Community Dental Health (2022) **39,** 33–39
Received 6 June 2021; Accepted 8 August 2021

doi:10.1922/CDH_00154Samman07

Diet drinks and dental caries among U.S. adults: cluster analysis

Meyassara Samman,[1] Elizabeth Kaye,[2] Howard Cabral,[3] Thayer Scott[2] and Woosung Sohn[4]

[1]*Dental Public Health, King Abulaziz University, Faculty of Dentistry, Saudi Arabia;* [2]*Health Policy & Health Services Research, Boston University, Henry M Goldman School of Dental Medicine, United States;* [3]*Biostatistics, Boston University School of Public Health, United States;* [4]*Population Oral Health, University of Sydney, School of Dentistry, Faculty of Medicine and Health, Australia*

Background: In recent years, the consumption of sugar sweetened beverages has been declining, while low calorie sweetener and diet beverage consumption is increasing. Evidence about the effect of diet drinks on dental caries is insufficient, and has not accounted for the complexity of beverage consumption patterns. Therefore, the aim of this study is to examine the association between consuming diet drinks and dental caries among US adults. ***Methods***: We analyzed 2011-2014 NHANES dietary data of adults using cluster analysis, with individuals grouped based on their beverage consumption. Clusters were identified based on the R-square statistic and the local peak of the pseudo F statistic. Survey procedure and sample weights were used to account for the complex NHANES sampling design. ***Results***: Four beverage consumption patterns were identified: "high soda", "high diet drinks", "high coffee/tea" and "high water". The "High soda" cluster was the only one associated with higher DMFT after controlling for confounders (β=1.02, 95% CI=0.42 - 1.63), whereas DT was associated with "high soda" (β=0.45, 95% CI=0.25 - 0.64) and "high coffee/tea" (β=0.24, 95% CI=0.01 - 0.47). On the other hand, the "high diet drinks" cluster was neither associated with DMFT (β=0.69, 95% CI=0.51 - -0.35) nor DT (β=0.07, 95% CI=-0.21 - 0.35). ***Conclusion***: Diet drinks consumption may not be associated with increased risk of dental caries. However, more studies should be conducted in order to confirm this finding.

Keywords*: Soft drinks, beverages, decay, tooth demineralization, low calorie sweetener, artificially sweetened drinks*

Introduction

Dental caries is a carbohydrate mediated disease, where carbohydrates are fermented by oral bacteria to form acids which demineralize the tooth, resulting in dental decay. Carbohydrates, and especially sugar sweetened beverages (SSB), have been a research focus due to their association with many systemic diseases. Results show that SSB consumption elevates the risk of type 2 diabetes and coronary heart disease in adults (de Koning *et al.*, 2012; de Koning *et al.*, 2011; Singh, 2016).

Research suggests that high SSB consumption, when combined with gingival plaque deposits, is a significant risk factor for dental caries (Kim *et al.*, 2013). A National Health and Nutrition Examination Survey (NHANES) analysis of US adults studied the association between soda consumption and dental caries experience, concluding that regular SSB consumption increased caries prevalence in adults (> 25 years old). However younger adults did not show this effect despite consuming more SSBs. The reason behind these findings is thought to be the lifelong exposure to fluoride (including fluoridated water and fluoride toothpaste) in younger people. Another possible explanation is that SSB effects on caries are cumulative, in other words, sufficient time needs to pass after the high SSB consumption in order to observe the disease outcome (Forshee and Storey, 2004; Heller *et al.*, 2001).

Most previous studies have examined single source beverage consumption and their effects on dental caries. However, people consume multiple beverages per day, which might have different effects on teeth. Thus, the best approach to examining beverage consumption relationships is to study consumption patterns as a whole. Few studies have analyzed concurrent beverage consumption, using either factor analysis or cluster analysis. Burt et al. (2006) measured the association between caries and dietary patterns using factor analysis. They concluded that having gingival plaque together with more frequent soda drink consumption was positively associated with DMFS (decayed, missing, or filled surfaces) scores.

As a result of public health campaigns and new policies focusing on soda consumption (Colchero *et al.*, 2015; Falbe *et al.*, 2016; Powell *et al.*, 2009; Sturm *et al.*, 2010), the consumption of regular soda and SSB has been declining over the past decade (Kit *et al.,* 2013). On the other hand, low calorie sweetener (LCS) and diet beverages (contains LCS or reduced sugar or a combination of both) consumption is increasing among the US population (Drewnowski and Rehm, 2015; Sylvetsky *et al.*, 2012). However, the relationships between diet beverage use and caries have been rarely studied, and most analyses combined these beverages with other drinks. When examined separately these beverages were not associated with caries, however few of the study participants consumed them, and only did so in small amounts (Forshee and Storey, 2004; Hendriksen *et al.*, 2011).

