nutrient intake, whereas the consumption of sugar-sweetened beverages, sugars and sweets, and sweetened grains reduced the intake of key nutrients. Adding sugars to nutritious foods may help increase nutrient intakes, they note, as long as energy needs are not exceeded.

Rennie and Livingstone conducted a systematic review of published studies, attempting to determine whether added sugars intake is associated with micronutrient intakes, and if so, the magnitude and the direction of the associations (27). After analyzing 15 studies the authors found no clear or consistent evidence of micronutrient dilution or a threshold for a quantitative amount of added sugars intake for the micronutrients investigated. Further research was recommended to determine which food products might adversely affect micronutrient intake by displacing other food items from the diet.

In the course of examining the various mechanisms by which sucrose could influence behavior, Benton found that the amount of sucrose in the diet is not related to micronutrient deficiency (28). Micronutrient intake is more closely associated with total energy rather than sucrose intake, he concluded.

In a further review of this topic, Rennie and Livingstone describe the methodological difficulties and conceptual issues that hamper resolution of the micronutrient dilution hypothesis (29). Noting that the increasing complexity of the food supply with respect to carbohydrates makes it more difficult to distinguish between added and naturally occurring sugars, they question whether it is feasible or necessary to make the distinction in light of the fact that sugars are chemically and physiologically indistinguishable. While stating that intervention studies might be the only way to answer the questions that have arisen in this area, the researchers caution that such studies are "very difficult logistically." They conclude: "In the absence of compelling evidence that micronutrient intakes are compromised by a high consumption of added sugars, it may now be appropriate to question the legitimacy of the nutrient dilution hypothesis as it is highly likely that it is oversimplifying more subtle and complex dietary issues."

Some researchers believe that consumption of foods with a high energy density (kcal/g) and a low nutrient density (nutrients/kcal) has the potential to displace needed nutrients in a diet. Others, however, disagree and suggest that the consumption of nutrient rich foods is independent of consumption of high energy density foods. In terms of communicating dietary guidelines to the public, Murphy and Johnson suggest that it might be more effective to advise choosing foods with a high nutrient density rather than focusing on added sugars content as the source of nutrient displacement (30).

Sugar Consumption and Dietary Recommendations –

The *Dietary Guidelines for Americans (DGA)* form the foundation for U.S. nutrition policy. The Guidelines are revised every five years to ensure that they represent state-of-the-art nutrition science. The 2000 edition of the DGA advised Americans to "Choose beverages and foods to moderate your intake of sugars." In contrast, the 2005 DGA departs from previous editions in that it does not include a message specifically directed toward sugars but advises Americans to "Choose carbohydrates wisely for good health" instead. The report of the Dietary Guidelines Advisory Committee states that carbohydrates (sugars and starches) are important energy sources for the body and the preferred energy source for the brain and central nervous system (31). However, it also cautions that "compared with individuals who consume small amounts of foods and beverages that are high in added sugars, those who consume large amounts tend to consume more calories but smaller amounts of vitamins and minerals."

Science policy groups have considered the question of whether there is an upper limit to the amount of sugars an individual should consume. This question is based on concerns that overconsumption of sugars may contribute to caloric excess and/or that sugars may dilute the nutrient density of the diet. Based on available evidence, the Dietary Guidelines Advisory Committee chose not to set a numerical value for sugars consumption, but advised individuals to focus on consuming nutrient dense foods and diets while treating added sugars and fats as "discretionary calories" (31).

The Institute of Medicine's Dietary Reference Intakes (DRI) Report recommends that Americans get the majority of their daily calories from carbohydrates—about 45 to 65 percent of daily calorie intake (2). Children and adults need a minimum of 130 grams of carbohydrates per day for proper brain function. The DRI report reviewed all available evidence on the effects of total and added sugars on chronic disease risk and micronutrient intakes. With respect to chronic disease risk, the report concluded that there was insufficient evidence to set an upper limit for total or added sugars. In its examination of the data regarding sugars and micronutrient intakes, the IOM found that very high and very low intakes of added sugars were associated with lower micronutrient intakes. The report suggested a maximum intake level of 25% or less of energy from added sugars in the total diet based on data showing decreased intake of some micronutrients of some population groups exceeding this level.

A different perspective on consumption is provided by the 2003 independent report of the World Health Organization (WHO) and the Food and Agriculture *Organization (FAO) (32)*. Entitled Diet, Nutrition and the *Prevention of Chronic Diseases*, the report has raised global awareness of the need to focus on the essential role of both diet and physical activity as key determinants of health. While acknowledging that the recommendation is "controversial," the report proposes a goal that "free sugars" (i.e., added sugars) not exceed 10% of total caloric intake. The American Dietetic Association commented on the recommendation, noting: "The strategies used in the panel's deliberations encompass their interpretation of a range of epidemiologic, economic, social, and political impacts on the prevention and control of noncommunicable diseases. Thus, the proposed 10% intake recommendation may not be based solely on scientific evidence." (4)

In a recent statement, the American Heart Association (AHA) recommends limiting added sugars intake to one-half the discretionary calorie allowance suggested in the *Dietary Guidelines for Americans* 2005 (100 calories per day for women, 150 calories per day for men (33). These amounts are less than the 10% of total calories suggested by WHO, which for most women would be about 180 calories and for most men about 250 calories. AHA based its recommendations on some studies that suggest that high intake of dietary sugars may be a contributing factor in the rise of obesity and cardiovascular disease. However, the IOM specifically examined the relationship of BMI and sugar intake and found no consistent relationship. Gaesser (34) examined over 100 studies and concluded: "A review of relevant literature indicates that most epidemiologic studies show an inverse relationship between carbohydrate intake and BMI, even when controlling for potential confounders. "These observational studies are supported by results from a number of dietary intervention studies wherein modest reductions in body weight were observed with an ad libitum, low-fat, high-carbohydrate diet without emphasis on energy restriction or weight loss."

AHA acknowledged that it is "unlikely" that a single food is primarily responsible for obesity, noting that the suggested limits are part of a "multifaceted" approach. "A reduction in added sugars is one means to achieve a reduction in energy density" (33).

A recent review by Ruxton et al, examined health aspects of sugars consumption in the context of dietary guidelines. After reviewing studies on obesity, nutrient adequacy, metabolic syndrome, attention deficit, dementia, and dental caries, the researchers concluded: "Overall, the available evidence did not support a single quantitative sugar guideline covering all health issues." (35) (See further discussion in next column under Sugars and Health.) Given the diverse recommendations on the issue of an upper intake level for added sugars consumption, suggested by several different reputable groups, it is clear that more research in this area is needed. To date, no consensus exists as to what an upper limit for added sugars intake should be, though all groups recommend that less than 25% of total daily calorie intake come from added sugars.

Sugars and Health

Overview –

Sugars have a long history of safe use in foods. They were placed on the Food and Drug Administration's list of foods that are "Generally Recognized as Safe" (GRAS) in 1958. In 1986 Glinsmann et al. conducted an extensive review of all the health aspects of sugars consumption (36). Based on this work, the FDA reaffirmed the GRAS status of sucrose, corn sugar (glucose), corn syrup, invert sugar and high fructose corn syrups (37, 38). Since that time a number of scientists and scientific organizations have kept the science of sugars up to date by evaluating more recent research as it is published.

