CROSS-SECTIONAL STUDY

Sugar-Sweetened Beverage Consumption and Caries Prevalence in Underserved Black Adolescents

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Abstract: ***Purpose:*** *The purpose of this study was to examine the association between sugar-sweetened beverage (SSB) consumption and dental caries prevalence among underserved Black adolescents.* ***Methods:*** *This was a cross-sectional study of 545 Black adolescents, ages 12 to 17 years, who participated in the Howard Meharry Adolescent Caries Study (HMACS). The outcome was dental caries prevalence, measured using the decayed, missing, and filled permanent tooth surfaces (DMFS) index. Participants were recruited from middle and high schools in Washington, D.C., USA, and Nashville, Tenn., USA. Questionnaires were used to assess beverage intake, demographic, and health-related behavioral characteristics. The multivariable analysis used marginalized zero-inflated Poisson regression (MZIP) stratified by toothbrushing frequency to estimate adjusted mean caries ratios (MRs), adjusted odds ratios (ORs), and 95 percent confidence intervals (95 percent CIs).* ***Results:*** *The mean age of the participants was 14.1 years. Participants in the highest quartile for SSB consumption had a higher caries ratio than those in the lowest quartile [MR equals (=) 1.59, 95 percent CI equals 1.15 to 2.20] and a lower odds of not being at risk for caries (OR = 0.24, 95 percent CI = 0.09 to 0.61). These findings were only observed among those brushing once a day or less (n=202).* ***Conclusions:*** *Among Black adolescents in this study who brushed once a day or less, high levels of sugar-sweetened beverage consumption were associated with greater caries prevalence and a reduced likelihood of remaining caries-free than those with lower levels of SSB consumption. Future studies will focus on interventions to reduce SSB consumption.* *(Pediatr Dent 2021;43(5):363-70) Received March 15, 2021 / Last Revision July 21, 2021 / Accepted July 23, 2021*

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Dental caries is the most common chronic disease of childhood, affecting a disproportionate number of children and adolescents from low socioeconomic and/or minority households.[1] In the United States, the prevalence of dental caries in patients aged two to 19 years from families below the federal poverty level was 56.3 percent compared to 34.8 percent in their peers from families at 300+ percent of the federal poverty level in 2015 to 2016.[2] The prevalence of dental caries in non-Hispanic Black children aged two to 19 years was 48.1 percent in 2015 to 2016[2]; the prevalence of untreated caries in non-Hispanic Black children aged five to 19 years was 15.7 percent in 2015 to 2018.[3]

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Untreated dental caries during childhood can negatively impact school performance and attendance as well as quality of life.[4] Furthermore, a previous history of dental caries is the primary risk factor for subsequent dental caries development, magnifying the extent of disparities observed in minority populations.[5] Given the high prevalence of dental caries in Black youth, understanding the factors contributing to the dental caries process during childhood and adolescence is necessary to design interventions and prevent disease progression throughout the lifespan.

Dental caries is a diet-related disease; fermentable carbohydrates are necessary, if not sufficient, for the caries process to occur.[6] The cariogenic bacteria produce acid as a byproduct of the carbohydrate fermentation process, which demineralizes enamel and/or dentin in a site-specific manner resulting in caries. In contemporary society, sugar-sweetened beverages (**SSBs**), defined as beverages containing added sugars, are the dietary item most closely associated with caries in young children.[7]

Marshall et al. reported associations between caries and soda pop, reconstituted powdered beverages, and to a lesser extent 100 percent juice in primarily white children aged two to five years.[7] More recently, that research group reported that higher SSB intake was associated with an increased risk of caries, and higher 100 percent juice intake was associated with a decreased risk of caries at age 17 years following adjustment for other beverage intakes, toothbrushing, total fluoride, sex, and baseline socioeconomic status.[8] Using NHANES data, Laniado et al. recently reported that untreated caries was higher in SSB consumers compared to nonconsumers both before and after adjustment for multiple demographic variables including race.[9] SSB intake declined steadily between 2003 and 2004

and between 2015 and 2016 for children aged two to 18 years, yet intakes remain high among non-Hispanic Black boys (i.e., 167 kilocalories per day) and girls (i.e., 156 kilocalories per day) aged two to 19 years.[10,11]

Most investigations of the association between SSBs and dental caries have been conducted in young children. More importantly, knowledge of associations among SSBs and dental caries among low socioeconomic and/or Black adolescents is limited. Evidence suggests that disruption of the oral biofilm at the tooth surface during toothbrushing limits plaque development and may decrease the risk of caries.[12] Kumar et al. reported that infrequent brushers had both higher incidence and increment of new carious lesions, although it is unknown definitively whether the effects of brushing are due to delivery of toothpaste fluoride, brushers' greater health awareness, or higher socioeconomic status.[13] While few studies exploring associations between SSB intakes and caries include an adjustment for toothbrushing, Marshall et al. recently reported that daily toothbrushing throughout childhood was associated with a reduced risk of caries at age 17 years after adjusting for beverage intake.[8] Both caries prevalence and SSB intakes are high among Black youth and few, if any, studies have investigated associations among SSBs, toothbrushing, and caries in this population.