Since caries severity increases with age, being caries free during childhood does not ensure being caries free during adulthood (Moynihan and Petersen, 2004). However, most studies examining the effect of different beverages on dental

Correspondence to: Dr. Meyassara Samman. Email:mbsamman@kau.edu.sa

caries are conducted with children. In addition, the evidence regarding the effect of diet and LCS drinks on dental caries is insufficient, and that that does exist has not accounted for the complexity of beverage consumption patterns. Finally, these studies did not compare diet drinks to highly cariogenic drinks, such as regular soda, or to protective effects of drinks such as milk or water. Such research could help us determine whether diet soda can safely substitute regular soda, or whether these drinks effects might fall between the elevated caries risk of regular soda and the protective or neutral effects of milk and water.

Our study examined whether there is any association between diet soda/LCS drink consumption and dental caries among the US adult population by analyzing recent NHANES cycles (2011-2014), utilizing cluster analysis to group beverages into consumption patterns.

Methods

This analysis used demographic, oral health-dentition, and dietary interview data from the 2011-2012 and 2013-2014 National Health and Nutrition Examination Surveys (NHANES). NHANES is a stratified, multistage, probability survey conducted by the National Center for Health Statistics. Sampling includes the civilian, non-institutionalized population residing in the 50 states and the District of Columbia (CDC, 2012a), aged between 21 and 60 years old, who completed both dental examinations and dietary interviews. Adults older than 60 years were not included because their beverage consumption is primarily water, tea, and coffee (based on findings from primary analysis. Results not shown).

NHANES dietary data were obtained from two 24-hour recall questionnaires in each cycle (CDC, 2000). For this analysis, the responses from the 2 dietary interviews were combined. The beverage categories used in this study were:

- milk (plain non-sweetened milk, butter milk)
- water (plain non-sweetened, non-flavored tap and bottle water)
- 100% juice (fresh fruit and vegetable juices with no added sugars)
- juice drink (drinks containing less than 100% fresh juice, bottled, canned or powder mix fruit-based drinks)
- soda (regular sugared carbonated soda)
- diet drinks (reduced sugar and diet soda, fruit drinks with reduced sugar or LCS, water with LCS, coffee with LCS, tea with LCS, LC sports/energy drinks)
- coffee and tea (non-sweetened coffee, and non-sweetened tea), sports/energy drinks (regular sugared sports/energy drinks)
- sugared drinks (flavored and sugared milk, sweetened water, sugared and flavored coffee, sugared tea, and nutritional and protein shakes)
- and other drinks (soy milk, almond milk, malted milk, coconut, and oatmeal beverages)

The mean grams of each beverage consumed, as well as the total beverages consumed, were calculated.

The dental examination in NHANES is conducted by trained and calibrated dentists. All teeth are examined (except the 3rd molars) using a mirror and No. 23 explorer with air drying when needed (CDC, 2012b; CDC, 2013). NHANES used the Radike et al. (1972) criteria to diagnose dental caries. Carious pits and fissures were identified if there was softness at the base and/or opacity adjacent to the area. Smooth surface lesions were identified if there was white spot or decalcification with softness of the area. When the proximal surface was accessible, the same criteria as smooth surfaces were considered. If they were not accessible, then other criteria were applied. Filled surfaces were identified if there was a permanent or temporary restoration placed because of caries. The outcome 'dental caries' was measured as DMFT (decayed, missing, and filled teeth) and DT (decayed teeth) scores as continuous variables.

Age was categorized into 10-year range groups and race/ethnicity as Mexican and Hispanic, non-Hispanic white, non-Hispanic black, and others including Asian and multiracial. We grouped the family income to poverty ratio into 4 groups based on Medicare eligibility criteria: less than or equal to 1.38, between 1.38 and 2.5, from 2.6 to 4.0, and more than 4.0 (Obamacare, 2014). Education was classified as high school or less, some college, and college graduate or above. For marital status, married and living with partner were combined as one group, while widowed, divorced, and separated were combined into another group, and singles were the 3rd group.

