The Science of Sugars

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Part 1: "A Closer Look At Sugars"

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Part 2: "Sugars and a Healthful Diet"

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Part 3: "Sugars and Chronic Disease Risks"

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Part 4: "Sugars and Other Health Issues"

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***Abstract and Introduction**

Abstract

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, summarizes nutrition and policy recommendations of the scientific community while relating their conclusions to supporting research, and explains how sugars fit into a healthful eating plan.

Introduction

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. Although recent research has focused on potential sugars and 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 overconsumption can be a problem with any food or nutrient. Available data show no direct link between moderate consumption of sugars and serious diseases or obesity.

It's true that 'moderate consumption' is a frequently-used but not well-defined term. The American Dietetic Association states that 'sugars, in moderation, are part of healthful eating'. They follow that with the caveat that 'if your energy needs are low, go easy' on sugars intake. (1)

However, sugars and all fermentable carbohydrates contribute to the multi-factorial etiology of tooth decay. For dietary guidance purposes, researchers generally recommend focusing on managing energy balance, without singling out specific sweeteners (e.g., high fructose corn syrup (HFCS) or sucrose (table sugar)) or specific foods. Experts largely agree that consumers can enjoy some calorically-sweetened foods and beverages that fit within the individual's calorie and nutrient requirements as part of a balanced diet and a physically active lifestyle.

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Science of Sugars: Part I

Part 1: "A Closer Look At Sugars"

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Introduction

Sugars are desirable for their sweet taste and for their palatability. People have sought the many forms of sugars for millennia, including even the biblical reference of Canaan as the "land of milk and honey". The Americas, too, owe much of their growth to the European demand for sugar, which fueled industrial growth. And we endearingly pay tribute to our love of sweets, calling favored ones 'honey' and 'sugar'.

More recently, however, individuals searching for a cause of the increased prevalence of obesity have suggested that sugars and other sweets may be a significant part of the problem.

This series of four papers will explore what is known about the science of sugars. The first paper examines the types of sugars, their functionality in foods, and the various words used to describe sweeteners. The second paper will examine the role of sugars in a healthy diet. Part 3 of this series will explore the relationship between sugars and both obesity and prevalent chronic diseases. The final paper will review the association between sugars and dental health, sugars and cognitive function as well as between sugars and physical activity.

A vast amount of research has been done on sugars and health. Although there is an emotional tie to sugar, this review attempts to separate fiction from the scientific facts.

Terminology

The terminology used to describe sugars can be confusing and imprecise (1,2,3). Researchers use a variety of terms to describe nutritive or caloric sweeteners. “Sugar” generally refers to sucrose, which is manufactured primarily from sugar cane or sugar beets. In addition to sucrose, other sugars include invert sugar (sucrose molecule in which the disaccharide bond has been cleaved), high fructose corn syrup (HFCS), crystalline fructose, and glucose. The term “sugar-sweetened” refers to those products sweetened *during manufacture* with either sucrose, one of the above-named sugars, or a combination of these sweeteners.

The term “added sugars” also has a variety of definitions. As defined by the United States Department of Agriculture (USDA), “added sugars” refers to sugars that are added to foods either during processing or at the table. They include those sugars listed above, apple or grape juice concentrates, agave juice and honey. By that definition, sugars that are naturally occurring in foods such as fructose in fruit or lactose in milk are not deemed “added sugars”. (4) Others have defined added sugars in a slightly different manner, at times omitting the sugars from fruit juices or other small differences.

This review also uses the terms “nutritive sweeteners” and “caloric sweeteners” to indicate the above-named sugars. It would be beneficial if there was a harmonization of commonly-accepted definitions as this would facilitate communication among regulators, scientists, manufacturers, health professionals and consumers. (1)

Call out: A useful way of classifying sugars is by the degree of polymerization, or DP

The Food and Agriculture Organization (FAO) and the World Health Organization (WHO) recommend classifying dietary carbohydrates by the number of saccharides, also called degree of polymerization (see table above). (5) So-called “simple sugars” contain one saccharide (monosaccharides); simple sugars may be strung together necklace-like into linear chains of two or more saccharides or connected like the branches of a tree. The number of monosaccharides hooked together indicates the degree of polymerization or DP. Chains of three to nine monosaccharides are called oligosaccharides and more than nine are called polysaccharides. (6).

[Insert Figure 1: Carbohydrate Classification Chart here]

Sugars occur naturally in a wide variety of fruits, vegetables, milk and dairy foods. In addition, they are produced commercially and added to foods both for their sweetness as well as other functions such as the texture of foods. When metabolized, sugars have approximately 4 calories per gram, the same as both protein and other carbohydrates. Some common sugars found in foods are:

Glucose: A simple sugar found naturally in corn. Glucose is the primary source of energy for the body and is the only fuel used by brain cells. Starch digestion in the body yields glucose; even nondigestible carbohydrates (e.g. cellulose) are composed primarily of glucose. 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 along with other sugars such as glucose. Fructose makes up half of the sugar of sucrose and about half of the most common form of HFCS. 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. Galactose is not found free in nature, but is bound to glucose to form lactose.

Sucrose: Often called table sugar, sucrose is a disaccharide that is composed of one glucose unit and one fructose unit joined together by a chemical bond that is readily broken in the small intestine. Sucrose is found naturally in fruits and vegetables, but in the highest quantities in sugar beets and sugar cane. When sucrose is digested or placed in an acidic environment (such as in many ready-to-drink beverages), it 'inverts' and yields 50% glucose and 50% fructose.

Lactose: A disaccharide found naturally in milk, it is composed of one galactose unit and one glucose unit. Lactose is 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: Contains either glucose or combinations of glucose and fructose monosaccharides. The term “corn syrup” can refer to any of several corn-derived products according to the Food and Drug Administration (FDA). Corn syrup, which is found in the baking section of the market, is usually 100% glucose. Occasionally, there is some confusion as the term “corn syrup” may be used to describe HFCS, pure fructose or glucose derived from corn.

High-Fructose Corn Syrup (HFCS): A mixture of glucose and fructose derived from corn. The most common form of high fructose corn syrup (HFCS-55) is similar in composition to sucrose, having 55 percent fructose and 42 percent glucose. Another commonly used form of HFCS is HFCS-42 with 42% fructose which is less fructose than found in sucrose (table sugar). Less common and primarily used to make the other forms of HFCS is HFCS-90, having 90% fructose and 10% glucose. HFCS is only used commercially and is not sold in the supermarket.

Other Sugars Products: Sugars are part of the makeup of fruit juice concentrates, honey, molasses, hydrolyzed lactose syrup and whey. Other sources of sugars found in food ingredient lists include evaporated cane sugar, agave syrup, brown rice syrup, maltodextrins and date syrup—all comprised of the same basic sugars described above, with agave syrup particularly high in fructose.

Functions of Sugars in Foods

In addition to sweetening, sugars perform many functions in foods. They contribute to food preservation by binding water in products such as jams, jellies and cured hams, thereby making them susceptible to microbial growth. (See Table 1 for additional functions).

Digestion and metabolism

Once ingested, carbohydrates (polysaccharides and disaccharides) are broken down into their component monosaccharides. In the digestion of sucrose, both glucose and fructose are released into the bloodstream. Glucose, but not fructose, utilization is insulin-dependent. 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 relatively constant glucose level in the blood. Dietary glucose is stored in the liver and muscle cells in polysaccharide units called glycogen. When the level of glucose in the blood starts to fall, liver glycogen can be converted to glucose to maintain blood glucose levels. Blood glucose levels are maintained by the regulatory hormones, insulin and glucagon. Insulin also allows the muscles to take up circulating glucose. Human metabolism does not distinguish between sugars that are added to foods and sugars that occur naturally in foods, as they are chemically identical. (1)

Fructose is predominantly metabolized in the liver, and unlike glucose it does not require insulin in order to be utilized by the body. The rate of fructose metabolism is more rapid than that of glucose, as metabolites by-pass the rate-limiting step in glycolysis. Glucose

and fructose are metabolized via separate pathways, but converge at a common point for energy production.

The Sugar Alcohols

Sugar alcohols, also called polyols, are hydrogenated carbohydrates in which one end, the aldehyde. has been reduced to a hydroxyl or 'alcohol. They occur naturally in a wide variety of fruits and vegetables, but are also commercially produced from other carbohydrates such as sucrose, glucose, and starch. Common sugar alcohols used in foods include sorbitol, xylitol, mannitol, maltitol, maltitol syrup, lactitol, erythritol, isomalt and hydrogenated starch hydrolysates. Although most sugar alcohols are approximately half as sweet as sucrose, maltitol and xylitol equal the sweetness of sucrose.

Call out: The polyols (sugar alcohols) have unique properties in addition to being non-cariogenic

Sugar alcohols are slowly and incompletely absorbed from the small intestine into the bloodstream The incomplete absorption causes some of the sugar alcohol to move through the small intestine where it is fermented by bacteria in the large intestine. Thus, consumption of sugar alcohols may result in abdominal gas and gastrointestinal (GI) discomfort in some individuals. However, there are differences among polyols with regard to these effects. (8) For example, erythritol has been reported to produce less GI distress than other sugar alcohols (9,10) and is well tolerated at 1 g/kg of body weight per day.

