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Original Article

Potential interaction of sugar intake and tobacco exposure on dental caries in adults-A cross-sectional study from the National Health and Nutrition Examination Survey

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KEYWORDS
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Tobacco exposure;
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Abstract *Background/purpose:* We suspected that there might be an interaction between sugar intake and tobacco exposure on the risk of dental caries. The study aimed to investigate the associations of sugar intake or tobacco exposure with the risk of dental caries.
Materials and methods: This cross-sectional study obtained data of 18804 participants from National Health and Nutrition Examination Survey (NHANES) between 2011 and 2018. Weighted univariable and multivariable logistic regression models were applied to explore the associations of total sugar intake or tobacco exposure with the risk of dental caries. The relative excess risk of interaction (RERI), attributable proportion of interaction (API), and synergy index (SI) evaluated the interaction between total sugar intake and tobacco exposure on the risk of dental caries. The effect size of odds ratio (OR), and 95% confidence interval (CI) was inputted.
Results: The OR of dental caries in adults with cotinine >10 ng/mL was 1.59 (95%CI: 1.38–1.82). The increased risk of dental caries was found in people with total sugar >19.5%E compared to those with total sugar ≤19.5%E (OR = 1.55, 95%CI: 1.34–1.78). Compared to people with cotinine ≤10 ng/mL and total sugar ≤19.5%E, adults with cotinine >10 ng/mL and total sugar >19.5%E were correlated with elevated risk of dental caries (OR = 2.76, 95%CI: 2.29–3.33). The interaction indicators RERI was 0.980 (95%CI: 0.413–1.547), API was 0.355 (95%CI: 0.192–0.517), and SI was 2.250 (95%CI: 1.344–3.767).

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Conclusion: There might be interaction between sugar intake and tobacco exposure on the occurrence of dental caries in adults.

Introduction

Dental caries, also known as dental cavities or tooth decay, is a global public health problem and poses a substantial economic burden all over the world.[1] The Global Burden of Disease Study revealed that untreated caries exhibited the highest prevalence impacting about 3.1 billion individuals worldwide among the 291 medical conditions assessed.[2,3] Dental caries can cause pain and discomfort, and eventually lead to tooth loss, which results in a major impact on quality of life and high costs for individuals, families and society.[4] To identify more modifiable risk factors associated with the risk of dental caries is necessary for the management of this disease.

High sugar intake was widely accepted as an important risk factor for dental caries, and there is a dose-response relationship between sugar and sugar-sweetened beverage intake and the risk of dental caries.[5] On the other hand, dental caries is regarded as a non-communicable disease, and factors associated with a non-communicable disease were considered to be related to dental caries.[6] There were studies demonstrated that smoking was associated with an increased risk of dental caries.[7,8] In addition, the results of a study in children showed that compared with the control group, the decayed, missing and filled tooth (DMFT) score, the colonization amount of *Streptococcus mutans* and Lactobacillus in saliva were increased, and the pH value, flow rate and buffer capacity of saliva were decreased in passive smoking children.[9] This may be due to increased tooth adhesion by *Streptococcus mutans*, an important cariogenic bacterium metabolizing sucrose in the presence of nicotine.[10] Therefore, we suspected that there might be an interaction between sugar intake and tobacco exposure on the risk of dental caries.

This aim of our study was to investigate the associations of sugar intake or tobacco exposure with the risk of dental caries in adults using the data from National Health and Nutrition Examination Survey (NHANES). Whether there was an interaction between sugar intake and tobacco exposure on the risk of dental caries was also evaluated. Subgroup analysis was performed in participants in different age, gender and body mass index (BMI) groups.

Materials and methods

Study design and population

This cross-sectional study obtained the data of 21501 participants aged ≥18 years with dental status data from the NHANES between 2011 and 2018. The NHANES is a continuous study evaluating the nutrition and health of adults and children in the U.S using a stratified, multistage probability design. The survey obtained the data via personal structured interviews at home, health examinations at a mobile examination center, and specimen analyses in the laboratory.[11] The records of participants were extracted if they met the following criteria: 1) ≥ 18 years; 2) with data on total sugar intake; 3) with data on serum cotinine; 4) with the measurement for coronal caries. Those without data of important covariates were excluded. Finally, 18804 participants were included. The requirement of ethical approval for this was waived by the Institutional Review Board of The Affiliated Nantong Stomatological Hospital of Nantong University, because the data was accessed from NHANES (a publicly available database). The need for written informed consent was waived by the Institutional Review Board of The Affiliated Nantong Stomatological Hospital of Nantong University due to retrospective nature of the study.

