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Added Sugar and Dental Caries in Children: A Scientific Update and Future Steps

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SYNOPSIS

Excess added sugars, particularly in the form of sugar sweetened beverages, is a leading cause of tooth decay in U.S. children. While added sugar intake is rooted behavioral and social factors, few evidence-based, theory-driven sociobehavioral strategies are currently available to address added sugar intake. Dental health professionals are in a position to help identify and address problematic sugar-related behaviors in pediatric patients and advocate for broader upstream approaches including taxes, warning labels, and policy changes that can help to reduce added sugar intake, prevent tooth decay, and improve health outcomes in vulnerable child populations.

Keywords

Added sugars; Sugar sweetened beverages; Dental caries; Children; Pediatric dentistry; Evidence-based dentistry; Behavioral determinants of health; Social determinants of health; Sugar sweetened beverage tax

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Introduction

Dental caries is the most common disease globally and among U.S. children.[1,2] The causal relationship between fermentable carbohydrates and caries was first documented in the scientific literature in the 1950s. The Vipeholm study underscored the importance of both frequency of sugar intake and the consistency of sugar consumed.[3-6] Until this landmark set of publications, there was no scientific consensus on the link between sugar and caries.[4] It is now widely accepted that excess intake of added sugars – defined as sugars found in foods

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other than grains, vegetables, whole fruit, and milk – leads to dental caries and other systemic health problems including obesity, diabetes, and cardiovascular diseases.[7-10]

Despite decades of research on sugar as one of the main causes of dental caries, there are currently few evidence-based clinical strategies known to reduce excess added sugar intake in children.[11] The goal of this paper is to present national data on the relationship between added sugar and dental caries in U.S. children; identify the sociodemographic, behavioral, and social determinants of added sugar intake in children; review evidence-based strategies that reduce added sugar intake; provide clinicians with chairside strategies to address excess added sugar intake in patients; and outline unresolved challenges, opportunities, and next steps. The goal of this review is to advance the field through promotion of high-quality, evidence-based strategies and policies that address added sugar intake in children, which in turn are expected to prevent oral and systemic diseases, reduce health inequalities, improve quality-of-life, and address other consequences related to excess added sugar intake.

Added sugar and dental caries.

Based on data from the 2011-2012 U.S. National Health and Nutrition Examination Survey (NHANES), there is a positive and statistically significant relationship between added sugar intake (grams/day) and dental caries (defined as the number of decayed, missing, or filled primary and permanent tooth surfaces as proportion of the total number of tooth surfaces in the mouth) for children ages 18 years and younger (Figure 1). While these data are cross-sectional and do not account for longitudinal or accumulated sugar intake, the noted relationship is consistent with the sugar-mediated pathobiology of dental caries.[12]

Sociodemographic determinants.

There are four sociodemographic determinants relevant in added sugar intake.[13] The first is age. Based on 2011-2012 NHANES data for U.S. children ages 18 years and younger with complete data on added sugar intake and dental caries (N=3,441), added sugar intake increases with age (Figure 2). Added sugar intake ranged from 3.5 grams per day for children under age 1 year to 102.1 grams per day for children age 18 years. Added sugar intake is significantly lower for children under age 6 years than for children ages 6 to 18 years. These data are consistent with findings from other studies examining age-based trends in added sugar intake.[14]

The second sociodemographic determinant is race and ethnicity. Added sugar intake was highest for non-Hispanic White children ages 18 years and younger (80.3 grams) compared to non-White children ($P<0.05$ for all comparisons) based on 2011-2012 NHANES data (Figure 3). Added sugar intake for non-Hispanic Black, Hispanic, other/multiple race, and Asian children was 72.2, 65.4, 57.4, 51.1 grams per day, respectively. Consistent with these data are findings from a study comparing added sugar intake for Black and Hispanic children enrolled in the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) in Chicago.[15] Calories from added sugar intake was significantly higher for Black children than for Hispanic children ($P<0.01$). A study focusing on American Indian preschoolers found that mean added sugar intake for children ages 2 to 3 years and children 4 to 5 years was 54.8 and 59.1 grams, respectively.[16] Added sugar intake was measured using 24-hour recalls. Using NHANES data as a historical comparison group, added sugar intake was 17.5% greater for American Indians than intake for White children ages 2 to 3 years but 13.3% lower for American Indians compared to White children ages 4 to 5 years. Another study of Alaska Native children ages 6 to 17 years reported a mean daily added sugar intake of 193 grams per day.[17] Added sugar was measured using a hair biomarker validated against 24-hour recalls. Added sugar intake for Alaska Native children was double the mean added sugar intake for White children ages 6 to 17 years in NHANES.