Cluster analysis was performed using PROC FASTCLUS in SAS Software version 9.4 (SAS Institute Inc., Cary, NC, USA). PROC FASTCLUS executes a disjoint cluster analysis where every observation is assigned to only one cluster, by grouping observations according to the Euclidean distance. This procedure initially selects cluster seeds, then assigns each observation to its nearest cluster. This causes the cluster mean to change, which is recalculated accordingly. The last 2 steps are repeated until the distances between observations are smaller than the distances between the clusters mean (Wirfält and Jeffery, 1997; Samman *et al.*, 2020; Sohn *et al.*, 2006).

The proportion of each beverage was calculated from the total beverages consumed and used for further analysis rather than the daily grams consumed, to simplify comparing and grouping individuals. Cluster analysis used the percentage of each of the beverages. Since there was no current determination (prior studies using the same methods) of what the appropriate number of clusters should be, we evaluated different cluster numbers (from 2 to 10). Based on the R-square value and the pseudo f-statistic, the appropriate cluster number was 2 (high water and high soda clusters), but because this number does not serve the purpose of this study hypothesis, the next appropriate cluster number was 4 which included the high diet drinks as a separate cluster. As a result, the final cluster number used for analyses was 4.

Crude associations between dental caries, beverage consumption clusters, and sociodemographic characteristics were examined with chi-square and ANOVA tests. Dental caries (DMFT, DT) was predicted from the beverage consumption clusters and sociodemographic variables using multiple linear regression. Survey procedures and sample weights were used throughout the analysis to account for the complex NHANES sampling design and to generate national level estimates. Weights were divided by 2 to account for the pooling of data from two 2-year cycles of the NHANES survey.

Results

The most consumed beverage among US adults was water (35.4%), followed by non-sweetened coffee and tea (19.7%) (Table 1). Soda comprised 14% of total beverage consumption, while diet drinks constituted 7.8%.

The analysis resulted in four different clusters: water, diet drinks, coffee/tea, and soda. The cluster names refer to the highest percentage beverage consumed. For instance, in the "high water" cluster, 67.2% of the daily beverage intake consisted of water, while in the "high diet drinks" cluster, 57.7% of consumption was diet drinks (Table 1). Other clusters were as follow: "high coffee/tea", and "high soda". The "High water" cluster had the highest number of adults (n=2233), while the "high diet drinks" cluster had the fewest adults (378).

Compared to the total population, more males were in the "high soda" cluster (55.7%), while more women were in the "high water", "high diet drinks", and "high coffee/tea" clusters (53%, 52.1%, and 54.2% respectively). "High diet drinks" and "high coffee/tea" clusters included more older adults, while "high soda" included more younger adults (Table 2).

Mexican American/Hispanics and Non-Hispanic Blacks were overrepresented in the "high soda" cluster (24.2% and 22.6% respectively), while non-Hispanic Whites were overrepresented in the "high water" (68.3%), "high diet drinks" (81.9%), and high coffee/tea" (65.6%) clusters (Table 2).

Adults with high school education or less were overrepresented in the "high soda" cluster (49.3%), while more adults with college degrees or above were in the "high water" cluster (46.5%). Higher income adults were more represented in the "high water" and the "high diet drinks" clusters (43.4% and 39.9% respectively) (Table 2).

Crude associations showed a significant difference between caries measures among the clusters (Table 3). While the "high coffee/tea" and "high diet drinks" consumption patterns had the highest DMFT scores (10.6 and 10.4, respectively), the "high diet drinks" cluster had the highest DT score (7.6).

After adjusting for sociodemographic variables, the "high soda" cluster had 1.02 more DMFT when compared to the "high water" cluster (β=1.02, 95% CI=0.42-1.63), while the relationships with "high diet drinks" and "high coffee/tea" clusters were increased, they were not statistically different (Table 4). When the "high soda" cluster was used as a control group, the "high diet drinks" cluster showed a decreased association with caries, although the relationship was not statistically significant (β=-0.33, 95% CI=-1.48-0.81) (results not tabulated). Males had lower DMFT when compared to females (β=-0.65, 95% CI=-1.03-(-0.27)). Older age, lower educational attainment, and lower income were associated with higher DMFT. In addition, being Mexican American increased the DMFT by 0.74 when compared to Whites (Table 4).

DT demonstrated similar results with smaller coefficients. The "high soda" cluster had 0.45 more DT when compared to the "high water" cluster (β=0.45, 95% CI=0.25-0.64), while the "high diet drinks" was not associated with dental caries (β=0.07, 95% CI=-0.21-0.35) (Table 4).