Potential confounding factors

Age (years), gender (male or female), race (non-Hispanic White, non-Hispanic Black or others), education (<high school, high school, or > high school), poverty-to-income ratio (PIR) (<1.0, or ≥1.0), drinking (<once/week, or ≥ once/week), physical activity [<450 metabolic equivalent of task (MET) × minutes/week, ≥450 MET × minutes/week, or unknown), hypertension or not, diabetes or not, dyslipidemia or not, cardiovascular disease (CVD) or not, bone loss around teeth or not, body mass index (BMI) (kg/m^2), white blood cell (WBC) (1000 cells/uL), carbohydrate (gm), fiber intake (gm), last dental visit (<1 year, 1–5 years, or ≥5 years), dental care or not, and frequency of using dental floss (<7 times/week, ≥7 times/week or unknown) were covariates analyzed in this study.

Main and outcome variables

Tobacco exposure was one of the main variables, which was evaluated based on the serum cotinine level. According to the previous studies, the serum cotinine cut-off value of active smoking is 10 ng/mL.[12] Total sugar intake was another main variable, which was calculated based on the first day's energy intake and supplement energy intake. The data were converted into energy supply ratio via total sugar × 4/total energy × 100 (%E). Total sugar intake was divided into the ≤19.5%E group and the 19.5%E group based on the median.

Dental caries was the outcome which was evaluated according to data from the examination by licensed dentists on a DMFT count. The DMFT scores were dichotomized into the DMFT>0 group and the DMFT = 0 group.[13]

The additive interaction model

The relative excess risk of interaction (RERI), attributable proportion of interaction (API), and synergy index (SI) are

indexes of the addictive model evaluating the interaction between total sugar intake and tobacco exposure on the risk of dental caries. RERI = R11-R10-R01 + 1, which shows the difference between the sum of the combined effects of the two factors and the sum of the separate effects. API = RERI/R11, which represents the proportion of total effects attributed to interaction. SI = R11 (R10 × R01), which has the same meaning as RERI. When 0 was involved in the confidence intervals (CIs) of RERI and API and 1 was included in the CIs of SI, there was no interaction.

Statistical analysis

The measurement data were described as Mean (standard error) [Mean (SE)], and independent sample t-test was used for comparisons between the two groups. The enumeration data were described as the number and percentage of cases [n (%)], and Chi-square test was used for comparisons between groups, and rank sum test was used for rank data. The missing values of physical activity and frequency of using dental floss were more than 20%, and the missing data were classified into the unknown group. Other missing variables were manipulated via the random forest multiple interpolation using the miceforest package in python (Supplementary Table 1). Sensitivity analysis was performed to evaluate the differences of data before and after missing values manipulation (Supplementary Table 2). The study was subjected to a weighted manner and a set of weights WTDRD1 was used. A weighted univariable logistic regression model was used to explore the covariates associated with dental caries. Weighted univariable and multivariable logistic regression models were applied to explore the associations of total sugar intake or tobacco exposure with the risk of dental caries, and the interaction between tobacco exposure and total sugar intake on the risk of dental caries. The multivariable logistic regression model adjusted for age, gender, race, education, PIR, drinking, physical activity, hypertension, diabetes, dyslipidemia, CVD, bone loss around teeth, BMI, fiber intake, last dental visit, and dental care. The effect size of odds ratio (OR), 95%CI, RERI, API and SI was inputted. All statistical tests were conducted using a two-sided test. SAS 9.4 (SAS Institute Inc., Cary, NC, USA) was used for statistical analysis and interaction test.

Results

The characteristics of participants with or without dental caries

A total of 21501 participants ≥18 years from the NHANES between 2011 and 2018 were identified. Participants without the assessment of total sugar intake (n = 1580), serum cotinine (n = 948), and without data on BMI (n = 169) were excluded. Finally, 18804 participants were included. The flow diagram for the identification of final participants was shown in Fig. 1.

The percentage of people with cotinine level >10 ng/mL in the non-dental caries group was lower than the dental caries group (17.20% vs 25.38%). The percentage of participants with total sugar >19.5%E in the non-dental caries group was lower than the dental caries group (42.42% vs 52.18%). The mean age of subjects in the non-dental caries group was lower than the dental caries group (36.39 years vs 49.75 years). The mean total energy intake in the non-dental caries group was higher than the dental caries group (2219.15 kcal vs 2146.97 kcal). More information on the characteristics of participants with or without dental caries was presented in Table 1.

