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Beverage Intakes and Toothbrushing During Childhood Are Associated With Caries at Age 17 Years

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Abstract

Background—Sugar-sweetened beverages (SSBs) have been associated with childhood caries; however, associations among lifelong beverage intakes and adolescent caries have received less attention.

Objective—To investigate associations between beverage intakes during childhood and adolescence and caries experience at 17 years of age, while adjusting for fluoride intakes and toothbrushing.

Design—Descriptive model analyses were conducted on data collected from a longitudinal birth cohort study.

Participants/setting—Participants included Iowa Fluoride Study members (n = 318) recruited at birth between 1992 and 1995 with at least 6 beverage questionnaires completed from ages 1 to 17 years and a caries examination at age 17.

Exposure—Predictors included mean daily milk, juice (100% juice and juice drinks before age 9), SSB (including juice drinks after age 9), and water/sugar-free beverage (SFB) intakes; daily fluoride intakes; and daily toothbrushing frequencies for ages 1 to 17.

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AUTHOR CONTRIBUTIONS

T. A. Marshall conceptualized and designed the study, drafted the initial manuscript, and reviewed and revised the manuscript. A. M. Curtis conducted statistical analyses, drafted the initial manuscript, and reviewed and revised the manuscript. J. E. Cavanaugh designed and supervised the statistical analyses and reviewed and revised the manuscript. J. J. Warren and S. M. Levy coordinated and supervised data collection, conceptualized and designed the study, and reviewed and revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

STATEMENT OF POTENTIAL CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

CLINICAL TRIAL REGISTRATION

NCT03547128.

Main outcome measures—The outcome was dental caries count at age 17, adjusted for the number of scored tooth surfaces (decayed and filled surfaces attack rate [DFSAR]).

Statistical analyses performed—Univariable generalized linear models were fit for each predictor and the outcome DFSAR. Multivariable models assessed combined effects of beverage types, fluoride variables, toothbrushing, sex, and baseline socioeconomic status.

Results—Based on multivariable models, each 8 oz of additional daily juice and water/SFB decreased expected DFSAR by 53% (95% confidence interval [CI]: 17%−73%) and 29% (95% CI: 7%−46%), respectively, and 8 additional oz SSBs increased expected DFSAR by 42% (95% CI: 5%−92%), after adjustment for other beverage intakes, toothbrushing, total fluoride intake excluding SSB fluoride (non-SSB total fluoride), sex, and baseline socioeconomic status. Each additional daily toothbrushing event decreased expected DFSAR by 43% (95% CI: 14%−62%) after adjustment for beverage intakes, non-SSB total fluoride intake, sex, and baseline SES.

Conclusions—Higher juice and water/SFB intakes and more toothbrushing were associated with lower caries at age 17, while higher SSB intakes were associated with higher caries.

Keywords

Sugar-sweetened beverages; Juice; Water; Fluoride; Dental caries

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DENTAL CARIES RESULTS FROM THE DISSOLUTION of enamel or dentin by acid produced during bacterial fermentation of carbohydrates at the tooth surface. Dental caries is the most common chronic childhood disease.[1] Total caries prevalence was 45.8% among youth aged 2 to 19 years participating in the US National Health and Nutrition Examination Survey in 2015–2016, and the prevalence of untreated caries was 13.0%.[2] Total caries prevalence increased with age and decreased with higher incomes.[2] Considered a noncommunicable disease, dental caries is associated with oral hygiene behaviors, fluoride exposures, and diet.

Oral hygiene, particularly toothbrushing with fluoride-containing toothpaste, is recommended to protect against caries development. Toothbrushing disrupts the oral biofilm at the tooth surface, limiting development of plaque.[3] Kumar et al[4] reported that infrequent brushers had both higher incidence and increment of new carious lesions. The authors noted that the effect of brushing was not necessarily associated with delivery of toothpaste fluoride and might be associated with brushers' greater health awareness and higher socioeconomic status.

The caries-protective effects of fluoride were first recognized by McKay in the early 1900s.[5] Fluoride protects against caries by preventing demineralization, aiding remineralization, and interfering with bacterial enzymatic activity.[6] Caries reduction estimates associated with community water fluoridation systems have ranged from 27% for permanent teeth[7] to 40% to 50% for primary teeth.[8] Caries experience is typically lower in individuals with access to fluoridated water systems than in those without similar access, yet caries remain a concern in all communities.[9] Other sources of fluoride (ie, toothpastes, mouth rinses) are also associated with caries reductions.[8,10]

Sheiham and James argued that "caries is a diet-mediated disease" and suggested that sugars are the primary factor necessary for caries development.[11] The World Health Organization sponsored a systematic review investigating the role of sugars in caries, which concluded that caries rates are lower when intakes of free sugars are restricted to less than 10% of total energy intake.[12] Numerous cross-sectional investigations support associations between the frequency and/or quantity of sugars intake and caries among US children.[13–17] More recently, cross-sectional investigations have suggested that sugar-sweetened beverages (SSBs), defined as beverages containing added sugars, are most commonly associated with caries in contemporary society.[13,17–20]

The majority of contemporary dietary studies have focused on early childhood caries, while caries during adolescence has received less attention. Furthermore, the majority of dietary studies have explored cross-sectional or short-term longitudinal relationships between current dietary behaviors and caries status, and few studies have had the ability to consider concurrent fluoride intakes and/or oral hygiene behaviors. The objective of the current study was to investigate associations between beverage intakes at ages 1 to 17 years and caries experience at 17 years of age, while adjusting for age 1 to 17 fluoride intakes and toothbrushing frequencies.

