The Science of Sugars, Part 4

Sugars and Other Health Issues

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Sugars are a key dietary component. In fact, the central nervous system (ie, the brain) contains cells that have an absolute requirement for the sugar glucose. In addition to the glucose requirement, sugars are also consumed for their pleasant taste and ease of digestion. The role of sugars in dental health, behavior, and mental and physical performance has been studied. All fermentable carbohydrates, including sugars, contribute to the etiology of tooth decay, but dental researchers who recommend tooth decay prevention efforts also focus on factors other than sugar intake that may have a greater impact, such as good dental hygiene routines that include regular toothbrushing and use of fluoride toothpaste. Numerous scientific studies have failed to support the theory that sugar consumption leads to hyperactivity in children. However, research does support a positive link between sugar consumption and cognitive ability, particularly in the elderly and those with memory impairment, although more research is needed. Nutr Today. 2012;00(0):00–00

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).

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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 2 key indicators of cariogenic potential—the form or texture of the food (ie, 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[6] concluded that control of sugar consumption does play a role in caries prevention, but since the advent of extensive fluoride exposure, it is not the most important aspect. In addition, an investigation by Gibson and

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Williams[7] concluded that regular toothbrushing with fluoride toothpaste may have a greater impact on caries in young children than does restricting sweetened foods.

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

Anderson and colleagues[8] reviewed 31 studies published from 1856 to 2007 to assess the relationship between quantity and pattern of sucrose use and dental caries. The analysis showed no reliable relationship between quantity of sugar consumption and dental caries, although frequency of sugar intake was significantly related to dental caries in 19 of the 31 articles considered.

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

According to Touger-Decker and van Loveren,[1] 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. 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% or less of total calories.[12]

The relationship between sugar 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 (ie, 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 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[20] 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. 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,[21] sugar ingestion induces neurochemical changes in areas of the brain that are involved in reward and energy. 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[22] has proposed a link between fructose, in particular, and ethanol, proposing a similar hedonic pathway.

Work by Thompson et al[23] in the mid-1970s 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. 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.

Sugar consumption is 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

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medical and scientific communities that sugar consumption is not responsible for causing hyperactivity.[9] Wolraich et al[26] 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. 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[28] found no evidence that sucrose adversely influences the behavior of children.

Research supports a positive link between sugar 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,[16,27,29–31] and in people with Alzheimer's disease[32] and Down syndrome.[33]

Busch et al[29] found that an afternoon confectionery snack enhanced the ability of boys to stay on task for an extended period of time. Kaplan and colleagues[30] 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. According to Bellisle,[27] 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. Sünram-Lea and colleagues[31] 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 1 for definition of GI 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 preexercise 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 to 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 postexercise 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 needs to be replaced to maintain carbohydrate oxidation and delay the onset of glycogen depletion fatigue, according to the National Athletic Trainers' Association.[39] The ideal fluid replacement solution should contain 6% to 8% carbohydrates as simple sugars (glucose or sucrose in simple polymer form), the National Athletic Trainers' Association stated.

In a study of high-intensity cycling, Coyle[40] found that both fluid replacement and carbohydrate ingestion improved performance, each by 6%. The benefits were additive, producing a 12% improvement when both were administered. Research on the performance impact 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 of regular toothbrushing 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. Preexercise consumption of sugars can maximize glycogen storage and sugar

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consumption during activity spares muscle glycogen. 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 (eg, high-fructose corn syrup 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[41] 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."

Diabetes is a complex medical condition and one in which a registered dietitian can play a critical role. Meals for people with type 2 diabetes should contain mostly nutrient-rich carbohydrates that 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 the amount of carbohydrate ingested (regardless of method) and 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. Although available data show no direct link between sugars and chronic diseases, recent research reflects increasing interest in possible indirect relationships, specifically whether sugar intake contributes to obesity or nutritionally inadequate diets. To date, the data suggest 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 sugar intake. Rather, the frequency of consumption of sugar-containing foods, the stickiness of the food, and the length of time between sugar intake and toothbrushing are the more important factors that explain the association between dietary sugar and dental caries. Therefore, 2 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% fruit or vegetable juices are healthful 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 sugar 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 body mass index have been consistently reported.[9] Weight management is a complex issue and should be addressed with a multifaceted 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 Dietary Guidelines Advisory Committee (DGAC) report suggests a percentage of total caloric intake for carbohydrates that is at the high end (65%) of

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the Accepted Macronutrient Distribution Range, even as they recommend that those on low-calorie diets consume at the low end (45%).[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 4-article review has summarized and examined recent scientific research on sugars. Part 1 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 article also reviewed temporal consumption trends for sugars, which have shown a decline since 1999.

Part 2 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% of energy, the European Food Safety Authority was more concerned with patterns of food intake than with establishing an upper limit. The 2010 DGAC also acknowledged the challenge to draw meaningful conclusions about the role of added sugars because of lack of appropriate analytical tools.

Part 3 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 GI and/or GL are *not* associated with body weight. The series highlights the fact that many controversies remain regarding sugars and health and that 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 nonrandomized 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. Because of confounding factors, some nutritional studies show a relative risk of 1.5, considered only a weak association.[45]

No doubt the science concerning sugar 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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