Discussion

This cross-sectional study used cluster analysis to examine the association between diet drinks consumption and dental caries in the US adult population. The analysis was limited to adults younger than 60 years old because older adults had a very different beverage consumption pattern, focusing mainly on water and coffee/tea. While diet drinks were initially positively associated with dental caries (DMFT and DT), after accounting for other beverage consumption patterns in cluster analysis and controlling for sociodemographic factors, the "high diet drinks" cluster was no longer associated with dental caries. These findings are similar to a NHANES III analysis, which found that carbonated diet beverages were not associated with DMFS, whether analyzed with Food Frequency Questionnaire (FFQ) or 24HR dietary data (Forshee and Storey, 2004).

Table 1. Beverage consumption profiles in total population and clusters

Beverage	*Total (n = 5444)*		*High water (n = 2233)*		*High diet drinks (n = 378)*		*High coffee/tea (n = 1127)*		*High soda (n = 1706)*	
	% of total	*Mean gm/day*	*% of total*	*Mean gm/day*	*% of total*	*Mean gm/day*	*% of total*	*Mean gm/day*	*% of total*	*Mean gm/day*
Water	35.4	801.8	**67.2**	**3197.9**	11.3	436.2	11.8	440.4	8.8	280.3
Coffee/tea	19.7	325.4	11.9	551.3	12.5	410.6	**56.7**	**1581.2**	7.4	222.1
Soda	14.0	207.3	4.8	212.0	2.7	64.7	5.5	165.6	**39.3**	**1057.1**
Diet drinks	7.8	135.4	3.0	153.2	**57.5**	**1820.4**	4.4	144.5	1.8	47.6
Juice drink	7.1	98.5	3.8	152.3	5.6	140.8	5.2	145.7	14.6	331.3
Milk	6.7	100.7	4.7	205.4	4.2	135.7	7.5	179.5	10.2	237.5
Sugared drinks	4.7	72.8	2.1	84.5	3.7	111.7	5.1	161.4	9.0	249.0
Sport/energy drinks	2.1	36.5	0.8	43.5	1.2	39.6	1.8	51.4	4.9	150.0
100% juice	2.0	25.6	1.3	57.2	1.0	26.6	1.8	39.6	3.6	59.4
Other drinks	0.5	6.7	0.5	18.6	0.4	9.5	0.3	7.5	0.6	10.6
Total	100	1810.5	100	4675.9	100	3195.9	100	2916.9	100	2644.9

All values are weighted. Bold numbers represent the highest proportion of intake in each cluster.

Table 2. Demographic characteristics of beverage clusters

Variable	N (%)	High water Weighted column % (SE)	High diet drinks Weighted column % (SE)	High coffee/tea Weighted column % (SE)	High soda Weighted column % (SE)	P (Chi-sq)
Gender						0.002
Male	2642 (49.2)	47 (1.5)	47.9 (3.5)	45.8 (1.9)	55.7 (1.9)	
Female	1375 (50.9)	53 (1.5)	52.1 (3.5)	54.2 (1.9)	44.3 (1.9)	
Age						<0.0001
21-30 years	1428 (26.6)	27.7 (1.5)	15.1 (2.5)	14.0 (1.7)	37.7 (2.7)	
31-40 years	1364 (23.9)	24.1 (1.4)	20.7 (3.2)	19.2 (1.9)	27.8 (2.0)	
41-50 years	1367 (24.2)	23.6 (1.5)	30.0 (4.1)	30.1 (1.7)	19.0 (1.4)	
51-60 years	1323 (25.3)	24.6 (1.5)	34.2 (2.6)	36.7 (2.3)	15.5 (1.4)	
Race/ethnicity						<0.0001
Mexican American+ Hispanic	1215 (16.7)	13.8 (1.8)	8.5 (1.8)	17.2 (2.1)	24.2 (2.9)	
Non-Hispanic White	2133 (62.9)	68.3 (2.4)	81.9 (2.6)	65.6 (2.9)	46.2 (3.3)	
Non-Hispanic Black	1222 (11.7)	7.3 (1.1)	5.8 (1.2)	8.4 (1.2)	22.6 (2.6)	
Other	912 (8.7)	10.6 (1.1)	3.9 (0.9)	8.9 (1.2)	7.0 (1.0)	
Education						<0.0001
High school or less	2105 (33.5)	22.9 (2.0)	31.6 (3.4)	36.3 (3.2)	49.3 (2.6)	
Some college	1759 (33.1)	30.7 (1.8)	32.0 (3.4)	35.2 (2.9)	35.9 (2.1)	
College graduate or above	1617 (33.5)	46.5 (2.4)	36.5 (3.9)	28.6 (2.6)	14.8 (1.4)	
Marital status						<0.0001
Married/living with partner	3301 (62.9)	65.0 (2.0)	65.7 (2.7)	68.0 (2.2)	54.6 (2.4)	
Widowed/divorced/separated	833 (14.5)	10.9 (0.8)	17.3 (2.6)	20.1 (2.1)	15.6 (1.7)	
Never married	1348 (22.6)	24.0 (2.0)	17.0 (1.7)	11.9 (1.2)	29.9 (2.8)	
Family income to poverty ratio						<0.0001
≤ 1.38	2250 (31.3)	25.3 (2.1)	23.7 (2.3)	29.0 (2.4)	45.1 (2.7)	
> 1.38 to ≤ 2.5	895 (16.0)	14.4 (1.3)	16.4 (3.4)	15.1 (2.1)	19.4 (1.5)	
> 2.5 to ≤ 4.0	928 (18.4)	16.8 (1.5)	20.0 (4.1)	21.9 (1.9)	18.0 (1.4)	
> 4.0	1409 (34.3)	43.4 (2.9)	39.9 (3.9)	34.0 (2.8)	17.6 (1.9)	

