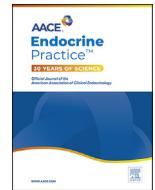




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Original Article

Trends and Risk Factors of Oral Health and Preventive Dental Care in Adults With Diabetes and Prediabetes: National Health and Nutrition Examination Survey 1999-2000 to 2017-2020



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ABSTRACT

Objective: To evaluate the prevalence, trends, and risk factors of major oral health indicators across diabetes mellitus (DM) subgroups.

Methods: A total of 22 082 adults of diagnosed DM, undiagnosed DM (UnDxDM), prediabetes mellitus (PreDM), and normal glucose groups were selected from the National Health and Nutrition Examination Survey (1999 to March 2020). We examined age, sex, and race-adjusted prevalence of preventive dental service (preventive dental service and self-dental cleaning) and oral health outcomes (≥ 10 missing teeth, self-rated oral health, and periodontitis). We used logistic regression to identify risk factors associated with each outcome DM population.

Results: The prevalence of lacking preventive dental service (DM, 52%; UnDxDM, 48%; PreDM, 44%; and normal, 42%, respectively), self-dental cleaning (38%, 37%, 30%, and 25%, respectively), missing teeth (39%, 31%, 19%, and 10%, respectively), poorly self-rated oral health (38%, 26%, 31%, and 27%, respectively), and periodontitis (50%, 51%, 42%, and 29%, respectively) remained consistently higher in those with DM than in normal glucose group. We observed a decline in the prevalence of lacking self-dental cleaning in the PreDM population and a decline in poorly self-rated oral health in all except the UnDxDM group. In the DM population, education, income, smoking, insurance, and glycemic control are risk factors for all outcomes.

Conclusion: The trends of lacking preventive dental care and suboptimal oral health outcomes were consistently higher in people with DM or PreDM than in those people without diabetes.

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Introduction

Individuals with diabetes mellitus (DM) have an increased risk of developing oral disease, such as dental caries,¹ dry mouth,² periodontitis,³ and other periodontal disorders.⁴ A potential mechanism underlying this heightened risk involves periodontitis-related bacteria forming biofilms on tooth surfaces and within the gingival crevice.⁵ In individuals with hyperglycemic and insulin

resistance, this process can trigger the continuous release of tumor necrosis factor- α and other cytokines from the surrounding tissues, contributing to inflammation and disease progression.⁶ These inflammation-released cytokines are also well known for their contributions to DM complications.⁷ Previous research has shown that periodontitis increases the risk of cardiac disorder among individuals with DM.⁸ Additionally, the risk of cardiorenal mortality is 3 times higher in people with diabetes with severe periodontitis than in those without severe periodontitis.⁹

Regular annual dental visits or daily flossing is associated with improved oral health.^{10,11} However, a growing number of studies have shown that people with DM were less likely to use preventive dental services or conduct self-dental cleaning.^{12,13} Although overall oral health has been stably improved in the overall population,¹⁴ there is a lack of research characterizing the utilization of preventive dental services and major oral health outcomes in individuals with DM. Prediabetes mellitus (PreDM), an intermediate

Abbreviations: BMI, body mass index; DM, diabetes mellitus; DxDM, diagnosed diabetes mellitus; FG, fasting glucose; HbA1C, hemoglobin A1C; NHANES, National Health and Nutrition Examination Survey; OR, odds ratio; PIR, poverty-income ratio; PreDM, prediabetes mellitus; UnDxDM, undiagnosed diabetes mellitus.

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phase for DM, is also at higher risk of oral disease.³ However, there is limited research describing disparities and trends of preventive dental care or oral outcomes in this subgroup. Additionally, we have limited knowledge about the risk factors associated with the underutilization of preventive dental services and those contributing to poor oral health outcomes in individuals with undiagnosed DM, who have poorer health outcomes than those with a timely diagnosis.¹⁵

The primary objective of this study was to assess the prevalence and trends of risk factors for key oral health indicators among diagnosed DM, undiagnosed DM, PreDM, and normal glucose groups, based on data from the National Health and Nutrition Examination Survey (NHANES) covering the periods from 1999–2000 and 2017 through March–2020.

Methods

Study Design

Participants

For this study, we combined and extracted data sets from 10 consecutive survey cycles (1999–2016 and 2017 to March 2020) from the NHANES. Due to the COVID-19 pandemic, the 2017 to March 2020 cycle only included data collected before the start of the pandemic. A total of 22 687 adults aged ≥ 18 years, who both completed a home interview and were invited for a dental examination, were included. Only participants with valid glycohemoglobin (hemoglobin A1C [HbA1C]), fasting glucose (FG), and 2-hour plasma glucose on oral glucose tolerance test (OGTT) measurement were considered. Pregnant women and individuals with a full set of dentures were excluded. For the subgroup analysis on periodontitis, adults aged ≥ 30 years were included. Figure 1 shows the sample selection process.

