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Diabetes and dental caries in US adults: an analysis of data from the National Health and Nutrition Examination Survey, 2011-2018

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Objectives: To determine the relationship between diabetes and dental caries among US adults participating in the 2011-2018 National Health and Nutrition Examination Survey (NHANES). ***Basic research design***: The NHANES was a cross-sectional study including clinical assessments, laboratory analysis, and interviews. The sample included 16,635 participants aged 20 years and older that represent 187,596,215 individuals in the US in a probability weighted sample. Outcome variables included overall total caries score (or number of decayed, missing, filled permanent teeth – DMFT index) and the presence of caries. Bivariate analysis, Poisson regression for total caries score, logistic regression for the presence of caries were used for analysis. ***Results***: Controlling for covariates, multiple Poisson regression revealed that total DMFT scores were associated with diabetes status (adjusted relative risk ratio $(RR)_{\text{controlled diabetes}} = 1.13$, $RR_{\text{uncontrolled diabetes}} = 1.18$; $p<0.001$), no college education, female sex, white race, elderly (≥ 65 years), cigarette smoking, obesity, yearly dental visits, seeing a dentist only for treatment. Similarly, multiple logistic regression shows that the odds of adults with diabetes having dental caries were higher than among those without diabetes (adjusted risk ratio $(OR)_{\text{controlled diabetes}} = 1.84$, $OR_{\text{uncontrolled diabetes}} = 1.87$; $p<0.05$). ***Conclusions***: Diabetes was associated with a higher caries score and a greater risk for dental caries among US adults.

Keywords*: oral health, dental caries, United States, glycemic control, adult, dental public health*

Diabetes mellitus (DM) is a chronic metabolic disease characterized by defects in insulin secretion and resistance resulting in hyperglycemia (Lamster *et al.*, 2008). DM is a major public health problem and the seventh leading cause of death in the United States (Centers for Disease Control and Prevention, 2020). An estimated 34.1 million adult Americans (13%) had DM in 2018. If left untreated, patients may suffer systemic complications such as cardiovascular disease, peripheral artery disease, renal disease, retinopathy, and neuropathy (Elter *et al.*, 2003; 2004; Han and Park, 2021). Approximately one-third of individuals with DM have severe periodontal disease. Attenuated immunity, which is a common consequence of hyperglycemia may be the pathophysiological etiology of increased prevalence and severity of periodontal disease (Kidambi and Patel, 2008).

Periodontal disease and severe dental caries are major causes of tooth loss (Patel *et al.*, 2013). Periodontal disease is referred as "the sixth complication of diabetes" (Majbauddin *et al.*, 2019). Dental caries, one of the most prevalent chronic oral diseases worldwide, is caused by the dissolution of tooth surface minerals by organic acids formed by sugar bacterial fermentation (Selwitz *et al.*, 2007). DM patients have an increased frequency of xerostomia, altered immune to infection, microvascular changes, and salivary glycemic concentration (Kidambi and Patel, 2008; Majbauddin *et al.*, 2019). They are often obese and consume dense, high-energy carbohydrate-containing foods, increasing susceptibility to dental caries (Lamster *et al.*, 2008; Majbauddin *et al.*, 2019).

However, no consensus exists on the relationship between DM and dental caries. Some studies (Majbauddin *et al.*, 2019; Suzuki *et al.*, 2018; Yonekura *et al.*, 2017) showed that DM patients had a higher prevalence of dental caries compared to those without. In contrast, two (Aziz, 2012; Khan *et al.*, 2019) reported no association between the two conditions. Previous studies used samples of convenience (e.g., hospital data) with small samples ($n < 200$). One Japanese study (Suzuki *et al.*, 2018) used a large sample ($n = 1,897$) from employment-based health insurance claims, but included mainly males (94.5%). Most studies (Aziz, 2012; Khan *et al.*, 2019; Suzuki *et al.*, 2018; Yonekura *et al.*, 2017) were conducted outside of the US. In the US, 92% of adults have experienced dental caries (National Institute of Dental and Craniofacial Research 2018a; 2018b). The association between dental caries with DM remains uncertain (Suzuki *et al.*, 2018). Increasing DM prevalence in the US may pose a growing threat to oral health and thus determination of the association of DM with dental caries using a large population-based sample from the US is needed.

The purpose of this study was to determine the association between DM and dental caries in US adults participating in the 2011-2018 National Health and Nutrition Examination Survey (NHANES).

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Method

The 2011-2018 NHANES data were used. NHANES is publicly available de-identified data with a stratified, multistage sampling cross-sectional design to obtain a representative probability sample of US civilian, noninstitutionalized population (Dye *et al.*, 2015). Sampling weights are included with the data to use for weighted regression analysis.