Associations of tobacco exposure or total sugar intake with the risk of dental caries

According to the data in Table 2, age, gender, race, education, PIR, drinking, physical activity, hypertension, diabetes, dyslipidemia, CVD, bone loss around teeth, BMI, last dental visit, dental care, and frequency of using dental floss were potential covariates associated with the risk of dental caries in adults (Table 2). Multivariable logistic regression depicted that age, gender, race, education, PIR, drinking, physical activity, hypertension, diabetes, dyslipidemia, CVD, bone loss around teeth, BMI, fiber intake, last dental visit, dental care, and frequency of using dental floss were covariates.

In the crude model, cotinine >10 ng/mL might be associated with elevated risk of dental caries in adults (OR = 1.64, 95%CI: 1.44−1.87). In the adjusted model 2, the OR of dental caries in adults with cotinine >10 ng/mL was 1.59 (95%CI: 1.38−1.82). There might be increased risk of dental caries in people with total sugar >19.5%E (OR = 1.48, 95%CI: 1.31−1.67). After adjusting for confounding factors, the increased risk of dental caries was also found in people with total sugar >19.5%E compared to those with total sugar ≤19.5%E (OR = 1.55, 95%CI: 1.34−1.78) (Table 3).

Interaction between tobacco exposure and total sugar intake on the risk of dental caries in adults

The additive interaction terms of tobacco exposure and total sugar intake included cotinine ≤10 ng/mL and total sugar ≤19.5%E, cotinine >10 ng/mL and total sugar ≤19.5%E, cotinine ≤10 ng/mL and total sugar >19.5%E, and cotinine >10 ng/mL and total sugar >19.5%E. Compared to people with cotinine ≤10 ng/mL and total sugar ≤19.5%E, adults with cotinine >10 ng/mL and total sugar >19.5%E were correlated with elevated risk of dental caries (OR = 2.76, 95%CI: 2.29−3.33) (Table 4).

The interaction indicators RERI was 0.980 (95%CI: 0.413−1.547) and API was 0.355 (95%CI: 0.192−0.517). The CIs of RERI and API did not contain 0 and were both >0. The SI was 2.250 (95%CI: 1.344−3.767), and the CI did not contain 1 and were >1. The results indicated that there was synergic interaction between tobacco exposure and total sugar intake on the risk of dental caries in adults. The API was 0.355, indicating in our study, tobacco exposure and total sugar intake attributed to 35.5% risk of dental caries (Table 4).

Subgroup analysis of the interaction between tobacco exposure and total sugar intake on the risk of dental caries in adults

Based on the results from Table 5, the interaction between tobacco exposure and total sugar intake on the risk of dental caries was identified in adults <45 years with RERI of