Measurement

The DM subgroups were categorized into 4 groups: (1) diagnosed DM (DxDM), (2) undiagnosed DM (UnDxDM), (3) PreDM, and (4) normal glucose. DxDM was defined by self-reported DM status and self-reported medications. UnDxDM was defined by an FG level of ≥ 126 mg/dL, HbA1C level of $\geq 6.5\%$, or OGTT result of ≥ 200 mg/dL among those without a diagnosis of DM. PreDM was defined as an FG level between 100 mg/dL and 126 mg/dL, HbA1C level between 5.7% and 6.4%, or OGTT result between 140 mg/dL and 199 mg/dL. The normal glucose group included those with normal glycemic measure status.

Sociodemographic data such as age, race/ethnicity (Mexican Americans, other Hispanics, non-Hispanic Whites, non-Hispanic Blacks, and other race), sex (men and women), education (<high school and \geq high school), health insurance status (yes or no), poverty-income ratio (PIR: PIR ≥ 4 , $1 \leq$ PIR < 4, and PIR < 1), and smoking status (never smoker, former smoker, and current smoker)¹⁶ were collected via interview questionnaires. Body mass index (BMI) was categorized into 2 groups: (1) underweight/healthy weight (BMI of <25 kg/m²) and (2) overweight/obese (BMI of ≥ 25 kg/m²).¹⁷ Glycemic control was categorized into 2 groups: (1) controlled, HbA1C level of $<7.0\%$, and (2) uncontrolled, HbA1C level of $\geq 7.0\%$. Preventive dental service was assessed through 2 indicators: (1) used any preventive dental services, that is, whether participants had used any preventive dental service within the past year (ie, visit for a checkup, examination, cleaning, or treatment for a condition discovered during a previous checkup), and (2) conducted self-dental cleaning, that is, whether participants used dental floss or other devices for interproximal tooth cleaning at least once in the past 7 days, in addition to tooth brushing. Oral

Highlights

- The prevalence of lacking preventive dental services and self-dental cleaning and the prevalence of suboptimal oral outcomes, including ≥ 10 missing teeth, self-rated oral health as fair or poor, and periodontitis, were consistently higher in people with diabetes than in euglycemic individuals over the past 2 decades
- The prevalence of lacking self-dental cleaning declined in the prediabetes group, and the prevalence of self-rated oral health as fair or poor declined in groups of diagnosed diabetes, prediabetes, and euglycemia, except the undiagnosed diabetes group
- Low socioeconomic status, insurance, smoking, and glycemic control are risk factors for preventive dental care and oral health outcomes in individuals with diabetes

Clinical Relevance

These findings highlight how risk factors could inform clinical decision-making, helping health care providers target high-risk individuals and improve preventive dental care and oral health outcomes in people with diabetes.

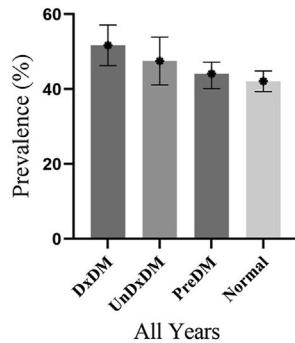
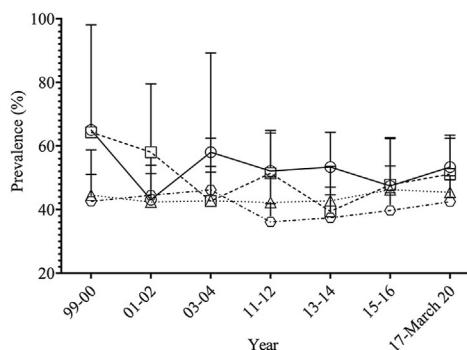
health outcomes were assessed through 3 indicators: (1) missing teeth (≥ 10),¹⁸ (2) self-rated oral health (categorized as excellent/good vs fair/poor), and (3) periodontitis (categorized as severe, moderate, or mild periodontitis, based on the Centers for Disease Control and Prevention definition¹⁹; details of how periodontitis were defined are shown in Supplementary Table 1). All these oral health surveillance data were collected by well-trained health technologists.

Statistical Analysis

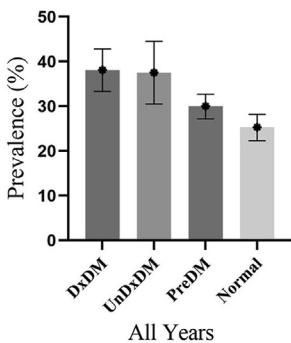
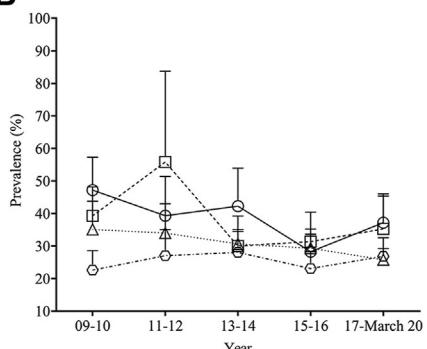
Descriptive statistics were used to summarize participants' sociodemographic, behavioral, and clinical features by DM subgroups. Subgroup differences were tested using the chi-square test for categorical variables (Fisher exact test for small counts) and 1-way ANOVA for continuous variables. All analyses were conducted in R (svydesign) using the "survey" package²⁰ to create weighted analysis groups for calculating percentages (%) (svyciprop) and mean with standard errors of the mean (svymean). The prevalences of oral health indicators were adjusted by age, race, and sex (svytotals). A linear regression model for the association between cycle years and adjusted prevalence of oral health indicators in each subgroup was used to calculate the Ptrend. Survey-weighted multivariable logistic regression models (svyglm) were applied to calculate adjusted odds ratios (ORs) for study outcomes controlling for all covariates in each DM subgroup, using the "nnet" and "svrepmiss" packages. All variables in the model were checked for multicollinearity. We followed the weighting instructions provided by the Centers for Disease Control and Prevention.²¹ A 2-sided *P* value of $<.05$ was considered statistically significant for all tests.