METHODS

Data Collection

Data used in the current descriptive model analyses were collected as part of the Iowa Fluoride Study (IFS), a longitudinal birth cohort study that investigated fluoride intakes, dietary intakes, and oral health.[21–25] This manuscript was prepared in accordance with STROBE guidelines. IFS questionnaires queried family demographics at birth (1992–1995) and in 2007 and participant beverage intakes, fluoride intakes, and oral hygiene behaviors at 3- to 6-month intervals following birth. Questionnaires were completed using a paper-and-pencil format by parents during early childhood, by parents and participants during later childhood and early adolescence, and by participants during later adolescence. Dental examinations were conducted at approximately 17 years of age. All components of the IFS were approved by the Institutional Review Board at the University of Iowa. Written informed consent was obtained from mothers at the time of their children's birth and from parents at IFS clinic visits, and written assent was provided by participants beginning at age 13 years.

Participants

Mothers (n = 1882) were recruited at the time of their children's birth for participation in the ongoing IFS, and 465 participants were examined at age 17 years. Inclusion in the current analyses (n = 318) required IFS questionnaires completed within a year of both ages 1 and 17 years to interpolate the end points for area-under-the-curve (AUC) calculations for beverage and fluoride intakes, as well as brushing frequency. In addition, at least 1 questionnaire completed between each of the ages 1.00 to 2.00 years, 2.01 to 4.00 years, 4.01 to 6.00 years, 6.01 to 10.00 years, 10.01 to 13.00 years, and 13.01 to 17.00 years, and an age 17-year IFS clinic examination were required.

Predictor Variables

Beverage Intakes.—The frequency and quantity of beverage intakes for the previous week were queried using validated beverage frequency questionnaires embedded in the 3- to 6-month IFS questionnaires.[26,27] Ready-to-drink liquid juice drinks were queried with 100% juice before age 9 years and separately from 100% juice beginning at age 9 years. Beverages were collapsed into 4 categories: cows' milk (including infant formulas and flavored milks), juice (including liquid juice drinks before age 9 years), SSBs (defined as beverages containing added sugars and including liquid juice drinks after age 9 years), and water/sugar-free beverages (water/SFBs). Weighted averages of these daily beverage intakes for ages 1 to 17 years were calculated for each subject from all available questionnaires using trapezoidal AUC. Trapezoidal AUC is calculated by determining the area under the trapezoids created by repeated measures of beverage or fluoride intakes over time, summing these areas, and dividing by the length of the age range.

Fluoride Intakes.—Fluoride intakes from juice, SSBs, water/SFBs, water-absorbing foods, dietary fluoride supplements, and ingested toothpaste were estimated from the IFS questionnaires mailed every 3 to 6 months using IFS specific databases and custom programs written in SAS (version 9.4, 2013 SAS Institute Inc, Cary, North Carolina), as described in earlier IFS publications.[21] Beverage fluoride intakes were calculated from beverage fluoride concentrations and include any water used in preparation. Food fluoride was calculated from the water fluoride concentrations used in preparation of water-absorbing foods (ie, pasta, soup) and quantity of food consumed. Ingested toothpaste fluoride was estimated from toothbrushing frequency, toothpaste fluoride concentration, estimated amount of toothpaste used, and estimated amount of toothpaste swallowed. Total fluoride intakes include juice fluoride, SSB fluoride, water/SFB fluoride, food fluoride, supplement fluoride, and ingested toothpaste fluoride. A variable for total fluoride excluding fluoride from SSBs (non-SSB total fluoride) includes fluoride from juice, water/SFBs, food, supplements, and ingested toothpaste. Daily fluoride intakes for ages 1 to 17 years were calculated for each subject from all available questionnaires using trapezoidal AUC.

Oral Hygiene.—Daily toothbrushing frequencies for ages 1 to 17 years were also estimated from the 3- to 6-month IFS questionnaires using trapezoidal AUC.

Socioeconomic Status.—Three tiers of socioeconomic status (SES) were defined using household income and mother's education at baseline. Low SES was defined by a baseline household income <$30,000 and maternal education below a 4-year college degree. Moderate SES was defined by a household income <$30,000 and a maternal education equivalent to a 4-year college degree or higher, or a household income of $30,000 to $49,999 and a maternal education below a graduate or professional degree. High SES was defined by a household income of $30,000-$49,999 and a maternal education equivalent to a graduate or professional degree, or a household income of $50,000 or more.