In 1997 Anderson conducted a literature review concluding that except for their contribution to dental caries, sugars are not the cause of chronic or acute disease (39). The same year a Joint Expert Consultation of the Food and Agriculture Organization (FAO) and the World Health Organization reported on "Carbohydrates in Human Nutrition, finding "no evidence of a direct involvement of sucrose, other sugars and starch in the etiology of lifestyle related diseases" and recommending that consumers avoid overconsumption of sugars (1).

In 2001 Mardis reviewed "Current Knowledge of the Health Effects of Sugar Intake" and reaffirmed the FDA's and Anderson's conclusion that aside from dental caries, sugars are not an independent risk factor in chronic diseases (40).

The Institute of Medicine's 2002 report on Dietary Reference Intakes (commonly referred to as the Macronutrient Report) focused on whether scientific evidence supported setting limits on sugars intake (2). IOM reviewed available research on the effects of sugars on chronic disease risk and concluded that there was insufficient evidence to set an upper intake level for total or added sugars.

In 2002 The Carbohydrates Technical Committee of the International Life Sciences Institute North America (ILSI NA) convened a scientific workshop addressing current scientific issues related to sugars and health. Participants included a group of internationally recognized experts, who reviewed current and emerging scientific research, wrote papers and critiqued the papers of other participants. Summarizing the proceedings, Lineback and Jones observed: "Available data show that there are few health concerns for which a direct association with sugar can be established" (3).

The American Dietetic Association periodically updates and revises its position paper on the use of nutritive and nonnutritive sweeteners. The 2004 version of this paper reaffirmed ADA's "total diet approach" to communicating food and nutrition information, advising dietetics professionals to "communicate science-based messages about recommendations for added sugar intake with the understanding that all foods can fit into healthful diets, even those high in added sugars. For individual recommendations on intakes of added sugars, dietetics professionals should assess food intake within the context of the entire diet and by considering personal health and nutrition goals" (4).

Gastrich et al. reviewed scientific literature from 1986 to 2006 concerning health aspects of sugars in the diets of both children and adults (41). They recommended a variety of additional long-term studies across different age groups, ethnicities and those with chronic diseases to further define the role of sugars in the diets of average and overweight individuals, as well as in people with diabetes and at risk for cardiovascular disease.

An expert workshop convened in 2007, "On the role and fate of sugars in human nutrition and health," reviewed the available evidence behind current intake recommendations for sugars, focusing on the strength and gaps of the scientific evidence available and the identification of those areas where further research is needed (42). A discussion by Arola, et al., noted that much of our information about the role of sugars in nutrition and health comes from observational epidemiological studies that do not establish causality, and in which carbohydrate in the diet may simply be a marker for other factors (43). The researchers emphasized the need for randomized controlled trials of sufficient size and duration to supplement epidemiological data.

Two recent scientific workshops brought researchers together to discuss the role of fructose-containing sweeteners in the diet and to clarify emerging questions related to metabolic effects and obesity.

In 2007, the American Society for Nutrition's Public Information Committee convened a symposium entitled "High Fructose Corn Syrup (HFCS): Everything You Wanted to Know, But Were Afraid to Ask." Symposium research papers were published in a supplement to the *American Journal of Clinical Nutrition.* Summarizing the presentations, Fulgoni stated that "the data presented indicated that HFCS is very similar to sucrose…, and thus, not surprisingly, few metabolic differences were found comparing HFCS and sucrose" (44). Stanhope and Havel cited evidence that "prolonged consumption of diets high in energy from fructose could lead to increased caloric intake or decreased caloric expenditure, thereby contributing to weight gain and obesity" and that fructose consumption increases blood triglyceride levels (45). They recommended long-term studies in a variety of populations to investigate the effects of fructose, sucrose and HFCS on lipid metabolism, glucose tolerance, insulin sensitivity and the development of obesity.

White stressed that HFCS is not meaningfully different in composition or metabolism from other fructose-glucose sweeteners such sucrose, honey, and fruit juice concentrates. He emphasized the dissimilarity between pure fructose and HFCS (46). "Although examples of pure fructose causing metabolic upset at high concentrations abound, especially when fed as the sole carbohydrate source, there is no evidence that the common fructose-glucose sweeteners do the same. Thus, studies using extreme carbohydrate diets may be useful for probing biochemical pathways, but they have no relevance to the human diet or to current consumption." It is important to emphasize that White was looking at studies on the effects of fructose in the absence of glucose and noting that these studies may lead to conclusions that are aberrant as the metabolism of fructose is effected by the presence or absence of glucose.

The Agricultural Research Service of the United States Department of Agriculture (USDA/ARS) and the International Life Sciences Institute of North America (ILSI) convened a roundtable of nutrition and health experts to address "The State of the Science on Dietary Sweeteners Containing Fructose." Research papers from the roundtable were published in a supplement to the *Journal of Nutrition.* In a summary of the presented papers, Murphy stated, "…high fructose corn syrup and sucrose are similar and one is not 'better or worse' than the other" (47). Dr. Murphy noted that "it does not appear to be practical to base dietary guidance on selecting or avoiding these specific types of sweeteners."

Angelopoulos and colleagues noted the lack of research information comparing HFCS with other sweeteners (48). However, they stated, "What little is available suggests that HFCS does not seem to be any more insidious than other caloric sweeteners, but clearly more short-term studies are needed to further substantiate this view."

A detailed analysis entitled "*Is Sugar Consumption Detrimental to Health?*" reviewed literature from 1995 through 2006. Results from high quality obesity studies did not suggest a positive association between body mass index and sugar intake. Consumption of sugars at 6 to 20% of energy intake could support diet adequacy, the authors found. Studies on metabolic syndrome reported no adverse effects of sugar in the long-term. In addition, the researchers concurred with other consensus reports that the amount of sugars consumed is not the primary causative factor in dental caries (35).

Glycemic Index/Glycemic Load –

The concept of a glycemic index (GI) was developed to provide a numerical classification of carbohydrate foods, as researchers believed the information would be useful in the treatment of individuals with impaired glucose tolerance (49). According to Jenkins, the glycemic index concept is an extension of the hypothesis that slowly absorbed, high-fiber foods may have metabolic benefits in relation to diabetes and to the prevention of coronary heart disease (CHD) risk (50).

Simply stated, the GI is a measure of the rise in blood glucose induced by the consumption of a carbohydrate. It is assessed under laboratory conditions, by having a group of people eat a specific amount of a single food (usually 50 grams of digestible carbohydrate, i.e., total carbohydrate minus fiber) and then measuring the change in blood sugar levels compared with the levels achieved after they have eaten a control food (usually glucose or white bread) containing the same amount of digestible carbohydrate. Glycemic load (GL) is a related concept that indicates glucose response or insulin demand produced by total carbohydrate intake. Thus it describes the quality (GI) and quantity of carbohydrate in a meal or diet. GL is calculated by multiplying the grams of carbohydrate in a serving of food by that food's glycemic index.