The third sociodemographic factor is income. The relationship between income and added sugar intake is curvilinear, increasing from the lowest income households to category three, then decreasing among children from the highest income households (Figure 4). Only the difference between categories one and three was statistically significant (P=0.01).

The fourth sociodemographic factor is health insurance status, a proxy for income. Added sugar intake was highest for children without health insurance (78.9 grams/day), lowest for publicly-insured children (70.9 grams), and intermediate for children with private insurance (74.3 grams). However, none of these differences were statistically significant.

Behavioral determinants.

The behavioral determinants of added sugar intake can be classified into three categories. The first is added sugar source. Four waves of NHANES data indicated that for U.S. children ages 6 to 11 years and ages 12 to 19 years, carbonated beverages, energy drinks, and sports drinks were the main source of added sugars (13% and 27%, respectively), followed by grain-based desserts (8.7% and 7.2%), fruit drinks (9.6% and 8.1%), ready-to-eat cereals (5.8% and 4.8%), and candies (5.7% and 5.4%).[18] In another study based on 2009-2012 NHANES data, sugar sweetened beverages (defined as carbonated beverages, fruit drinks, sport and energy drinks, but not including 100% fruit juices) were the most common source of added sugars for U.S. children ages 2 to 18 years.[19] Two-thirds of children ages 2 to 18 years consumed at least one sugar sweetened beverage serving per day, and 7.3% of total daily calories were from sugar sweetened beverages.[20]

The second is parent beliefs and practices. In an online survey of U.S. parents of children ages 2 to 17 years (N=982), parent beliefs that sugary fruit drinks are healthy were significant associated with purchases of sugary fruit drinks.[21] Another study of parents of children ages 8 to 14 years in Australia (N=1,302) examined parent attitudes about soft drinks.[22] More specifically, attitudes that soft drinks were enjoyable, good, convenient, and good value were associated with increased intake. Similarly, a qualitative study of Hispanic parents of preschool-aged children (N=19) reported convenience, cost, and taste as factors related to parents providing children with sugar sweetened beverages.[23]

The third is child demand and related factors. Parent intake of sugar sweetened beverages is strongly associated with child intake.[24] Another study found a significant association between child and parent sugar sweetened beverage intake in African American children ages 3 to 13 years.[25] The previously cited study from Australia found that frequency of soft drink intake was associated with increased demand from children for soft drinks they had seen advertised on television.[22] A review of studies on the psychosocial determinants of eating behaviors in children and adolescents identified norms, liking, and preferences as being positively associated with sugar sweetened beverage intake.[26] Another study of U.S. adolescents ages 12 to 18 years (N=102) found that adolescents' subjective norms, defined as the extent to which people important to the adolescent want the adolescent to consume less sugary drinks, were associated with intention to limit sugary drinks.[27] A longitudinal observational study of Dutch adolescents ages 12 to 13 years (N=348) found that high perceived behavioral control was associated with decreased sugar sweetened beverage intake over a four-month period in the absence of an intervention.[28] Offering sugary snacks to children ages 5 to 10 years during after-school programs increased intake.[29] Prospectively restricting sweets among Dutch children ages 5 to 7 years led to a desire for sweets that remained high.[30]

Social determinants.

The social determinants of added sugar intake can be classified into four categories. The first is socioeconomic disadvantage, for which there are a number of proxy variables. A study based on 2007-2009 NHANES data found that food insecurity was associated with added sugar intake for U.S. children ages 2 to 15 years.[31] A study of American Indian children ages 2 to 5 years found that those living in food insecure homes were significantly more likely to consume sodas and sports drinks.[32] Other studies on food insecurity arrived at similar findings.[33] Another study found that among preschoolers from low socioeconomic households studied longitudinally from birth to age 14 years, externalizing behaviors (defined as angry, aggressive behaviors, including fighting and bullying other children, and physically hitting others) were associated with increased added sugar intake in boys, but lower added sugar in girls.[34] Hypothesized mechanisms proposed by the authors for these sex differences included low impulse control among boy and parents pacifying children with foods differentially. This is the age at which girls start dieting because of media influences on body image.[35] It is also possible that externalizing behaviors mediate poverty and added sugar intake.[36]

The second is household dietary habits. Four studies found that in-home availability was associated with increased sugar sweetened beverage intake.[23,25,28,37] Healthier snacking and beverage habits were associated with lower added sugar intake for urban Black children ages 8 to 11 years (N=126).[38] Similar findings were reported for rural children.[39] Stricter family food rules were associated with lower adolescent sugar sweetened beverage intake.[28]