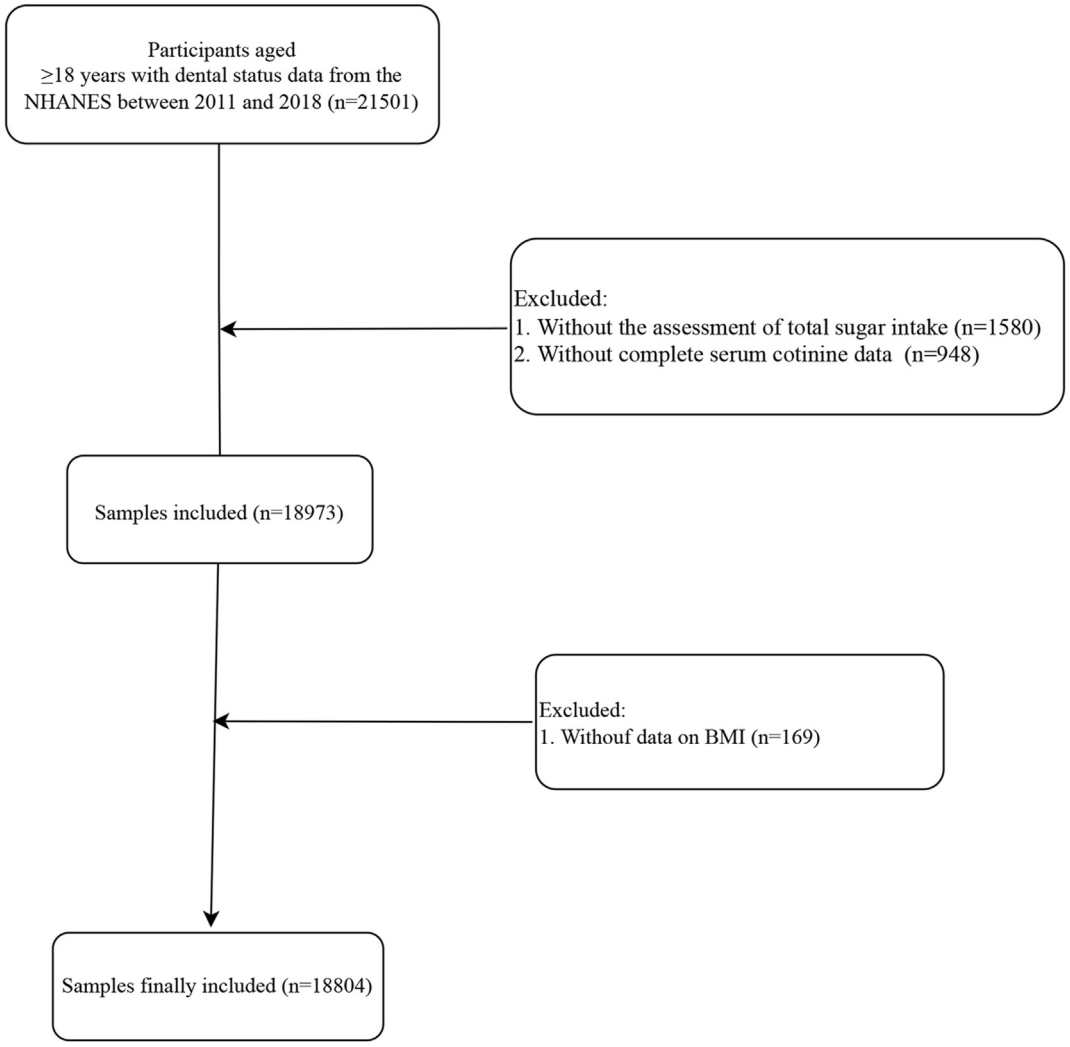

Figure 1 The flow diagram for the identification of final participants in this study.

Table 1 The characteristics of participants with or without dental caries.

Variables	Total (n = 18804)	People without dental caries (n = 3387)	People with dental caries (n = 15417)	Statistics	*P*
Cotinine, n (%)				$\chi^2 = 63.72$	<0.001
≤10 ng/mL	14320 (76.42)	2779 (82.80)	11541 (74.62)		
>10 ng/mL	4484 (23.58)	608 (17.20)	3876 (25.38)		
Total sugar, n (%)				$\chi^2 = 44.36$	<0.001
≤19.5%E	9166 (49.97)	1877 (57.58)	7289 (47.82)		
>19.5%E	9638 (50.03)	1510 (42.42)	8128 (52.18)		
Cotinine and total sugar level, n (%)				$\chi^2 = 100.48$	<0.001
Cotinine ≤10 ng/mL and total sugar ≤19.5%E	7095 (38.84)	1533 (47.24)	5562 (36.47)		
Cotinine >10 ng/mL and total sugar ≤19.5%E	2071 (11.13)	344 (10.34)	1727 (11.35)		
Cotinine ≤10 ng/mL and total sugar >19.5%E	7225 (37.58)	1246 (35.56)	5979 (38.15)		
Cotinine >10 ng/mL and total sugar >19.5%E	2413 (12.45)	264 (6.85)	2149 (14.03)		
Age, years, Mean (S.E)	46.81 (0.35)	36.39 (0.53)	49.75 (0.31)	t = −26.95	<0.001
Gender, n (%)				$\chi^2 = 7.24$	0.007
Male	9230 (48.89)	1712 (51.92)	7518 (48.04)		
Female	9574 (51.11)	1675 (48.08)	7899 (51.96)		
Race, n (%)				$\chi^2 = 9.16$	0.010

(*continued on next page*)

Table 1 (*continued*)