Results

Participant characteristics across glycemic subgroups from 1999 to March 2020 are shown in Table 1. The overall mean age of the included participants was 46 years. There was a significant age difference across subgroups (*P* < .0001). The normal glucose group

A

	DxDM	UnDxDM	PreDM	Normal
All Years	51.7(463, 57.1)	47.5(41.1, 53.9)	44.1(40.1, 47.2)	42.1(39.4, 44.9)
99-00	65.0(32.0, 98.1)	64.3(30.6, 98.0)	44.6(30.4, 58.7)	42.6(34.1, 51.1)
01-02	43.1(29.9, 56.3)	58.1(36.6, 79.5)	42.4(30.8, 53.9)	44.5(37.7, 51.3)
03-04	58.1(26.8, 89.3)	42.7(22.9, 62.4)	42.8(31.9, 53.6)	46.2(40.6, 51.8)
11-12	52.1(40.1, 64.1)	51.4(38.0, 64.9)	42.2(34.2, 50.2)	36.1(30.4, 41.8)
13-14	53.4(42.5, 64.3)	39.4(25.2, 53.6)	42.8(38.5, 47.0)	37.4(30.3, 44.6)
15-16	47.4(32.6, 62.3)	47.8(33.0, 62.6)	46.3(38.3, 53.7)	39.7(34.2, 45.3)
17-March 20	53.4(44.3, 62.4)	51.2(38.9, 63.4)	45.4(40.2, 50.6)	42.5(35.6, 49.4)
Ptrend	0.45	0.18	0.25	0.38

B

	DxDM	UnDxDM	PreDM	Normal
All Years	38.1(33.3, 42.8)	37.5(30.5, 44.5)	30.0(27.2, 32.7)	25.3(22.3, 28.2)
09-10	47.2(37.1, 57.3)	39.3(30.3, 48.2)	35.1(26.4, 43.8)	22.6(16.9, 28.6)
11-12	39.3(27.2, 51.4)	55.8(28.0, 83.7)	34.0(25.0, 43.0)	27.1(19.0, 35.1)
13-14	42.3(30.6, 53.9)	30.0(20.8, 39.2)	30.7(26.8, 34.5)	28.1(21.1, 35.1)
15-16	28.3(21.3, 35.2)	31.4(22.3, 40.4)	29.3(25.0, 33.7)	23.1(17.9, 28.3)
17-March 20	37.2(29.0, 45.3)	35.3(24.5, 46.0)	25.8(22.4, 29.2)	26.9(21.2, 32.6)
Ptrend	0.18	0.39	0.002	0.63

○ DxDM □ UnDxDM △ PreDM ◊ Normal

Fig. 1. Trends for adjusted prevalence (with 95% CI) of preventive dental service across diabetes mellitus subgroups. A, Not used any preventive dental services. B, Not conducted self-dental cleaning. DxDM = diagnosed diabetes mellitus; PreDM = prediabetes mellitus; UnDxDM = undiagnosed diabetes mellitus.

was the youngest (39 years), whereas the DxDM group was the oldest (59 years). The PreDM group had the highest percentage of men (56.4%), whereas the normal glucose group had the least male participants (44.2%). Compared with the normal glucose group, the DxDM and UnDxDM groups had a higher proportion of participants with racial/ethnic minority backgrounds, low education attainment, current smokers, overweight, low income, and no insurance. People with DxDM had a higher proportion of uncontrolled HbA1C than those with UnDxDM (49.1%). The crude prevalence of no preventive dental service was higher in the DxDM group (51.7%), followed by the UnDxDM group (47.5%). The crude prevalence of no self-dental cleaning was higher in the DxDM group (38.1%), followed by the UnDxDM group (37.5%). The crude prevalence for ≥10 missing teeth was higher in the DxDM group (38.6%), followed by the UnDxDM group (30.5%). The crude prevalence for self-rated oral health as fair or poor was higher in the DxDM group (38.2%), followed by the UnDxDM group (35.7%). The crude prevalence for periodontitis was higher in the UnDxDM group (51.3%), followed by the DxDM group (50%).