(11) Reviewing the health aspects of polyols, Livesey found that they help in reducing constipation. (12)

Due to their incomplete absorption, sugar alcohols have fewer calories than other sugars and may be useful in weight management. The caloric content ranges from 0 to 3 calories per gram (kcal/g) compared to about 4 kcal/g for sucrose and most other sugars. Livesey found that they have a role in reducing constipation and promoting health. (12)

Incomplete absorption of polyols makes them beneficial for people with diabetes. Sugar alcohols have little impact on blood sugar compared to glucose and cellular uptake does not require insulin. The American Diabetes Association notes that “the total amount of carbohydrate in meals or snacks will be more important than the source or type”. (13) In essence, all types of carbohydrates, including sugars and sugar alcohols, can be included in the diet. Nonetheless, all carbohydrates need to be accounted for in the carbohydrate intake of people with diabetes.

Sugar alcohols are not acted upon by bacteria in the mouth, and therefore do not contribute to dental caries. (8,12) Xylitol has been found to inhibit oral bacteria, and is often used in sugarless mints and chewing gums. FDA has authorized a health claim stating that sugar alcohols do not promote tooth decay. (14)

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. (15) These data report the amounts of sugars that are manufactured or the deliveries of sugars to manufacturers and consumers. [Note: According to the USDA Farm Service Agency, sugars deliveries are defined as "the movement of refined sugar from a cane sugar refiner, a sugar beet processor, a sugarcane processor, or a trader, to end-users or brokers for consumption, either as sugar or for use in products containing sugar, including sugar delivered to manufacturers for use in products to be exported." (16)]

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 in the home. Also, expressing sugar disappearance per capita assumes equal usage across population groups and does not allow for investigating the use of sugars by different ages, genders, socioeconomic or ethnic groups.(3) The ERS data show that from 1966 to 1999 annual per capita sugars disappearance increased from approximately 113 pounds to approximately 151 pounds. Since 1999, sugars deliveries decreased and stabilized at about 137 pounds per capita per year. (15)

Call out: ERS estimates for per capita sweetener consumption, which rose between 1985 and 1999, have modestly decreased since 1999.

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 (non-edible 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 135 pounds in 1999 to 121 pounds in 2007.(17) ERS notes that its disappearance calculations are 'first estimates' intended to serve as starting points for discussion and further research (18).

Statistics on sugar consumption were included in the deliberations of the 2010 Dietary Guidelines Advisory Committee. The DGAC delved into the sources of calories and how the dietary makeup has changed. They considered both changes in nutrient composition as well as the food sources of those nutrients. Between 1970 and 2008, despite an increase in total caloric consumption, the percent of calories from caloric sweeteners (as well as meat, eggs, and nuts) declined. (18).

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 food consumption study participants may not be aware of some of their sugar consumption. Also, a number of people are known to underreport their intake, and may particularly underestimate intakes of sugars or sugars-containing foods. Overweight and obese populations show a greater disparity between actual intake and reported intake.(19,20)

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[1] rather than chemical analyses. Such overestimation may be due to several factors: (a) failure to account for sugars that are unavailable either because they are not consumed or lost to waste, or (b) processes such as the Maillard reaction, caramelization, or fermentation (leavening) which occur during cooking or baking and break down the sugars. (3)[2]

Food intake survey information was obtained primarily 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 Services. 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 only added sugars. (21)

[1] Browning reactions involving sugars produce many different compounds, but the amount of free sugar is substantially reduced. Caramelization and the Maillard reactions are examples of the effect of high temperatures on sugar. See McGee H, On Food and Cooking, Scribner, New York, 2004, p.778-779 for further discussion. Food labels based on database calculations are unable to account for such reduction in sugars and lead to overestimate of sugar content of certain foods.

[2] There are no published estimates for the amount of sugar 'lost' due to yeast action, caramelization or browning in baked goods. Yet this could be a significant amount. The USDA food composition database shows that mixed grain bread contains 2.6 grams sugar per slice (26 gm) and an English muffin has 1.80 grams sugar. Using an average of 2 grams sugar per serving, the USDA Factbook indicates that Americans consumed 10 servings of grain per day, on average, this amounts to 20 grams sugar per day from grain servings or roughly 16 lbs per person per year. (Source: USDA Agricultural Fact Book 2001-2002, Chapter 2: Profiling Food Consumption in America)

Call out: Consumption and disappearance data need to be reconciled so that communications about sugars are more straightforward.

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 (3). 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 (3). Steps to control underreporting include the multiple-pass technique for dietary recalls refined by NHANES.

Added Sugars

The term “added sugars” refers to sugars added to foods in the home kitchen or during commercial food preparation. Guthrie and Morton examined the 1994-1996 CSFII and found 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.(21) Children and adolescents consumed 19% and 20% of energy respectively. Relative intakes decreased in adulthood, ranging from about 12% to about 18% depending on age and gender (2). Marriott et al. determined usual intakes from NHANES (2003-2006) data and found a mean intake of added sugars for all

people aged four years and above to be 83 g (22), similar to the mean of 82 g reported by Morton and Guthrie from the 1994-1996 data. According to data from NHANES III (1988 -1994) intake 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). (6)

Marriott et al. also analyzed NHANES (2003-2006) data to determine the approximate contribution of specific food categories to added sugar intake. (22) They found regular soft drinks contributed almost one-third (30.7%) of the intake of added sugars. Sugars/sweets contributed 13.7% of added sugars, followed by sweetened grains (12.6%). Regular fruitades/fruit drinks contributed 10.3% of total intake. These four categories account for just over two-thirds (67.3%) of the intake of added sugars. These values have changed very little since 2000, when Guthrie and Morton analyzed CSFII data. (21) It should be noted, however, that recent data from the National Cancer Institute found that consumption of soda, fruit drinks, energy and sports drinks combined accounted for 6.9% of average total caloric intake, (18) which varies by age group. (23)

Consumption of added sugars is declining, according to a 2011 report which reviewed NHANES data from 1999 to 2008. (24) Overall, consumption of added sugars decreased twenty-five percent, from 101.1 g/d to 76.7 g/d despite an increase in incidence of obesity. Two-thirds of this decline came from reduced intake of sugar-sweetened beverages (SSB). In fact, Americans consumed 37% less added sugar from soft drinks in that period. Added sugars as a percent of total calories declined from 18.1 to 14.6%, with the reduction noted across all age, ethnicity and income groups.

Call out: Americans consumed 37% less added sugar from SSB from 1999 to 2008

High Fructose Corn Syrup (HFCS)

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.(25) Most of the HFCS consumed comes from sweetened beverages (soda, fruit drinks), 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. Since 1998, sucrose use and HFCS use have been roughly equivalent. 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. (26)

Fructose

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 HFCS. Marriott et al. compared fructose intakes from the 1977-1978 Nationwide Food Consumption Survey (NFCS) with data from NHANES 1999-2004 survey.(27) During this time period, mean daily intakes of both added and total fructose increased in all gender and age groups, with total fructose intake rising from 37g to 49g.(28) Lustig came to a similar conclusion by analyzing USDA/ERS disappearance data.(28) However, according to Marriott et al. this increase “was dwarfed by greater increases in total daily energy and carbohydrate intakes.” Between 1978 and 2004,

estimated mean total fructose intake decreased from 18.6% to 17.1% of total carbohydrate intake.(27) They conclude that "sweetener consumption is only one part of the complex dietary component of trends in overweight." Additionally, Forshee et al. found the typical diet to have a fructose:glucose ratio of 0.72, and that the dietary balance of fructose and glucose has not changed since the 1960s (29). Numerous researchers and clinicians attribute some of the chronic diseases of Western society to the consumption of fructose, noting the difference in absorption and metabolism from glucose. Investigators have examined the associations between fructose intake and diabetes, hypertension, and hyperlipidemia. These studies will be addressed in part two of this series. Nonetheless, the metabolic effects of fructose consumption, particularly as sugar consumption increased since the mid-1960's, continue to be of concern.

Summary

This paper summarizes the complex terminology used to define various sugars. There are overlapping uses of the term "fructose" to indicate pure fructose or fructose-containing sweeteners, such as high-fructose corn syrup. In addition, the term "added sugars" has varying definitions. The authors argue that the degree of polymerization or DP may provide a useful method to classify sugars.

Subsequent papers in this series will address the association between sugars and dietary quality, obesity and chronic diseases, dental health, and physical and cognitive performance.