Using GI/GL in the prevention and treatment of disease has been controversial, as existing studies have produced inconsistent results, probably due in part to inadequate tools to accurately determine these dietary components (31). Many factors affect the consistency and reproducibility of GI calculations, such as the ripeness of fruit, the physical form of the food, its temperature, its processing and preparation (51). Also, the GI of a food depends on whether it is eaten alone or consumed with other foods. Since the determination of GL depends on the GI calculation, similar uncertainties apply to its utilization.

A recent study by Vega-López and colleagues sought to assess the reproducibility of glycemic index values for white bread (52). In three test runs healthy adults were given 50 g of commercial white bread, and blood glucose responses were measured. The researchers found that inter-individual (between subject) responses varied by 17.8%, and intra-individual variation was 42.8%. The findings suggest that more information is needed about the reliability of the glycemic index before health recommendations are based on this measure.

GI has become the basis of a number of popular weight loss plans, its popularity fueled by claims that low GI foods can help control appetite and weight, and may be useful to diabetic individuals. These claims are based on the theory that high GI foods raise blood sugar levels, cause excess insulin to be secreted, and lead to the storage of fat (53). In a recent study, Lau, et al. concluded that habitual intake of diets with a high glycemic index and high glycemic load or diets with a high content of total carbohydrate including simple sugars was not associated with the probability of having insulin resistance (54). Van Baak and Astrup found some evidence that lower GL diets may result in lower body weight, but stated that "the effect is likely to be small" (55).

Proponents of GI recommend that low GI foods be emphasized in the dietary management of diabetes as a method of optimizing blood glucose control. The Canadian Diabetes Association advises that "the Glycemic Index (GI) is a useful concept for the management of blood glucose in those affected by diabetes" (56). Diabetes Australia, in conjunction with the University of Sydney and the Juvenile Diabetes Research Foundation, endorsed a program that would label food with its GI value, provided the food meets specified nutritional criteria, and the GI testing is performed by an approved laboratory (57). A position statement from the American Diabetes Association concluded that "there is not sufficient, consistent information to conclude that low-glycemic load diets reduce the risk for diabetes" (9). However, they advise that "The use of glycemic index and load may provide a modest additional benefit over that observed when total carbohydrate is considered alone."

Those experts who support the clinical utility of the glycemic index caution that it should not be the only criterion by which to judge a food (58). Other factors to consider include a food's fat content and nutrient density. When discussing glycemic index it is also important to consider that sugars are moderate to low in both GI and glycemic load. Also, they have a lower GI than do many starchy or starch-containing foods (3).

As an alternative to the glycemic index, Segal and colleagues propose the use of a fructose index (FI) to categorize foods (59). FI is defined as the percentage of energy of a food item derived from fructose, and the fructose load (FL) is the amount of fructose present in a single serving. They hypothesize that eating foods that induce insulin resistance increases risk for obesity and cardiovascular disease, as opposed to eating foods that stimulate insulin secretion. Evidence-based trials to test this hypothesis are suggested.

Several professional groups in the U.S. advise caution and further research before supporting the use of GI to make dietary recommendations for the general population or for the prevention and treatment of disease (60, 61). The American Dietetic Association advises: "There is insufficient research to show that the GI of a food or a meal has any effect on weight loss or gain" (62). In the U.S., prevailing nutrition wisdom is represented by the 2005 Report of the Dietary Guidelines Advisory Committee which states, "Current evidence suggests that the glycemic index and/or glycemic load are of little utility for providing dietary guidance for Americans" (31).

Diabetes –

The prevalence of diabetes in the United States has been increasing over time, according to an analysis of data from the 2005-2006 National Health and Nutrition Examination Survey (63). Cowie, et.al., reported that 13 percent of adults age 30 and older have diabetes, but 40 percent of them have not been diagnosed. According to the National Institute of Diabetes and Digestive and Kidney Diseases, the risk factors for diabetes include being overweight or obese, genetics, ethnicity, inactivity, family history, and having had gestational diabetes.

There is general agreement among the scientific community that total sugars intake is not associated with the development of type 2 diabetes (2, 31). This is confirmed by recent prospective studies (64, 65) including one that shows a negative association between sucrose intake and diabetes risk (66).

Manders compared the effects of consumption of sucrose-containing beverages on lean and obese diabetic and non-diabetic men (67). He found that moderate consumption (approximately two cans per day) did not further increase the prevalence of hyperglycemia in type 2 diabetic subjects or in normoglycemic lean or obese men.

Research has identified many lifestyle and dietary risk factors that contribute to the development of type 2 diabetes. Obesity has long been recognized as one of the most significant risk factors for this disease. A sedentary lifestyle is also considered a risk factor with increased physical activity providing a measure of protection (68).

The introduction of the glycemic index in 1981(49) stimulated a number of studies examining the body's blood glucose response to different carbohydrates and the implications for diabetic meal planning. Glycemic index research established that sugars do not increase plasma glucose concentrations to a greater extent than do isocaloric amounts of dietary starch. This finding led to the relaxation of previous restrictions and to the current recommendation that moderate amounts of sugars can be safely incorporated in diets for diabetic individuals.

A number of researchers now believe, and some studies indicate, that people who consume diets with a high glycemic index or glycemic load may be more likely to develop type 2 diabetes than those at lower levels (59, 69, 70). However, two recent large prospective studies found no relationship between dietary glycemic index or glycemic load and risk of developing diabetes (66, 71).

Researchers have continued to explore the idea that glycemic index and glycemic load may be useful tools for measuring diabetes risk. Results from two large prospective studies, the Nurses' Health Study (70, 72) and the Health Professionals' Follow-Up Study (69), showed a positive association between dietary glycemic index and diabetes risk. However, results from the Iowa Women's Health Study (66) did not show a consistent association between the glycemic index and diabetes risk. The American Diabetes Association notes that current information is neither sufficient nor consistent enough to conclude that low-glycemic load diets reduce risk for diabetes (9).

A further analysis of the Nurse's Health Study found that women who changed their consumption of sugar sweetened beverages from a very low level (less than one per week) to a very high level (more than one a day) over time had a greater magnitude of weight gain and a higher risk of developing type 2 diabetes compared to women who consistently consumed few sugar-sweetened drinks (73). The results seem to suggest that dramatically increasing the intake of sugar-sweetened beverages over time may indirectly increase diabetes risk by providing excess calories, thereby contributing to obesity, which increases risk for the disease. However, the researchers also state that increasing the intake of sugars-containing beverages could increase the glycemic load of the diet which may also increase diabetes risk. Since the preponderance of evidence shows that total sugars intake is not related to diabetes risk, it is clear that more research is needed to put these findings into perspective. Additionally, women in this study who consumed the highest levels of sugar-sweetened beverages tended to be physically less active, smoked more, had higher daily caloric intake and lower intake of protein, alcohol and cereal fiber compared to women in the study who drank sugared soft-drinks at a low level (one drink or less per week).