The purpose of this study was to address this gap in the literature by investigating the association between sugar-sweetened beverage intake and dental caries among underserved Black adolescents living in Washington, D.C., USA, and Nashville, Tenn., USA, utilizing a marginalized zero-inflated Poisson (**MZIP**) regression analysis. The authors hypothesized that SSB intake is associated with dental caries in Black adolescents and that the association is modified by toothbrushing frequency.

Methods

Data source. The Howard Meharry Adolescent Caries Study (HMACS) was a cross-sectional study designed to examine the association between SSB consumption and dental caries.[14] The participants included underserved adolescents ages 12 to 17 from two locations in the United States with high proportions of Black residents that comprised areas classified as underserved by the District of Columbia or the state of Tennessee. Participants were recruited from middle and high schools from May 2017 through June 2019. The Institutional Review Boards at Howard University and Meharry Medical College approved the study protocols. Caregivers and adolescents provided written informed consent and assent, respectively.

Students were eligible to participate in the study if they attended any of the participating middle and high schools in Washington, D.C. or Nashville. The study investigators approached the leadership of middle and high schools located in underserved areas and discussed the study details to determine if the schools would be willing to participate. Schools were then selected after conversations between members of the research team and community leaders. Schools were included that indicated a willingness to participate in the study after the community-based engagement phase. Adolescents were excluded from participating if they were on anticoagulant medication, were currently receiving chemotherapy, had received organ transplants of any type, or were diagnosed with leukemia. Adolescents were recruited through the use of flyers or contacted directly during school hours by school staff. Potential participants also approached the staff about participating in the study after hearing about the study from other students. Staff members who completed Institutional Review Board (**IRB**)-approved human subject research training recruited students at school while in session or at the end of the school day and enrolled them if the parent or caregiver provided positive signed informed consent. Participants received a $20 gift card as compensation after successfully completing all phases of the study.

Exposure variables. The principal independent variables were beverage intake categorized into the various types of beverages that participants consumed. A detailed questionnaire, answered by the adolescent participant and based on a previously validated beverage instrument, included the following two questions for each beverage listed: (1) How many times do you drink (specific beverage) per week? and (2) How much (specific beverage in ounces) do you usually drink each time?[15] To determine drink type and consumption volume, the questionnaire included photo representations of each type of beverage consumed. Calculation of average daily intake for each beverage used responses to these two questions.

During the initial study phase, the authors pilot-tested the questionnaire with the target audience and made repeated content revisions to ensure that the beverage options, including photo representations, reflected beverages the participants most commonly consumed. After this phase was completed, data collection was initiated and specifics on beverage consumption were collected by the dental investigators or students approved by the IRB and trained by the dental investigators in survey administration. The beverages consumed were collapsed into four distinct categories for analysis: (1) milk, which included cow's milk, chocolate milk, and plant-based milk; (2) 100 percent juice; 3) SSBs, which included juice drinks, flavored waters, powdered sugar beverages, regular soda, sports drinks, energy drinks, and other SSBs including lemonade or sweet tea; and (4) sugar-free beverages (**SFBs**), which included diet soda, unsweetened iced tea, and water.

Outcome variable. This study defined caries experience as a count outcome in terms of the number of cavitated decayed, missing, and filled primary tooth surfaces (**DMFS**), where missing surfaces are included if the examiner determined the tooth was missing due to dental decay. Examiners completed standardized examinations for dental caries on the permanent dentition and did not include noncavitated carious lesions in their diagnosis.[16] Before data collection, two examiners each from the Howard University College of Dentistry, Washington, D.C., and two examiners from the Meharry Medical College School of Dentistry, Nashville, were calibrated in diagnosing dental caries over two days. The gold-standard examiner from Howard University was the first author, and the gold examiner for Meharry Medical College was the third author. Training included the examiners receiving a manual describing study protocols and examination criteria and the use of photographic slides in the training session to explain the caries diagnostic criteria and examination protocol. Thirty adolescents participated in the two-day calibration session with a gold-standard examiner. After the calibration session, the inter-examiner Kappa scores ranged from 0.71 to 0.80. The intra-examiner Kappa scores ranged from 0.68 to 0.86, and the one examiner whose intra-examiner scores fell below 0.70 was provided with additional training before the end of the two-day session. Following the training sessions and during data collection, the examiners performed oral examinations in the participating schools using portable equipment and compressed

air without radiographs. Data capture used hard copy forms in the field that were transferred to online software for data management. All entries from the hard copy to the online software used were entered twice to reduce the likelihood of error.