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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

Figure 1 - FAO/WHO Carbohydrate Classification based on the degree of polymerization

Table 1. Functions of Sugars in Foods
Retard spoilage by binding water
Add flavor, texture, color to baked goods
Provide fuel for growth of yeast in breads
Contribute "bulk" or volume in ice cream, baked goods, preserves and jams
Enhance 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, e.g. salad dressings, sauces, condiments
Preserve the flavor, aroma, and color of fruits in preserves, jams, jellies
Help preserve natural color and shape of fruits used for canning and freezing
Improve flavor and texture of canned and frozen fruit

Table 1. Functions of Sugars in Foods (7)

The Science of Sugars: Part II

Part 2: "Sugars and a Healthful Diet"

Nutr Today. 2012;47(4):175-182

Introduction

Much is known about the science of sugars. Part 1 of this series reviewed the food science and technology of sugars as well as the nomenclature of sugars. Consumption data for sugars was also reviewed. Part 2 of this series examines the role of sugars in a healthful diet. It includes an assessment of the association between dietary quality, intake of sugars, and dietary recommendations for sugar. In Part 3, the relationship of sugar intake to chronic diseases will be examined. Part 4 will focus on the relationship between sugar intake and dental health as well as the effect of sugar intake on mental performance and behavior.

Dietary Quality and Sugars Intake

In its familiar form, cane sugar and beet sugar provide only carbohydrates and are devoid of vitamins or minerals. Similarly, corn syrup, which like cane and beet sugar is used in many convenience foods, has no micronutrients. Yet sugar and corn syrup are added to numerous foods that do provide essential vitamins and minerals. This raises the question: Does intake of sugars dilute the nutritional quality of the diet? The data are not clear-cut, but, on balance, they do not support the nutrient-dilution hypothesis.

Gibney et al. analyzed data from the 1987-88 United States Department of Agriculture (USDA) Nationwide Food Consumption Survey (NFCS) and examined nutrient analysis

based on sugar consumption ('low' sugar consumers in the bottom quartile, 'high sugar consumers in the top quartile). They found that high consumption of sugars was not associated with a poorer quality diet.(1) 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 (CSFII) (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.(2) Excluded from the analysis were infants under 2 years of age or those who were breast-fed, and pregnant and lactating women. Analyzing the same data among children and adolescents (CSFII), Forshee and Storey used a different research design that controlled for all possible sources of energy and reached a different conclusion.(3) They examined micronutrient intake in relation to servings of food in the USDA Food Guide Pyramid. They found the correlation between added sugars and micronutrients inconsistent. For 6-to-11-year-old children, for example, added sugars negatively correlated with dairy intake, but positively correlated with grains, vitamin C, iron, and folate. Added sugars were not linked to vegetable, fruit, lean meat, vitamin A or calcium intake among children. Among adolescents, added sugars negatively correlated with fruit consumption and positively correlated with grains, vitamin C and iron intake.

Calcium and phosphorus intakes of school-aged children and adolescents improved with consumption of sugar-sweetened flavored-milk.(4) Flavored milk drinkers had more milk and fewer soft drinks and fruit drinks, demonstrating that consuming added sugars in

nutritious foods such as dairy products may increase intakes of at-risk nutrients such as calcium.

Forshee and Storey also analyzed data from the National Health and Nutrition Examination Survey III (NHANES III) for 9 age-gender categories and determined that the association of energy from added sugars with micronutrient intake from that data, like that of CSFII, was inconsistent and small.(5) "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 is comparable to CSFII data from the mid-1990s.(6) More than 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 (IOM) suggested maximum intake (see below). It is useful to note that, regardless of intake from added sugars, few individuals in the population met recommended nutrient intake.

Call out: Studies indicate that the effects of sugars on micronutrient intakes depend on the nutrient-density of sugars-containing foods consumed.

Other studies have reported that individuals who are high consumers of sugar-sweetened beverages (SSB) have lower intakes of some micronutrients such as calcium and magnesium.(7,8) 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. (8) They found that as intakes of SSBs, sugars and sweets, and sweetened grains (baked goods) increased, the percentage intakes of the Daily Reference Intake (DRI) for calcium and iron decreased, and saturated fat intakes increased. As the consumption of sweetened dairy products and presweetened cereals mounted, the percentage of the DRI for calcium rose. 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 SSBs, sugars and sweets, and sweetened grains reduces the intake of key nutrients. Adding sugars to nutritious foods may help increase nutrient intakes.

Rennie and Livingstone conducted a systematic review of published studies, attempting to determine whether added sugars intake was associated with micronutrient intakes, and if so, the magnitude and the direction of the associations. (9) After analyzing 15 studies the authors found no consistent evidence of micronutrient dilution or a threshold for the effect 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 exploring various mechanisms by which sucrose could influence behavior, Benton found that, although micronutrient supplementation reduced anti-social behaviors, sucrose intake is not related to micronutrient deficiency. (10) Micronutrient intake is more closely associated with total energy than sucrose intake. In a further review of this topic, Livingstone and Rennie describe the methodological difficulties and

conceptual issues that hamper resolution of the micronutrient dilution hypothesis. (11) They question whether it is feasible or necessary to make the distinction between natural and added sugars given that sugars are chemically and physiologically indistinguishable. In fact, the intricacy of measuring added sugars was a topic specifically addressed by the 2010 Dietary Guidelines Advisory Committee (DGAC). According to the 2010 DGAC, means of assessing intake of added sugars vary across studies and "reliable and standardized measures of exposure to added sugars are necessary to draw meaningful conclusions." Further, accurate evaluation of added sugars "is challenging because no analytical methods exist with which to measure sugars added to foods." (12)

Intervention studies might be the only way to answer questions of micronutrient dilution. Rennie and Livingstone caution: "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." (9)

Call out: The theory that sugars dilute nutritional quality of the diet is overly simplistic

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. For a modeling study

of dietary patterns that satisfy the RDA, optimized food patterns exceeded the 2010 Dietary Guidelines for Americans in Solid Fats and Added Sugars (SoFAS); the model patterns had 17-33% vs. prescribed 5-15% of energy from SoFAS. (13) 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. (14)

In 2010, the European Food Safety Authority Panel (EFSA) on Dietetic Products, Nutrition and Allergies (NDA) issued a Scientific Opinion on Dietary Reference Values for carbohydrates and dietary fiber. With regard to a relationship between sugars and diet quality, the EFSA NDA panel concluded that "Observed negative associations between added sugar intake and micronutrient density of the diet are mainly related to patterns of intake of the foods from which added sugars in the diet are derived rather than to intake of added sugars *per se*. The available data are not sufficient to set an upper limit for (added) sugar intake." (15)

Sugar Consumption and Dietary Recommendations

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 wording of the guidelines has evolved over time to reflect both newer scientific knowledge as well as changes in nutrition policy. The 2000 edition of the DGA advised Americans to "Choose beverages and foods to moderate your intake of sugars." (16) In contrast, the 2005 DGA departed from previous editions in that it did not

include a message specifically directed toward sugars but advised Americans to “Choose carbohydrates wisely for good health” instead. (17)

The 2010 DGAC reviewed recent science to support the recommendations of the 2010 DGA. The 2010 DGAC report speaks specifically to shifting eating patterns to be more plant-based in composition while addressing both carbohydrates and sugars. Furthermore, unlike past versions of the DGAC, the 2010 report recommends that carbohydrate consumption should vary by activity level. For active people, suggested percentage of total caloric intake for carbohydrates should be at the high end of the Acceptable Macronutrient Distribution Range (AMDR) (45-65%), whereas those are on low calorie diets should consume diets at the low end of the AMDR. (12) In addition, sedentary populations, or “most Americans,” are advised to reduce consumption of high-energy, non-nutrient-dense carbohydrate sources to aid in calorie control. (12)

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 2005 DGAC chose not to set a numerical limit for sugars consumption, but advised individuals to focus on consuming nutrient dense foods and diets while treating added sugars, fats and alcohol as “discretionary calories.” (17) The 2010 DGAC moved away from the discretionary calorie concept citing difficulty in educating consumers; they examined the total diet and encouraged consumers to significantly reduce intakes of SoFAS, to no more than 5 to 15% of total calories (12). At present, Americans consume approximately 35% of total calories as SoFAS.

The IOM'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. (18) 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 reduced intakes of calcium, vitamin A and zinc were associated with increasing intakes of added sugars, particularly when added sugars accounted for more than 25% of energy.

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). (19) 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 non-communicable diseases. Thus, the proposed 10% intake recommendation may not be based solely on scientific evidence." (20)

Call out: Recommended limits on sugar intakes vary among food policy and scientific organizations, although all agree that reducing caloric intake is essential to fight growing obesity prevalence.

In a recent statement, the American Heart Association (AHA) recommends limiting added sugars intake to one-half the discretionary calorie allowance suggested in the 2005 DGA (100 calories per day for women, 150 calories per day for men. (21) 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 body mass index (BMI) and sugar intake and found no consistent relationship. Nonetheless, Vartanian et al. (22) found a positive association between body weight and soft drink consumption in a meta-analysis of 88 studies. Despite looking at the association between all carbohydrates – not only sugars – and body weight, Gaesser (21) 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.”

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.” (21)

A comprehensive review of global dietary recommendations for sugar and added sugar noted the absence of a consensus among the 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.” (24) (See further discussion in the next section: Sugars and Health.) Additionally, the 2010 EFSA NDA panel concluded, “Evidence on the relationship between patterns of consumption of sugar-containing foods and dental caries, weight gain and micronutrient intake should be considered when establishing nutrient goals for populations and recommendations for individuals and when developing food-based dietary guidelines.” (15)

To date, no consensus on the upper limit for added sugars intake has prevailed. The diverse recommendations for upper levels of added sugars consumption demand clarification by additional research.