The third is location of added sugar source. A 2014 study compared places where children ages 2 to 18 years obtained added sugars using 2009-2010 U.S. NHANES data.[40] Stores were the most common source of sugar sweetened beverages, compared to schools and fast food restaurants. Another study found that introducing a full-scale supermarket in a former food desert reduced added sugar intake.[41] Corner stores were a common source of sugary beverages for children.[42]

The fourth is peer influence. A study from the U.S. found that adolescent sugar sweetened beverage intake was significantly associated with peer intake.[43] A prospective study of 141 Dutch children (mean age: 7.7±1.3 years) found that a peer modeling intervention involving photos, video clips, and interactive activities instructing children not to follow other peers' food intake behaviors significantly reduced candy intake.[44]

Evidence-based strategies.

There are a number of evidence-based strategies that reduce added sugar intake. A 2015 systematic review concluded that interventions involving physical access to sugary beverage alternatives, like water, plus health education significantly reduce sugared-sweetened beverage consumption in children ages 8 to 18 years.[45] However, improvements are not sustained over time. A meta-analysis reported that school-based behavioral interventions resulted in reductions in sugar sweetened beverage intake, but the changes were modest.[46] A student-designed and student-led intervention called "sodabriety" was piloted with adolescents ages 12 to 18 years in two Ohio high schools.[47] The "30-day challenge" intervention involved a promotional campaign, facts about soda delivered during daily announcements, and promotion of unsweetened beverages like water, unsweetened tea, and diet soda. Pre- and post-intervention daily sugar sweetened beverage intake decreased and water intake increased significantly. A school- and community-based water intervention in the Netherlands significantly reduced sugar sweetened beverage intake for children ages 6 to 12 years (N=1,288).[48] Another systematic review found that home-based interventions are more effective than school-based interventions for children.[49]

One study evaluating state bans on sodas in school vending machines to address "pouring rights" revealed increased intake of sport drinks, energy drinks, sweetened coffees and teas, and other sugar sweetened beverages among 9^{th} to 12^{th} grade students, if these other beverages remained available to students.[50] Intake of non-soda sugar sweetened beverages did not increase if these other beverages were also removed from the school. This study highlighted the possibility of unhealthy substitution effects associated with soda bans in schools.

To evaluate the effects of warning labels, an online randomized trial involved a hypothetical vending machine task with adolescents ages 12 to 18 years (N=2,202). Participants who received beverages with one of three safety warning labels significantly reduced hypothetical purchase of sugar sweetened beverages compared to participants who received beverages with no warning label.[51] The warning label for which there was no significant difference included the words "obesity" rather than "weight gain" and "diabetes" rather than "type 2 diabetes" as noted consequences of drinking sugary beverages.

Sugar sweetened beverage taxes have significantly reduced per capita intake of sugary beverages in places like New York City,[52] Berkeley, California,[53] Mexico,[54] and Brazil.[55] At least one study from Chile reported modest beverage intake changes associated with sugar sweetened beverage taxes.[56]

Clinical strategies to address excess added sugar intake.

Evidence-based clinical strategies to address added sugar intake i have yet to be developed and refined. In the meantime, the following strategies can be used by dental health professionals to address added sugar intake in children.

1. Collect and record added sugar intake. A routine caries risk assessment should include data collection on the source, amount, and frequency of added sugars consumed by the child.[57] These data should be collected using standardized questions administered at each dental recall visit. Responses should be recorded in the patient's chart and reviewed at subsequent visits to track trends.

2. Deliver health education consistent with professional guidelines. Sugar sweetened beverages are one of the main sources of added sugars in children.[58] Parent preferences for sugar sweetened beverages and availability are strong predictors of child preferences and intake. Dental professional should provide education regarding 100% fruit juices that is consistent with the American Academy of Pediatric guidelines.[59] Children under age 1 year should not be given any fruit juice unless indicated by a health professional. Daily intake should be limited to 4 ounces per day for children ages 1 to 3 years, 4 to 6 ounces per day for children ages 4 to 6 years, and no more than 8 ounces per day (1 cup) for children ages 7 years and older. Furthermore, the American Heart Association recommends that children consume no more than 25 grams of sugar per day or 6 teaspoons from all dietary sources.[60] This means that ideally children should not consume any sugar sweetened beverages. Plain water and milk are the healthiest beverages. However, restricting sugary beverages for children who are used to sweet drinks or encouraging water intake are not feasible or effective long-term strategies. For children who demand sugary beverages, sugar-free alternatives are an option. Currently, there is no evidence that sugar-free sweeteners are unsafe for children when consumed in small amounts. Sugar-free sweeteners like sucralose (e.g., Splenda) and acesulfame-potassium (e.g., Sunett, Sweet One) are well established as safe, based on extensive toxicological safety data submitted to the U.S. Food and Drug Administration and other regulatory agencies worldwide.[61-65] Particularly when weighed against the known adverse consequences associated with extreme added sugar intake, including tooth decay and other systemic diseases, the potential benefits of sugar-free beverages outweigh the risks.