Table 3. Association between dental caries status measures and beverages clusters.

Caries	Total population Weighted mean (SE)	High water Weighted mean (SE)	High diet drinks Weighted mean (SE)	High coffee/tea Weighted mean (SE)	High soda Weighted mean (SE)	P (ANOVA)
DMFT	9.2 (0.2)	8.4 (0.2)	10.4 (0.6)	10.6 (0.3)	9.1 (0.4)	<0.0001
FT	0.8 (0.1)	0.5 (0.0)	0.6 (0.2)	0.8 (0.1)	1.4 (0.1)	<0.0001
DT	6.1 (0.2)	6.4 (0.2)	7.6 (0.5)	6.6 (0.3)	4.7 (0.2)	<0.0001
MT	2.3 (0.2)	1.5 (0.2)	2.2 (0.3)	3.2 (0.3)	3.0 (0.3)	<0.0001

Roberts and Wright (2012) suggest that this is because the sweeteners used in diet drinks were not metabolized by the oral bacteria, thus, do not increase caries risk.

Substituting sugar with intense artificial sweeteners (such as: acesulfame-K, aspartame, cyclamate and saccharin) in carbonated drinks was studied by Hendriksin et al. (2011) among young adults in the Netherlands. The authors concluded that the weight loss and the reduced energy intake was a benefit of substituting for sugar, however the health hazards of using these sweeteners might become risks if larger amounts were consumed and the daily recommended amount was exceeded. On the other hand, they mentioned that the evidence for the adverse effects of artificial sweeteners comes primarily from animal studies, and that human research is lacking. This study is limited in that it can only be applied to healthy young adults, and it used 2 scenarios: either consuming 100% added sugar or consuming 100% artificial sweeteners in carbonated beverages. These scenarios were too extreme and do not represent the diverse beverage consumption patterns found in the population. The reduced energy intake in the 100% sweetener group was not assumed to be replaced, while in life, people will probably compensate for their decreased energy intake, perhaps by substituting other sugared beverages, which might put these persons back at high risk for obesity or dental caries (Hendriksen *et al.*, 2011).

Another important finding from our study was that being in the "high soda" cluster had higher DMFT (by 1.02) and DT (by 0.45). These findings agree with those of Bernabè et al. (2014), where Finnish adults consuming SSB had 1.33 more DMFT compared to those not drinking SSB. Other data have indicated higher caries prevalence in adults who consumed SSBs regularly (Forshee and Storey, 2004; Heller *et al.*, 2001). A study of young Australian adults showed that those who drank five or more acidic drinks daily had more cavitated lesions than people who did not. However, after controlling for other

Table 4. Multiple regression models for predictors of DMFT and DT.