Laville and Nazare reviewed a variety of studies (intervention, prospective, cross-sectional) on the relationship between sugars, insulin resistance and diabetes (74). The studies failed to demonstrate an obvious relationship between simple carbohydrate intake and glycemic control or diabetes risk. With regard to fructose, the authors noted existing discrepancies among studies' conclusions about its long-term effect on diabetes development.

Although fructose produces a lower postprandial glucose response than sucrose, the American Diabetes Association does not recommend the use of added fructose as a sweetening agent in the diabetic diet due to evidence that fructose may adversely affect plasma lipids (9). Bantle noted that fructose ingestion results in lower circulating insulin and leptin, which might inhibit appetite less than other carbohydrates and lead to increased energy intake (75). However, he added that there is not yet any convincing experimental evidence that dietary fructose actually increases energy intake.

A further concern about fructose is experimental evidence indicating that it reacts with protein molecules to form advanced glycation end-products (AGEs), which may accelerate the aging process and contribute to complications of diabetes (76). Schalkwijk noted that although direct evidence is not available, it is likely that fructose, as a highly reactive sugar in the Maillard reaction, promotes the formation of AGEs to a greater extent than other reducing sugars (e.g., glucose and lactose) (77). However, a review of fructose and metabolic syndrome and diabetes by Bantle found no evidence that fructose accelerates protein glycation (78).

White highlighted the similarities between sucrose and high fructose corn syrup and addressed misconceptions about HFCS (46). HFCS is not a unique and important contributor of RDC (reactive dicarbonyl compounds) and AGE to foods and beverages, he stated. These compounds are produced from many simple sugars and are formed in common foods and beverages. Further, they are continually produced in human metabolism.

With respect to the role of sugars in the nutritional management of diabetes, consensus recommendations do not support the widespread use of the glycemic index (79). The American Diabetes Association recommends a balanced diet that includes carbohydrate from fruits, vegetables, whole grains, legumes and low-fat milk. Monitoring carbohydrate is a key element of glycemic control and sucrose-containing foods can be substituted for other carbohydrates in the meal plan. Excess energy intake should be avoided (9).

Given their important taste contribution, sugars in the diets of persons who must restrict fat intake, such as people with diabetes, may offer important benefits in terms of satisfaction with and ultimate adherence to prescribed diets.

Obesity –

It is well accepted that increases in body weight and body fat content occur only when energy intake exceeds energy expenditure. Behind this simple statement is the inescapable fact that obesity is a complex condition with multiple causes, with research providing only partial answers to the obesity puzzle. Increasing prevalence in the United States and other developed countries has led to examination and reexamination of possible dietary habits that may contribute to obesity.

As sugars are ingredients in many favorite foods it may be natural to suspect that they have a role in contributing to overconsumption and increased body weight. However, many epidemiologic studies find a surprising but clear inverse relation between sucrose intake and body weight or body mass index, as well as sucrose intake and total fat intake (80, 81, 82). These studies found that body weight and BMI decrease as the percent of sugar in the diet increases. The Institute of Medicine found "no clear and consistent association between increased intake of added sugars and body mass index (BMI)." In fact, it was noted that higher intakes of total or added sugars are actually associated with a lower incidence of obesity (2). The report states that "a negative correlation between total sugar intake and BMI has been consistently reported for children and adults," and "a negative correlation between added sugar intake and BMI has been observed."

Further, high sucrose diets are not incompatible with weight loss. In one study, 42 women consumed identical low-fat, low-calorie diets except one diet was high in sugar (43% of total daily energy intake) and one was high in complex carbohydrates. The two groups showed no difference in weight loss, mood, concentration levels or hunger. Both groups exhibited an equal decrease in blood pressure, percentage of body fat, resting energy expenditure, stress hormone levels, thyroid hormones and plasma lipids (83).

Benton examined the hypothesis that an addiction to sucrose could play a role in obesity and eating disorders. Epidemiologic data show that "although high intake of dietary fat is positively associated with indexes of obesity, high intake of sugar is negatively associated with indexes of obesity." After examining and comparing data from animal and human studies, he concluded: "There is no support from the human literature for the hypothesis that sucrose may be physically addictive or that addiction to sugar plays a role in eating disorders (84)."

Scientists have also studied the effect of sugars on total food intake, finding that under laboratory conditions, sucrose contributes to satiety and reduces subsequent food intake (85, 86). Anderson reported that food intake is reduced when 50 g sucrose is ingested in drinks 20 to 60 minutes before a meal. Larger amounts prolong satiety as expected (85). The literature does not address the effects of corn syrups or of high fructose corn syrup (HFCS) on satiety, but since HFCS is similar in composition to sucrose, Anderson noted: "It seems unlikely that there would be a difference in satiety between a beverage containing sucrose and one containing high-fructose corn syrup."

Evidence available to date continues to show no direct connection between sugars intake and obesity (4). Nevertheless, nutrition researchers have continued investigating whether sugars might have a role in obesity apart from an indirect contribution as a source of calories. Various possibilities for a connection between sugar intake and obesity have been proposed.

Obesity and Insulin Resistance –

McMillan-Price and Brand-Miller propose that insulin resistance is more prevalent now than in the past, and that reducing the glycemic index (GI) of the carbohydrate portion of the diet would aid fat loss by promoting higher satiety, higher metabolic rate and increased fat oxidation (87). Sloth and Astrup respond that the evidence is insufficient to establish that a low GI diet is more effective than traditional weight loss plans (88). Since it is difficult to distinguish the effects of GI from other factors that influence satiety, they suggest that future studies focus on individual food factors, such as the effects of whole grains, fiber, energy density and preparation methods.

Coulston and Johnson note that insulin resistance is a genetic trait characterized by an impaired biological response to insulin (89). Although, many older children and adults who are overweight or obese have insulin resistance, the notion that insulin resistance leads to obesity is unfounded, they state. People with insulin resistance "live a perfectly healthy life unless they overeat and markedly decrease their physical activity."

Satiety: Liquids vs. Solids –

Some researchers have speculated that the body may respond differently to calories depending upon whether they are consumed in liquid or in solid form. In a prospective study of 548 schoolchildren, Ludwig et al. examined the association between baseline and the change in consumption of sugar-sweetened drinks, finding that for each additional serving of sugar-sweetened drink consumed, both body mass index (BMI) and frequency of obesity increased (90). Bray and colleagues proposed that the increased intake of soft drinks and other beverages sweetened with HFCS was at least partially responsible for the current epidemic of obesity (91). Researchers at the Harvard School of Public Health reviewed more than 30 studies conducted between 1966 and 2005 and found a positive association between greater intakes of sugar-sweetened beverages and weight gain and obesity in both children and adults. (92). Authors of these studies acknowledged the multifactorial nature of obesity and that their study results do not establish causality.

Several other studies have produced different results. Forshee and colleagues used data from the third National Health and Nutrition Examination Survey to examine the relative importance of demographics, beverage consumption, physical activity, and sedentary behavior for maintaining a healthy body weight (93, 94). No statistical association between consumption of sugar-sweetened beverages and fruit drinks and BMI was found. Television viewing was positively associated with BMI, while participation in sports demonstrated a negative association.