Other variables (covariates). Information was collected on potential confounding and interacting variables for dental caries using the adolescent and caregiver questionnaires, with the former administered verbally and the latter via a self-reported written form. Trained and calibrated IRB-approved researchers administered the adolescent questionnaire with the key question on toothbrushing frequency posed as an open-ended question: "How many times a day do you brush your teeth?" The caregiver questionnaire was sent home to parents with the adolescents and made available when present at the participating schools. The caregiver completed the questionnaire during school hours or on their own at a location other than the participating school. The adolescent participants reported their age and gender on the student questionnaire, whether or not they had a dentist, and the reason for the last dental visit. Caregivers provided information about the adolescents' race/ethnicity, highest educational level, and the annual income level of the caregiver on the questionnaire.

The sample size was determined by powering the coefficient of the independent variable of interest, "SSB consumption" in the count regression model. For this study, the power was set at 0.90, the desired alpha level was set at 0.025, and the baseline response rate was assumed to be 60 percent based on previously published studies. The overall sample size necessary to detect an effect size of 15 percent was determined to be 344 patients. These estimates were obtained using the participant as the unit of analysis and a count regression where the number of carious lesions was the dependent variable.

Statistical methods. The distribution of dental caries in children and adolescents is often characterized by high numbers of zero counts, which suggests the use of zero-inflated count regression models.[17] Most recently, the use of marginalized zero-inflated count models has been recommended for the analysis of caries data in oral health surveys and epidemiological studies as a useful alternative to zero-inflated models when exposure effects in the overall population are of interest.[18] Zero-inflated and marginalized zero-inflated count models include a mixture of standard probability distributions for count data representing a population at risk for caries and a subpopulation with only zero counts considered to be not at risk for developing caries.[18]

The MZIP allows researchers to model the likelihood of remaining without caries (in other words, of being not at risk for caries) expressed as an odds ratio (**OR**) and also the mean overall caries count rate expressed as the mean ratio (**MR**) when comparing an exposed group to its baseline reference group. Researchers cannot observe whether a zero caries count is from the group not at risk for caries or a random zero from the at-risk group. The two groups are considered latent classes, meaning that class membership for a child with zero caries cannot be known except probabilistically. Unlike zero-inflated models, marginalized zero-inflated regression directly estimates the mean caries ratio (ratio of mean caries counts) for the overall study population instead of only in the latent class mean of those considered to be at risk of caries.[18]

The MZIP model estimated the associations between beverage consumption and dental caries count. As discussed earlier, the advantages of the MZIP are that it allows the analysis to account for the excess zero caries counts common in the participants and also permits directly modeling the association between exposure variables, covariates, and the marginal (overall) mean caries count in a cross-sectional study. This

Table 1. DEMOGRAPHICS OF BLACK PARTICIPANTS AND NON-BLACK EXCLUDED PARTICIPANTS AND CAREGIVERS IN A STUDY POPULATION FOR THE HOWARD MEHARRY ADOLESCENT CARIES STUDY

Variable	Category	Black (N=545)	Non-Black (N=63)	*P*-value†
*Age**		14.1(0.1)	14.8(0.2)	<0.01
Gender		%	%	
	Male	44.9	31.1	<0.05
	Female	55.1	68.9	
Household income of caregiver		%	%	
	$0 $10,000	11.2	6.3	0.34
	$10,001-$20,000	8.1	12.7	
	$20,001-$30,000	15.9	23.8	
	$30,001-$40,000	16.9	11.1	
	$40,001-$50,000	10.6	11.1	
	$50,001 or more	15.0	17.5	
	Other/left blank	22.3	17.5	
Education level of caregiver		%	%	
	Some high school	16.6	33.3	<0.01
	High school grad or GED	33.3	23.8	
	Some college	18.3	7.9	
	≥2-year degree	31.8	35.0	
Region		%	%	
	Tennessee	47.9	77.4	<0.01
	Distric of Columbia	52.1	22.6	
Toothbrushing frequency		%	%	
	≥2x/day	58.5	66.1	0.25
	≤1x/day	41.5	33.9	
Participant has a dentist		%		
	Yes	85.3	65.6	<0.01
	No	14.3	34.4	
	Other/left blank	0.1	0.0	
Reason for last dental visit		%		
	Checkup or prophylaxis	75.3	66.7	0.11
	Planned treatment	16.3	21.7	
	Accident or injury	1.3	1.6	
	Tooth pain	1.3	3.3	
	Other/left blank	5.8	6.7	

* Values for age are mean values and standard deviations in parentheses.