Outcome Variable: Dental Caries

Trained and calibrated dental examiners assessed individual tooth surfaces for cavitated caries and fillings to calculate the number of decayed and filled surfaces (DFS) at age 17 years.[24,25] Examinations were conducted using a portable dental chair, mouth mirror, and examination light.

Statistical Analyses

Descriptive statistics (median, 25th percentile, 75th percentile) were calculated for beverage intake AUCs (ounces per day), fluoride intake AUCs (milligrams per day), toothbrushing frequency AUC (times per day), and caries experience at age 17 (DFS count), as well as the count of the number of participants in each SES category (low, moderate, high).

The DFS count is the number of tooth surfaces with decay and/or a filling at age 17. Not all participants had all 128 tooth surfaces present at the age 17-year examination, so an offset term (the number of surfaces scored for a participant) was used to account for missing surfaces. Due to the offset term, instead of the expected DFS count, the expected DFS attack rate (abbreviated DFSAR), which is the expected DFS count for a subject divided by the number of surfaces available for scoring, was modeled.

Although there is considerable evidence that fluoride is protective against caries,[14] there is also evidence that SSBs increase caries.[10] To complicate this matter, all beverages—including SSBs—can contain fluoride. Spearman correlation coefficients and variance inflation factors were used to assess the associations (and potential collinearity) between the AUC values for SSB intakes, total fluoride, and SSB fluoride since both beverage and fluoride intake variables were included in models predicting DFSAR at age 17.

Descriptive model analyses were conducted to identify associations between the predictors (ie, beverage intakes, fluoride intakes, toothbrushing frequency, sex, and SES) and the outcome at age 17 (ie, expected DFSAR at age 17). The DFS count variable had a much smaller mean than variance, suggesting overdispersion. Thus, a negative binomial distribution was used to characterize the adjusted DFS count outcome variable. Univariable generalized linear models (PROC GENMOD in SAS) with a log link function were fit for each beverage, fluoride, toothbrushing, and SES variable under study as the predictor of interest. The log of the number of scored surfaces was used as an offset, effectively rendering the DFS attack rate (DFSAR, as opposed to the DFS count) as the outcome variable.

All multivariable models were adjusted for sex and SES. Since the primary goal of this analysis was to understand the associations between beverage intakes and caries, the first multivariable model included the 4 beverage types and shows the effect of 1 beverage type (8 oz/d) on expected DFSAR after adjusting for intakes of the other beverage types. Additional multivariable models added fluoride variables and/or toothbrushing frequency to the beverage intake model and modeled the effects of intakes from each beverage type, each additional 0.1 mg of fluoride intake, or one additional toothbrushing event per day on the expected DFSAR.

Model selection was guided by the Akaike Information Criterion (AIC), a measure of model fit that penalizes for complexity.[28] Models with lower AIC values are preferred, but models within 2 AIC units are considered roughly equivalent.

Finally, a significance level of .05 was used for all statistical testing.

RESULTS

The mean (±standard deviation) age of participants was 17.7 (±0.7) years at the age 17 clinic examination. Approximately half of the participants were female (53.5%) and most were non-Hispanic white (95.3%). Considering household income and mother's education at baseline, 22.0%, 36.8%, and 41.2% of participants belonged to the low, middle, and high SES categories, respectively.

Median daily beverage intakes are presented in Table 1; milk and water/SFB intakes were generally higher than SSB and juice intakes. Total fluoride intake includes each fluoride source, and medians of the subject-specific ratios of fluoride from SSBs (18%), water/SFBs (35%), and ingested toothpaste fluoride (16%) to total fluoride were calculated to identify the proportion that each fluoride source contributed to total fluoride. The Spearman correlation coefficient between SSB intake and fluoride from SSBs ($r = 0.94$) was high. Moreover, the correlation between SSB intake and total fluoride ($r = 0.34$) was appreciable; collinearity between SSB intake and total fluoride intake was suspected due to the presence of fluoride in SSBs. Although the variance inflation factor for SSB intake was mild when considered in the context of a model with total fluoride intake (1.25 for SSB intake and 2.02 for total fluoride intake), modeling SSB intakes and non-SSB total fluoride allowed us to consider the effects of these 2 factors separately. Total fluoride intake was also correlated with non-SSB total fluoride ($r = .92$). Participants brushed their teeth approximately 1.53 times per day throughout childhood and adolescence. The median (25th, 75th percentile) DFS count was 1 (0, 4) at age 17.

Water/SFB intakes were associated with an unadjusted decrease in expected DFSAR ($P = .034$; Table 2), juice and milk intakes with an unadjusted decrease in expected DFSAR ($P = .057$ and .131, respectively), and SSB intakes with an unadjusted increase in expected DFSAR ($P = .060$). Although total and individual sources of fluoride were not associated with expected DFSAR, toothbrushing frequency was associated with a statistically significant decrease in expected DFSAR. Neither sex nor SES were significantly associated with expected DFSAR in univariable models.