Variables	Total (n = 18804)	People without dental caries (n = 3387)	People with dental caries (n = 15417)	Statistics	*P*
Non-Hispanic White	7215 (64.93)	1208 (64.79)	6007 (64.97)		
Non-Hispanic Black	4162 (10.98)	615 (8.93)	3547 (11.56)		
Others	7427 (24.09)	1564 (26.28)	5863 (23.47)		
Education, n (%)				$\chi^2 = 95.68$	<0.001
<high school	3832 (13.40)	392 (6.85)	3440 (15.24)		
high school	4218 (22.75)	611 (18.19)	3607 (24.04)		
>high school	10754 (63.85)	2384 (74.95)	8370 (60.72)		
PIR, n (%)				$\chi^2 = 7.19$	0.007
<1.0	4192 (15.48)	631 (12.68)	3561 (16.27)		
≥1.0	14612 (84.52)	2756 (87.32)	11856 (83.73)		
Drinking, n (%)				$\chi^2 = 8.14$	0.004
<Once/week	14610 (73.00)	2711 (76.51)	11899 (72.01)		
≥Once/week	4194 (27.00)	676 (23.49)	3518 (27.99)		
Physical activity, n (%)				$\chi^2 = 98.31$	<0.001
<450 MET × minutes/week	1848 (9.28)	277 (7.70)	1571 (9.72)		
≥450 MET × minutes/week	12402 (69.98)	2599 (79.18)	9803 (67.38)		
Unknown	4554 (20.74)	511 (13.12)	4043 (22.89)		
Hypertension, n (%)				$\chi^2 = 244.58$	<0.001
No	10439 (59.53)	2622 (76.89)	7817 (54.64)		
Yes	8365 (40.47)	765 (23.11)	7600 (45.36)		
Diabetes, n (%)				$\chi^2 = 103.15$	<0.001
No	15296 (85.49)	3131 (93.14)	12165 (83.33)		
Yes	3508 (14.51)	256 (6.86)	3252 (16.67)		
Dyslipidemia, n (%)				$\chi^2 = 143.35$	<0.001
No	6074 (32.24)	1613 (44.31)	4461 (28.84)		
Yes	12730 (67.76)	1774 (55.69)	10956 (71.16)		
CVD, n (%)				$\chi^2 = 194.53$	<0.001
No	15026 (82.68)	3130 (91.73)	11896 (80.13)		
Yes	3778 (17.32)	257 (8.27)	3521 (19.87)		
Bone loss around teeth, n (%)				$\chi^2 = 67.31$	<0.001
No	16485 (87.89)	3223 (94.95)	13262 (85.90)		
Yes	2319 (12.11)	164 (5.05)	2155 (14.10)		
BMI, kg/m^2, Mean (S.E)	29.18 (0.12)	28.76 (0.24)	29.30 (0.12)	t = −2.23	0.029
WBC, 1000 cells/uL, Mean (S.E)	7.34 (0.04)	7.31 (0.05)	7.35 (0.04)	t = −0.66	0.510
Carbohydrate, gm, Mean (S.E)	254.38 (1.27)	252.00 (3.30)	255.05 (1.50)	t = −0.79	0.432
Fiber intake, gm, Mean (S.E)	17.43 (0.19)	18.06 (0.34)	17.26 (0.19)	t = 2.32	0.023
Last dental visit, n (%)				$\chi^2 = 17.35$	<0.001
<1 year	10336 (60.25)	2003 (63.31)	8333 (59.39)		
1−5 years	5377 (26.25)	932 (26.25)	4445 (26.25)		
≥5 years	3091 (13.51)	452 (10.45)	2639 (14.37)		
Dental care, n (%)				$\chi^2 = 59.23$	<0.001
No	14683 (81.63)	2958 (88.75)	11725 (79.63)		
Yes	4121 (18.37)	429 (11.25)	3692 (20.37)		
Frequency of using dental floss, n (%)				$\chi^2 = 478.93$	<0.001
<7 times/week	9915 (52.33)	1229 (40.11)	8686 (55.77)		
≥7 times/week	4913 (25.87)	579 (17.65)	4334 (28.19)		
Unknown	3976 (21.80)	1579 (42.24)	2397 (16.04)		
Total energy, kcal, Mean (S.E)	2162.92 (9.14)	2219.55 (24.46)	2146.97 (11.15)	t = 2.48	0.016

S.E: standard error; PIR: poverty-to-income ratio; MET: metabolic equivalent of task; CVD: cardiovascular disease; BMI: body mass index; WBC: white blood cell.

Table 2 Potential covariates associated with the occurrence of dental caries.