The sample includes 16,635 adults aged 20 years and older that represent 187,596,215 individuals in the US in a probability weighted sample. Participants received dental examination by trained and calibrated dentists in mobile examination centers (MEC). Participants were listwise excluded if their diabetes status remained unknown or if they had incomplete information on one or more variables of interest to this study.

Two main outcome variables for caries experience were created from dental examination data. The first was the total count of the number of currently decayed (untreated caries) (D), missing (M), and filled (F) teeth (T) in the permanent dentition (DMFT index, ranging from 0 through 28) (Dye *et al.*, 2015; Vemulapalli *et al.*, 2021). Third molars and implants were not included in the count. The DMFT index reflects an adult's cumulative experience of past and present dental caries, whether untreated (the number of decayed teeth) and treated (filled teeth or missing teeth extracted because of caries) (Yonekura *et al.*, 2017). The second was the presence or absence of caries experience, which was created by dichotomized the DMFT index (≥ 1, < 1). These variables represent the severity and prevalence of a participant's cumulative dental caries and treatment experience, respectively.

Diabetes status was the key independent variable, categorized as no diabetes, diabetes with controlled HbA1c, and diabetes with uncontrolled HbA1c) based the participant's (1) self-reported response to the diabetes survey question and (2) laboratory report of HbA1c level. The question was "Other than during pregnancy, have you ever been told by a doctor or health professional that you have diabetes?" Participants were classified as having no diabetes if their response to the questionnaire was "No." The question did not differentiate between types 1 and 2 diabetes mellitus. If the response was "Yes" and HbA1c $< 9\%$, the authors classified a participant as controlled diabetes. If the response was "yes" and HbA1c $\geq 9\%$, the participant was classified as uncontrolled. The combination of binary diabetes status (yes, no) and HbA1c level ($< 9\%$, $\geq 9\%$) was used to measure the severity of diabetes more parsimoniously and avoid redundancy of using both variables simultaneously.

Potential confounders were selected based on previous studies (Aziz, 2012; Dye *et al.*, 2015; Khan *et al.*, 2019; Majbauddin *et al.*, 2019; National Institute of Dental and Craniofacial Research 2018a; National Institute of Dental and Craniofacial Research 2018b; Suzuki *et al.*, 2018; Vemulapalli *et al.*, 2021; Yonekura *et al.*, 2017). Demographic variables included age, sex, race/ethnicity, educational level, and income status. Age (in years) was dichotomized (< 65, ≥ 65). The race/ethnicity of participants were identified as non-Hispanic White, non-Hispanic Black, Hispanic, and other. Participants' educational level included two groups (high school diploma or lower, college or above). The authors dichotomized each participant as below 200% federal poverty guidelines (FPG), or 200% FPG or higher. In addition, participants' previous dental visits were categorized as $\leq$12 months, 12-36 months or $\geq$36 months. Information regarding reasons for a dental visit were dichotomized as (1) annual/biannual checkups or prophylaxis and (2) having dental-related pain or needing a dental treatment. Body mass index (BMI) measured by height and weight in the laboratory report was dichotomized as obesity (≥ 30) and no obesity (< 30). The participants were classified as never smoker, former smoker, and current smoker (Patel *et al*., 2013).

SAS Version 9.4 (SAS Institute, Cary, NC, USA) and R software (version 3.6.3) with the *survey* package (R Foundations) were used for data management and data analysis. The MEC sampling weights were used to account to the complex survey design and yield estimates generalizable to the US population (Dye *et al.*, 2015). Chi-squared tests were used to test whether unadjusted prevalence of dental caries was associated with explanatory variables and *t* tests examined whether DMFT differed by characteristic (Vemulapalli *et al.*, 2021). Multiple Poisson regression was used to test the association between DMFT and diabetes status using adjusted relative risk ratios (RR) with 95% confidence intervals (CIs). Multiple logistic regression analyzed the association between the presence of dental caries and diabetes status using adjusted odds ratios (OR) with 95% CIs. The same covariates were used in both regression models.

Results

After applying the selection criteria, the sample comprised of 16,635 individuals from the NHANES 2011-2018 cycles. Mean age of the participants was 49.3 years (sd = 17.6) and weighted mean age of the sample was 47.6 years (17.0). Mean HbA1c (sd) in the sample and weighted sample were 5.78 (1.11) and 5.64 (0.95) respectively.