Sugars and Health

Sugars have a long history of safe use in foods. They were placed on the Food and Drug Administration’s (FDA) 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. (25) Based on this work, the FDA reaffirmed the GRAS status of sucrose, corn sugar (glucose), corn syrup, invert sugar and high fructose corn syrups (HFCS) (26,27). Since that time, scientists and scientific organizations have kept the science of sugars up to date by periodically evaluating newer research.

In 1997 Anderson reviewed sugar-health scientific literature, concluding that except for their contribution to dental caries, sugars are not the cause of chronic or acute disease (28). The same year a Joint Expert Consultation of the FAO and the WHO 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 recommended that consumers avoid overconsumption of sugars. (29) This topic was again reviewed in 2001 and reaffirmed the FDA's and Anderson's conclusion that aside from dental caries, sugars are not an independent risk factor in chronic diseases. (30)

The IOM's 2002 report on DRIs (commonly referred to as the Macronutrient Report) focused on whether scientific evidence supported setting limits on sugars intake. (18) After reviewing available research on the effects of sugars on chronic disease risk, they found 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." (31)

The American Dietetic Association (ADA) periodically updates and revises its position paper on the use of nutritive and nonnutritive sweeteners. The 2004 version of this paper

reaffirmed the 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 intake of added sugars, dietetics professionals should assess food intake within the context of the entire diet and by considering personal health and nutrition goals." (20)

A subsequent review of the sugar-health scientific literature from 1986 to 2006 considered diets of both children and adults. (32) Additional long-term studies across different age groups, ethnicities and those with chronic diseases were recommended 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.

A group of 20 European nutrition, obesity, and dental health expert researchers convened a workshop in 2007, "On the role and fate of sugars in human nutrition and health," in which they reviewed the available evidence behind current intake recommendations for sugars, focusing on the strengths and gaps of the scientific evidence available and identifying those areas needing further research. (33) 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. (34) The investigators did not specify the other factors, but considered dietary satiety, the complex of obesity-metabolic syndrome-insulin resistance and other potential regulators of gene expression. 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." (35) 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. (36) 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 as sucrose, honey, and fruit juice concentrates. He emphasized the dissimilarity between pure fructose and HFCS. (37) "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." Still, the hypothesis that fructose

itself in the diet causes significant health issues continues to be explored. (38,39) 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 affected by the presence or absence of glucose.

Call out: Fructose-containing sweeteners have been studied by several expert groups; the metabolic effects of pure fructose and HFCS are quite different. More research that reflects common human consumption patterns of fructose is needed.

The Agricultural Research Service of the United States Department of Agriculture (USDA/ARS) and ILSI NA 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*. The roundtable addressed a wide range of issues including fructose and satiety, trends in fructose consumption, effects of fructose on glucose and lipid metabolism, metabolic syndrome and diabetes. 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." (40) Murphy noted that "it does not appear to be practical to base dietary guidance on selecting or avoiding these specific types of sweeteners." Others noted the lack of research information comparing HFCS with other sweeteners, (41) but found HFCS no more insidious than other caloric sweeteners. They called for more short-term studies to further explore the relationship.

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 BMI 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. (24) (See part 4 of this series for more information on sugars and dental health.) More recent scientific opinion from the 2010 EFSA NDA also acknowledges the many variables involved in the formation of dental caries; not only the amount of sugar consumed, but also frequency of consumption, oral hygiene, exposure to fluoride, and various other factors. (15)

Glycemic Index/Glycemic Load

The glycemic index (GI) was developed to compare the effects of various carbohydrate foods on blood sugar, a useful tool in the treatment of individuals with impaired glucose tolerance. (42) According to Jenkins, the GI 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. (43) Simply stated, the GI is a measure of the rise in blood glucose induced by the consumption of a carbohydrate compared to a standard food (white bread or glucose) which is set at 100. It is assessed under laboratory conditions, by measuring blood sugar following consumption of a set amount of a single food, usually 50 grams of digestible carbohydrate.

Glycemic load (GL) represents glucose response or insulin demand produced by total carbohydrate intake. Thus, GL combines both 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 GI.

In practice, GI and GL cannot always be reproduced consistently among individuals or even in the same individual at different times. (44,45) Many factors affect the consistency and reproducibility of GI calculations, including the ripeness of fruit, the physical form of the food, its temperature, its processing and preparation. (45) Consumption of carbohydrate foods as a component of a mixed meal may also alter the glycemic response. One Canadian multicenter trial of individuals with NIDDM demonstrated that the higher the sugar intake, the lower the diet's GI (46); another study found nearly identical GI between sweetened and unsweetened foods. (47)

Using GI/GL in the prevention and treatment of disease has been controversial, as studies have produced inconsistent results, probably due, in part, to inadequate tools to accurately determine these dietary components. (17) GI is 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. Such 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. (48) 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." (49)

Call out: Opinions differ on the clinical utility of the GI and GL concepts in the US and Canada

Other investigators found support for reduced-GI diet on maintenance of weight loss (50). Nonetheless, the EFSA NDA concluded in 2010 that "although there is some experimental evidence that a reduction of the dietary glycaemic index and glycaemic load may have favourable effects on some metabolic risk factors such as serum lipids, the evidence for a role in weight maintenance and prevention of diet-related diseases is inconclusive." (15) The Dietary Guidance Advisory Committee was more definitive: "Strong evidence shows that glycemic index and/or glycemic load are not associated with body weight; thus, it is not necessary to consider these measures when selecting carbohydrate foods and beverages for weight management." (12)

In the past, diabetes treatment involved restricting sugar consumption, due to its expected hyperglycemic effect. That advice has been modified as glycemic impact of starchy and sugary foods has been documented. Numerous studies have demonstrated beneficial effects of using GI/GL in treatment of individuals with Type 2 diabetes (47,51,52), although it is not universal (44,53,54).

Use of GI/GL may permit more sugar in diets of people with diabetes. Even with a normal distribution of GI values in this group, those consuming a low GI diet are apt to consume more simple sugars than low-GI starchy foods, according to Wolever et al. (46) A low-GI diet also produced better glycemic control (HbA_{1c} and fasting glucose) than one emphasizing cereal fiber (55).

Use of GI/GL is acknowledged but not universally accepted as a tool for diabetes management. 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 for labeling food with its GI value, provided (a) the food meets specified nutritional criteria, and (b) 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." (58) However, it advises that "the use of glycemic index and load may provide a modest additional benefit over that observed when total carbohydrate is considered alone."

Even experts who support the clinical utility of the GI caution that it should not be the only criterion by which to judge a food. (59) Other factors to consider include a food's fat content and nutrient density. When discussing GI it is important to consider that sugars are moderate-to-low in both GI and GL. Sugars have a lower GI than do many starchy or starch-containing foods. (30)

As an alternative to the GI, Segal and colleagues propose the use of a fructose index (FI) to categorize foods. (60) 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. (61, 62) 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.” (63) In the U.S., prevailing nutrition perspective is represented by the 2010 DGAC report which declares, “When selecting carbohydrate foods, there is no need for concern with their glycemic index or glycemic load. What is important to heed is their calories, caloric density, and fiber content.” (12)

Summary

Three key concerns prevail in the investigation of sugars and dietary quality. The need to obtain adequate intakes of vitamins and minerals drove the IOM analysis. They noted that micronutrient intake was affected by sugar intake exceeding 25% of calories. Specific micronutrient relationships were clarified by other research groups.

Second, the effect of all carbohydrates, including sugars, on blood sugar propelled the creation of the glycemic index and concept of glycemic load. The utility of the index remains controversial in that similar glycemic control can be achieved by monitoring the type and amount of carbohydrate consumed.

Calorie control and obesity dominates concerns of several professional organizations, who advocated varying limits on free or added sugars. Despite disagreement on specific limitations for sugar or added sugar, there is consensus that total caloric intake must not exceed caloric expenditure.

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The Science of Sugars: Part III

Part 3: "Sugars and Chronic Disease Risks"

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Introduction

Almost everyone enjoys sugars and sweets, but many consumers wonder whether consumption of sugars affects health. Part three of the series, the Science of Sugars, explores associations between intake of sugars and obesity and chronic diseases such as diabetes mellitus and cardiovascular disease. The first paper in the series explored the nomenclature of various sugars and the function of sugars in foods. Part two examined the association between sugars and indices of dietary quality as well as dietary recommendations for sugar. Recommendations for changing dietary intake of sugars are often based on suggestive but inconclusive data relating sugar consumption and the incidence of chronic disease or obesity. Part 4 will focus on the relationship between sugar intake and dental health as well as the effect of sugar intake on mental performance and behavior.