† *P*-values are for chi-square tests for categorical variables or t-tests for continuous variables comparing Black participants and excluded non-Black participants.

Table 2. BEVERAGE CONSUMPTION AND DECAYED, MISSING, FILLED, SURFACES (DMFS) SCORES FOR HOWARD MEHARRY ADOLESCENT CARIES STUDY OF ADOLESCENT PARTICIPANTS*

	Beverage consumption†	DMFS score ‡
Drink type (N)		
Milk (N=455)	8.9±12.1	3.2±3.3
100% juice (N=437)	7.1±10.0	3.1±3.4
SSBs (N=527)	28.8±32.5	3.3±3.5
SFBs (N=524)	32.1±57.9	3.3±3.5

* Abbreviations used in this table: SSBs=sugar-sweetened beverages; SFBs= sugar-free beverages.

† Beverage consumption in ounces per day showing mean values and standard deviation.

‡ Decayed, missing, filled, surfaces score showing mean values and standard deviation.

analysis was conducted following an a priori plan to adjust models for age, gender, socioeconomic status, and region and to also stratify by toothbrushing frequency.[19,20] The beverage consumption volumes for each beverage type were collapsed into quartiles, with the lowest quartile serving as the reference. As there were many missing values for income (23.4 percent), the adjusted models included the educational level of the caregiver instead of household income level as a measure of socioeconomic status. Excluded were all who were not identified as Black or African American by their caregiver following the study hypothesis.

For sensitivity analysis, the demographic characteristics of the excluded non-Black participants (N=63) were compared to the Black participants (N=545) and the multivariable regression analysis repeated with the full complement of participants, regardless of race/ethnicity. All tests were two-sided with an alpha level of up to 0.05. Analyses were completed using SAS 9.4 software (SAS Institute, Cary, N.C., USA) and STATA 16 software (STATACorp, College Station, Texas, USA).[21] Participants with missing values were excluded from their respective analyses.

Table 3. ESTIMATED ODDS RATIOS AND MEAN CARIES COUNT RATIOS AMONG BLACK ADOLESCENTS AGES 12 TO 17 STRATIFIED BY TOOTHBRUSHING FREQUENCY USING THE MARGINALIZED ZERO-INFLATED POISSON REGRESSION MODEL IN THE HOWARD MEHARRY ADOLESCENT CARIES STUDY*

	Odds ratio (95% CI)				Mean caries ratio (95% CI)			
	≤1x/day	*P*-value†	≥2x/day	*P*-value	≤1x/day	*P*-value	≥2x/day	*P*-value
Beverage								
Milk								
≤3.1	1.00 (reference)	–	1.00 (reference)	–	1.00 (reference)	–	1.00 (reference)	–
>3.1-6.0	0.63 (0.23,1.72)	0.37	0.79 (0.30,2.07)	0.62	1.19 (0.84,1.71)	0.30	0.72 (0.56,0.93)	<0.05
>6.0-11.4	0.91 (0.34,2.43)	0.84	2.03 (0.85,4.81)	0.11	0.79 (0.53,1.17)	0.24	0.72 (0.52,1.01)	0.06
>11.4	0.25 (0.09,0.69)	<0.05	1.01 (0.34,3.00)	0.98	1.17 (0.81,1.70)	0.40	0.96 (0.71,1.29)	0.77
100% juice								
≤2.3	1.00 (reference)	–	1.00 (reference)	–	1.00 (reference)	–	1.00 (reference)	–
>2.3-4.3	2.27 (0.83,6.17)	0.11	1.03 (0.40,2.66)	0.96	0.83 (0.54,1.28)	0.41	1.22 (0.92,1.61)	0.17
>4.3-8.0	0.80 (0.24,2.72)	0.73	1.55 (0.62,3.86)	0.35	0.80 (0.60,1.13)	0.21	0.89 (0.66,1.21)	0.47
>8.0	0.37 (0.11,1.31)	0.13	1.53 (0.64,3.67)	0.34	1.35 (0.99,1.85)	0.05	1.08 (0.81,1.44)	0.58
Sugar-sweetened beverages (SSBs)								
≤10.9	1.00 (reference)	–	1.00 (reference)		1.00 (reference)	–	1.00 (reference)	
>10.9-19.0	0.22 (0.07,0.68)	<0.01	2.05 (0.86,4.94)	0.11	1.17 (0.83,1.66)	0.37	0.90 (0.69,1.18)	0.44
>19.0-35.0	0.52 (0.21, 1.27)	0.15	1.42 (0.58,3.60)	0.46	1.22 (0.84,1.76)	0.30	0.95 (0.73,1.23)	0.68
>35.0	0.24 (0.09, 0.61)	<0.01	1.79 (0.73,4.39)	0.21	1.59 (1.15,2.20)	<0.01	0.88 (0.67,1.16)	0.38
Sugar-free beverages (SFBs)								
≤10.5	1.00 (reference)	–	1.00 (reference)		1.00 (reference)	–	1.00 (reference)	
>10.5-20.0	0.51 (0.24, 1.07)	0.08	0.83 (0.37,1.87)	0.65	1.06 (0.78,1.45)	0.70	0.90 (0.69,1.16)	0.40
>20.0-40.0	0.13 (0.04, 0.36)	<0.01	0.86 (0.35,2.12)	0.74	1.87 (1.37,2.54)	<0.01	0.99 (0.76,1.30)	0.95
>40.0	0.12 (0.04, 0.35)	<0.01	2.16 (0.93,5.10)	0.08	1.99 (1.41,2.83)	<0.01	0.71 (0.51,0.99)	<0.05