Of the participants, 10.7% self-reported as diabetic. Most (61%) had annual dental care, and 63.1% went to the dentist for emergency treatment and pain (Table 1). Approximately one third (34.7%) had family incomes less than 200% of federal poverty level, and 35% had a high school education or less. Non-Hispanic whites comprised 67.5% of the sample and 18.7% were 65 years old and older. Half (56.4%) had never smoked tobacco and 18.5% were current smokers. Obesity (BMI > 30) prevalence was was similar to the US average at 38.8%.

In Poisson regression having diabetes (controlled RR = 1.13, 95% CI 1.09 – 1.18; uncontrolled RR = 1.18, 95% CI 1.12 – 1.24) (Table 2) was associated with greater DMFT. DMFT relative risk also associated with having an annual dental visit (RR=1.09, 95% CI 1.06 – 1.12), seeing a dentist for oral pain or for treatment (RR = 1.31 (95% CI 1.27 – 1.36). Family income was unrelated to DMFT, but college education was associated with lower DMFT. Females were more likely to have higher DMFT than males (RR=1.11, 95% CI 1.08 – 1.13). Non-white racial groups (Black, Hispanic, Other) had lower DMFTs (RR=0.90, 0.85, 0.89 respectively). Participants >65 years old also had higher DMFTs (RR=1.79, 95% CI 1.74 – 1.85). Current tobacco smoking was associated with higher DMFT (RR=1.24, 95% CI 1.20 – 1.29), as was

Table 1. Dental status of NHANES 2011-2018 participants.

	n	*Weighted estimate % (95% CI)*	*DMFT Mean (95% CI)*	*DMFT ≥1 % (95% CI)*
Overall	16,635	100	10.9 (10.6 – 11.2)	93.0 (92.3 – 93.7)
Diabetes status				
No diabetes	14,277	89.3 (88.7 – 90.0)	10.4 (10.1 – 10.7)	92.5 (91.7 – 93.2)
Controlled diabetes	1,955	9.1 (8.5 – 9.7)	15.0 (14.4 – 15.6)	97.5 (96.5 – 98.4)
Uncontrolled diabetes	403	1.6 (1.4 – 1.8)	13.8 (12.9 – 14.7)	97.5 (95.9 – 99.2)
Annual dental visit				
No	7,394	39.0 (37.0 – 40.9)	10.8 (10.4 – 11.2)	90.8 (89.7 – 91.9)
Yes	9,231	61.0 (59.1 – 63.0)	11.0 (10.7 – 11.3)	94.4 (93.7 – 95.1)
Reason for a dental visit				
Checkup/Cleaning	9,344	63.1 (61.2 – 64.9)	9.5 (9.2 – 9.8)	90.7 (89.8 – 91.6)
Hurting/Treatment	7,291	36.9 (35.1 –38.8)	13.3 (12.9 – 13.7)	97.0 (96.4 – 97.6)
Family Income level				
≥ 200% FPG	8,690	65.3 (62.9 – 67.7)	10.6 (10.3 – 11.0)	93.2 (92.4 – 94.0)
< 200% FPG	7,945	34.7 (32.3 – 37.1)	11.4 (10.9 – 11.8)	92.7 (91.7 – 93.7)
Education				
High school or less	7,018	35.2 (32.9 – 37.4)	12.4 (11.9 – 12.8)	94.1 (93.0 – 95.1)
College or above	9,617	64.8 (62.6 – 67.1)	10.1 (9.8 – 10.4)	92.3 (91.6 – 93.2)
Sex				
Male	8,037	48.0 (47.2 – 48.8)	10.4 (10.1 – 10.8)	92.1 (91.1 – 92.9)
Female	8,598	52.0 (51.2 – 52.8)	11.3 (11.0 – 11.6)	93.9 (93.1 – 94.7)
Race				
White	6,649	67.5 (64.2 –70.7)	11.5 (11.2 – 11.9)	93.8 (93.1 – 94.6)
Black	3,610	10.4 (8.6 – 12.1)	10.1 (9.8 – 10.5)	92.1 (91.1 – 93.1)
Hispanic	3,755	13.6 (11.4 – 15.9)	9.2 (8.8 – 9.6)	91.6 (90.3 – 92.9)
Others	2,621	8.5 (7.5 – 9.5)	9.5 (8.9 – 10.0)	89.8 (88.2 – 91.4)
Age group				
< 65	12,846	81.3 (80.1 – 82.5)	9.2 (9.0 – 9.5)	91.5 (90.7 – 92.3)
≥ 65	3,789	18.7 (17.5 – 19.9)	18.0 (17.6 – 18.4)	99.5 (99.3 – 99.8)
Cigarette smoking status				
Never smoked	9,440	56.4 (55.0 – 57.8)	9.6 (9.3 – 9.9)	91.7 (90.8 – 92.5)
Former smoker	3,963	25.1 (23.9 – 26.2)	13.0 (12.6 – 13.3)	95.2 (94.2 – 96.2)
Current smoker	3,222	18.5 (17.5 – 19.6)	12.0 (11.5 – 12.5)	94.1 (93.0 – 95.2)
Obesity				
No obesity	10,152	61.2 (59.7 – 62.7)	10.3 (10.3 – 11.0)	92.1 (91.3 – 92.9)
Obesity	6,483	38.8 (37.3 – 40.3)	11.2 (10.9 – 11.6)	94.4 (93.5 – 95.3)