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 (NHANES). (1) Cowie et.al. report that 13 percent of adults age 20 and older have diabetes; however, 40 percent of them have not been diagnosed. Figures from the

Centers for Disease Control are similar, stating that 11.3% of adults have diabetes, 27% of whom are undiagnosed. (2) The prevalence of diabetes has risen steeply since 1980, when 3.7% of the population was diagnosed with the disease. (3) [See Figure 1].

The National Institute of Diabetes and Digestive and Kidney Diseases note that the risk factors for diabetes include overweight or obesity, genetics, ethnicity (high incidence among Asians, native Americans and non-Hispanic Blacks), inactivity, family history, and prior gestational diabetes. Research has identified many lifestyle and dietary risk factors that contribute to the development of Type 2 diabetes mellitus (T2DM). 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. (4)

There is general agreement among the scientific community that total sugars intake does not cause T2DM. (5,6) This has been confirmed by several prospective studies (7,8,9) including one that shows a negative association between sucrose intake and diabetes risk. (10)

A number of researchers now believe, and some studies indicate, that people who consume diets with a high glycemic index (GI) (11) or glycemic load (GL), which is GI related to the amount of carbohydrate consumed, may be more likely to develop T2DM. (12,13,14). However, two recent large prospective studies found no relationship between dietary GI or GL and risk of developing diabetes. (9.15)

Researchers continue to explore the idea that GI and GL may be useful tools for measuring diabetes risk. Results from two large prospective studies, the Nurses' Health

Study (14,16) and the Health Professionals' Follow-Up Study (13), showed a positive association between dietary GI and diabetes risk. However, results from the Iowa Women's Health Study (10) did not show a consistent association between the GI and diabetes risk. The American Diabetes Association notes that current information is neither sufficient nor consistent to conclude that low GI diets reduce risk for diabetes. (17) More recently, the 2010 Dietary Guidelines Advisory Committee (DGAC) report addressed the relationship between GL and T2DM, with the report explicitly concluding, "Strong, convincing evidence shows little association between glycemic load and type 2 diabetes." (18)

Further analysis of the Nurses' Health Study data found that women who increased their consumption of sugar sweetened beverages (SSB) from fewer than one per week to more than one a day over time (1991-1995, 1995-1999) gained more weight and had a higher risk of developing T2DM than women who maintained a consistent SSB intake. (19) The authors suggest that dramatically increasing the intake of SSB over time may contribute to obesity and, thus, indirectly increase diabetes risk. On the other hand, 1.95% of the cohort (1,007 nurses) in the Nurses' Health Study II, who changed their SSB consumption from low to high, had more weight gain than that of the other groups mentioned above (about 1.5 kg more than the constant-consuming group during the first 4 years and 2.0 kg more during the second 4 years). The other 1.98% of the cohort (1,020 nurses), who changed their SSB consumption from high to low, had less weight gain (about 2 kg less than the constant-consuming groups in each 4-year period). Based on these outcomes from less than 4% of the total study cohort, the authors concluded ''Higher consumption of sugar-sweetened beverages is associated with a greater magnitude of weight gain.''

However, this conclusion was not reconciled with the data from the 96% of the nurses who did not change their dietary beverage pattern.

Van Horn et al. cite the same analysis, but assert that about half the increase in incidence of T2DM is attributable to consumption of sugar-sweetened beverages and above that due to obesity. (20) Body mass index and calorie intake attenuated the positive relationship between SSB and diabetes (19); however, the authors cautioned that increasing the intake of sugars-containing beverages could increase the GI 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 SSBs 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 (fewer than one per week).

Laville and Nazare reviewed a variety of studies (intervention, prospective, cross-sectional) on the relationship between sugars, insulin resistance and diabetes. (21) The studies failed to demonstrate an obvious relationship between sucrose intake and glycemic control or diabetes risk. With regard to fructose, the authors noted discrepancies among studies' conclusions about its long-term effect on diabetes development.

Management of Diabetes: Although sugar is not directly implicated in causing T2DM, investigators have examined the role of dietary sugars in disease management. The

challenge is that some studies examine total sugar, while others investigate the type or source of sugar or the GI of the diet.

Manders compared the effects of consumption of sucrose-containing beverages on lean and obese diabetic and non-diabetic men. (10) 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.

The introduction of the GI in 1981 (11) stimulated a number of studies examining the body's blood glucose response to different carbohydrates and the implications for meal planning for people with diabetes. GI 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 people with diabetes.

With respect to the role of sugars in the nutritional management of diabetes, consensus recommendations do not support the widespread use of the GI. (22) The 2010 DGAC stated, "A moderate body of inconsistent evidence supports a relationship between high glycemic index and type 2 diabetes." (18) According to the 2010 European Food Safety Authority Panel (EFSA) on Dietetic Products, Nutrition and Allergies (NDA), the evidence is inconclusive for a relationship of GI and GL on diet-related disease. (23) 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. (17)

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. (17) Bantle noted that fructose ingestion results in lower circulating insulin and leptin, which might inhibit appetite less than other carbohydrates. (24) However, he added that, as yet, there is no convincing experimental evidence that dietary fructose actually stimulates excess energy intake.

Experimental evidence indicates that fructose reacts with protein molecules to form advanced glycation end-products (AGEs), which may accelerate the aging process and contribute to complications of diabetes. (25) Schalkwijk postulates 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). (26) However, a review of fructose and metabolic syndrome and diabetes by Bantle found no evidence that fructose accelerates protein glycation. (27)

Within the context of a dietary pattern that meets caloric and nutrient requirements, moderate intake of sugars may benefit individuals such as those with diabetes by increasing satisfaction and improving adherence to prescribed diets. (28, 29, 30, 31)

The chemistry of sugar alcohols (polyols) was addressed in Part One of this series. Sugar alcohols may be beneficial in managing diabetes as no insulin is required for absorption and the slow metabolism of the compounds does not produce spikes in blood sugar. In

addition, they have fewer calories (gram for gram) than other carbohydrates. However, sugar alcohols and other products that may be labeled as “sugar free” do contain carbohydrate and calories, and must be accounted for in meal planning for people with diabetes. (32)

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 popular foods it may be logical to suspect that they have a role in contributing to overconsumption and increased body weight. However, some epidemiologic studies find a surprising but clear inverse relationship between sucrose intake and body weight or body mass index (BMI), as well as sucrose intake and total fat intake. (33,34,35) These studies found that body weight and BMI decrease as the percent of sugar in the diet increases. Other investigators show a positive relationship between added sugars, particularly SSB, and BMI. (36,37) The American Heart Association noted the relationship between SSB and obesity is inconsistent. (38) Similarly, the Institute of Medicine (IOM) found “no clear and consistent association between increased intake of added sugars and BMI.” In fact, it was noted that higher intakes of total *or* added sugars are associated with a lower incidence of obesity. (5) 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. (39)

Call out: Causal relationship between calorically-sweetened beverages and obesity still controversial

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.” (40)

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.

(41,42,) 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. (41) The literature does not address the effects of corn syrups or of HFCS on satiety, but as 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 total sugars intake and obesity. (43) Nevertheless, nutrition researchers have continued investigating whether sugars might have a role in obesity apart from the caloric contribution. Various possibilities for a connection between sugar intake and obesity have been proposed.

Moran reviewed research on the impact of fructose-containing sweeteners on feelings of satiety. (44) 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 HFCS and sucrose are similar, but consider that excessive consumption of pure fructose may be problematic to energy intake regulation. (45) Therefore, short-term studies show no significant differences in satiation 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. (46) Bachman and colleagues reviewed several mechanisms that could explain a possible association between SSBs and obesity,

including satiety issues. (36) "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. (37)

Other theories relating SSBs to obesity have to do with the composition of HFCS, the most prevalent sweetener found in soft drinks and other beverage products in the U.S. Noting that the rise in obesity has paralleled the increased use of HFCS 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. (47) These studies posit that fructose is a less satiating sweetener than sucrose. (47,48)

To study this question Akhavan and Anderson compared the effects on appetite and satiety of a variety of sugar solutions in 31 subjects. (49) 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. (50)

In a recent study Soenen and Westerterp-Plantenga compared the satiating effects of HFCS and sucrose with milk. (51) 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." (27) Use of HFCS is almost entirely limited to the United States,

although the epidemic of obesity is a global phenomenon. 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)." (49) 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." (52)

Forshee et al. also point out that HFCS and sucrose have similar monosaccharide compositions and sweetness values. (53) 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." (54) AMA called for further independent research on the health effects of HFCS and other sweeteners.

This reinforces a conclusion highlighted in Part One of this series that "…high fructose corn syrup and sucrose are similar and one is not 'better or worse' than the other." (55)

Citing recent studies, Anderson made the case for putting the HFCS-obesity theory to rest. (56) 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. Anderson acknowledges the challenges to address lifestyle factors that create energy imbalance and obesity, but holds that "a reductionist approach that focuses on one food...is unlikely to succeed."

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 GI of the carbohydrate portion of the diet would aid fat loss by promoting higher satiety, higher metabolic rate and increased fat oxidation. (57) Sloth and Astrup respond that the evidence is insufficient to establish that a low GI diet is more effective than traditional weight loss plans. (58) 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. (59) 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."