3. Assess readiness to change. Before an attempt is made to help change problematic added sugar behaviors, the caregiver's and/or child's readiness to change should be assessed. The Transtheoretical Model (TTM) posits that there are five stages of an individual's readiness to change: precontemplation, contemplation, preparation, action, and maintenance.[66] Attempts at behavior change for individuals in the precontemplation stage may need to be delayed until there is self-motivation and social supports in place to facilitate behavior change. Research on the TTM and dietary change has identified additional processes that facilitate movement between the stages that could help interested individuals engage in healthier behaviors.[67]

4. Use behavioral methods to supplement health education. Research has shown that health education alone is insufficient in changing health behaviors.[68] Attempts to change patient behaviors should be based on health behavior theories.[69,70] For instance, interventions incorporating concepts from motivational interviewing may help clinicians work with patients to set and monitor health behavior goals.[71] Studies on motivational interviewing in dentistry have yielded mixed results,[72] but other specialties within pediatric medicine have reported success with motivational interviewing-based approaches.[73-75] Other relevant

behavioral approaches have been documented, including application of the Theory of Planned Behavior, which focuses on modifying an individual's intention to take action.[27,75]

5. Reply on non-dental health colleagues. For patients that cannot be managed in a dental setting, dental professionals should work with nutritionists to help patients address excess added sugar intake.[76] The Screening, Brief Intervention, and Referral for Treatment (SBIRT) model can be used to systematically refer patients who require specialty care in addressing added sugar intake.[77]

6. Promote preventive oral health behaviors. For children at increased risk for dental caries, especially for whom added sugar intake is a significant risk factor, dental professionals should reinforce the importance of fluorides. Use of fluoridated water, toothbrushing with fluoridated toothpaste, and professional fluoride varnish treatments should be recommended. Particular attention should be given to identify caregivers who refuse fluoride, especially among caregivers with children at high caries risk.[78,79]

Challenges, opportunities, and next steps.

The following section outlines current challenges of addressing added sugar intake in children. The goal is to highlight opportunities and provide recommendations on future steps.

1. There is a dearth of theory-driven sociobehavioral interventions to address added sugar intake. Interventions in dentistry continue to focus almost exclusively on tooth-level strategies (e.g., fluoride varnish treatments, sealants, restorative dental treatment) rather than upstream sociodemographic, behavioral, and social determinants of health behaviors that are the root causes of added sugar intake and dental diseases. Fields outside of dentistry, like psychology, sociology, anthropology, and economics, have developed novel theoretical perspectives that could be used to derive potential solutions in dentistry. Dental researchers should continue working with social and behavioral scientists to develop and test interventions rooted in health behavior theories. When developing and refining interventions, end-users from the target community or patient population should be involved to optimize intervention relevance and feasibility.[80] Given the complex etiology of dietary behaviors, interventions should incorporate behavior change at multiple levels relevant for the target population (e.g., home, school, community) and address dental as well as non-dental disease outcomes using a common risk factors approach.[81,82] Measurement bias in assessing added sugar intake can be minimized by adopting subjective (e.g., 24-hour recalls) as well as objective (e.g., biomarkers) measures. Sustainability should be part of the intervention planning process to ensure that effective programs can continue without requiring ongoing external resource investments.[83] Attention to sustainability can also ensure that such programs are more easily disseminated to new communities and populations.

2. Public health programs need to focus on the highest risk children. One of the potential unintended consequences of public health programs is widening disparities,[84] especially when the most vulnerable participants are unable to benefit from the program compared to less vulnerable program enrollees. From a health equity perspective, interventions should

focus on child subgroups with disproportionately higher levels of dental disease. For instance, based on the sociodemographic factors associated with added sugar presented earlier, one subgroup that might be logically targeted for an added sugar intervention is White children. However, U.S. data indicate caries rates are significantly higher for non-White minority children.[85] Thus, an intervention aimed at reducing added sugar intake should focus on minority children to address the highest need subgroup and reduce oral health disparities. There is current intervention work in Alaska Native communities to address sugared fruit drinks and unhealthy foods using community-based approaches appropriate for local populations.[86,87] Both interventions focus on dietary behavior change, though at least one will include caries as an outcome measure.