Variables	OR (95%CI)	*P*
Age	1.05 (1.05–1.06)	<0.001
Gender		
Male	Ref	
Female	1.17 (1.04–1.31)	0.009
Race		
Non-Hispanic White	Ref	
Non-Hispanic Black	1.29 (1.05–1.59)	0.016
Others	0.89 (0.75–1.06)	0.178
Education		
<high school	Ref	
high school	0.59 (0.48–0.74)	<0.001
>high school	0.36 (0.30–0.45)	<0.001
PIR		
<1.0	Ref	
≥1.0	0.75 (0.60–0.93)	0.008
Drinking, n (%)		
<Once/week	Ref	
≥Once/week	1.27 (1.07–1.49)	0.006
Physical activity, n (%)		
<450 MET × minutes/week	Ref	
≥450 MET × minutes/week	0.67 (0.54–0.84)	<0.001
Unknown	1.38 (1.08–1.77)	0.012
Hypertension		
No	Ref	
Yes	2.76 (2.40–3.17)	<0.001
Diabetes		
No	Ref	
Yes	2.72 (2.20–3.35)	<0.001
Dyslipidemia		
No	Ref	
Yes	1.96 (1.73–2.22)	<0.001
CVD		
No	Ref	
Yes	2.75 (2.35–3.21)	<0.001
Bone loss around teeth		
No	Ref	
Yes	3.09 (2.34–4.07)	<0.001
BMI	1.01 (1.01–1.02)	0.034
WBC	1.00 (0.99–1.02)	0.590
Carbohydrate	1.00 (1.00–1.00)	0.436
Fiber intake	0.99 (0.99–0.99)	0.019
Last dental visit		
<1 year	Ref	
1–5 years	1.07 (0.92–1.23)	0.375
≥5 years	1.47 (1.22–1.76)	<0.001
Dental care		
No	Ref	
Yes	2.02 (1.69–2.42)	<0.001
Frequency of using dental floss		
<7 times/week	Ref	
≥7 times/week	1.15 (0.97–1.36)	0.112
Unknown	0.27 (0.23–0.32)	<0.001

OR: odds ratio; CI: confidence interval; Ref: reference.

0.781 (95%CI: 0.258–1.304), API of 0.328 (95%CI: 0.145–0.510), and SI of 2.294 (95%CI: 1.196–4.401). In male people, the interaction between tobacco exposure and total sugar intake on the risk of dental caries was also observed. The RERI was 1.046 (95%CI: 0.308–1.784), API was 0.384 (95%CI: 0.178–0.591), and SI was 2.544 (95%CI: 1.237–5.234). In participants with BMI <25 kg/m^2, the interaction between tobacco exposure and total sugar intake on the risk of dental caries was significant [(RERI = 1.546, 95%CI: 0.393–2.699), API = 0.481 (95%CI: 0.263–0.699), and SI = 3.311 (95%CI: 1.403–7.814)]. The RERI was 0.722 (95%CI: 0.103–1.342), API was 0.279 (95%CI: 0.071–0.487), and SI was 1.833 (95%CI: 1.027–3.274) in adults with BMI≥25 kg/m^2, suggesting that the interaction between tobacco exposure and total sugar intake on the risk of dental caries was significant.

Discussion

The present study evaluated the associations of sugar intake or tobacco exposure with the risk of dental caries in adults, and further assessed the interaction between sugar intake and tobacco exposure on the risk of dental caries was also evaluated. The results showed that high levels of tobacco exposure or high total sugar intake were related to increased risk of dental caries. Additionally, a synergic interaction between sugar intake and tobacco exposure was identified to be associated with the risk of dental caries. The findings might provide a reference for the management of oral health in common people, and offer a direction for future prospective studies to explore the roles of sugar intake and tobacco exposure on the risk of dental caries.

In previous studies, smoking was reported to be associated with higher caries prevalence and more severe periodontal disease.[14] Liu et al. reported that residents of Liaoning, China with a history of smoking habits were more susceptible to dental caries.[15] Another Sweden cohort study indicated that smoking and use of smokeless tobacco were determinants of dental caries increment in young adults.[16] In our study, we found that cotinine level >10 ng/mL was associated with increased risk of dental caries in adults. This might because tobacco smoking was associated with elevated levels of *Streptococcus mutans* and Lactobacilli.[9] *Streptococcus mutans* is the major cariogenic microorganism in the oral cavity.[17] While nicotine increases the biofilm formation and metabolic activity of *Streptococcus mutans*.[18] Nicotine also enhances extracellular polysaccharides, which attract other microorganisms, such as *Candida albicans*, onto the dental plaque.[19] Another possible reason might be that smokers had decreased levels of secretory immunoglobulin A (SIgA) that was associated with the prevalence of dental caries.[20]

Growing numbers of studies indicated the risk of dental caries might due to sugar intake, and sugar consumption is one of the main aetiological factors for dental caries.[21] A systematic review indicated that the between-meal consumption of processed sugar-containing foods was consistently associated with greater caries experience.[22] A

Table 3 Associations of tobacco exposure or total sugar intake with the risk of dental caries.