Sugar-Sweetened Beverages

In a secondary analysis of 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 BMI and frequency of obesity increased. (60) 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. (47) 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 SSBs and weight gain and obesity in both children and adults. (61) 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. (62,63) No statistically significant association between consumption of SSBs and fruit drinks and BMI was found. Television viewing was positively associated with BMI, while participation in sports demonstrated a negative association.

Call out: Association between calorically-sweetened beverages and obesity still controversial

In addition, in the largest cross-sectional study to date Janssen et al. looked at intakes of over 120,000 children and adolescents in 34 countries and found no association between SSB consumption and obesity levels. (64) 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. (65) Research by Sun and Empie also found that frequent vs. infrequent consumers of sweetened soft drinks had similar percent obesity. (66) The cross-sectional study found higher obesity rates were related to other factors, such as television and computer screen time and high-fat diets. A 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. (67)

Using dietary recall data from the 2003-2004 NHANES, 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. (68) 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 and found that; “Overall, because SSBs represent 35% of all beverage weight consumed, replacing all SSBs among NHANES respondents with water would translate to a net reduction of 235 kcal/d (95% CI, 215 to 255 kcal/d) in total energy intake, on average.”

Bleich and colleagues examined trends in SSB consumption by age, race/ethnicity and weight loss intention and found higher SSB consumption among populations at greater risk for obesity and T2DM. (69)

According to Bremer et al. high levels of SSB consumption and low levels of physical activity are two lifestyle behaviors associated with obesity, insulin resistance, and metabolic syndrome. (70) Analyzing NHANES data for a nationally representative sample

of US adolescents, the researchers found that low SSB 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.

Science establishing a causal association between SSB consumption and obesity is imperfect. A 2010 systematic review and meta-analysis of 12 RCTs found that "the current evidence does not demonstrate conclusively that nutritively-sweetened beverage (NSB) consumption has uniquely contributed to obesity or that reducing NSB consumption will reduce BMI levels in general." (71)

A longitudinal cohort study of roughly 260 children followed for 18 months to assess the impact of physical activity, screen time, and dietary habits on body weight found no correlation between SSB intake and BMI. (72) Similarly, a randomized trial of 1,140 9-12 year-old students focused on determining whether an educational program aimed at discouraging students from drinking SSBs could prevent excess weight gain found, as a general matter, that "[a] statistically significant decrease in the daily consumption of carbonated drinks in the intervention compared to control . . . was followed by a non-significant overall reduction in BMI." (73) These studies suggest that SSBs do not play a unique role in adiposity in children and adolescents. The American Heart Association Nutrition Committee also noted that evidence regarding an association between SSBs and obesity is inconsistent. The committee recommends in 2011 that women limit SSB's to ≤450 kcal per week *for CVD prevention (*74*)*, although it acknowledged in 2009 that

"because overweight and obesity are complex metabolic conditions, it is unlikely that a single food or food group is causal." (38)

The 2010 DGAC report noted mixed results on the topic. While it concluded that "A moderate body of epidemiologic evidence suggests that greater consumption of sugar-sweetened beverages is associated with increased body weight in adults", it also states that "A moderate body of evidence suggests that under isocaloric controlled conditions, added sugars, including sugar-sweetened beverages, are no more likely to cause weight gain than any other source of energy." (18) In examining existing research on the subject, the DGAC concluded that "RCTs [randomized controlled trials] report that added sugars are not different from other calories in increasing energy intake or body weight. Prospective studies report relationships between SSB and weight gain, but it is not possible to determine if these relationships arise from additional calories, as opposed to added sugars *per se*. The systematic reviews in this area are also inconsistent, and may be relying on different measures used to determine added sugars intake or intake of SSB." (18)

Satiety: Liquids vs. Solids

Some researchers have investigated whether sugar is less satiating in liquid (as a beverage) than in solid form. (75,76) Some investigators hypothesize that liquids may not trigger physiological satiety mechanisms, so the body does not compensate completely for liquid calorie intake. 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. Almiron-Roig and colleagues noted that some studies found liquids to be less satiating than solids, while other studies found the converse. (77) Drewnowski reviewed a variety of studies and concluded that "the notion that liquid calories are not perceived by the body rests on inconclusive evidence." (78) In particular, he cited a number of studies showing that SSBs used as meal replacements in calorie-controlled diets are effective weight-loss tools, and, therefore, the 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." (79)
Call out: The hypothesis that solids are more satiating than liquids remains unproven.

The 2010 DGAC concluded that "A limited body of evidence shows conflicting results about whether liquid and solid foods differ in their effects on energy intake and body weight except that liquids in the form of soup may lead to decreased energy intake and body weight." They further note that "Americans are advised to pay attention to the calorie content of the food or beverage consumed, regardless of whether it is a liquid or solid. Calories are the issue in either case." (18)

Cardiovascular Health

Intake of carbohydrates, including sugars, is not considered an independent risk factor in the etiology of cardiovascular disease. (5) Dietary advice to help reduce heart disease risk urges intake of fruit and vegetables, whole-grain high-fiber foods, fish, foods prepared

with little or no salt and minimized intake of added sugar. (80) In addition, the American Heart Association focuses on controlling the amount and types of fats in the diet, since certain fats increase low-density lipoprotein (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. (81) Short term studies indicate that diets high in carbohydrates (60% of energy), particularly sugars (>20% of energy), increase serum triglyceride levels and decrease serum high-density lipoprotein (HDL) cholesterol. (82) However, longer-term studies show that the hypertriglyceridemic effects of high-sugar, high-carbohydrate diets may dissipate with time. (83,84) Also, diets that meet recommendations for fiber, saturated fat, and unsaturated fat lessen the effect of sugars on triglycerides. (85)

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. (86) 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. (81)

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 levels. (83,87,88,89)

McCarty suggests that the increased coronary risk associated with elevated triglycerides in Western epidemiology reflects the fact that high triglycerides serve as a marker for insulin resistance syndrome, rather than pointing to an inherent pathogenic role of triglycerides *per se*. (88) 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). (83) 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. (83, 85)

Several investigators have examined the relationship of sugar to blood pressure. Brown et al. did a cross-sectional association between blood pressure and sugar-sweetened beverages for US and UK adult participants of the Intermap Study. (90) They noted a 1.6 mm Hg rise in systolic pressure and 1.1 mm Hg rise in diastolic pressure among those consuming more than one serving per day. Elevated fructose intake has been associated with increases in blood pressure in rodents and dogs; however, extrapolations to usual human intakes of HFCS have not been published. (91)* The American Heart Association statement on added sugars and cardiovascular health states that cross-sectional studies suggest an association between excessive fructose consumption and hypertension. (38) Many questions remain about whether there is a direct relationship between sugar intake and high blood pressure and, if so, whether the relationship exists at usual intakes.

Gao et al. analyzed data from the 2001-2002 NHANES on the relationship between the intakes of added sugars and SSBs and serum uric acid concentrations. (92) 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 play a causal role in metabolic syndrome, hypertension, and other chronic disease, they noted, and suggested further research to clarify these associations and the observed gender differences.

To date, only one study has evaluated the potential relationship between SSBs and cardiovascular disease (CVD) risk. Fung et al. analyzed data from the Nurses' Health Study to prospectively examine consumption of SSBs and the risk of coronary heart disease. (93) They found an association between regular consumption of SSBs and a small increased risk of coronary heart disease in women. This risk was significantly attenuated after adjustment for other known risk factors.

Call out: Short-term studies suggest a link between high consumption of calories from sugars (e.g., more than 20%) and increased triglyceride levels, but hypertriglyceridemic effects of sugars are diminished by diets that meet recommendations for fiber and fats.

The 2010 EFSA NDA panel concluded that "Although there is some evidence that high intakes (>20% energy) of sugars may increase serum triglyceride (TG) and cholesterol concentrations, and that >20 to 25% of energy might adversely affect glucose and insulin response, the available data are not sufficient to set an upper limit for (added) sugar intake." (23) Similarly, the IOM concluded that there are insufficient data for setting an Upper Level for sugars based on increased risk for CHD. (5)

The AHA Nutrition Committee scientific statement on sugars and health reviewed selected studies on sugars and blood pressure. They concluded that increased intake of added sugars might raise blood pressure, but results are inconsistent and chronic effects of a high intake of simple sugars remain uncertain. (38)

It is generally agreed that long term clinical studies are needed to clarify the relationships among carbohydrates and sugars intake and triglycerides. Uncertainly about the role of type of carbohydrate, type of sugar or just a specific sugar moiety on cardiovascular health continues to prevail. Some research shows that Americans are consuming more fructose, primarily from sucrose and high fructose corn syrup and that fructose *per se* might adversely affect the heart health of Americans. The increasing consumption of fructose may be related to the obesity problem in the U.S. and may also be a potential risk factor for cardiovascular disease. (94, 95) Fructose is metabolized in the liver, in a metabolic pathway that can lead to an increase in serum triglycerides.