3. Local beverage taxes are effective and are part of the solution. Sugar sweetened beverage taxes reduce intake and may also prevent chronic diseases like obesity.[88] However, depending on local politics, beverage taxes may not be a feasible solution and in cases like Chicago's soda tax are easily repealed.[89,90] Federal legislation prevents point-of-sale taxes on beverages purchased through the Supplemental Nutrition Assistance Program (SNAP) and the beverage industry continues to resist local efforts to pass taxes.[91,92] Federal legislation is needed to counter the influence of the beverage industry.[93] Similar to the passing of cigarette taxes to prevent youth tobacco use, beverage taxes should be viewed as part of a multi-pronged approach to address sugar sweetened beverage intake in children.[94]

4. Current sugar intake benchmarks may not be sufficient in preventing caries. The World Health Organization has set the recommended threshold for sugar intake at 10% of total energy intake.[95] Based on 2011-2012 U.S. NHANES data, sugar comprises 17% of total energy of U.S. children.[96] Data from Japan on the longitudinal relationship between sugar intake and caries suggests that sugar intake needs to be below 3% or at most 5% of total energy to prevent caries.[97,98] These stringent benchmarks are not likely to be achieved using current approaches. Rather than being based on what is realistically achievable, dietary benchmarks should be set on meaningful disease prevention outcomes. The hope is that these benchmarks will encourage researchers, clinicians, policymakers, and others to develop collaborative, holistic, and novel approaches in addressing sugar intake.

5. Corporate industries are motivated by profits and self-interest. The sugar industry has been likened to Big Tobacco.[99] Corporate industries that support the marketing and distribution of sugar products include food and beverage companies, advertising agencies, and grocers. In addition, schools, hospitals, community centers, and other public spaces where child-related activities and business take place have been complicit in perpetuating access to and consumption of sugars. Beverage labels are difficult for consumers to interpret and studies show that labels on nearly a quarter of foods and beverages marketed to children overestimate or underestimate the product's listed sugar content by 10%.[100,101] Despite laws allowing industries to self-regulate, advertisers routinely target sugary products to children[102,103] and adverse advertising disproportionately targets low-income and minority children.[104] In addition, there are data exposing the sugar industry's role in suppressing science on the adverse effects of sugar,[105,106] funding studies with null results associated with sugar intake,[107] and influencing the research priorities of federal agencies and public

policies.[108,109] As a recent example, the role of the alcohol industry's influence on a study funded by the National Institutes of Health has been publicized.[110]

Government regulation and oversight are needed to hold industries and corporations accountable for inaccurate product labeling, illegal advertising, and unethical influence pedaling.[111] To educate the public on the risks associated with sugar, positive and negative front-of-pack labels should be added to sugar sweetened beverages and public health awareness campaigns should be promulgated.[112,113] Efforts to address pouring rights in schools should ensure that sodas as well as all other sugary beverages are removed from vending machines to avoid substitution effects.[50]

6. Out-of-date government nutrition programs continue to subsidize the consumption of unhealthy foods and beverages among vulnerable populations. The U.S. Supplemental Nutrition Assistance Program (SNAP) allows sugar sweetened beverage purchases and the Women, Infant, Children (WIC) program's allowable food list includes 100% fruit juices, which may inadvertently convey the message that these beverages are healthy. Legislation is required to restrict SNAP purchases, but political and logistic complexities make such legislation unlikely in the near future.[114] In addition, ethical concerns have been raised about restricting choice in vulnerable populations.[115] In the meantime, plausible solutions include incentive-based approaches that allow government nutrition program beneficiaries more flexibility in how funds are spent (e.g., Electronic Benefits Transfer use at farmer's markets) or subsidies to encourage healthy spending.[116-119]

In conclusion, sugar sweetened beverages are a major contributor to dental caries in U.S. children. Future intervention research should account for relevant sociodemographic, behavioral, and social determinants of added sugar intake, which will enable the field to develop and refine evidence-based strategies to prevent dental caries. Dental health professionals are in a position to implement clinical strategies that can help to reduce added sugar intake in patients and should advocate for broader policy-based solutions.