The adjusted effects of beverage intakes were considered in a model that was also adjusted for sex and SES (Table 3). Although higher daily intakes of milk, juice, and water/SFB were associated with a decrease in expected DFSAR, juice had the most pronounced and only statistically significant effect. Higher daily intakes of SSBs were associated with a statistically significant increase in expected DFSAR.

From the univariable models in Table 2, toothbrushing frequency was observed to have a protective association with expected DFSAR. This result remained when toothbrushing was added to the beverage model adjusted for sex and SES (Table 4). The effects of juice and SSBs on expected DFSAR were attenuated in this model, possibly due to confounding between toothbrushing and these variables (ie, increased toothbrushing might lessen the harmful effects of SSBs).

Finally, the addition of the non-SSB total fluoride variable to the beverage model adjusted for toothbrushing, sex, and SES resulted in similar estimated multiplicative effects for the associations of DFSAR with beverage intakes and toothbrushing, except for water/SFB, which became more pronounced and statistically significant. The variable for non-SSB total fluoride was associated with a statistically significant increase in expected DFSAR (Table 5). The model indicates that, after adjustment for other beverage intakes, toothbrushing, non-SSB total fluoride, sex, and baseline SES, each 8 oz of additional daily juice intake throughout childhood and adolescence decreased expected DFSAR at age 17 by 53% (95% confidence interval [CI]: 17%−73%), each 8 oz of additional daily water/SFB intake decreased the expected DFSAR at age 17 by 29% (95% CI: 7%−46%), and each 8 oz of additional daily SSB intake increased the expected DFSAR at age 17 by 42% (95% CI: 5%−92%). After adjustment for beverage intakes, non-SSB total fluoride, sex, and baseline SES, each additional daily tooth brushing event decreased expected DFSAR at age 17 by 43% (95% CI: 14%−62%). Of interest, sex was statistically significant only in models containing toothbrushing, with female subjects having a statistically significant increase in expected DFSAR.

The models with the best penalized fit based on AIC values have been presented in Tables 2 to 5. Of note, the model presented in Table 5 and a model that replaced the non-SSB total fluoride variable with total fluoride from the model in Table 5 had similar penalized fit according to AIC values. Including fluoride from SSBs attenuated the association between SSB intakes and expected DFSAR. Given the correlation and mild collinearity between fluoride and beverage intakes and concerns that fluoride within SSBs might confound the effect of added sugars within SSBs, the model including the non-SSB total fluoride variable was presented (Table 5).

DISCUSSION

In the current analyses, the hypotheses that childhood and adolescent beverage intakes were associated with adolescent caries experience and that the associations were influenced by fluoride intakes and toothbrushing behaviors were investigated. Juice and water/SFB intakes were associated with decreased risks of caries, and SSB intakes were associated with increased risk of caries in unadjusted models and the beverage model adjusted for sex and SES. Adjustment for toothbrushing reduced the effects of beverages on the expected DFSAR, and subsequent adjustment for non-SSB total fluoride had little impact on the beverage effects, with the exception of water/SFBs.

The findings reported herein are consistent with previous investigations of beverages and dental caries in children, adolescents, and adults.[13,16–18,29–31] Age 1- to 5-year regular soda pop and reconstituted powdered beverage intakes were associated with caries risk in IFS participants at age 5 years.[18] More recently, Palmer et al[17] reported that children aged 2 to 6 years from Boston with severe early childhood caries had more frequent intakes of cariogenic liquids than their caries-free peers (4.66 ± 0.36/d vs 2.72 ± 0.34 exposures/d, respectively; $P < .05$). Similarly, Evans et al[13] reported that children aged 2 to 6 years from Columbus or Cincinnati, Ohio, or Washington, DC, with severe early childhood caries had higher SSB intakes than their caries-free peers (1.80 ± 2.21 vs 1.17 ± 1.66 8-oz servings/d, respectively; $P < .001$). In addition, juice intakes were not consistently associated with increased caries risk in IFS children at 1 to 5 years,[16,18] and Evans et al[13] reported that 100% juice was not associated with an increased caries risk in their cohort. Kolker et al[30] reported that 100% juice excluding orange juice was associated with a reduced caries risk in African American children aged 3 to 5 years from Detroit, Michigan.

The current findings extend previous knowledge of associations between SSBs and caries by considering all beverage categories within one model, and considering the effects of exposures during childhood and adolescence on caries experience at age 17. The findings suggest that childhood and adolescent SSB intakes increase caries risk, juice, and water/SFB intakes reduce caries risk, and milk intakes do not influence caries risk.

Few previous investigations of the associations between beverage intakes and caries experience have considered concurrent fluoride exposures and/or toothbrushing behaviors. The findings reported herein are consistent with those of Armfield et al,[9] who investigated cross-sectional associations among SSB frequency, water fluoride exposure, toothbrushing frequency, and dental caries in Australian children aged 5 to 16 years. They reported that caries was significantly higher with greater SSB frequency after controlling for toothbrushing frequency, and exposure to water fluoride reduced the impact of SSB exposure. Kolker et al[30] reported that brushing frequency was not associated with caries when investigating associations among beverage intakes and caries.