The overall adjusted prevalence of no preventive dental services was 43%. The DxDM group had the highest prevalence, followed by the UnDxDM, PreDM, and normal glucose groups (52.1%, 48.7%, 44.1%, and 41.2%, respectively). The trend across years remained consistently high across all DM subgroups ($P_{trend} > .05$, Fig. 1 A). Over 30% of participants did not conduct self-dental cleaning, and the DxDM group had the highest prevalence (38.1%), followed by the UnDxDM (37.5%), PreDM (30.0%), and normal glucose (25.3%)

groups. Despite a consistently high prevalence of no self-dental cleaning in most DM subgroups, we observed a significant decline in the PreDM ($P_{trend} = .002$) (Fig. 1 B). Approximately 17% of all participants had ≥10 missing teeth, with the highest prevalence observed in the DxDM group (38.5%), followed by the UnDxDM (30.5%), PreDM (19.1%), and normal glucose (9.6%) groups. Missing teeth significantly declined from 10% to 7% in the normal glucose group ($P_{trend} = .04$, Fig. 2 A). The overall adjusted prevalence of self-rated oral health as fair or poor was 38.9% and there was a decline in the prevalence in the DxDM, PreDM, and normal glucose groups across years ($P_{trend} = .03$, $P_{trend} = .02$, and $P_{trend} = .004$, respectively; Fig. 2 B). For periodontitis, the overall adjusted prevalence was 38.5%. The UnDxDM group had the highest prevalence (51.3%), and the normal glucose group had the lowest prevalence (29.5%). The prevalence of periodontitis remained high in the DxDM group from 2009-2010 to 2013-2014 (overall prevalence here 50.0%). In other glycemic groups, we observed a decline in periodontitis (all $P_{trend} < .05$, Fig. 2 C). Further stratification analysis found the highest severe periodontitis in the UnDxDM group (overall 11.3%); however, the prevalence significantly declined in this group ($P_{trend} = .01$, Fig. 3 A). The highest prevalence of moderate periodontitis was found in the DxDM group (38.6%, Fig. 3 B), and the highest prevalence of mild periodontitis was found in the UnDxDM group (14.1%, Fig. 3 C). We observed a decline in moderate and mild periodontitis in the normal glucose group across the years but not in the DM or PreDM group (Fig. 3 B and C).

Table 1

Baseline Characteristics of 22 082 Adults Categorized by Different Diabetes Subgroups Using the National Health and Nutrition Examination Survey 1999–2000 to 2017 to March 2020 Data

Variable	Overall	Diagnosed diabetes	Undiagnosed diabetes	Prediabetes	Normal glucose	P value
Total, n (%)	22 082	2669 (8.8)	1429 (5.2)	9107 (40.3)	8877 (45.7)	
Mean age, year \pm SEM	46 \pm 0.2	59 \pm 0.3	58 \pm 0.4	49 \pm 0.2	39 \pm 0.2	<.0001
Age, n (%)						<.0001
18–49 y	11 178 (57.7)	491 (23.9)	351 (28.6)	4094 (48.9)	6242 (75.7)	
50–69 y	6946 (31.4)	1367 (50.5)	629 (44.5)	3294 (38.1)	1656 (20.1)	
\geq 70 y	3383 (10.9)	806 (25.6)	445 (26.9)	1565 (13.0)	567 (4.2)	
Sex, n (%)						<.0001
Men	11 193 (50.2)	1389 (51.4)	777 (53.1)	5087 (56.4)	3940 (44.2)	