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KEY POINTS

- Added sugar intake is strongly associated with tooth decay in U.S. children.
- Sugar sweetened beverages are the main source of added sugars. Health education is necessary but insufficient in improving beverage behaviors.
- Social factors like socioeconomic disadvantage, household habits, and availability through local stores influence added sugar intake.
- Sociobehavioral interventions are relatively uncommon but are a promising approach in reducing added sugar intake and preventing tooth decay in children.
- Upstream approaches like sugar sweetened beverage bans in schools, warning labels, and taxes can further reduce excess added sugar intake.
- There is a dearth of evidence-based clinical strategies, but dental health professionals can adopt systematic clinical practices to identify and address excess added sugar intake in pediatric patients.
- There is a need for additional sociobehavioral intervention research, public health programs that target the highest-risk children, and health policy changes.

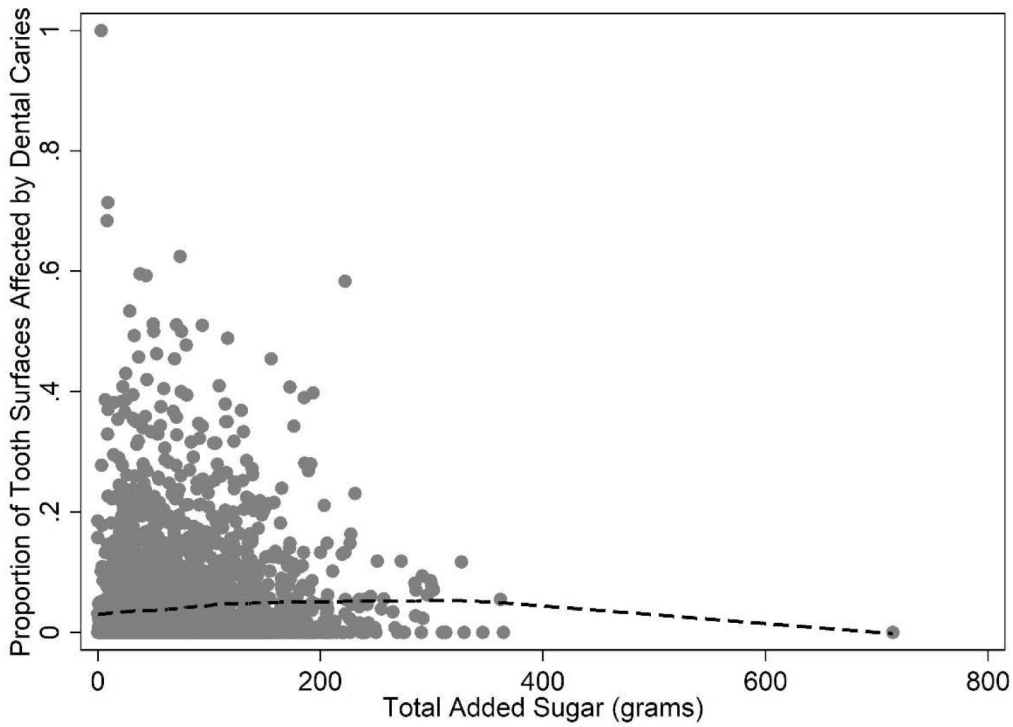

Figure 1.

Plot of Mean Daily Added Sugar Intake and Tooth Decay for U.S. Children Ages 18 Years and Younger (N=3,441). Plot not adjusted for potential outliers.

Data from National Center for Health Statistics. 2011-2012 U.S. National Health and Nutrition Examination Survey (NHANES) for participants ages 18 years and younger with added sugar and caries data. Available at: https://wwwn.cdc.gov/nchs/nhanes/ContinuousNhanes/Default.aspx?BeginYear=2011