being a former smoker (RR=1.17, 95% CI 1.14 – 1.20). Obesity slightly increased the RR for DMFT (RR=1.03, 95% CI 1.01 – 1.06).

Multiple logistic regression for the presence of dental caries or treatment (DMFT ≥1) associated controlled and uncontrolled diabetes with dental caries (OR=1.84, 95% CI 1.18 – 2.86 and OR=1.87, 95% CI 1.13 – 3.10 respectively) (Table 3). Annual dental visits and attending for pain or treatment also predicted DMFT ≥1. Indicators of socioeconomic status (poverty and education) were unrelated to the presence of caries or treatment experience. Women, current or former smokers, people who were obese and those aged >65 years were more likely to have had dental caries.

Table 2. Multiple Poisson regression analysis for predictors of number of decayed, missing, and filled teeth (DMFT) among 16,635 US adults.

	Adjusted relative risk ratio RR (95% CI)
Diabetes status	
No diabetes	Reference
Controlled diabetes	1.13 (1.09 – 1.18)
Uncontrolled diabetes	1.18 (1.12 – 1.24)
Annual dental visit	
No	Reference
Yes	1.09 (1.06 – 1.12)
Reason for a dental visit	
Checkup/Cleaning	Reference
Hurting/Treatment	1.31 (1.27 – 1.36)
Family income level	
≥ 200% FPG	Reference
< 200% FPG	0.99 (0.96 – 1.02)
Education	
High school or less	Reference
College or above	0.89 (0.86 – 0.92)
Sex	
Male	Reference
Female	1.11 (1.08 – 1.13)
Race	
White	Reference
Black	0.90 (0.87 – 0.92)
Hispanic	0.85 (0.81 – 0.88)
Others	0.89 (0.84 – 0.93)
Age group	
< 65	Reference
≥ 65	1.79 (1.74 – 1.85)
Cigarette smoking status	
Never smoker	Reference
Former smoker	1.17 (1.14 – 1.20)
Current smoker	1.24 (1.20 – 1.29)
Obesity	
No obesity	Reference
Obesity	1.03 (1.01 – 1.06)

Table 3. Multiple logistic regression analysis for predictors of the presence of dental caries and treatment experience among 16,635 US adults.

	Adjusted OR (95% CI)
Diabetes status	
No diabetes	Reference
Controlled diabetes	1.84 (1.18 – 2.86)
Uncontrolled diabetes	1.87 (1.13 – 3.10)
Annual dental visit	
No	Reference
Yes	2.06 (1.07 – 2.48)
Reason for a dental visit	
Checkup/Cleaning	Reference
Hurting/Treatment	3.50 (2.84 – 4.32)
Family income level	
≥ 200% FPG	Reference
< 200% FPG	0.83 (0.67 – 1.02)
Education	
High school or less	Reference
College or above	0.88 (0.69 – 1.12)
Sex	
Male	Reference
Female	1.35 (1.15 – 1.58)
Race	
White	Reference
Black	0.80 (0.65 – 0.99)
Hispanic	0.85 (0.69 – 1.04)
Others	0.67 (0.54 – 0.84)
Age group	
< 65	Reference
≥ 65	13.94 (8.04 – 24.15)
Cigarette smoking status	
Never smoker	Reference
Former smoker	1.37 (1.10 – 1.71)
Current smoker	1.46 (1.13 – 1.88)
Obesity	
No obesity	Reference
Obesity	1.39 (1.17 – 1.65)

Discussion

The association between diabetes and dental caries was assessed in the adult population in the United States using the 2011-2018 NHANES data. Adults with diabetes (uncontrolled and controlled) had a higher prevalence of dental caries and treatment and higher DMFT scores than non-diabetes. Dental caries is a significant public health problem with a considerable burden in the population (Majbauddin *et al.*, 2019). In the US, diabetes is a major public health problem and the seventh leading cause of death (Centers for Disease Control and Prevention, 2020). The association between caries and diabetes is important because patients at higher risk for dental caries may be identified and proper preventive measures implemented.