Women	10 889 (49.8)	1280 (48.6)	652 (46.9)	4020 (43.6)	4937 (55.8)	
Race/ethnicity, n (%)						<.0001
Mexican American	3726 (8.3)	493 (8.8)	246 (9.3)	1558 (8.7)	1429 (7.6)	
Other Hispanic	1960 (5.7)	266 (6.4)	153 (6.0)	832 (5.4)	709 (5.8)	
Non-Hispanic White	9405 (68.7)	940 (61.6)	607 (67.9)	3863 (68.6)	3995 (70.2)	
Non-Hispanic Black	4731 (10.5)	709 (14.8)	288 (10.6)	1866 (9.9)	1868 (10.2)	
Other Race	2260 (6.8)	261 (8.4)	135 (6.2)	988 (7.4)	876 (6.2)	
Education level, n (%)						<.0001
<High school	5153 (16.2)	916 (23.9)	447 (21.3)	2221 (17.1)	1569 (13.3)	
\geq High school	15 470 (83.8)	3175 (76.1)	968 (78.7)	6465 (82.9)	6302 (86.7)	
Smoking status, n (%)						<.0001
Never smoker	11 588 (54.7)	1346 (50.6)	712 (50.1)	4704 (52.5)	4826 (58.0)	
Ever smoker	5169 (25.5)	887 (34.1)	461 (33.1)	2307 (28.2)	1514 (20.4)	
Current smoker	4054 (19.8)	392 (15.3)	241 (16.8)	1708 (19.3)	1713 (21.6)	
Body mass index, n (%)						<.0001
<25 kg/m ²	7513 (34.9)	446 (15.4)	299 (18.9)	2636 (27.3)	4132 (47.1)	
\geq 25 kg/m ²	14 359 (65.1)	2197 (84.6)	1101 (81.1)	6382 (72.7)	4679 (52.9)	
PIR, n (%)						<.0001
PIR \geq 4	5280 (37.2)	473 (28.6)	285 (30.4)	2212 (38.3)	2310 (38.7)	
1 \leq PIR < 4	10 663 (49.7)	1364 (55.6)	745 (55.6)	4381 (49.3)	4173 (48.3)	
PIR < 1	3981 (13.1)	540 (15.8)	252 (14.0)	1606 (12.4)	1583 (13.0)	
Health insurance, n (%)						<.0001
Yes	17 460 (82.8)	2346 (90.3)	1175 (84.2)	7158 (83.3)	6781 (80.7)	
No	4542 (17.2)	317 (9.7)	249 (15.8)	1918 (16.7)	2058 (19.3)	
Glycemic control						<.0001
Controlled, HbA1C level of <7%	1533 (5.2)	1243 (50.9)	1159 (85.6)	8088 (100%)	8078 (100%)	
Uncontrolled, HbA1C level of \geq 7%	19 288 (94.8)	1291 (49.1)	242 (14.4)	0 (0)	0 (0)	
Preventive dental service						
Used any preventive dental service, ^a n (%)/% ^b						<.0001
Yes	6854 (56.0)/56.4	702 (48.3)/47.9	328 (52.5)/51.3	6854 (55.9)/55.9	3097 (58.8)/57.8	
No	6867 (44.0)/43.6	924 (51.7)/52.1	435 (47.5)/48.7	6867 (44.1)/44.1	2698 (42.2)/41.2	
Conducted self-dental cleaning, ^c n (%)/% ^b						<.0001
Yes	6127 (70.0)/70.4	894 (61.9)/61.9	458 (62.5)/62.5	2931 (70.0)/70.0	1844 (74.7)/74.7	
No	3195 (30.0)/30.0	630 (38.1)/38.1	314 (37.5)/37.5	1489 (30.0)/30.0	762 (25.3)/25.3	
Oral health outcomes						
\geq 10 missing teeth, n (%)/% ^c						<.0001
Yes	4637 (16.8)/16.8	1058 (38.6)/38.5	478 (30.5)/30.5	2071 (19.1)/19.1	1030 (9.6)/9.6	
No	16 122 (83.2)/83.2	1235 (61.4)/61.5	802 (69.5)/69.5	6469 (80.9)/80.9	7616 (90.4)/90.4	
Self-rated oral health, n (%)/% ^b						<.0001
Excellent, good above, or good	14 163 (69.8)/69.8	1486 (61.8)/61.8	856 (64.3)/64.3	5764 (69.1)/69.1	6057 (72.6)/72.6	
Fair or poor	7804 (30.2)/30.2	1159 (38.2)/38.2	557 (35.7)/35.7	3293 (30.9)/30.9	2795 (27.4)/27.4	
Periodontitis status, ^d n (%)/% ^b						<.0001
Severe, moderate, or mild	2497 (38.9)/38.9	404 (50.0)/50.1	266 (51.3)/51.3	1225 (41.9)/41.9	602 (29.5)/29.5	
Normal	2955 (61.1)/61.1	362 (50.0)/49.9	218 (48.7)/48.7	1292 (58.1)/58.1	1083 (70.5)/70.5	