* Multivariable models adjusted for age, gender, region, and educational level of caregiver; CI=confidence interval.

† *P*-values are from the multivariable marginalized zero-inflated Poisson regression model.

Results

The sample size included 545 12- to 17-year-old Black adolescent participants. The response rate as a percentage of students eligible for participation at the schools was 39.3 percent in Washington, D.C., and 40.8 percent in Nashville. The distributions of demographic variables for the included Black participants and non-Black adolescents excluded from the analysis are shown in Table 1. Compared to Black adolescents, the excluded non-Black adolescents were more likely to be female, have lower educational levels for the caregiver, more likely to be from Tennessee than Washington, D.C., and less likely to have a dentist. The mean DMFS score was lower for the included Black participants than the excluded non-Black participants (3.2±3.5 versus 4.6±4.2).

The mean age of the Black adolescent participants was 14.1 years, and a higher proportion (55.1 percent) of the participants were female. In addition, 85.3 percent of the Black adolescents indicated they had a dentist while 91.6 percent of the Black adolescents reported having seen the dentist for preventive services or planned treatment during their last dental visit. Approximately 50 percent (50.1 percent) of the caregivers for the Black adolescents reported some college education or more. The mean DMFS score was higher for Black adolescents from Nashville, Tennessee than those from Washington, D.C. (3.8±3.8 versus 2.7±3.0). Black adolescents from Tennessee were more likely to be older, have more education, and be female compared to Black adolescents from Washington, D.C., providing further support for including these variables in the multivariable analysis per the a priori plan.

Table 2 shows the mean values for the average daily beverage intake in ounces and the mean values for the DMFS score for the four groups of drink types. The median values for the daily consumption of SSBs and SFBs were similar to one another, and both were much higher than the median values for milk and 100 percent fruit juice. There were significant differences between the mean daily intake values for milk versus SSBs ($P<0.01$), milk versus SFBs ($P<0.01$), 100 percent juice versus SSBs ($P<0.01$), and 100 percent juice versus SFBs ($P<0.01$). The mean values for DMFS scores across all beverage types were similar, and statistical testing found no significant differences among the groups.

Per the a priori hypothesis, the analysis stratified by toothbrushing frequency and examined the associations in the entire Black adolescent participant population, among Black adolescents brushing two or more times a day, and those brushing once a day or less in the multivariable analysis. Among all Black adolescents, no associations were observed between the caries outcomes and beverage consumption with any of the beverage groups when not stratifying by toothbrushing frequency. The results of the multivariable analysis for the four identified beverage categories for those brushing once a day or less and those brushing two or more times a day are shown in Table 3.

Among those brushing once a day or less, for those in the highest quartile for SSB consumption, the mean caries count was 59 percent higher than those in the lowest quartile (MR = 1.59, 95 percent confidence interval [**95% CI**]=1.15 to 2.20) after controlling for age, gender, region, and socioeconomic status. For those in the highest quartile of SSB consumption, the estimated odds of remaining caries-free was 76 percent lower (OR = 0.24, 95% CI = 0.09 to 0.61). Significant associations were also observed among those consuming SFBs with those in the third and fourth quartiles having mean caries counts that were 87 percent (MR = 1.87, 95% CI = 1.37 to 2.54) and 99 percent (MR = 1.99, 95% CI = 1.41 to 2.83) higher than those in the lowest quartile, respectively. In addition, those in the highest third and fourth quartiles had much lower odds of remaining caries-free, with reductions in odds of 87 percent (OR = 0.13, 95% CI = 0.04 to 0.36) and 88 percent (OR = 0.12, 95% CI = 0.04 to 0.35), respectively. Finally, for those in the highest quartile for milk consumption, the odds of remaining caries-free was 75 percent lower than for those in the lowest quartile (OR = 0.25, 95% CI = 0.09 to 0.69).