	DMFT	*DT*
Parameter	*Estimate (95% CI)*	*Estimate (95% CI)*
Beverage cluster		
High diet drinks	0.69 (-0.35 – 1.73)	0.07 (-0.21 – 0.35)
High coffee/tea	0.63 (-0.10 – 1.37)	0.24 (0.01 – 0.47) *
High soda	1.02 (0.42 – 1.63)	0.45 (0.25 – 0.64) *
High water (reference)	------	------
Gender		
Male	-0.65 (-1.03 – -0.27) *	0.14 (-0.02 – 0.31)
Female (reference)	------	------
Agem		
21-30 years	-8.38 (-9.07 – -7.69) *	0.27 (-0.01 – 0.54)
31-40 years	-5.78 (-6.48 – -5.07) *	0.32 (0.08 – 0.56) *
41-50 years	-2.94 (-3.62 – -2.26) *	0.07 (-0.14 – 0.29)
51-60 years (reference)	-------	------
Race/ethnicity		
Mexican American+ Hispanic	0.74 (0.08 – 1.41) *	0.15 (-0.06 – 0.36)
Non-Hispanic Black	-0.11 (-0.87 – 0.64)	-0.07 (-0.40 – 0.35)
Other	-0.52 (-1.40 – 0.36)	0.26 (0.01 – 0.51) *
Non-Hispanic White (reference)	------	------
Education		
High school or less	2.16 (1.62 – 2.71) *	0.73 (0.52 – 0.94) *
Some college	1.43 (0.80 – 2.06) *	0.38 (0.25 – 0.50) *
College graduate or above (reference)	------	------
Marital status		
Married/living with partner	-0.27 (-0.96 – 0.43)	0.01 (-0.23 – 0.26)
Widowed/divorced/separated	0.22 (-0.57 – 1.02)	0.19 (-0.06 – 0.45)
Never married (reference)	------	------
Family income to poverty ratio		
≤ 1.38	0.96 (0.26 – 1.66) *	0.70 (0.45 – 0.95) *
> 1.38 to ≤ 2.5	0.59 (-0.38 – 1.55)	0.37 (0.13 – 0.62) *
> 2.5 to ≤ 4.0	0.04 (-0.76 – 0.84)	0.07 (-0.08 – 0.22)
> 4.0 (reference)	------	------

* Indicates 95% CI does not include 0.

factors, caries was not associated with acidic beverages. One limitation of that study was that they did not specify exactly what drinks were in their acidic drinks category, however we might assume that soda was one of them (Roberts-Thomson and Stewart, 2008).

Diet is a complex concept, with many factors playing a role. We only accounted for the complexity of beverage consumption, however other factors, such as consuming sugary food or having a healthy diet, also play a role in caries development. In addition, our clusters were not discrete, so that juice and sugary drinks comprised appreciable proportions of the consumption (14.6% and 9.0% respectively) in the "high soda" category. This contrasts with the "high diet drinks" cluster patterns with lower juice drinks (5.6%) and sugary drinks intake (3.7%), suggesting that diet drink consumers have a healthier overall diet pattern and perhaps other healthy behaviors, which may explain their lower risk for dental caries.

This study has several strengths. To our knowledge, it is the first to use cluster analysis to examine the link between diet drinks and dental caries among NHANES data, allowing us to study a large representative sample of the US population. In addition, we were able to compare the relationships between diet drinks and sugary soda and dental caries. Cluster analysis has the advantage of grouping observations into homogenous, distinct clusters, which we used to identify patterns by categorizing individuals based on their beverage consumption. This allowed us to study beverage consumption as a whole behavior, rather than beverages, since people usually consume more than one beverage per day. Using 2 days of 24 hour recall dietary assessments is a strength as it is a reliable measure to study diet with demonstrable validity in nationwide studies (Ahluwalia *et al.,* 2016; Lee and Nieman, 1996).

Among our study limitations is that it is cross-sectional, therefore, we cannot indicate causality. In addition, one might challenge the accuracy of the 24-hour dietary recall data and whether it represents the regular individual's diet, as well as the possibility of recall bias. This method asked about the last 24-hours before the interview, and interviewers probed again about forgotten food. Interviewers were adequately trained and used measuring guides to assess respondents in reporting food amounts. We combined 2 days dietary recall data, which are needed to estimate habitual intakes and intakes of episodically consumed foods. Although there is no single dietary intake assessment tool that can measure intake perfectly, the 24-HR is a valid method for national data and epidemiological study.

The relationship between caries and diet drinks remains unclear, so more longitudinal studies are needed to determine causal relationships. We cannot yet recommend consuming diet drinks to decrease dental caries based only on this study. While these drinks are widely used nowadays to reduce weight, research shows that they induce heavier adults to consume more solid food (mainly snacks) to compensate for the lost calories, compared to adults consuming sugared beverages (Bleich *et al.,* 2014). In addition, the literature demonstrates a link between diet drinks and LCS with multiple systemic diseases including: diabetes, dementia and strokes and vascular diseases (Gardener *et al.*, 2012; Nettleton *et al.*, 2009; Pase *et al.*, 2017; Suez *et al.*, 2014).