Although fluoride is known to protect against caries, the preventive fraction attributable to any one source is difficult to ascertain. Individuals choose to use fluoridated toothpaste and mouth rinses and are exposed to varying concentrations of fluoride in water, juices, and foods or beverages prepared with water.[32–34] In the current analyses, the main sources of fluoride intake were investigated in addition to total fluoride exposure (data not shown). SSBs contain both sugar and fluoride, with each having hypothesized opposite effects on the caries process. Adjustment for SSB fluoride intake induced confounding and reduced the estimated multiplicative effect of SSB intake. Therefore, SSB fluoride was excluded from the analyses to obtain a more meaningful estimate of the associations among SSB intake, fluoride intake, and DFSAR.

Furthermore, fluoride intake variables were not associated with decreased risks of caries in any multivariable model, suggesting that ingested fluoride effects were attenuated by beverage intakes or toothbrushing. There is inherent collinearity between beverage and fluoride intakes due to most beverages containing some fluoride; similarly, there is collinearity between fluoride intake and toothbrushing due to virtually all participants using fluoride toothpaste. Both of these relationships make it difficult to identify true individual contributors to DFSAR. Moreover, these analyses considered fluoride ingested from toothpaste, which may not accurately reflect fluoride exposure from toothpaste or other dental products. Finally, IFS participants had a limited range of fluoride intakes, which could also explain the lack of a significant effect. These findings suggest that future investigations of fluoride should consider fluoride exposures, and the sources of fluoride, including competing antagonistic risk factors, such as SSB intake.

The IFS has both strengths and weaknesses. The IFS is a unique study with which to investigate the effects of exposures during childhood and adolescence on adolescent caries in a cohort followed for over 17 years. Validated instruments were used to query beverage intakes, and calibrated examiners assessed caries experience. The long follow-up period allowed us to examine beverage, fluoride, and toothbrushing effects on caries without concerns regarding cohort effects that could impact repeat cross-sectional studies. Weaknesses include caregiver-reported (early ages) and self-reported (later ages) dietary intakes and toothbrushing frequency that might not reflect reality. Beverage questionnaires combined 100% juice and liquid juice drinks prior to age 9 years, as the beverage frequency questionnaire was initially designed to capture beverage fluoride intakes. The nutritional and oral health significance of juice vs juice drink differences were not appreciated when this study was initiated in the early 1990s. Inclusion of liquid juice drinks with 100% juice prior to 9 years of age could have reduced the strength of both 100% juices' and SSBs' effects on caries. The self-selected sample is relatively small, mostly White, reasonably well educated and wealthy, and likely not representative of other US or international populations.

CONCLUSIONS

The current findings extend previous research associating higher SSB intakes with increased risk of dental caries by investigating the effects of childhood and adolescent beverage exposures on caries attack rates, while adjusting for fluoride intakes and toothbrushing behaviors over the same age ranges. Herein, higher SSB intakes were identified as a risk factor for higher expected DFSAR and higher intakes of juice and water/SFB and greater toothbrushing frequency as protective factors. The findings support public health initiatives targeting reduction of SSB consumption during childhood and adolescence.

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References

1. US Department of Health and Human Services. Oral Health in America: A Report of the Surgeon General. Rockville, MD: U.S. Department of Health and Human Services, National Institute of Dental and Craniofacial Research, National Institutes of Health; 2000.
2. Fleming E, Afful J. Prevalence of total and untreated dental caries among youth: United States, 2015–2016. NCHS Data Brief. No 307 Hyattsville, MD: National Center for Health Statistics; 2018.
3. Figuero E, Nobrega DF, Garcia-Gargallo M, Tenuta LM, Herrera D, Carvalho JC. Mechanical and chemical plaque control in the simultaneous management of gingivitis and careis: A systematic review. J. Clin Periodontol 2017;44(Suppl 18):116–134.
4. Kumar S, Takadamadla J, Johnson NW. Effect of toothbrushing frequency on incidence and increment of dental caries: A systematic review and meta-analyses. J Dent Res. 2016;95(1):1230–1236. [PubMed: 27334438]