For Black adolescents brushing two or more times a day, no association was observed among any of the beverage groups except for the highest quartile of SFB consumption for the mean caries ratio (which bordered on statistical significance) and the second quartile for the mean caries ratio for milk. As a form of sensitivity analysis, when the analysis was repeated to include non-Black participants, the results were not significantly different in stratified analysis by toothbrushing frequency or when not stratified.

Discussion

In this study among participants from Washington, D.C., and Nashville, the primary finding was that, in an underserved Black adolescent population brushing once a day or less, consuming high levels of SSBs was associated with 59 percent higher mean caries counts in the overall study population and a 76 percent lower likelihood of remaining caries-free. Supporting the study hypothesis, this association was only observed among those participants brushing once a day or less. No signifi0cant association was observed among those brushing twice a day or more. The results of this study are consistent with the body of evidence documenting associations between SSB consumption and dental caries in children.[7-10] The results are also concordant with the few studies that have examined the associations between dental caries and SSB consumption while factoring in toothbrushing behavior.[8,22] In addition, the study adds to the limited number of publications to date that examine risk factors for dental caries using zero-inflated count models.[24-26]

The present study is the first to examine this association among an exclusively underserved Black adolescent population, a group known to be at higher risk for dental caries. The methodology of the present study is similar to that of another study that examined the association between SSB consumption and dental caries in children using a zero-inflated count model, but it was not a marginally mean-specified zero-inflated model. In that study, the authors found a greater likelihood of becoming susceptible to caries among those with higher SSB consumption using a zero-inflated generalized Poisson model (**ZIGP**).[23] They also observed a greater mean caries count among those drinking more SSBs in the group considered to be at risk for dental caries. There were some additional differences between the previous study using the ZIGP and the present study. First, the present study used marginalized zero-inflated count models as opposed to zero-inflated count models. In addition, in the ZIGP study, the authors did not stratify by toothbrushing frequency and categorized beverage consumption using only frequency of consumption. The authors did not record the estimated daily intake in ounces or any other unit of volume. Finally, the study population in the present study was significantly older, ranging from 12 to 17 years versus 10 to 12 years of age in the ZIGP study.

The secondary finding, among those brushing once a day or less, was that consuming high levels of SFBs was also associated with higher mean caries counts in the overall study population and a lower likelihood of remaining caries-free. The results from the present study differ from a recent study by Marshall et al., which included participants from the Iowa fluoride study (**IFS**); the latter study observed that a greater intake of water/SFBs was associated with a lower risk of caries.[8] The population for that study included participants recruited at birth between 1992 and 1995; most of the participants were non-Hispanic whites (95.3 percent) in contrast to the present analysis that focused on Black adolescents and their caregivers. As noted in the Marshall et al. paper, the self-selected sample used for the IFS was "relatively small, mostly white, reasonably well educated, and wealthy" in contrast to the underserved Black population recruited for the present study. Another difference was that the IFS was a longitudinal cohort study in contrast to the cross-sectional nature of the present study. There are similarities, however, between the two studies; for example, beverage intake was measured using a validated beverage frequency questionnaire in the IFS, and that instrument served as the template to develop the beverage intake questionnaire used in the present study. The authors of the present study hypothesized that the associations observed between high levels of SFB consumption and a higher mean caries ratio/lower odds of remaining caries-free in the present study may be in part due to misclassification by the adolescent participants about the differences between SFBs and SSBs, especially when asked about unsweetened versus sweetened iced tea. However, given the contrasting outcomes and the lack of research to date on the association between SFBs and dental caries, more research is needed in this area.

As mentioned earlier, this study adds to the sparse literature examining the association between beverage intake and dental caries while considering toothbrushing frequency.[8,22] A systematic review of the effect of toothbrushing frequency on incidence and increment of dental caries concluded that those who brush their teeth less frequently are at greater risk for the incidence of new caries lesions than those brushing more frequently.[13] The authors of that review suggest that the effect is independent of the presence of fluoride in toothpaste and may be associated with other factors in those who brush more frequently, such as greater health awareness and motivation, higher socioeconomic status, and a healthier diet. The fact that associations between SSB consumption and dental caries were only observed among those brushing once a day or less in the present study provides further support that toothbrushing can interrupt the development of dental caries due to SSB consumption. Finally, the observed association in the present study between the highest quartile of milk consumption and a 75 percent lower odds (OR = 0.25, CI = 0.09-0.69) of remaining caries-free is consistent with a recent study that demonstrated an association between increased milk consumption and dental caries[27] (OR=1.23, CI=1.03-1.45) but not with other studies that show lower odds or no association.[8,28] The association observed in the present study may be a result of chance or due to the potential sugary intake of the milk-based beverages consumed by the Black adolescent participants in this study.