Abbreviations: HbA1C = hemoglobin A1C; PIR = poverty-income ratio.

Adjusted age, race/ethnicity, and sex were applied to calculate the prevalence of used any preventive dental service, use of dental floss or other devices, \geq 10 missing teeth, self-rated oral health conditions, and periodontitis status. Rao-Scott Chi-square test was used for categorical analysis across different diabetes subgroups.

^a 1999–2004 and 2011 to March 2020.

^b Age-, race-/ethnicity-, and sex-adjusted prevalence.

^c 2009 to March 2020.

^d 2009 to 2014.

Risk factors for preventive dental services and suboptimal oral health outcomes in all DM groups are presented in Table 2. We found that lower income, lower education attainment, current

smoking status, no health insurance, and an HbA1C level of \geq 7.0% are associated with a higher risk of not using preventive dental services (ORs²² ranging from 1.32 to 3.20) and poor oral health

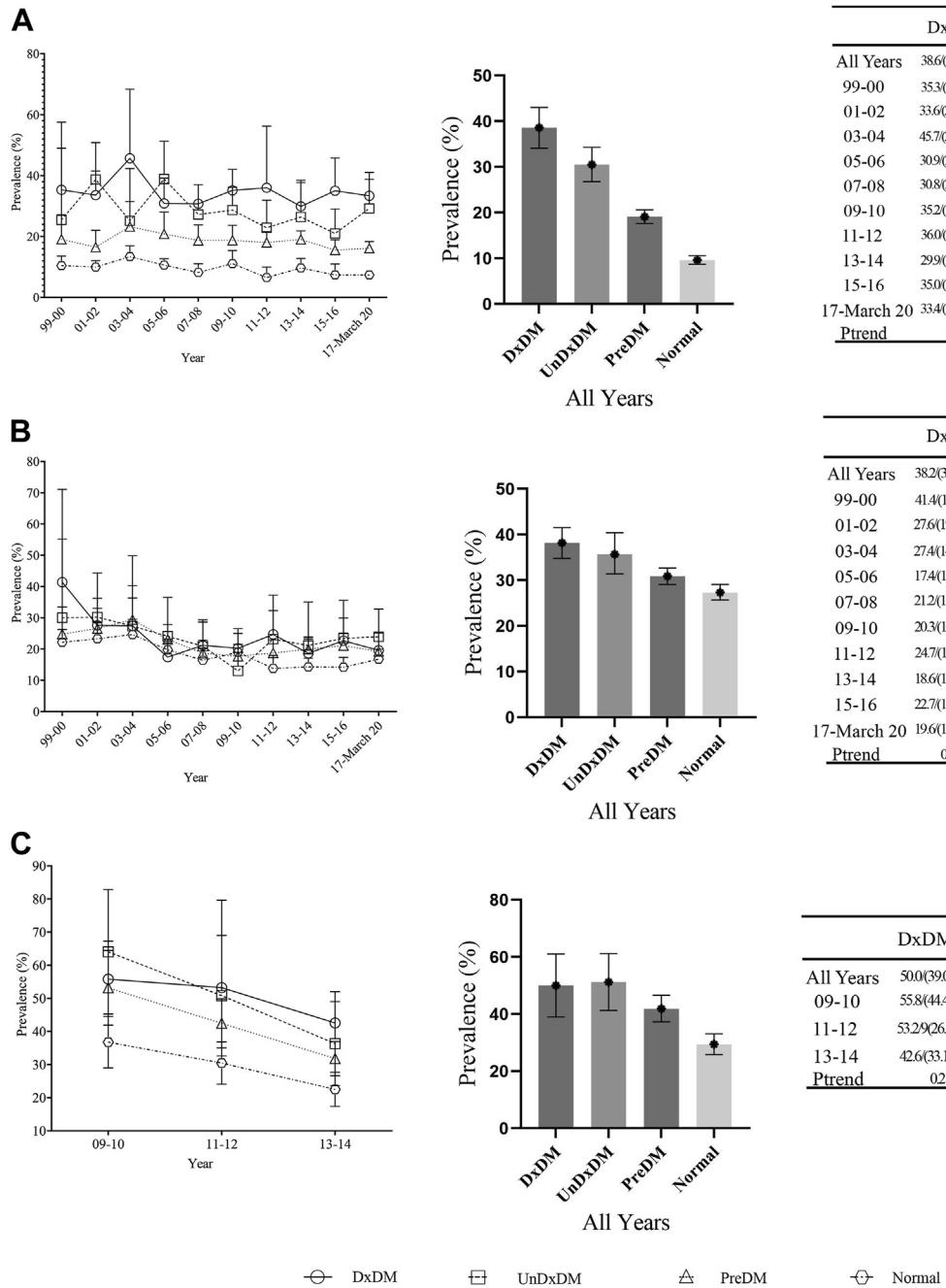


Fig. 2. Trends for adjusted prevalence (with 95% CI) of oral health outcomes in all individuals with diabetes mellitus. A, Ten or more missing teeth. B, Self-rated oral health conditions fair or poor. C, Periodontitis. DxDM = diagnosed diabetes mellitus; PreDM = prediabetes mellitus; UnDxDM = undiagnosed diabetes mellitus.

outcomes (ORs ranging from 1.20 to 4.05). Older age (≥ 70 years) had a higher risk of not conducting self-dental cleaning, ≥ 10 missing teeth, and being diagnosed with periodontitis (ORs ranging from 1.82 to 16.76), whereas age was inversely associated with self-rated oral health as fair or poor (OR, 0.8; 95% CI, 0.7–0.9). Compared with men, women had a reduced risk of diagnosis with any level of periodontitis, no self-dental cleaning, no preventive dental services, and self-rated oral health as fair or poor (ORs, 0.55, 0.59, 0.84, and 0.96, respectively) but had a higher risk of ≥ 10 missing teeth (OR, 1.33; 95% CI, 1.14–1.55). These findings indicate a notable disparity among socioeconomic factors, lifestyle, age, and sex that significantly impact oral health and preventive dental

service utilization in all DM groups. Compared with non-Hispanic Whites, racial/ethnic minorities had a higher risk of most oral health outcomes (ORs ranging from 1.20 to 2.22). However, compared with non-Hispanic Whites, Other Hispanics and Mexican Americans had a lower risk of no self-dental cleaning (ORs, 0.71 and 0.62; 95% CIs, 0.53–0.95 and 0.45–0.85, respectively). Other Hispanics individuals also have a lower risk of ≥ 10 missing teeth (OR, 0.55; 95% CI, 0.44–0.69). Further stratification analysis on DxDM, UnDxDM, and PreDM individuals found a similar trend of OR for risk factors that contributed to no access to preventive dental services or poor oral health outcomes (Supplementary Tables 2 through 4).