Lê and Tappy compared animal and human studies with respect to the metabolic aspects of fructose. (96) 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. (97) Results from this and another study by Stanhope et al. also indicated that a high fructose diet decreased insulin sensitivity. (98) 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." (99)

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. (100) 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. (101) However, in studies in which subjects consumed the highest levels of fructose, triglycerides were elevated, highlighting the need for further studies of dietary fructose at customary intake levels.

Reviewing studies on the dose effects of fructose, Livesey found that the balance of beneficial and adverse metabolic effects of fructose is "difficult to assess." (102) 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 or body weight when consumed at levels approaching 95th percentile estimates of intake. (46)

Summary

Sugar consumption has generated significant scientific investigation in the face of rising rates of diabetes, obesity and hypertension. Investigators have examined the questions of whether sugar causes type 2 diabetes and effects on glycemic control and insulin resistance for those with the illness. There is no evidence for sugar causing diabetes; diets to control the disease must account for total carbohydrate, not merely the sugar component. No differences have been found between the effects of sucrose or high-fructose corn syrup on diabetes, but pure fructose differs from these sugars and from glucose. More research is needed to better understand the effects of fructose.

Sugar is not an independent risk factor for cardiovascular disease. Nonetheless, sugar raises blood triglyceride levels, but not LDL-cholesterol. High intakes of fructose may adversely affect lipid profiles but whether intake at typical levels are of any concern remains to be determined. Dietary advice to limit sugar will depend upon the lipid profile, BMI, and risk of CVD. Consuming added sugars may increase blood pressure, but the results are inconsistent and no conclusions may be drawn.

The etiology of obesity is multifactorial, involving genetic, social, and environmental factors. No single food or ingredient has been shown to cause obesity or excess calorie consumption. In fact, evidence that sugar consumption leads to obesity is inconsistent and parallels diverse studies showing both reduced as well as enhanced satiating effects. Although there is evidence that sugar-sweetened beverages may be less satiating than solid forms of carbohydrate and increasing consumption of such beverages has generated scientific concern, most of the evidence is observational and well-designed intervention trials are lacking.

Thus, the evidence for an effect of sugars on chronic diseases is generally not conclusive and sugars can be a component of a diet that is designed to achieve and maintain normal body weight.

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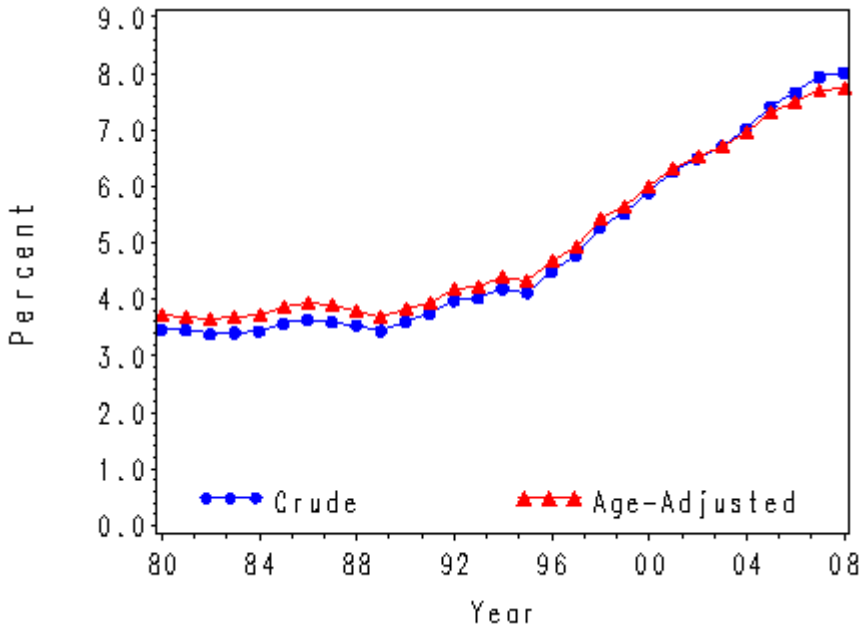

Figure 1. Crude and Age-Adjusted Percentage of Civilian, Non-Institutionalized Adults with Diagnosed Diabetes, United States, 1980–2008

Ssource: Centers for Disease Control
http://www.cdc.gov/diabetes/statistics/prev/national/figageadult.htm. Accessed April 16, 2011

The Science of Sugars: Part IV

Part 4: "Sugars and Other Health Issues"

Nutr Today. 2012;47(6):275-280

Introduction

This fourth article in the series on the science of sugars focuses on special issues related to sugars and health that have been studied for a number of years, specifically dental health and metabolic and physiologic conditions linked with cognition and behavior. Previous articles covered the functionality of sugars in foods and the various types of sugars used by consumers and by food and beverages manufacturers (part 1), the relationship between sugar and dietary quality and dietary recommendations (part 2), and sugars and chronic disease, including obesity (part 3).

Dental Health

Tooth decay or dental caries, promoted by oral bacteria, is a common cause of poor dental health, especially in children. (1) The causes of dental caries are complex and multifactorial. They include nutritional status, oral hygiene, fluoride exposure, dietary habits, heredity, intrauterine environment, socioeconomic status, general health, and use of medications. (1, 2)

Although many people associate dental caries with sugars, all fermentable carbohydrates, including cooked starches and sugars in fruits, can promote cavity formation (3). 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, carbohydrate is not the sole determinant of caries formation. The texture of the food, the duration of exposure, nutrient composition, sequence of eating, salivary flow, presence of buffers, and oral hygiene all play important roles. (1)

Researchers have identified two key indicators of cariogenic potential – the form or texture 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. (4) Foods that adhere to the teeth or between the teeth prolong exposure and increase the risk of tooth decay. (5) 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 reduce the acidogenic effect and promote remineralization. (1) In a recent systematic research review, Burt and Pai concluded that control of sugars consumption does play a role in caries prevention, but since the advent of extensive fluoride exposure, it is not the most important aspect. (6) Also, an investigation by Gibson and Williams concluded that regular tooth brushing with fluoride toothpaste may have a greater impact on caries in young children than does restricting sweetened foods. (7)

Call out: Cariogenicity is a complicated concept, and both the frequency and form of cariogenic carbohydrates are important.

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. (8) The analysis showed no reliable relationship between quantity of sugar consumption and dental caries, although frequency of sugars intake was significantly related to dental caries in 19 of the 31 papers considered.

The Institute of Medicine (IOM) concluded, therefore, that “it is not possible to determine an intake level of sugars at which increased risk of dental caries can occur.” (9) For this reason, dental researchers recommend that programs aimed at preventing tooth decay focus on factors other than sugars intake. (3)

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 toothpastes and professional dental products), the use of sealants, improved oral hygiene, and increased access to dental care. (10) However, for youths aged 2 to 5 years, the incidence of dental caries in primary teeth has increased, (11) which may be attributed, 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. (1) In reference to a specific amount of added sugars in the diet, the 2002 IOM Dietary Reference Intakes for Macronutrients, states that intake of added sugars be limited to 25 percent or less of total calories. (12)

The relationship between sugars consumption and dental caries remains an area of continuing interest for researchers who cite the lack of well-designed clinical studies

regarding effective prevention. (13) Other suggested areas of research include: study of the intake of sugars and fermentable carbohydrates by different populations and age groups (14) and determining how to improve caries prevention in high-risk populations, such as the poor and racial and ethnic minorities. (6)

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. (9) Estimation of glucose utilization by the brain is the primary determinant for the Estimated Average Requirement (EAR) for carbohydrate calculated by the IOM. Although the brain demands glucose for fuel, sugars and sweet tastes also stimulate specific brain reward centers and responses.

Research has found that human liking for sweets has a genetic component. (15) 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. (16) This preference provides an evolutionary advantage because sweetness often predicts a source of energy, whereas bitterness signals toxicity. Several studies have shown that sucrose exerts a calming effect on crying infants. (17,18) Paradoxically, finding that aspartame had a similar effect, one researcher suggests that subjects are responding to sweetness itself rather than to sucrose or carbohydrate. (19)

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. (20) 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. (21) The effects of sugars on reward pathways merit further study, they stated, as they may have implications for the prediction and treatment of substance abuse. Some researchers postulate an association between sugar or fat intake and addictive-like behavior. Lustig has proposed a link between fructose, in particular, and ethanol, proposing a similar hedonic pathway. (22)

Work by Thompson et al. in the mid-1970's revealed that hedonic preferences for sweet differ between lean and obese individuals, with normal-weight, but not overweight subjects reporting less pleasurable ratings with increasing sweetness. (23) It is possible that physiological, behavioral, and economic factors may all be involved in how sucrose and other fructose-containing sweeteners may affect body weight. (24) More research is needed to determine whether the relationship between sugars and reward is unique to sugars or whether it applies to all highly-palatable diets.

Call out: Sugars consumption not responsible for children's behavior problems.