Given the higher prevalence of dental caries and higher SSB consumption among Black adolescents, the results of this study provide evidence that the potentially large public health burden of excessive SSB consumption among Black adolescents should not be discounted. While a variety of approaches have been utilized to reduce SSB consumption, including the use of advocacy, legislation, and policy initiatives, there is little evidence to date summarizing the success of these various approaches and a clear need for increased monitoring and reporting of these differing efforts.[29-32] One summary of the evidence concluded that the effects of policies to reduce SSB consumption are unclear, that taxation has no clear effect on SSB purchasing, and there is no evidence that reducing the availability of SSBs in schools leads to a reduction in consumption.[32] Cognitive behavioral therapy (**CBT**) has strong research support across diverse samples for improving behavior, including among African American adolescents, but not specifically for reducing SSB consumption.[33,34] This study's investigators are in the early stages of developing and testing an intervention that utilizes a CBT approach to reducing SSB consumption among Black adolescents.

The findings are also best evaluated in the context of the study's strengths and weaknesses. A major strength of the study was the recruitment of a population of Black adolescents from underserved communities in two different regions of the country. There were significant differences in the demographic characteristics of the excluded non-Black adolescent population and the Black adolescent population, providing further justification for the a priori plan to focus on Black adolescents. Other strengths include the ability to control for important confounding variables, given the demonstrated differences between the Black participants in Washington, D.C., and Nashville, Tenn. in the present study's population, the fact that examiners were calibrated for the measurement of dental caries, and the use of validated beverage consumption questions. The ability of the MZIP to provide both mean caries ratios for the overall study population and the odds of remaining caries-free adds to the strengths of this study.

Study limitations include the absence of the use of dietary records to measure beverage consumption and the reliance on the recall of study participants. However, the likelihood of error was reduced through the use of visual aids. In addition, the population selected was a convenience sample based on the willingness of the adolescents and caregivers to participate. The authors were unable to control for fluoride intake and, as this was a cross-sectional study, cannot make any causal inferences based on the findings. Given the unique characteristics of the study population, the results of the present study may not be generalizable to different populations such as non-Black or higher-income groups. Other weaknesses included a large amount of missing data on caregiver income, which led to the use of an educational level as a marker of socioeconomic status instead of income. Finally, in stratified analysis using those participants brushing once a day or less versus those brushing twice a day or more, the final sample for analysis was limited to 202 participants versus 545 in the full sample; the reduced sample size may have limited the ability to detect more meaningful differences.

This work is important, as it demonstrates the authors' ability to recruit a study population of Black adolescents despite the difficulties researchers face when researching underserved communities. Future prospective studies among study population cohorts should include longitudinal measures of beverage consumption to further understand the association between SSB and dental caries among adolescents.

Conclusions

Based on this study's results, it can be concluded that, among underserved Black adolescent patients brushing once a day or less:

1. High levels of sugar-sweetened beverage consumption were associated with higher mean caries counts and a reduced likelihood of remaining caries-free among Black adolescents in Nashville, Tenn. and Washington, D.C., a clinically important outcome given that Black adolescents have a higher prevalence of dental caries and SSB consumption.
2. Further research is needed to determine if interventions based on cognitive behavioral therapy are associated with reduced SSB consumption.