	Crude model		Model 1		Model 2	
Variables	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Cotinine						
≤10 ng/mL	Ref		Ref		Ref	
>10 ng/mL	1.64 (1.44–1.87)	<0.001	1.83 (1.60–2.09)	<0.001	1.59 (1.38–1.82)	<0.001
Total sugar						
≤19.5%E	Ref		Ref		Ref	
>19.5%E	1.48 (1.31–1.67)	<0.001	1.50 (1.31–1.71)	<0.001	1.55 (1.34–1.78)	<0.001

OR: odds ratio; CI: confidence interval; Ref: Reference.
Crude model: Weighted univariable logistic regression model.
Model 1: Weighted multivariable logistic regression model adjusted for age, gender, race, education, and PIR.
Model 2: Weighted multivariable logistic regression model adjusted for age, gender, race, education, PIR, drink, physical activity, hypertension, diabetes, dyslipidemia, CVD, bone loss around teeth, BMI, fiber intake, last dental visit, dental care, frequency of using dental floss.

Table 4 Interaction between tobacco exposure and total sugar intake on the risk of dental caries in adults.

	Crude model		Model 1		Model 2	
	OR (95%CI)	*P*	OR (95%CI)	*P*	OR (95%CI)	*P*
Cotinine and total sugar level						
Cotinine ≤10 ng/mL and total sugar ≤19.5%E	Ref		Ref		Ref	
Cotinine >10 ng/mL and total sugar ≤19.5%E	1.42 (1.18–1.71)	<0.001	1.56 (1.28–1.90)	<0.001	1.34 (1.09–1.65)	0.006
Cotinine ≤10 ng/mL and total sugar >19.5%E	1.39 (1.21–1.59)	<0.001	1.39 (1.19–1.63)	<0.001	1.44 (1.23–1.69)	<0.001
Cotinine >10 ng/mL and total sugar >19.5%E	2.65 (2.19–3.21)	<0.001	3.05 (2.55–3.64)	<0.001	2.76 (2.29–3.33)	<0.001
RERI	0.840 (0.276–1.404)		1.094 (0.487–1.701)		0.980 (0.413–1.547)	
API	0.317 (0.147–0.487)		0.359 (0.202–0.516)		0.355 (0.192–0.517)	
SI	2.037 (1.248–3.323)		2.148 (1.363–3.384)		2.250 (1.344–3.767)	

OR: odds ratio; CI: confidence interval; Ref: Reference; RERI: relative excess risk of interaction; SI: the synergy index; API: attributable proportion of interaction.
Crude model: Weighted univariable logistic regression model.
Model 1: Weighted multivariable logistic regression model adjusted for age, gender, race, education, and PIR.
Model 2: Weighted multivariable logistic regression model adjusted for age, gender, race, education, PIR, drink, physical activity, hypertension, diabetes, dyslipidemia, CVD, bone loss around teeth, BMI, fiber intake, last dental visit, dental care, frequency of using dental floss.

position paper of the Brazilian Academy of Dentistry demonstrated that excessive sugar consumption is the main cause of dental caries.[23] Herein, high total sugar intake was related to elevated risk of dental caries in adults. The role of sugars as well as its aetiology in oral health is well established.[24,25] Sugar can be used as a substrate for oral bacteria, and oral bacteria metabolized acid, which reduces PH value and exceeds the buffer adjustment capacity of saliva, thus increasing the favorable conditions for dental demineralization.[26] The WHO recommended that for minimising lifelong risk of dental caries, free sugars intake should be limited to below 5% of energy intake.[27] Addressing the universally high free sugars intake, is an important part of the Global Strategy on Oral Health.

Additionally, the synergistic interaction of cotinine level and sugar intake was identified on the occurrence of dental caries. These suggested that people with both smoking habits and high sugar intake might have higher risk of dental caries. Increasing knowledge of the role of risk factors, namely smoking, and high sugar intake might enable public health policies to be implemented that reduce the probability of progression to pathology. Dental health professionals should incorporate anti-smoking activities, and sugar limiting in their preventive strategies. Active disease prevention strategies and multidisciplinary actions may help achieve early pathological detection and thereby early treatment.[14,28]

The present study initially evaluated the interaction between sugar intake and tobacco exposure on dental caries in adults, which might provide a reference for the formulation of more specific prevention and control strategies. The sample size of this study is large, and multistage complex sampling was conducted, which has a good representation of the American population. Also, the use of cotinine level as a marker can more objectively reflect tobacco exposure in individuals. Several limitations existed in this study. Firstly, the current study was a cross-sectional study, and no causal relationship between cotinine level or total sugar intake and dental caries could be identified. Secondly, although the influence of possible confounding factors such as floss use was considered, there were still some missing points due to database limitations.