	DxDM	UnDxDM	PreDM	Normal
All Years	38.6(34.1, 43.0)	30.5(26.8, 34.3)	19.1(17.6, 20.6)	9.6(8.7, 10.6)
99-00	35.3(13.1, 57.5)	25.5(19.4, 49.0)	19.1(11.0, 27.2)	10.5(7.3, 13.6)
01-02	33.6(25.7, 41.5)	38.7(26.6, 50.8)	16.5(11.0, 22.0)	10.0(7.8, 12.1)
03-04	45.7(23.0, 68.4)	25.2(8.0, 42.3)	23.3(15.0, 31.5)	13.4(9.9, 17.0)
05-06	30.9(22.6, 39.2)	38.9(26.5, 51.3)	20.9(13.7, 28.1)	10.6(8.5, 12.7)
07-08	30.8(24.5, 37.0)	27.2(17.4, 37.0)	18.7(13.6, 23.8)	8.2(5.3, 11.1)
09-10	35.2(28.3, 42.1)	28.7(21.2, 36.2)	18.8(13.8, 23.7)	11.1(6.8, 15.4)
11-12	36.0(15.8, 56.2)	22.9(13.8, 32.0)	18.0(14.5, 21.6)	6.5(3.1, 10.0)
13-14	29.9(21.4, 38.5)	26.4(15.1, 37.8)	19.1(16.2, 21.9)	9.7(6.5, 12.8)
15-16	35.0(24.3, 45.8)	21.0(13.0, 29.0)	15.5(12.2, 18.9)	7.4(3.8, 11.0)
17-March 20	33.4(25.7, 41.1)	29.2(19.6, 38.8)	16.2(14.0, 18.3)	7.4(5.9, 8.9)
Ptrend	0.44	0.25	0.13	0.04

	DxDM	UnDxDM	PreDM	Normal
All Years	38.2(34.8, 41.5)	35.7(31.4, 40.4)	30.9(29.1, 32.7)	27.3(25.7, 29.1)
99-00	41.4(11.7, 71.1)	30.0(4.8, 55.2)	24.8(16.1, 33.5)	22.2(18.1, 26.3)
01-02	27.6(19.0, 36.2)	30.2(16.1, 44.3)	26.6(20.1, 33.0)	23.3(18.2, 28.4)
03-04	27.4(14.6, 40.3)	27.3(4.8, 49.9)	29.4(22.5, 36.3)	24.7(19.8, 29.5)
05-06	17.4(11.7, 23.2)	24.1(11.7, 36.5)	23.1(18.3, 27.8)	19.8(17.5, 22.0)
07-08	21.2(13.8, 28.6)	20.9(12.5, 29.4)	18.7(14.5, 22.8)	16.4(12.6, 20.2)
09-10	20.3(14.0, 26.5)	13.0(7.1, 18.9)	17.7(13.9, 21.5)	19.0(13.0, 25.0)
11-12	24.7(17.1, 32.3)	23.2(9.1, 37.2)	18.8(14.5, 23.0)	13.8(9.6, 18.0)
13-14	18.6(13.4, 23.9)	21.2(7.3, 35.0)	20.0(16.7, 23.3)	14.3(11.5, 17.1)
15-16	22.7(15.4, 29.9)	23.4(11.3, 35.6)	21.1(17.1, 25.1)	14.2(11.0, 17.4)
17-March 20	19.6(14.0, 25.1)	24.0(15.1, 32.8)	19.2(16.0, 22.5)	16.8(13.8, 20.0)
Ptrend	0.03	0.11	0.02	0.004

	DxDM	UnDxDM	PreDM	Normal
All Years	50.0(39.0, 61.1)	51.2(41.3, 61.2)	41.9(37.3, 46.6)	29.4(25.8, 33.1)
09-10	55.8(44.4, 67.3)	64.0(45.3, 82.8)	53.2(41.9, 64.5)	36.8(29.0, 44.5)
11-12	53.2(9.268, 79.6)	50.8(32.6, 69.0)	42.4(35.0, 49.9)	30.5(24.1, 36.8)
13-14	42.6(33.1, 52.0)	36.3(23.6, 49.0)	31.8(26.6, 37.0)	22.5(17.3, 27.6)
Ptrend	0.21	0.01	0.001	0.04