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References

1. Dye B, Thornton-Evans G, Li X, Iafolla TJ. Dental caries and sealant prevalence in children and adolescents in the United States, 2011-2012. NCHS Data Brief 2015;Mar (191):1-8.
2. Fleming E, Afful J. Prevalence of total and untreated dental caries among youth: United States, 2015-2016. NCHS Data Brief 2018;Apr(307):1-8.
3. National Center for Health Statistics. Table 028. Untreated dental caries, by selected characteristics: United States, selected years 1988-1994 through 2015-2018. Health, United States, 2019. Centers for Disease Control and Prevention. Hyattsville, Md., 2021. Available at: "https://www.cdc.gov/nchs/data/hus/2019/028-508.pdf". Accessed September 17, 2021.
4. Peres MA, Macpherson LMD, Weyant RJ, et al. Oral diseases: A global public health challenge. Lancet 2019; 394(10194):249-60.
5. Correa-Faria P, Paixao-Goncalves S, Paiva SM, Pordeus IA. Incidence of dental caries in primary dentition and risk factors: A longitudinal study. Braz Oral Res 2016;30(1): S1806-83242016000100254.
6. Sheiham A, James WP. Diet and dental caries: The pivotal role of free sugars reemphasized. J Dent Res 2015;94 (10):1341-7.
7. Marshall TA, Levy SM, Broffitt B, et al. Dental caries and beverage consumption in young children. Pediatrics 2003;112(3 Pt. 1):e184-e191.
8. Marshall TA, Curtis AM, Cavanaugh JE, Warren JJ, Levy SM. Beverage intakes and toothbrushing during childhood are associated with caries at age 17 years. J Acad Nutr Diet 2021;121(2):253-60.
9. Laniado N, Sanders AE, Godfrey EM, Salazer CR, Badner VM. Sugar-sweetened beverage consumption and caries experience: An examination of children and adults in the United States, National Health and Nutrition Examination Survey 2011-2014. J Am Dent Assoc 2020;151(10): 782-9.
10. Marriott BP, Hunt KJ, Malek AM, Newman JC. Trends in intake of energy and total sugar from sugar-sweetened beverages in the United States among children and adults, NHANES 2003-2016. Nutrients 2019;11(9):2004.
11. Rosinger A, Herrick K, Gahche J, Park S. Sugar-sweetened beverage consumption among U.S. youth, 2011-2014. NCHS Data Brief 2017;(271):1-8.
12. 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 caries: A systematic review. J Clin Periodontol 2017;44 (S18):116-34.
13. 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):1230-6.
14. Laurence B, Shara N, Gonzalez F, et al. An approach to engaging schools in oral health initiatives: The Howard Meharry Adolescent Caries Study (HMACS). J Health Care Poor Underserved 2020;31(1):35-42.
15. Marshall TA, Eichenberger Gilmore JM, Broffitt B, Stumbo PJ, Levy SM. Relative validity of the Iowa 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):465-72.
16. Warren JJ, Weber Gasparoni K, Tinanoff N, et al. Examination criteria and calibration procedures for prevention trials of the Early Childhood Caries Collaborating Centers. J Public Health Dent 2015;75(4):317-26.
17. Preisser JS, Stamm JW, Long DL, Kincade ME. Review and recommendations for zero-inflated count regression modeling of dental caries indices in epidemiological studies. Caries Res 2012;46(4):413-23.
18. Preisser JS, Long DL, Stamm JW. Matching the statistical model to the research question for dental caries indices with many zero counts. Caries Res 2017;51(3):198-208.
19. 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): 321-8.
20. Warren JJ, Van Buren JM, Levy SM, et al. Dental caries clusters among adolescents. Community Dent Oral Epidemiol 2017;45(6):538-44.
21. Cummings TH, Hardin JW. Modeling count data with marginalized zero-inflated distributions. STATA J 2019; 19(3):499-509.
22. 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.
23. Almasi A, Rahimiforoushani A, Eshraghian MR, et al. Effect of nutritional habits on dental caries in permanent dentition among schoolchildren aged 10-12 years: A zero-inflated generalized Poisson regression model approach. Iran J Public Health 2016;45(3):353-61.
24. Holmes RD. Toothbrushing frequency and risk of new carious lesions. Evid Based Dent 2016;17(4):98-99.
25. Todem D, Zhang Y, Ismail A, Sohn W. Random effects regression models for count data with excess zeros in caries research. J Appl Stat 2010;37(10):1661-79.

References continued on the next page.

26. Ismail AI, Sohn W, Lim S, Willem JM. Predictors of dental caries progression in primary teeth. J Dent Res 2009; 88(3):270-5.
27. Zeng L, Peng, Xu T et al. Dental caries and associated factors among adolescents aged 12 to 15 in Jiangxi Province, China. J Public Health Dent 2020;80(3):217-26.
28. Lempert SM, Christensen LB, Froberg K, Raymond K, Heitmann B. Association between dairy intake and caries among children and adolescents, results from the Danish EYHS follow-up study. Caries Res 2015;49(3):251-8.
29. Sanghavi A, Siddiqui NJ. Advancing oral health policy and advocacy to prevent childhood obesity and reduce children's consumption of sugar-sweetened beverages. J Public Health Dent 2017;77(suppl 1):S88-S95.
30. Vann WF, Bouwens TJ, Braithwaite AS, Lee JY. The childhood obesity epidemic: A role for pediatric dentists? Pediatr Dent 2005;27(4):271-6.
31. Beaglehole RH. Dentists and sugary drinks: A call to action. J Am Dent Assoc 2015;146(2):73-4.
32. Momin SR, Wood AC. Sugar-sweetened beverages and child health: Implications for policy. Curr Nutr Rep 2018; 7(4):286-93.
33. Steinka-Fry KT, Tanner-Smith EE, Dakof GA, Henderson C. Culturally sensitive substance use treatment for racial/ethnic minority youth: A meta-analytic review. J Subst Abuse Treat 2017;75:22-37.
34. Hogue A, Henderson CE, Becker SJ, Knight DK. Evidence base on outpatient behavioral treatments for adolescent substance use, 2014-2017: Outcomes, treatment delivery, and promising horizons. J Clin Child Adolesc Psychol 2018;47(4):499-526.