Conclusion

Among a representative sample of US adults, diet drinks were not associated with dental caries after adjusting for confounders. This relationship needs to be interpreted carefully, however, as diet drinks have been linked to other systematic diseases. Additional studies need to be conducted to establish the effect of diet drinks on caries.

Acknowledgment

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The Authors declare that there is no conflict of interest.

References

Ahluwalia, N., Dwyer, J., Terry, A., Moshfegh, A. and Johnson, C. (2016): Update on NHANES dietary data: Focus on collection, release, analytical considerations, and uses to inform public policy. *Advances in Nutrition* **7**, 121-134.

Bernabe, E., Vehkalahti, M.M., Sheiham, A., Aromaa, A. and Suominen, A.L. (2014): Sugar-sweetened beverages and dental caries in adults: A 4-year prospective study. *Journal of Dentistry* **42**, 952-958.

Bleich, S.N., Wolfson, J.A., Vine, S. and Wang, Y.C. (2014): Diet-beverage consumption and caloric intake among us adults, overall and by body weight. *American Journal of Public Health* **104**, e72-e78.

Burt, B.A., Kolker, J.L., Sandretto, A.M., Yuan, Y., Sohn, W. and Ismail, A.I. (2006): Dietary patterns related to caries in a low income adult population. *Caries Research* **40**, 473-480.

Colchero, M.A., Salgado, J.C., Unar-Munguia, M., Molina, M., Ng, S. and Rivera-Dommarco, J.A. (2015): Changes in prices after an excise tax to sweetened sugar beverages was implemented in mexico: Evidence from urban areas. *PloS One* **10**, e0144408.

de Koning, L., Malik, V.S., Kellogg, M.D., Rimm, E.B., Willett, W.C. and Hu, F.B. (2012): Sweetened beverage consumption, incident coronary heart disease, and biomarkers of risk in men. *Circulation* **125**, 1735-1741, S1.

de Koning, L., Malik, V.S., Rimm, E.B., Willett, W.C. and Hu, F.B. (2011): Sugar-sweetened and artificially sweetened beverage consumption and risk of type 2 diabetes in men. *American Journal of Clinical Nutrition* **93**, 1321-1327.

Drewnowski, A. and Rehm, C. (2015): Socio-demographic correlates and trends in low-calorie sweetener use among adults in the United States from 1999 to 2008. *European Jouranl of Clinical Nutrition* **69**, 1035-1041.

Wirfält, A.K. and Jeffery, R.W. (1997): Using cluster analysis to examine dietary patterns. *Journal of American Dietetic Association* **97**, 272-279.

Falbe, J., Thompson, H.R., Becker, C.M., Rojas, N., McCulloch, C.E. and Madsen, K.A. (2016): Impact of the berkeley excise tax on sugar-sweetened beverage consumption. *American Journal of Public Health* **106**, 1865-1871.

Forshee, R.A. and Storey, M.L. (2004). Evaluation of the association of demographics and beverage consumption with dental caries. *Food and Chemical Toxicology* **42**, 1805-1816.

Gardener, H., Rundek, T., Markert, M., Wright, C.B., Elkind, M.S.V. and Sacco, R.L. (2012): Diet soft drink consumption is associated with an increased risk of vascular events in the northern manhattan study. *Journal of General Internal Medicine* **27**, 1120-1126.

Heller, K.E., Burt, B.A. and Eklund, S.A. (2001): Sugared soda consumption and dental caries in the united states. *Journal of Dental Research* **80**, 1949-1953.

Hendriksen, M.A., Tijhuis, M.J., Fransen, H.P., Verhagen, H. and Hoekstra, J. (2011): Impact of substituting added sugar in carbonated soft drinks by intense sweeteners in young adults in the netherlands: Example of a benefit-risk approach. *European Journal of Nutrition* **50**, 41-51.

Kim, J., DeBate, R.D. and Daley, E. (2013): Dietary behaviors and oral-systemic health in women. *Dental Clinics of North America* **57**, 211-231.

Kit, B.K., Fakhouri, T.H., Park, S., Nielsen, S.J. and Ogden, C.L. (2013): Trends in sugar-sweetened beverage consumption among youth and adults in the United States: 1999–2010. *American Journal of Clinical Nutrition* **98**.

Lee, R.D. and Nieman, D.C. (1996): *Nutritional assessment*.

Moynihan, P. and Petersen, P.E. (2004): Diet, nutrition and the prevention of dental diseases. *Public Health Nutrition*. **7**, 201-226.