5. Peterson J Solving the mystery of the Colorado brown stain. J Hist Dent. 1997;45(2):57–61. [PubMed: 9468893]
6. Featherstone JDB. Prevention and reversal of dental caries: Role of low level fluoride. Community Dent Oral Epidemiol. 1999;27:31–40. [PubMed: 10086924]
7. Griffin SO, Regnier E, Griffin PM, Huntley V. Effectiveness of fluoride in preventing caries in adults. J Dent Res. 2007;86(5):410–415. [PubMed: 17452559]
8. Aoun A, Darwiche F, Al Hayek S, Doumit J. The fluoride debate: The pros and cons of fluoridation. Prev Nutr Food Sci. 2018;23(3):71–180.
9. Armfield JM, Spencer J, Roberts-Thomson KF, Plastow K. Water fluoridation and the association of sugar-sweetened beverage consumption and dental caries in Australian children. Am J Public Health. 2013;103(3):494–500. [PubMed: 23327241]
10. Pollick H The role of fluoride in the prevention of tooth decay. Pediatr Clin N Am. 2018;65:923–940.
11. Sheiham A, James WPT. Diet and dental caries: The pivotal role of free sugars reemphasized. J Dent Res. 2015;94(10):1341–1347. [PubMed: 26261186]
12. Moyniham PJ, Kelley SAM. Effect on caries of restricting sugars intakes: Systematic review to inform WHO guidelines. J Dent Res. 2014;93(1):8–18. [PubMed: 24323509]
13. Evans EW, Hayes C, Palmer CA, Bermudez OI, Cohen SA, Must A. Dietary intake and severe early childhood caries in low-income, young children. J Acad Nutr Diet. 2013;113(8):1057–1061. [PubMed: 23706351]
14. Hong J, Whelton H, Douglas G, Kang J. Consumption frequency of added sugars and UK children's dental caries. Community Dent Oral Epidemiol. 2018;46:457–464. [PubMed: 30125961]
15. Johansson I, Holgerson PL, Kressin NR, Nunn ME, Tanner AC. Snacking habits and caries in young children. Caries Res. 2010;44: 421–430. [PubMed: 20720422]
16. Marshall TA, Broffitt B, Eichenberger-Gilmore, Warren JJ, Cunningham MA, Levy SM. The roles of meal, snack and daily total food and beverage exposures on caries experience in young children. J Pub Health Dent. 2005;65(3):166–173. [PubMed: 16171262]
17. Palmer CA, Kent R, Loo CY, et al. Diet and caries-associated bacteria in severe early childhood caries. J Dent Res. 2010;89(11):1224–1229. [PubMed: 20858780]
18. Marshall TA, Levy SM, Broffitt B, et al. Dental caries and beverage consumption in young children. Pediatr. 2003;112(3):e184–e191.
19. Marshall TA, Eichenberger-Gilmore JM, Broffitt BA, Warren JJ, Levy SM. Dental caries and childhood obesity: Roles of diet and socioeconomic status. Community Dent Oral Epidemiol. 2007;35:449–458. [PubMed: 18039286]
20. Wilder JR, Kaste LM, Handler A, Chapple-McGruder T, Rankin KM. The association between sugar-sweetened beverages and dental caries among third-grade students in Georgia. J Public Health Dent. 2016;76(1):76–84. [PubMed: 26339945]
21. Curtis AM, VanBuren J, Cavanaugh JE, Warren JJ, Marshall TA, Levy SM. Longitudinal associations between dental caries increment and risk factors in late childhood and adolescence. J Public Health Dent. 2018;78(4):321–328. [PubMed: 29752831]
22. Janz KF, Gilmore JM, Burns TL, et al. Physical activity augments bone mineral accrual in young children: The XXXX Bone Development study. J Pediatr. 2006;148(6):793–799. [PubMed: 16769389]
23. Marshall TA, Curtis AM, Cavanaugh JE, Warren JJ, Levy SM. Higher longitudinal milk intakes are associated with increased height in a birth cohort followed for 17 years. J Nutr. 2018;148(7):1144–1149. [PubMed: 29924327]
24. Warren JJ, Levy SA, Kanellis MJ. Dental caries in the primary dentition: Assessing prevalence of cavitated and noncavitated lesions. J Public Health Dent. 2002;62(2):109–114. [PubMed: 11989205]
25. Warren JJ, Levy SM, Broffitt B, Kanellis MJ. Longitudinal study of noncavitated carious lesion progression in the primary dentition. J Public Health Dent. 2006;66(2):83–87. [PubMed: 16711625]