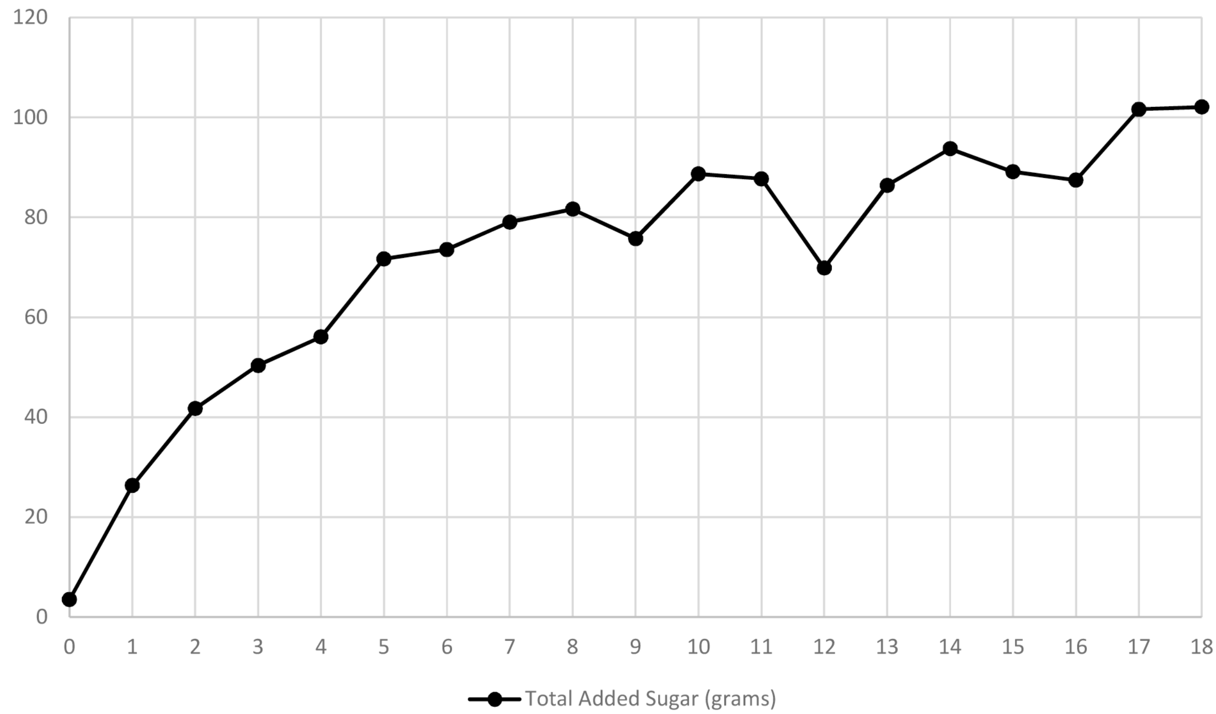

Figure 2.

Mean Daily Added Sugar Intake by Age Group for U.S. Children Ages 18 Years and Younger (N=3,441).

Data from National Center for Health Statistics. 2011-2012 U.S. National Health and Nutrition Examination Survey (NHANES) data for participants ages 18 years and younger with added sugar and caries data. Available at: https://wwwn.cdc.gov/nchs/nhanes/ContinuousNhanes/Default.aspx?BeginYear=2011