In addition, in the largest study to date Janssen et al looked at over 120,000 children in 34 countries and found no association between sugar-sweetened beverage consumption and obesity levels (95). A further quantitative meta-analysis and qualitative review of longitudinal and randomized controlled trials (RCTs) found the association between sweetened beverage consumption and BMI to be near zero (96). Research by Sun and Empie also found that frequent consumers of sweetened soft drinks had similar obesity percentages compared to infrequent users (97). The study found higher obesity rates were related to other factors, such as television and computer screen watching time and high-fat diets. A research review by van Baak and Astrup concludes that while observational studies suggest a possible relationship between consumption of sweetened beverages and body weight, there is currently insufficient supporting evidence from randomized controlled trials (55).

A basic question is whether there is a plausible physiological mechanism to explain the suggested hypothetical difference between calories from liquid sources and calories from solid foods. Some investigators hypothesize that liquids may not trigger physiological satiety mechanisms, so the body does not compensate completely for liquid calorie intake. Almiron-Roig and colleagues found that some studies reported that liquids are less satiating than solids, while other studies found solids to be less satiating than liquids (98). Drewnowski reviewed a variety of studies and concluded that "the notion that liquid calories are not perceived by the body rests on inconclusive evidence" (99). In particular, he cited a number of studies showing that sugar-sweetened beverages used as meal replacements in calorie-controlled diets are effective weight-loss tools, and, therefore, claims that liquids have particular obesity-inducing properties are unfounded. Anderson agreed, noting that "the associations between sugars-sweetened beverages and obesity must be viewed as circumstantial because biological plausibility, based on known physiologic mechanisms regulating food intake and energy balance, and short-term experimental studies, does not support cause and effect conclusions" (100).

Moran reviewed research on the impact of fructose-containing sweeteners on feelings of satiety (101). Results depended on a variety of factors ranging from how the sweeteners were administered to the timing of hunger measurements. "On balance, the case for fructose being less satiating than glucose or HFCS being less satiating than sucrose is not compelling," he concluded. Melanson et al., state that while excessive consumption of pure fructose may be problematic to energy intake regulation, HFCS is more similar to sucrose than it is to fructose (102). Therefore, short-term studies show no significant differences in appetite and energy intake when HFCS is compared with sucrose.

A review by Dolan et al, found no convincing evidence that ingestion of up to approximately 100 g/day fructose (the highest level of intake used in studies designed to assess the effect of fructose on blood lipids) instead of glucose or sucrose is associated with an increase in food intake or body weight (103).

Sweetened Beverages –

Using dietary recall data from the 2003-2004 NHANES survey, Wang and colleagues examined the impact of sweetened beverage consumption on calorie intake by estimating the amount of kilocalories that could be replaced by drinking water (104). They predicted that a significant reduction in total energy intake would occur that would not be offset by a compensatory increase in food or beverage consumption.

Bleich and colleagues examined trends in sugar-sweetened beverage consumption by age, race/ethnicity and weight loss intention and found higher sugar-sweetened beverage consumption among populations at greater risk for obesity and type 2 diabetes (105).

According to Bremer, et al. high levels of sugar-sweetened beverage consumption and low levels of physical activity are two lifestyle behaviors associated with obesity, insulin resistance, and metabolic syndrome (106). Analyzing NHANES data for a nationally representative sample of US adolescents, the researchers found that low sugar-sweetened beverage intake and high physical activity levels had the effect of decreasing insulin resistance and triglyceride concentrations and increasing high-density lipoprotein cholesterol concentrations. They called for prospective studies of how dietary modifications and exercise patterns may affect the health of pediatric populations.

Bachman and colleagues reviewed several mechanisms that could explain the possible association between sugar-sweetened beverages and obesity, including satiety issues (107). "Assessing the contributions of one food group (e.g., sweetened beverages) to obesity is a difficult task, because energy balance is likely a function of total caloric intake and total caloric expenditure," they wrote. A number of areas for further research were suggested. Pereira dubbed the evidence to date "equivocal" and called for more high-quality randomized trials on this topic (108).

Other theories relating sugar-sweetened beverages to obesity have to do with the composition of high fructose corn syrup, the most prevalent sweetener found in soft drinks and other beverage products. Noting that the rise in obesity has paralleled the increased use of high fructose corn syrup in beverages and other processed foods, some studies hypothesize that it is the increasing consumption of fructose that is at least partly responsible for the current obesity epidemic (91). These studies posit that fructose is a less satiating sweetener than sucrose (91, 109).

To study this question Akhavan and Anderson compared the effects on appetite and satiety of a variety of sugar solutions in 31 subjects (110). They found no significant differences among three test solutions (sucrose; HFCS; 50%glucose/50%fructose) in effects on satiety. Similarly, Monsivais and colleagues compared the effects on appetite suppression of various beverages and found no difference between sugar-sweetened cola, HFCS-sweetened cola and 1% milk (111).

In a recent study Soenen and Westerterp-Plantenga compared the satiating effects of HFCS and sucrose with milk (112). They found that the energy balance consequences of HFCS-sweetened soft drinks are not different from those of other isoenergetic drinks.

Bantle noted that "although increasing fructose consumption is temporally associated with the increasing worldwide prevalence of obesity, there is little or no evidence proving cause and effect" (78). Several experts have pointed out that it is important to consider that fructose and HFCS are different sweeteners, and that despite its name, HFCS is not high in fructose. Akhavan and Anderson note that "HFCS is a nutritive sweetener containing an unbound form of the same monosaccharides as sucrose (sugar)" (110). In another study comparing the metabolic effects of sucrose and HFCS, Melanson found that "when fructose is consumed in the form of HFCS, the measured metabolic responses do not differ from sucrose in lean women" (113).

Forshee et al. also point out that HFCS and sucrose have similar monosaccharide compositions and sweetness values (114). In an extensive literature review plus original analysis, the researchers found that the ratio of fructose to glucose in the U.S. food supply has not changed appreciably. "It is unclear why HFCS would affect satiety or absorption and metabolism of fructose any differently than would sucrose." HFCS does not contribute to overweight and obesity any differently than do other energy sources, they concluded. However, the group noted the absence of studies on whether HFCS is metabolized differently than sucrose, and they recommended future research in this and several other areas.

After studying current research, the American Medical Association (AMA) issued a policy statement concluding that "high fructose corn syrup does not appear to contribute more to obesity than other caloric sweeteners" (115). AMA called for further independent research on the health effects of HFCS and other sweeteners.

This reinforces a conclusion highlighted in the Sugars & Health section of this paper that "…high fructose corn syrup and sucrose are similar and one is not 'better or worse' than the other" (30).

Citing recent studies, Anderson made the case for putting the HFCS-obesity theory to rest (116). He noted the "multidimensional determinants of obesity," and the generally accepted fact that neither sugars nor carbohydrate consumption has been clearly delineated as a direct cause of obesity. "A food solution to obesity remains elusive," he wrote, "but a reductionist approach that focuses on one food...is unlikely to succeed."