26. Marshall TA, Eichenberger Gilmore JM, Broffitt B, Levy SM, Stumbo PG. Relative validation of a beverage frequency questionnaire in children ages 6 months through 5 years using 3-day food and beverage diaries. J Am Diet Assoc. 2003;103(6):714–720. [PubMed: 12778043]
27. Marshall TA, Eichenberger Gilmore JM, Broffitt B, Stumbo PH, Levy SM. Relative validity of the XXXX Fluoride Study targeted nutrient semi-quantitative questionnaire and the Block Kids' Food Questionnaire for estimating beverage, calcium and vitamin D intakes by children. J Am Diet Assoc. 2008;108(3):465–472. [PubMed: 18313429]
28. Akaike H Information theory and an extension of the maximum likelihood principle In: Petrov BN, Csáki F, eds. Second International Symposium on Information Theory. Budapest: Akadémiai Kiadó; 1973: 267–281.
29. Kim S, Park S, Lin M. Permanent tooth loss and sugar-sweetened beverage intake in U.S. young adults. J Public Health Dent. 2017;77(2):148–154. [PubMed: 27886383]
30. Kolker JL, Yuan Y, Burt BA, Sandretto AM, Sohn W, Lang SW, Ismail A. Dental caries and dietary patterns in low-income African American children. Pediatr Dent. 2007;29(6):457–464. [PubMed: 18254414]
31. Wiener RC, Shen C, Findley PA, Sambamoorthi U, Tan X. The association between diabetes mellitus, sugar-sweetened beverages, and tooth loss in adults: Evidence from 18 states. J Am Dent Assoc. 2017;14(7):500–509.
32. Heilman JR, Kiritsy MC, Levy SM, Wefel JS. Assessing fluoride levels of carbonated soft drinks. J Am Dent Assoc. 1999;130(11):153–1599.
33. Kiritsy MC, Levy SM, Warren JJ, Guha-Chowdury N, Heilman JR, Marshall T. Assessing fluoride concentrations of juices and juice-flavored drinks. J Am Dent Assoc. 1996;127(7):895–902. [PubMed: 8754464]
34. Van Winkle S, Levy SM, Kiritsy MC, Heilman JR, Wefel JS, Marshall T. Water and formula fluoride concentrations: Significance for infants fed formula. Pediatr Dent. 1995;17(4):305–310. [PubMed: 7567636]

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RESEARCH SNAPSHOT

Research Question:

Are childhood and adolescent beverage intakes associated with caries at 17 years of age, following adjustment for fluoride intakes and toothbrushing?

Key Findings:

Each 8 oz of additional daily juice and water/sugar-free beverage intakes decreased the expected decayed or filled surface attack rate (DFSAR) by 53% and 29%, respectively, and 8 oz of sugar-sweetened beverages (SSBs) increased expected DFSAR by 42%, after adjustment for other beverage intakes, toothbrushing, total fluoride intake excluding SSB fluoride (non-SSB total fluoride), sex, and baseline socioeconomic status (all $P < .05$).

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Table 1.

Age 1- to 17-year median (25th, 75th percentile) AUC[a] of daily beverage intakes, fluoride intakes, and toothbrushing frequencies and DFS[b] counts at age 17 years of Iowa Fluoride Study participants (n = 318)

Variable	Median (25th, 75th percentile)
Milk (oz/d)	12.4 (8.8, 16.3)
Juice[c] (oz/d)	4.0 (2.7, 5.4)
SSBs[d] (oz/d)	6.6 (4.3, 10.2)
Water/SFB[e] (oz/d)	10.6 (7.9, 15.4)
Total fluoride (mg/d)	0.70 (0.55, 0.87)
SSB fluoride (mg/d)	0.13 (0.08, 0.20)
Water/SFB fluoride (mg/d)	0.24 (0.14, 0.37)
Ingested toothpaste fluoride (mg/d)	0.10 (0.05, 0.17)
Total fluoride excluding SSB fluoride (mg/d)	0.55 (0.41, 0.72)
Toothbrushing (times/d)	1.53 (1.16, 1.81)
DFS count	1 (0, 4)

[a]AUC = area under the curve.

[b]DFS = decayed and filled surfaces.

[c]100% juice, including juice drinks before age 9 years.

[d]SSB = sugar-sweetened beverages, including liquid juice drinks after 9 years.

[e]Water/SFB = water and other sugar-free beverages.

Table 2.

Unadjusted effects of age 1- to 17-year AUC[a] of daily beverage intakes, fluoride intakes, toothbrushing frequency, sex and SES[b] on expected DFSAR[c] at age 17 years in Iowa Fluoride Study Participants (AIC[d] range: 1404.4–1414.4)

Variable of interest	Estimated multiplicative effect of exposure (95% CI[e])[f]	*P* value
Milk[g]	0.83 (0.66–1.06)	.131
Juice[gh]	0.59 (0.34–1.02)	.057
SSB[gi]	1.31 (0.99–1.74)	.060
Water/SFB[gj]	0.80 (0.65–0.98)	.034
Total fluoride[k]	1.01 (0.95–1.07)	.792
SSB fluoride[k]	1.15 (0.98–1.36)	.094
Water/SFB fluoride[k]	0.97 (0.89–1.06)	.456
Ingested toothpaste fluoride[k]	1.07 (0.93–1.24)	.334
Total fluoride excluding SSB fluoride[k]	0.99 (0.92–1.05)	.668
Toothbrushing[l]	0.57 (0.39–0.83)	.003
Female indicator	1.22 (0.88–1.70)	.235
Baseline SES—low	1 (reference)	—
Baseline SES—middle	0.83 (0.54–1.30)	.422
Baseline SES—high	0.87 (0.57–1.34)	.539

[a]AUC = area under the curve.

[b]SES = socioeconomic status.

[c]DFSAR = decayed and filled surface.

[d]AIC = Akaike Information Criterion.

[e]CI = confidence interval.

[f]Estimated multiplicative effect of exposure of variable on expected DFSAR from unadjusted generalized linear models based on the negative binomial distribution with a log link function.

[g]Effect for each additional 8 oz beverage/d.