Previous theories held that sugar consumption leads to hyperactivity in children. Although numerous studies have failed to support this theory scientifically, this view remains robust among consumers. (25) It is generally accepted by the medical and scientific communities that sugars consumption is not responsible for causing hyperactivity. (9) 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 or cognitive performance in children. (26) 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. (27) After analyzing 109 published studies on the subject, Benton found no evidence that sucrose adversely influences the behavior of children. (28)

Research supports a positive link between sugars consumption and cognitive ability. Studies have found that, under certain circumstances, intake of sugars can boost performance on cognitive tasks in diverse groups including infants, the elderly (16, 27, 29, 30, 31), as well as in people with Alzheimer's disease (32) and Down syndrome. (33)

Busch et al. found that an afternoon confectionery snack enhanced the ability of boys to stay on task for an extended period of time. (29) 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 people with memory deficits. (30) 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. (27) 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. (31)

The mechanism by which glucose enhances memory is poorly understood according to Benton and Nabb. (34) They suggest that future research should consider the possible effect of the glycemic index (GI) of carbohydrates on memory, as low GI foods are known

to improve glucose tolerance. [See Part I for definition of glycemic index and glycemic load (GL)]

Sugars and Physical Performance

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, not simply sugar, before and immediately after exercise. (35) 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. (36)

A key goal of pre-exercise nutritional strategies is to maximize liver and muscle glycogen, thereby minimizing the detrimental effects of subsequent 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. (37)

Carbohydrates are important during prolonged or sustained exercise to maintain blood-glucose levels and to replace muscle glycogen. The recommended carbohydrate intake for athletes ranges 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, gender, and environmental conditions. (38)

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. (38) The post-exercise carbohydrate that is consumed is usually sugar, both for the ease of consumption and its pleasant taste.

The American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine “Position Statement on Nutrition and Athletic Performance” 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. (39) During exercise, the body uses 30 to 60 g of carbohydrates 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). (39) The ideal fluid replacement solution should contain 6 percent to 8 percent 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 percent. (40) The benefits were additive, producing a 12 percent improvement when both were administered.

Research on the impact on performance of high versus low GI foods has produced inconsistent results and further research on this subject has been recommended. (9)

Summary

Sugar intake can contribute to dental caries; yet good dental hygiene as regular tooth-brushing and use of fluoride toothpaste has a greater impact on caries prevention than limiting sweetened foods. Sugars play a positive role in enhancing endurance performance. Pre-exercise consumption of sugars can maximize glycogen storage. Sugar consumption during activity spares muscle glycogen and after exercise, sugar intake helps replenish glycogen.

The ability to perform cognitive tasks may be enhanced by consuming sugars, particularly in the elderly and those with memory impairment, although more research is needed to confirm and extend these findings.

Implications for Practice

Available data show no direct link between moderate consumption of sugars and chronic diseases or obesity. As dietary guidance, researchers generally recommend focusing on managing energy balance, without singling out specific sweeteners (e.g., high-fructose corn syrup (HFCS) or sucrose (table sugar)) or specific foods. Experts largely agree that consumers can enjoy some calorically-sweetened foods and beverages that fit within the individual's calorie and nutrient requirements as part of a balanced diet and a physically active lifestyle. In addition, the use of caloric sweeteners may enhance the overall nutrient density of the diet when these sweeteners are used in healthful foods that may otherwise be avoided such as oatmeal.

The amount of sugars that are "moderate" will vary, based on individual energy needs and overall health. The American Dietetic Association Evidence Analysis Library

concludes that “sucrose intakes of 10 percent to 35 percent of total energy intake do not have a negative effect on glycemic or lipid responses in persons with either type 1 or type 2 diabetes when sucrose is substituted for isocaloric amounts of starch.” (41)

Diabetes is a complex medical condition and one in which a Registered Dietitian (RD) can play a critical role. Meals for people with Type 2 diabetes should contain mostly nutrient-rich carbohydrates which stress portion control. (42) The GI and GL concepts were developed in the effort to classify the impact of specific carbohydrate foods on blood glucose and were originally believed to be useful in treating those with impaired glucose tolerance. However, use of GI and GL in the prevention and treatment of disease has been controversial, as existing studies have produced inconsistent results. Key nutritional strategies to maintaining glycemic control among those with diabetes emphasize monitoring (1) the amount of carbohydrate ingested (regardless of method) and (2) plasma glucose to determine whether carbohydrate content of meals or insulin doses need adjustment to achieve blood glucose goals. (42)

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. While available data show no direct link between sugars and chronic diseases, 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 of sugars, which can be a problem with any food or nutrient. Even though there is insufficient scientific evidence to support a maximum intake of sugars (9), it is important to recognize the needs of specific population groups. Dietary guidance on sugar consumption can differ greatly depending upon a multitude of factors such as stage of life, weight status, physical activity level, and postprandial blood glucose response.

In children, hyperactivity and dental caries are common concerns. Behavior is not adversely affected by sugar intake. (26) Although children are especially vulnerable to the cariogenic effects of carbohydrates, the development of caries is not related to total sugars intake. Rather, the frequency of consumption of sugar-containing foods, the stickiness of the food, and length of time between sugar intake and teeth-brushing are the more important factors that explain the association between dietary sugar and dental caries. Therefore, two simple food-based strategies for prevention of caries in children are to provide set meal and snack times, and to provide only water between meals (milk or 100 percent fruit or vegetable juices are healthy options to be enjoyed with meals or snacks). Consistent oral hygiene routines utilizing fluoridated toothpaste are critical. (1,7)

Whether an individual is attempting to lose, gain, or maintain weight, balance and moderation in sugars consumption can be achieved by recommendations to focus on choosing nutrient-dense foods, including fruits, vegetables, whole grains and dairy products. Nearly all of these foods contain naturally-occurring sugars and many contain added sugars to enhance taste, palatability and food safety. Although the presence of sugar in foods is not associated with overconsumption and increased body weight, overconsumption of any food can lead to weight gain. In fact, negative correlations

between total sugar intake and BMI have been consistently reported. (9) Weight management is a complex issue and should be addressed with a multi-faceted approach, rather than a singular focus on one component of an individual's diet.

Although caloric intake is a key element in the energy balance equation, the critical factor in weight management is offsetting calorie intake with energy expenditure regardless of the calorie source. Therefore, physical activity level should be considered when making dietary carbohydrate recommendations. For physically-active individuals, the 2010 DGAC report suggests a percentage of total caloric intake for carbohydrates that is at the high end (65 percent) of the Accepted Macronutrient Distribution Range (AMDR), even as they recommend that those on low-calorie diets consume at the low end (45 percent). (43) Furthermore, sedentary populations are advised to reduce intake of high-calorie carbohydrate sources that are low in nutrients. (43) In other words, as calories required for weight maintenance decrease, consuming nutrient-dense carbohydrate sources becomes more critical if energy balance and nutrient needs are to be achieved simultaneously.

Summary: The Science of Sugars

This four-paper review has summarized and examined recent scientific research on sugars. Part one carefully examined the terms that are used to identify sugars and the areas of overlap and distinction. Key issues are the confusion between fructose and fructose-containing sweeteners, such as high-fructose corn syrup. The ambiguity has allowed assertions about the metabolic effects of fructose to be broadly defined. Similar

confusion exists for the term “added sugar,” which has varying definitions in different surveys. This paper also reviewed temporal consumption trends for sugars, which show a decline since 1999.

Part two explored the impact of sugars on dietary quality. The evidence that sugar dilutes the nutrient density of the diet is inconclusive. Although there is widespread American acceptance of guidance to limit sugar intake to less than 25 percent of energy, the European Food Safety Authority was more concerned with patterns of food intake than with establishing an upper limit. The 2010 Dietary Guidelines Advisory Committee (DGAC) also acknowledged the challenge to draw meaningful conclusions about the role of added sugars due to lack of appropriate analytical tools.

Part three reviewed the relationships between sugar intake and obesity as well as type 2 diabetes, cardiovascular disease, and hypertension. The association between sugar intake and obesity is controversial. The DGAC summed up the dilemma, by acknowledging that “added sugars” do not inherently increase energy intake or body weight. They did find that glycemic index and/or glycemic load are *not* associated with body weight.

The series highlights the fact that many controversies remain regarding sugars and health and additional research is needed. Several evidence-based reviews of the literature have been performed, including those by the DGAC, the American Dietetic Association’s Evidence Analysis Library, and the Life Sciences Research Organization. Each of these organizations has emphasized the need, whenever possible, for well-designed clinical trials in evaluating diet and health relationships.

Criteria for classifying studies are well-developed and proceed from randomized controlled trials (the strongest) to cohort studies to non-randomized or case-control studies. Cross-sectional studies are the weakest. (44) Although each type of study has value, there are challenges to interpretation, with many confounding factors. The classic criteria for causation are often not met by nutritional epidemiologic studies, in large part because many dietary factors are weak and do not show linear dose-response relations with disease risk within the range of exposures common in the population. Furthermore, epidemiological studies must carefully follow the Bradford-Hill guidelines for using relative risk in determining causality rather than associations. Due to confounding factors, some nutritional studies show a relative risk of 1.5, considered only a weak association. (45)

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 sweetened foods and beverages when consumed as part of a balanced diet with a physically active lifestyle, in the context of an individual's caloric needs.

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