The continuing concern about obesity as a major public health issue was highlighted by the report of the American Institute for Cancer Research and the World Cancer Research Foundation—*Food, Nutrition, Physical Activity and the Prevention of Cancer: A Global Perspective* (117). The report found that excess weight and obesity can increase the risk for several types of cancers and recommended that consumers limit their intake of energy-dense foods including sugar-sweetened beverages.

Cardiovascular Health –

Intake of carbohydrates, including sugars, is not considered an independent risk factor in the etiology of cardiovascular disease (2). Dietary advice to help reduce heart disease risk generally focuses on controlling the amount and types of fats in the diet, since certain fats increase LDL cholesterol in the blood. However, replacing dietary fat with carbohydrates may result in an increase in blood triglyceride levels, a phenomenon known as carbohydrate-induced hypertriglyceridemia (118). Short term studies indicate that diets high in carbohydrates (60% of energy), particularly sugars (>20% of energy), increase serum triglyceride levels and decrease serum HDL cholesterol. However, longer term studies show that the hypertriglyceridemic effects of high-sugar, high-carbohydrate diets may dissipate with time (119, 120). Also, diets that meet recommendations for fiber, saturated fat, and unsaturated fat lessen the effect of sugars on triglycerides (121).

Nordmann pointed out that choosing between a low-fat diet and a low-carbohydrate diet involves weighing potential favorable changes in triglyceride and HDL cholesterol against potential unfavorable changes in LDL cholesterol (122). Parks notes that it is difficult to predict whether carbohydrate induced hypertriglyceridemia will have negative health consequences because of the concurrent reduction in low-density lipoprotein cholesterol concentration (118).

Researchers have identified factors, such as abdominal obesity and insulin resistance, which exacerbate the effects of sugars on triglycerides. Increased physical activity and weight reduction can improve insulin resistance and minimize the tendency of high-carbohydrate diets to boost triglyceride (119, 123, 124, 125).

McCarty suggests that the increased coronary risk associated with elevated triglycerides in Western epidemiology reflects the fact that high triglycerides are a marker for insulin resistance syndrome, rather than any inherent pathogenic role of triglycerides per se (124). Thus, attention has been focused on metabolic syndrome as a risk factor for cardiovascular and other diseases. Triglyceride levels are more likely to increase in obese individuals with metabolic syndrome who consume a high sugars diet (29-34% of energy) (119). However, studies indicate that modest weight loss coupled with a shift to a diet rich in fruits, vegetables, and whole grains prevents a rise in triglyceride levels even when diets are high in sugars (119, 121).

Gao et al. analyzed data from the *National Health and Nutrition Examination Survey 2001-2002* to examine the relationship between the intakes of added sugars and sugar-sweetened beverages and serum uric acid concentrations (126). They found that higher intakes of added sugars or sugar-sweetened drinks were associated with higher serum uric acid concentrations in men but not in women. Hyperuricemia might have a causal role in metabolic syndrome, hypertension, and other chronic disease, they noted, and suggested further research to clarify these associations and the observed difference by gender.

Fung et al. analyzed data from the Nurses' Health Study to prospectively examine consumption of sugar-sweetened beverages and the risk of coronary heart disease (127). They found an association between regular consumption of sugar-sweetened beverages and a higher risk of coronary heart disease in women.

Fructose-

It is generally agreed that long term clinical studies are needed to clarify the relationships among carbohydrates and sugars intake and triglycerides. Recently, research has focused on the possibility that the changing consumption of fructose might be affecting the cardiovascular health of Americans. Bray suggested that increasing fructose consumption in recent years may be related to the obesity problem in the U.S., and may also be a potential risk factor for cardiovascular disease (128). Fructose is metabolized in the liver, in a metabolic pathway that can lead to an increase in serum triglycerides.

Aeberli and colleagues investigated whether dietary fructose was associated with LDL-particle size in 74 Swiss children aged 6-14 years old (129). Compared with the normal weight group, the overweight children had significantly higher plasma triglyceride concentrations, lower HDL-cholesterol levels and smaller LDL-particles, which may be a risk factor for atherosclerosis. According to the authors' summary, although there were no significant differences in total fructose intake, the overweight children consumed a far higher percentage of fructose from sweets and sweetened drinks than did the normal weight children.

Lê and Tappy compared animal and human studies with respect to the metabolic aspects of fructose (130). In rodents, consuming large amounts of fructose can lead to metabolic syndrome. The researchers found that in humans, fructose consumption increases blood triglycerides in the short term but does not cause muscle insulin resistance. Further human studies were recommended to delineate the effects of fructose in humans.

Stanhope and Havel conducted a study in which feeding very high levels of fructose caused an increase in blood triglycerides compared with glucose (131). Results from this and another study by Stanhope et al. also indicated that a high fructose diet decreased insulin sensitivity (132). Jones commented that such studies "are important to understand the effects of extremes in dietary consumption, but studies that reflect what is commonly consumed are needed to understand the impact of its use" (133).

Teff and colleagues compared the effects of glucose- and fructose-sweetened beverages on 17 obese men and women, finding that triglyceride levels increased in all subjects (134). However, consumption of the fructose-sweetened beverages resulted in a total amount of triglycerides almost 200 per cent higher over a 24-hour period than consumption of the glucose-sweetened beverages. The study used pure fructose, which is not typically used alone as a sweetener. The researchers conclude: "Additional short-term and long-term dose-response studies in both metabolically normal and "at risk" subjects will be required to determine the amounts of dietary fructose that have adverse effects on lipid metabolism in different populations."

In a comprehensive review Schaefer found that many studies showed no difference in lipid metabolism in either diabetic or normal subjects when comparing glucose or sucrose to fructose (135). However, in studies where subjects consumed the highest levels of fructose, triglycerides were adversely affected, highlighting the need for further studies of dietary fructose at customary levels.

Reviewing studies on the dose effects of fructose, Livesy found that the balance of beneficial and adverse metabolic effects of fructose is "difficult to assess" (136). The effects of consuming very high levels of fructose (>100 g/d) can be very different and may be diametrically opposite to effects produced by low (<50 g/d) or moderate (50 to 100 g/d) consumption.

According to Dolan et al., a possible reason for inconsistent study results on the effects of fructose on triglycerides is that they are dependent on study population, study design, and/or the amount of fructose administered. The results of their critical evaluation of existing evidence indicate that "fructose does not cause biologically relevant changes in TG (triglycerides) or body weight when consumed at levels approaching 95th percentile estimates of intake (103).

Dental Health –

Tooth decay or dental caries is an infectious disease that is a common cause of poor dental health, especially in children (137). The causes of dental caries are complex and multifactorial. Some of the factors that play a role in caries etiology include: nutritional status, oral hygiene, fluoride exposure, dietary habits, heredity, socioeconomic status, general health and use of medications (137, 138).

Although many people associate sugars with dental caries, all fermentable carbohydrates, including cooked starches and sugars in fruits, can promote cavity formation (139).

The cavity-producing process starts when food or drinks are ingested and plaque bacteria metabolize the carbohydrate component to form organic acids. These acids lower the pH of the plaque, which can dissolve tooth structure and enamel – leading to tooth decay. Thus, all carbohydrate food residues have caries-promoting properties. However, many factors influence this process including the form of the food, the duration of exposure, nutrient composition, sequence of eating, salivary flow, presence of buffers, and oral hygiene (137).