Nettleton, J.A., Lutsey, P.L., Wang, Y., Lima, J.A., Michos, E.D. and Jacobs, D.R., Jr. (2009): Diet soda intake and risk of incident metabolic syndrome and type 2 diabetes in the multi-ethnic study of atherosclerosis (mesa). *Diabetes Care* **32**, 688-694.

National Center for Health Statistics (NCHS), Centers for Disease Control and Prevention (CDC) (2000): [*National health and nutrition examination survey dietary interviewers procedures manual 1999-2000*]. Hyattsville, md: U.S. Department of health and human services. https://wwwn.cdc.gov/nchs/data/nhanes/1999-2000/manuals/dr-1-5.pdf.

National Center for Health Statistics (NCHS), Centers for Disease Control and Prevention (CDC) (2012a): [*National health and nutrition examination survey 2011-2012 overview*]. https://wwwn.cdc.gov/nchs/nhanes/ContinuousNhanes/overview.aspx?BeginYear=2011.

National Center for Health Statistics (NCHS), Centers for Disease Control and Prevention (CDC) (2012b): [*National health and nutrition examination survey oral health examiners manual*]. https://wwwn.cdc.gov/nchs/data/nhanes/2011-2012/manuals/Oral_Health_Examiners_Manual.pdf.

National Center for Health Statistics (NCHS), Centers for Disease Control and Prevention (CDC) (2013): [*National health and nutrition examination survey oral health examination protocol*]. Hyattsville, md: U.S. Department of health and human services. https://wwwn.cdc.gov/nchs/data/nhanes/2013-2014/manuals/Oral_Health_Examiners.pdf.

Obamacare Facts (2014): [*Federal poverty level guidelines*]. http://obamacarefacts.com/federal-poverty-level/.

Pase, M.P., Himali, J.J., Beiser, A.S., Aparicio, H.J., Satizabal, C.L., Vasan, R.S., Seshadri, S. and Jacques, P.F. (2017): Sugar- and artificially sweetened beverages and the risks of incident stroke and dementia: A prospective cohort study. *Stroke* **48**, 1139-1146.

Powell, L.M., Chriqui, J. and Chaloupka, F.J. (2009): Associations between state-level soda taxes and adolescent body mass index. *International Journal of Adolescent Medicine and Health* **45,** S57-63.

Radike, A. (1972): Criteria for diagnosing dental caries [abstract]. In: *Proceedings of the conference on the clinical testing of cariostatic agents*, held at American Dental Association, Chicago, 1968. 1972, ADA council on dental research and council on dental therapeutics; Chicago, 87-88.

Roberts-Thomson, K. and Stewart, J.F. (2008): Risk indicators of caries experience among young adults. *Australian Dental Journal* **53**, 122-127.

Roberts, M.W. and Wright, J.T. (2012): Nonnutritive, low caloric substitutes for food sugars: Clinical implications for addressing the incidence of dental caries and overweight/obesity. *International Journal of Dentistry* **2012,** 625701.

Samman, M., Kaye, E., Cabral, H., Scott, T. and Sohn, W. (2020): The effect of diet drinks on caries among us children: Cluster analysis. *Journal of American Dental Association* **151**, 502-509.

Singh, G.M. (2016): Sugar sweetened beverages are associated with greater incidence of diabetes but there is a paucity of evidence on healthfulness of artificially-sweetened beverages and fruit juices. *Evidence Based Medicine* **21**, 35.

Sohn, W., Burt, B.A. and Sowers, M.R. (2006): Carbonated soft drinks and dental caries in the primary dentition. *Journal of Dental Research* **85**, 262-266.

Sturm, R., Powell, L.M., Chriqui, J.F. and Chaloupka, F.J. (2010): Soda taxes, soft drink consumption, and children's body mass index. *Health Affairs* (Millwood) **29**, 1052-1058.

Suez, J., Korem, T., Zeevi, D., Zilberman-Schapira, G., Thaiss, C.A., Maza, O., Israeli, D., Zmora, N., Gilad, S., Weinberger, A., Kuperman, Y., Harmelin, A., Kolodkin-Gal, I., Shapiro, H., Halpern, Z., Segal, E. and Elinav, E. (2014): Artificial sweeteners induce glucose intolerance by altering the gut microbiota. *Nature* **514**, 181-186.

Sylvetsky, A.C., Welsh, J.A., Brown, R.J. and Vos, M.B. (2012): Low-calorie sweetener consumption is increasing in the united states. *American Journal of Clinical Nutrition* **96,** 640-646.