These findings are consistent with previous studies associating diabetes with dental caries. Several investigations (Majbauddin *et al.*, 2019; Suzuki *et al.*, 2018; Yonekura *et al.*, 2017) associated caries and diabetes, but two (Aziz, 2012; Khan *et al.*, 2019) did not find an association. However, the findings of these studies (Aziz, 2012; Khan *et al.*, 2019; Majbauddin *et al.*, 2019; Suzuki *et al.*, 2018; Yonekura *et al.*, 2017) may not be directly comparable due to different sample sizes, study design, and dental caries assessment methods. In the present study, a large, representative national data set collected by clinical examination confirmed a strong association between dental caries frequency and severity and diabetes among US adults.

The observed association may have several underlying mechanisms. Dental caries is considered as a biofilm-mediated, sugar-driven, and multifactorial disease that is the result of demineralization and remineralization of dental hard tissues (Majbauddin *et al.*, 2019; Selwitz *et al.*, 2007). Risk factors for dental caries occur as a result of chemical reactions over time between a large number of acid-producing microflora (e.g., mutans streptococci, lactobacilli, *Actinomyces*), fermentable carbohydrate, inadequate salivary flow, immunologic compromise, and genetic factors (Majbauddin *et al.*, 2019; Selwitz *et al.*, 2007). Glycemic control is an important predisposing factor for dental caries development among diabetic patients (Majbauddin *et al.*, 2019). Uncontrolled diabetes may lead to impaired salivary gland function that may decrease enamel remineralization, predispose to excessive attrition, and eventual tooth decay (Majbauddin *et al.*, 2019). Diabetic patients' oral environment changes (e.g., decreased salivary flow, increased blood and salivary glucose concentrations) favor oral bacterial growth that may lead to a high risk of dental caries, although some diabetic patients may limit carbohydrate consumption (i.e., low cariogenic diet) (Yonekura *et al.*, 2017). Diabetic patients may not be as aware of favorable dental hygiene habits to maintain a healthy oral environment, with a low frequency of toothbrushing or interdental cleaning (Kanjirath *et al.*, 2011), and fewer dental visits (Tomar and Lester 2000) compared to non-diabetics (Yonekura *et al.*, 2017). One US study reported only 18.2% of participants recognized the association between oral health and diabetes (Moore *et al.*, 2000).

Data from this sample of US adults aged 20 years and older were restricted to the permanent dentition. They may not be generalisable to other settings or the primary dentition. Differences between our finds and those of international studies may be due to variation in the methods used, health care delivery systems (including oral services) and population age. Additionally, the DMFT index includes teeth that were missing or filling due to other reasons (e.g., trauma, orthodontic extraction, congenitally missing) rather than dental caries (Yonekura *et al.*, 2017).

The limitations of the present study include the cross-sectional design of NHANES that did not account for temporality (Vemulapalli *et al.*, 2021). The timing of dental caries experience with respect to diabetes diagnosis is unknown (i.e., were caries present before diabetes diagnosis). The cross-sectional analysis cannot identify casual relationships. The NHANES self-reported survey question only indicates whether the participants had diabetes (Centers for Disease Control and Prevention, 2020) and did not specify whether Type 1 or Type 2 diabetes was diagnosed. A meta-analysis reported that individuals with Type 1 might have a higher caries risk than those with Type 2 (Coelho *et al.*, 2017). Type 1 diabetics may have different treatment regimens, oral habits, history of oral disease treatment, and course of disease compared to individuals with Type 2 diabetes. Coelho et al. found that half of Type 1 diabetic patients had hypoglycemic episodes at night, necessitating ingestion of sugar. Only one of 60 (1.7%) patients brushed their teeth after this nocturnal "rescue" sugar intake.

Strengths of the study include use of the most recent cycles of NHANES (2011-2018), a well-known cross-sectional study representative of 187,596,215 adults aged 20 years and older (including diabetes and dental caries). Objective clinical and laboratory data collected by the well-trained clinical examiners was also an important strength of NHANES.

Analysis of the potential casual association between diabetes and caries should adjust for confounders such as lifestyle factors (e.g., exercise habit, daily intake of glucose), oral hygiene (tooth brushing, use of toothpaste), and dental examinations (e.g., pocket depth, bleeding on probing, attachment loss) (Yonekura *et al.*, 2017). Physicians and dentists should work together to promote annual oral check-ups for people with diabetes who are obese and/or aged $\geq$ 65 years because this profile is associated with higher caries risk.

In conclusion, diabetes was associated with greater risk for dental caries and treatment experience. Annual oral check-ups for diabetic individuals who are obese and/or aged $\geq$ 65 years may help reduce their dental caries experience.

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