Researchers have identified two key indicators of cariogenic potential – the form of the food (i.e., sticky to the teeth) and the frequency of consumption. The longer a cariogenic substance remains in the oral cavity, the greater the probability of extended acid production and demineralization (31). Foods that adhere to the teeth or between the teeth prolong exposure and increase the risk of tooth decay (140). Frequent consumption of fermentable carbohydrate foods, particularly between meals, also can promote caries production. Sugars and starches are less cariogenic when they are ingested as part of a meal rather than eaten continuously throughout the day. The caries risk of foods may be modified by combining cariogenic foods with dairy products that may reduce the acidogenic effect and promote remineralization (137). In a recent systematic research review Burt and Pai concluded that controlling sugars consumption plays a role in caries prevention, but with the advent of extensive fluoride exposure, it is not the most important aspect (141). Also, an investigation by Gibson and Williams concluded that regular tooth brushing with a fluoride toothpaste may have a greater impact on caries in young children than does restricting sweetened foods (142).

Anderson and colleagues reviewed 31 studies published from 1856 to 2007 to assess the relationship between quantity and pattern of sucrose use and dental caries (143). The analysis showed no reliable relationship between quantity of sugar consumption and dental caries, but a significant relationship of frequency of use of sugars to dental caries was reported in 19 of the 31 papers considered.

The Institute of Medicine recently concluded, therefore, that "it is not possible to determine an intake level of sugars at which increased risk of dental caries can occur" (2). For this reason dental researchers recommend that programs aimed at preventing tooth decay focus on factors other than sugars intake (139).

Tooth decay has declined markedly in the United States over the past 30 years. Researchers credit the widespread use of fluoride in public water supplies, in toothpaste and in professional dental products, the use of sealants, as well as improved oral hygiene and increased access to dental care (144). However, for youths aged 2 to 5 years, the incidence of dental caries in primary teeth has increased (145). The reported increase may be due in part to increased consumption of non-fluoridated bottled water.

According to Touger-Decker and van Loveren, it is not feasible to consume a diet free of naturally occurring sugars and fermentable carbohydrates, and it would be difficult to achieve and maintain a diet free of added sugars (137). Therefore, moderate use of added sugars and sweets is recommended in accordance with the U.S. Dietary Guidelines for Americans.

The relationship between sugars consumption and dental health remains an area of continuing interest for researchers who cite the lack of well designed clinical studies regarding effective prevention (146). Other suggested areas of research include: study of the intake of sugars and fermentable carbohydrates by different populations and age groups (147) and determining how to improve caries prevention in high-risk populations, such as the poor and racial and ethnic minorities (141).

Sugars, Mental Performance and Behavior

The brain is the only carbohydrate-dependent organ in the body. The central nervous system (i.e., the brain) contains cells that have an absolute requirement for glucose as an oxidizable fuel (2). Estimate of glucose utilization by the brain is the primary determinant for the Estimated Average Requirement (EAR) calculated by the Institute of Medicine.

Research has found that our liking for sweets has a genetic component (148). Studies examining facial expressions of infants show that there is an innate preference for sweet and salty and a dislike for bitter and sour tastes (149). This preference provides an evolutionary advantage because sweetness often predicts a source of energy, whereas bitterness predicts toxicity. Several studies have shown that sucrose exerts a calming effect on crying infants (150, 151). However, finding that aspartame had a similar effect, one researcher suggests that subjects are responding to sweetness itself rather than to sucrose or carbohydrate (152).

Reed and McDaniel pointed out that although the "sweet tooth" is universal, the perception of sweetness can differ greatly across individuals and groups and varies even in the same individual over time (153). Overall, sugars are consumed because of pleasant taste, ease of digestion and positive effect on mood, they noted, and each factor makes a contribution to overall behavior. According to Levine et al., sugars ingestion induces neurochemical changes in areas of the brain that are involved in reward and energy (154). The effects on reward pathways merit further study, they stated, as they may have implications for the prediction and treatment of substance abuse. It will also be important to determine whether the relationship between sugars and reward is unique to sugars or whether it applies to all highly palatable diets.

It is generally accepted by the medical and scientific communities that sugars consumption is not responsible for adversely affecting childhood behavior (2). Wolraich et al. conducted a meta-analysis of 23 studies performed over a 12-year period and concluded that sugar intake does not affect behavior in children (155). A recent review concurred, noting that overall, the literature suggests that good regular dietary habits are the best way to ensure optimal mental and behavioral performance. It remains controversial, the author stated, whether dietary manipulations can produce additional benefits (156). After analyzing 109 published studies on the subject, Benton found no evidence that sucrose has an adverse influence on the behavior of children (28).

Research supports a link between sugars consumption and cognitive ability. Studies have found that, in some circumstances, intake of sugars can boost performance on cognitive tasks from infants to the elderly (149, 156, 157, 158, 159) as well as in people with Alzheimer's disease (160) and Down syndrome (161).

Busch, et al. found that an afternoon confectionery snack enhanced the ability of boys to stay on task for an extended period of time (157). Kaplan and colleagues note that a wide range of studies have shown that a glucose drink enhances cognitive performance in both healthy subjects and in subjects with memory deficits (158). According to Bellisle, the beneficial cognitive effects of a glucose load are particularly obvious in persons with some level of mental disability, such as patients with Alzheimer's disease (156).

Sünram-Lea and colleagues measured the effect of glucose on verbal and non-verbal memory in young adults. They found that glucose significantly enhanced long-term verbal and long-term spatial memory (159).

The mechanism by which glucose enhances memory is poorly understood according to Benton and Nabb (162). They suggest that future research should consider the possible effect of the glycemic index of carbohydrates on memory since low-glycemic index foods are known to improve glucose tolerance.

Sugars and Physical Performance

As carbohydrates, sugars are the preferred metabolic fuel for high-intensity exercise. Sports nutritionists recommend that athletes maintain body stores of carbohydrate or glycogen by consuming adequate amounts of carbohydrate before and immediately after exercise (163). Adequate dietary carbohydrate supports physical activity by building glycogen stores in the muscles and liver. In addition, a regular intake of carbohydrate during prolonged activity prevents fatigue, by providing fuel directly to the brain and working muscles, sparing muscle and liver glycogen (164).

A key goal of pre-exercise nutritional strategies is to maximize carbohydrate stores, thereby minimizing the detrimental effects of carbohydrate depletion. Increased dietary carbohydrate intake in the days before competition increases muscle glycogen levels and enhances exercise performance in endurance events lasting 90 minutes or more. Ingestion of carbohydrate 3-4 hours before exercise increases liver and muscle glycogen and enhances subsequent endurance exercise performance (165).

Carbohydrates are important during prolonged or sustained exercise to maintain blood-glucose levels and to replace muscle glycogen. Recommendations for athletes range from 6 to 10 g/kg body weight per day, with the amount depending on the athlete's total daily energy expenditure, type of sport performed, sex of the athlete, and environmental conditions (166).