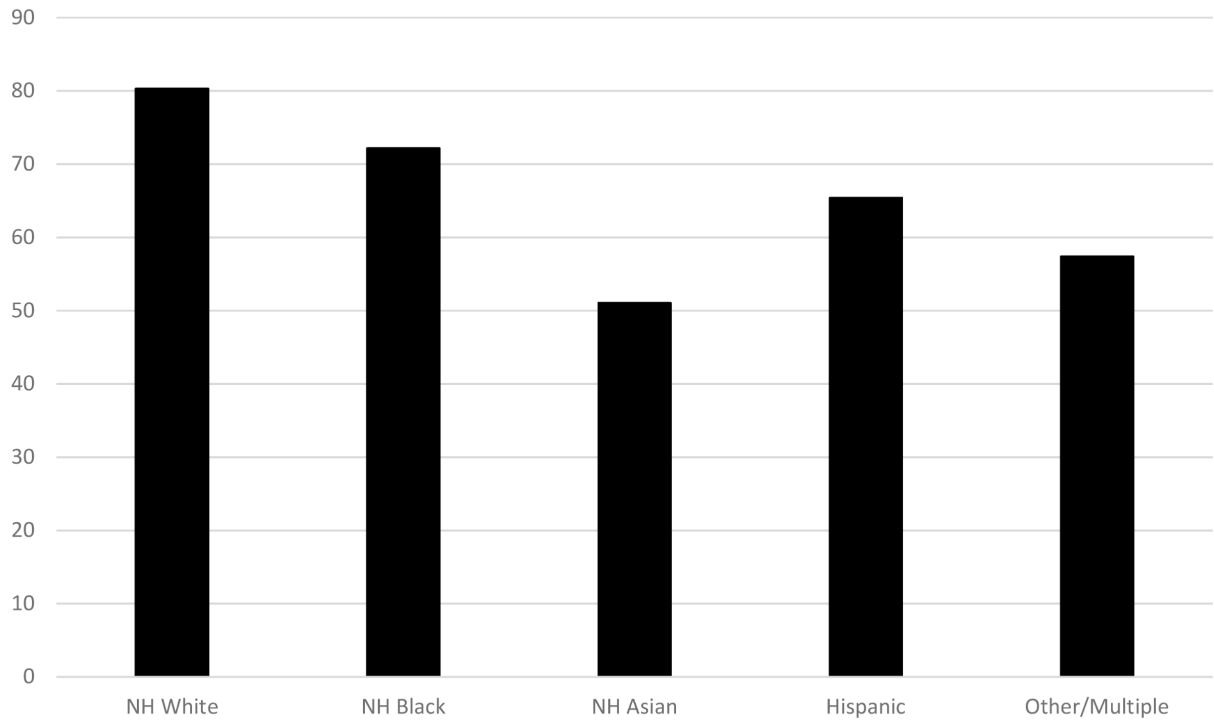

Figure 3.

Mean Daily Added Sugar Intake by Race and Ethnicity for U.S. Children Under Ages 18 Years and Younger (N=3,441). NH = Non-Hispanic.

Data from National Center for Health Statistics. 2011-2012 U.S. National Health and Nutrition Examination Survey (NHANES) data for participants ages 18 years and younger with added sugar and caries data. Available at: https://wwwn.cdc.gov/nchs/nhanes/ContinuousNhanes/Default.aspx?BeginYear=2011

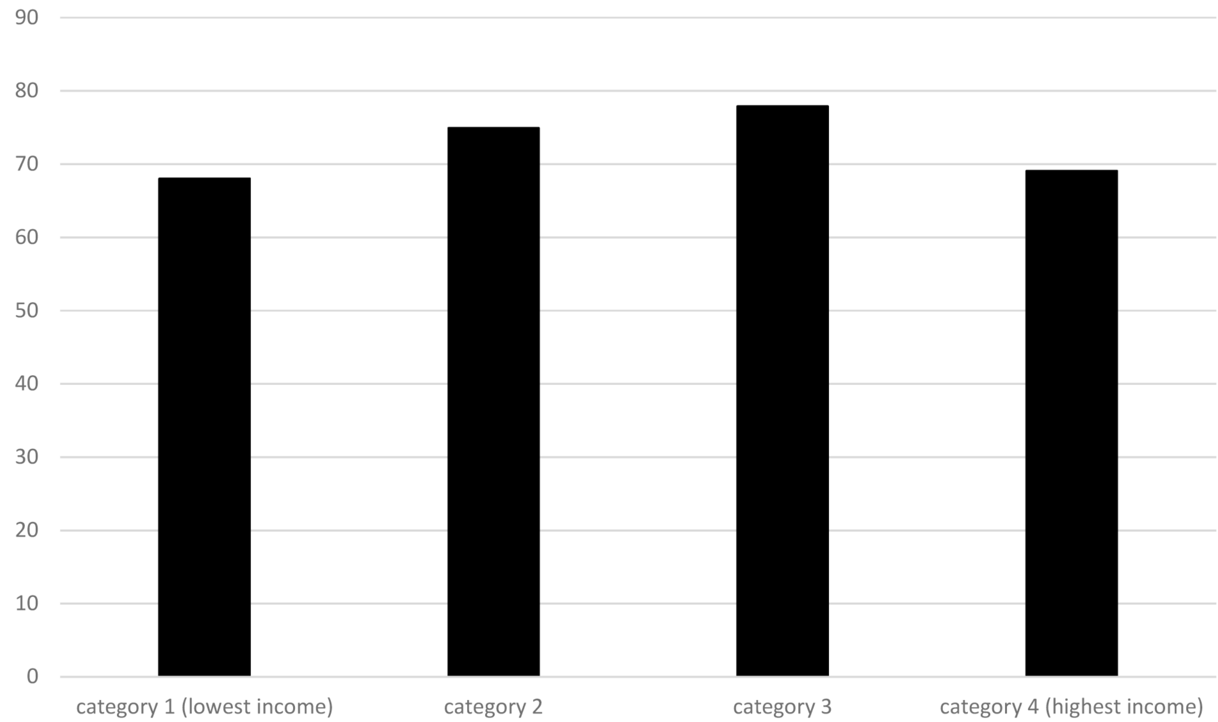

Figure 4.

Mean Daily Added Sugar Intake by Income Category for U.S. Children Under Ages 18 Years and Younger (N=3,441). Income categories calculated as poverty to household income ratio.

Data from National Center for Health Statistics. 2011-2012 U.S. National Health and Nutrition Examination Survey (NHANES) data for participants ages 18 years and younger with added sugar and caries data. Available at: https://wwwn.cdc.gov/nchs/nhanes/ContinuousNhanes/Default.aspx?BeginYear=2011