In conclusion, this study identified that there might be interaction between sugar intake and tobacco exposure on

Table 5 Subgroup analysis of the interaction between tobacco exposure and total sugar intake on the risk of dental caries in adults.

Subgroup	n (%)	Model		n (%)	Model	
		OR (95%CI)	*P*		OR (95%CI)	*P*
Subgroup I: Age		Age<45 (n = 8452)			Age≥45 (n = 10352)	
Cotinine ≤10 ng/mL and total sugar ≤19.5%E	3073 (37.55%)	Ref		4022 (39.95%)	Ref	
Cotinine >10 ng/mL and total sugar ≤19.5%E	993 (12.38%)	1.15 (0.91–1.46)	0.242	1078 (10.05%)	1.60 (0.90–2.85)	0.106
Cotinine ≤10 ng/mL and total sugar >19.5%E	3062 (35.15%)	1.45 (1.25–1.70)	<0.001	4163 (39.68%)	1.34 (1.01–1.79)	0.049
Cotinine >10 ng/mL and total sugar >19.5%E	1324 (14.92%)	2.38 (1.97–2.89)	<0.001	1089 (10.32%)	4.50 (2.33–8.70)	<0.001
RERI		0.781 (0.258–1.304)			2.562 (−0.392–5.516)	
API		0.328 (0.145–0.510)			0.569 (0.229–0.908)	
SI		2.294 (1.196–4.401)			3.719 (1.005–13.762)	
Subgroup II: Gender		Male (n = 9230)			Female (n = 9574)	
Cotinine ≤10 ng/mL and total sugar ≤19.5%E	3459 (38.79%)	Ref		3636 (38.89%)	Ref	
Cotinine >10 ng/mL and total sugar ≤19.5%E	1368 (14.30%)	1.20 (0.95–1.53)	0.128	703 (8.10%)	1.64 (1.20–2.24)	0.002
Cotinine ≤10 ng/mL and total sugar >19.5%E	3026 (32.59%)	1.47 (1.20–1.82)	<0.001	4199 (42.35%)	1.40 (1.12–1.76)	0.004
Cotinine >10 ng/mL and total sugar >19.5%E	1377 (14.32%)	2.72 (2.14–3.46)	<0.001	1036 (10.66%)	2.75 (1.91–3.98)	<0.001
RERI		1.046 (0.308–1.784)			0.710 (−0.299–1.719)	
API		0.384 (0.178–0.591)			0.258 (−0.038–0.554)	
SI		2.544 (1.237–5.234)			1.680 (0.840–3.360)	
Subgroup III: BMI		BMI<25 kg/m^2 (n = 5519)			BMI≥25 kg/m^2 (n = 13285)	
Cotinine ≤10 ng/mL and total sugar ≤19.5%E	1968 (35.72%)	Ref		5127 (40.14%)	Ref	
Cotinine >10 ng/mL and total sugar ≤19.5%E	699 (11.50%)	1.35 (0.96–1.92)	0.088	1372 (10.97%)	1.36 (1.03–1.80)	0.030
Cotinine ≤10 ng/mL and total sugar >19.5%E	2006 (37.61%)	1.31 (1.07–1.62)	0.011	5219 (37.57%)	1.50 (1.24–1.82)	<0.001
Cotinine >10 ng/mL and total sugar >19.5%E	846 (15.17%)	3.22 (2.20–4.70)	<0.001	1567 (11.32%)	2.59 (2.11–3.18)	<0.001
RERI		1.546 (0.393–2.699)			0.722 (0.103–1.342)	
API		0.481 (0.263–0.699)			0.279 (0.071–0.487)	
SI		3.311 (1.403–7.814)			1.833 (1.027–3.274)	

OR: odds ratio; CI: confidence Interval; Ref: reference; RERI: relative excess risk of interaction; SI: the synergy index; API: attributable proportion of interaction; BMI: body mass index.
OR: odds ratio; CI: confidence interval; Ref: Reference.
Crude model: Weighted univariable logistic regression model.
Model: Weighted multivariable logistic regression model, if not stratified, adjusted for age, gender, race, education, PIR, drink, physical activity, hypertension, diabetes, dyslipidemia, CVD, bone loss around teeth, BMI, fiber intake, last dental visit, dental care, frequency of using dental floss.

dental caries in adults. The findings suggested that less tobacco exposure and sugar intake might be policies worth promoting and benefit for oral health in adults.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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