Adequate carbohydrate consumption immediately after exercise enables multiple activities in a single day and renews carbohydrate stores on a daily basis. If an athlete is glycogen-depleted after exercise, a carbohydrate intake of 1.5 g/kg body weight during the first 30 minutes and again every 2 hours for 4 to 6 hours will be adequate to replace glycogen (166).

The American College of Sports Medicine stresses the importance of hydration for athletes, stating that sports beverages containing carbohydrates and electrolytes may be consumed before, during, and after exercise to help maintain blood glucose concentration, provide fuel for muscles, and decrease risk of dehydration and hyponatremia (167). During exercise, the body uses 30 to 60 g of CHOs per hour that need to be replaced to maintain carbohydrate oxidation and delay the onset of glycogen depletion fatigue, according to the National Athletic Trainers' Association (NATA) (168). The ideal fluid replacement solution should contain 6% to 8% carbohydrates as simple sugars (glucose or sucrose in simple polymer form), NATA stated.

In a study of high-intensity cycling, Coyle found that both fluid replacement and carbohydrate ingestion improved performance, each by 6% (169). The benefits were additive, producing a 12% improvement when both were administered.

Research on the impact on performance of high versus low- glycemic index foods has produced inconsistent results and further research on this subject has been recommended (2).

The Science of Sugars and the Media

Media coverage can have a significant impact on consumer perceptions of a particular issue, according to an analysis by Borra and Bouchoux (170). The authors noted that the publication of two studies in 2007, linking the consumption of sweetened beverages and foods to the rising incidence of obesity, triggered a substantial increase in media coverage of sugars. "The intersection of science, dietary advice, and media coverage of complicated topics is one in which information clutter can override clarity," they state.

Jones noted that "many scientists and consumers erroneously equate the feeding of high levels of pure fructose with the feeding of HFCS" (133). Consumer confusion results when the media and some researchers fail to distinguish clearly between the two sweeteners.

Over the last few years, high fructose corn syrup has been frequently mentioned in the media as a primary culprit in our nation's obesity problem. Allison and Mattes noted that some research, reviews and news reports have been influenced by "extrascientific" factors (i.e., biases), and they urge authors, reviewers, editors and news reports to "maintain the commitment to reporting objective science…" (171).

According to White: "Misconceptions about high-fructose corn syrup (HFCS) abound in the scientific literature, the advice of health professionals to their patients, media reporting, product advertising, and the irrational behavior of consumers. Foremost among these is the misconception that HFCS has a unique and substantive responsibility for the current obesity crisis" (46).

Current Issues and Research Needs

The scientific and nutrition policy communities continue to study the health aspects of sugars with a view toward providing the public with science-based dietary guidance. This paper has made note of a variety of unanswered questions and future research needs, some of which appear to have special significance for ensuring that consumers can apply these guidelines in a way that insures nutritionally adequate, calorically balanced and enjoyable diets.

Experts continue to recommend consumption of a balanced and healthful diet that can include modest amounts of sugars. Most scientists and policymakers relate the concept of moderation to determining what levels of sugars consumption are compatible with a nutritionally adequate and calorically balanced diet. However, the search for an agreed-upon numerical definition (as a percentage of total caloric intake) has proved elusive. Complexities encountered include numerous problems related to measuring and defining a person's sugars intake in relation to the rest of his/her diet. Confusing terminology, imprecise methods for calculating sugars content of foods, combined with inaccurate consumer reporting of food intake, make this a particularly difficult issue to address from a scientific vantage point. Some experts have suggested that perhaps we have tackled this question from an unproductive perspective. They propose that the emphasis be placed on advising consumers to focus on choosing foods with a high nutrient density rather than the avoidance of added sugars.

Others propose that consumers should observe discretionary calorie recommendations regarding added sugars consumption as discussed in the 2005 *Dietary Guidelines for Americans*. Recommendations will vary for different population groups and should be tailored to individual needs. As an example, USDA has developed discretionary calorie guidelines recognizing that achieving energy balance is a function of age, gender and level of physical activity (172).

Many researchers continue to view glycemic index and glycemic load as useful tools for examining associations between diet and disease even though scientific concerns about the measurement and reliability of GI and GL have yet to be resolved. While the concept of a numerical measure of a healthful diet is appealing, it seems clear that more research is needed in this area. In terms of providing dietary advice to the public, most nutrition scientists concur that the amount of carbohydrate in a food, as well as its nutrient density, are more important than the glycemic index.

Researchers continue to seek fresh approaches to the problem of obesity including consideration of possible differences among carbohydrate sweeteners. It is generally agreed that given the similarities between HFCS and sucrose, there is no scientific basis for distinguishing between these sweeteners for dietary guidance purposes. However, there is a consensus that additional studies should be conducted to determine the metabolic effects of various sweeteners (fructose, glucose, sucrose, HFCS) on a variety of populations, including the physically active and sedentary, the lean and overweight, and individuals with diabetes, insulin resistance, and/or hyperlipidemia.

Finally, several studies reviewed here make note of the difficulties encountered in attempting to isolate and study the effects of one food component on the multidimensional milieu of human health. Sugars are but one aspect of a complex food supply, and consumption effects must be considered against a backdrop of other elements of the diet, as well as lifestyle, health status, age, gender, physical activity, etc. This is particularly relevant with respect to research concerns about obesity. As one researcher aptly wrote: "…it is clear that energy imbalance for most individuals is accounted for by energy intake exceeding expenditure. The lifestyle factors that lead to this problem are too little exercise and too much food, but the determinants of such vary greatly between individuals" (116).

Research into other sugars and health relationships beyond obesity poses equally complex challenges, and rigorous evidence-based reviews using accepted methodologies are needed to further examine these issues.

Summary and Conclusions

Scientific research has answered many questions about the role of sugars in health and nutrition. Sugars perform many roles in the diet, with glucose being the primary substrate for cognitive activity. Our liking for sweet taste is innate from birth, and sweet taste preferences are in part genetically determined. Available data show no direct link between sugars and life-threatening diseases. However, recent research reflects increasing interest in possible indirect relationships, specifically whether sugars intake contributes to obesity or nutritionally inadequate diets. To date, the data suggests that diets high in sugars are not associated with higher body weight.

Fundamentally, these concerns are not about consumption of sugars, per se, but about overconsumption, which can be a problem with any food or nutrient. Consumers can achieve balance and moderation in sugars consumption by following recommendations to focus on choosing more nutrient-dense foods, including fruits, vegetables, whole grains and dairy products. Nearly all of these foods contain naturally-occurring sugars and many contain some added sugars to enhance taste, palatability and safety. For weight management, balancing calorie intake with physical activity is the critical factor regardless of the source of those calories.

This review has highlighted a number of key areas where additional research is needed. No doubt the science concerning sugars intake will continue to evolve and answers to important questions will emerge. Meanwhile, policy and professional groups, nutrition experts, and the scientific community generally agree that consumers can continue to enjoy modest amounts of sweetened foods and beverages as part of a balanced diet and a physically active lifestyle.

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