[h]100% juice, including juice drinks before age 9 years.

[i]SSB = sugar-sweetened beverages, including liquid juice drinks after 9 years.

[j]Water/SFB = water and other sugar-free beverages.

[k]Effect for each additional 0.1 mg fluoride/d.

[l]Effect of each additional toothbrushing/d.

Table 3.

Effect of beverage intakes on expected DFSAR[a] at age 17 years, adjusted for other beverage intakes, sex, and SES[b] in Iowa Fluoride Study Participants (AIC[c] = 1405.9)

Variable of interest	Estimated multiplicative effect of exposure (95% CI[d])[e]	*P* value
Milk[f]	0.87 (0.68–1.11)	.258
Juice[fg]	0.45 (0.25–0.78)	.005
SSB[fh]	1.52 (1.12–2.06)	.007
Water/SFB[fi]	0.82 (0.66–1.01)	.057
Female indicator	1.31 (0.94–1.82)	.107
Baseline SES—low	1 (reference)	—
Baseline SES—middle	0.86 (0.55–1.33)	.491
Baseline SES - high	1.09 (0.70–1.72)	.701

[a]DFSAR = Decayed and filled surfaces.

[b]SES = Socioeconomic status.

[c]AIC = Akaike Information Criterion.

[d]CI = confidence interval.

[e]Estimated multiplicative effect of exposure of beverage on expected DFS from gender and SES adjusted generalized linear models based on the negative binomial distribution with a log link function.

[f]Effect for each additional 8 oz beverage/d.

[g]100% juice, including juice drinks before age 9 years.

[i]Water/SFB = water and other sugar-free beverages.

[h]SSB = sugar-sweetened beverages, including liquid juice drinks after 9 years.

Table 4.

Effect of beverage intakes on expected DFSAR[a] at age 17 years, adjusted for other beverage intakes, toothbrushing frequency, sex, and SES[b] in Iowa Fluoride Study participants. (AIC[c] = 1402.0)

Variable of interest	Estimated multiplicative effect of exposure (95% CI[d])[e]	*P* value
Milk[f]	0.88 (0.69–1.12)	.293
Juice[fg]	0.51 (0.29–0.90)	.019
SSB[fh]	1.40 (1.03–1.90)	.034
Water/SFB[fi]	0.86 (0.69–1.07)	.172
Toothbrushing[j]	0.59 (0.39–0.90)	.014
Female indicator	1.45 (1.03–2.03)	.031
Baseline SES—low	1 (reference)	—
Baseline SES—middle	0.79 (0.51–1.23)	.302
Baseline SES—high	1.11 (0.71–1.74)	.644

[a]DFSAR = decayed and filled surfaces.

[b]SES = socioeconomic status.

[c]AIC = Akaike Information Criterion.

[d]CI = confidence interval.

[e]Estimated multiplicative effect of exposure of beverage on expected DFSAR from gender and SES adjusted generalized linear models based on the negative binomial distribution with a log link function.

[f]Effect for each additional 8 oz beverage/d.

[g]100% juice, including juice drinks before age 9 years.

[h]SSB = sugar-sweetened beverages, including liquid juice drinks after 9 years.

[i]Water/SFB = water and other sugar-free beverages.

[j]Effect of each additional toothbrushing event/d.

Table 5.

Effect of beverage intakes on expected DFSAR[a] at age 17 years, adjusted for other beverage intakes, fluoride intake, toothbrushing frequency, sex, and SES[b] in Iowa Fluoride Study participants (AIC[c] = 1399.1)

Variable of interest	Estimated multiplicative effect of exposure (95% CI[d])[e]	*P* value
Milk[f]	0.87 (0.69–1.11)	.254
Juice[fg]	0.47 (0.27–0.83)	.009
SSB[fh]	1.42 (1.05–1.92)	.025
Water/SFB[fi]	0.71 (0.54–0.93)	.014
Total fluoride, excluding SSB fluoride[j]	1.10 (1.01–1.20)	.029
Toothbrushing[k]	0.57 (0.38–0.86)	.008
Female indicator	1.55 (1.11–2.18)	.011
Baseline SES—low	1 (reference)	—
Baseline SES—middle	0.82 (0.53–1.27)	.366
Baseline SES—high	1.13 (0.73–1.76)	.582

[a]DFSAR = decayed and filled surfaces.

[b]SES = socioeconomic status.

[c]AIC = Akaike Information Criterion.

[d]CI = confidence interval.

[e]Estimated multiplicative effect of exposure of beverage on expected DFSAR from gender and socioeconomic adjusted generalized linear models based on the negative binomial distribution with a log link function.

[f]Effect for each additional 8 oz beverage/d.

[g]100% juice, including juice drinks before age 9 years.

[h]SSB = sugar-sweetened beverages, including liquid juice drinks after 9 years.

[i]Water/SFB = water and other sugar-free beverages.

[j]Effect for each additional 0.1 mg fluoride/d.

[k]Effect of each additional toothbrushing event/d.