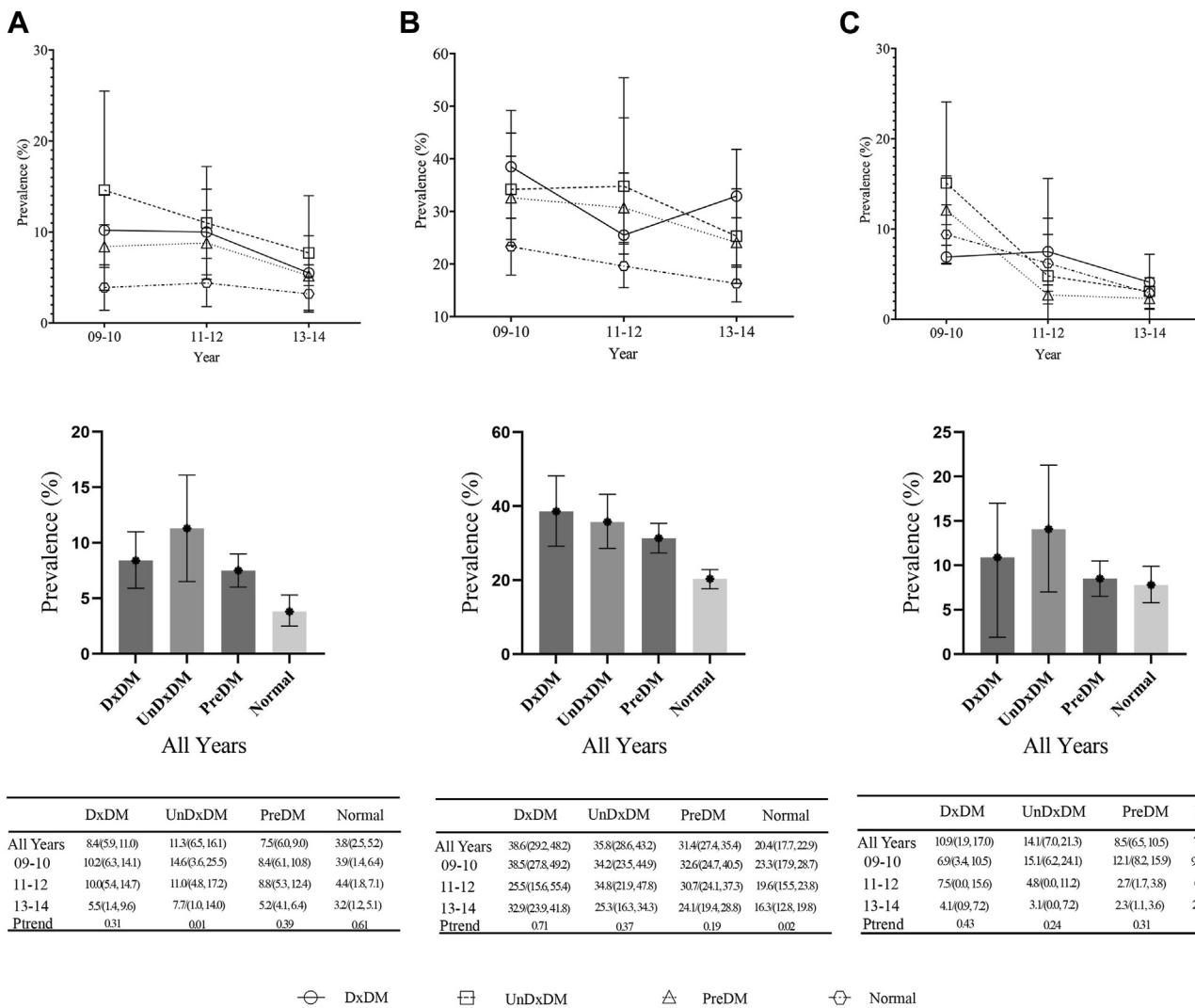


Fig. 3. Trends for adjusted prevalence (with 95% CI) of periodontitis in all individuals with diabetes mellitus. *A*, Severe periodontitis. *B*, Moderate periodontitis. *C*, Mild periodontitis. DxDM = diagnosed diabetes mellitus; PreDM = prediabetes mellitus; UnDxDM = undiagnosed diabetes mellitus.

Discussion

Overall, the DxDM and UnDxDM groups alternately hold the highest prevalence of lack of preventive dental services or poor oral health outcomes in the past 2 decades. We observed significant declines in ≥ 10 missing teeth and self-rated oral health conditions as fair or poor in the normal glucose group but not among individuals with DM. Low income, low education, current smokers, no health insurance, and poor glycemic control are risk factors for all oral health indicators among individuals with DM.

The results of our study align with previous reports that adults with DM are less likely to access and use preventive dental services and have poor oral health outcomes compared with healthy individuals.^{12,13} In contrast to the unchanged percentage in dental visits observed in the general population,²³ we did not observe significant changes in people with DM over the years. Further stratified analysis on the DM subgroups extended the observations that there are unchanged trends of using preventive dental services across years in groups of DxDM, UnDxDM, and PreDM.²⁴ Our estimated mean prevalence of no preventive dental services in the NHANES was also higher than the findings from the Behavioral Risk Factor Surveillance System.¹² This difference may be due to a more

stringent classification of DM status in our study, where we included not only self-reported DM status and antidiabetes medications but also 3 glycemic markers (ie, FG, HbA1C, and OGTT). Previous studies have shown that adults with DM tend to use dental floss less frequently compared with healthy individuals.^{9,25} Our results confirmed this conclusion with a larger data set. In addition, we observed a decline in lacking self-dental cleaning in the PreDM group, indicating an improvement in self-dental care in those with PreDM.

The prevalence of ≥ 10 missing teeth significantly declined in the normal glucose group, which is consistent with previous findings in the general population.²⁶ However, in the DxDM and UnDxDM groups, this trend remained stably high across the years. In our study, we found that self-reported oral health as fair or poor remained unchanged in the UnDxDM individuals, which contrasts with a declined trend in other DM groups. Eke et al¹⁹ have reported that the overall prevalence of periodontitis in the United States is 42.2%, with 7.8% belonging to severe periodontitis. We found that approximately 50% of individuals with DM had periodontitis, in contrast to 30% in the normal glucose group. The prevalence of severe periodontitis was higher in the DxDM (8.4%) and UnDxDM (11.3%) groups than in the normal glucose group (3.8%). These

Table 2

Risk Associated With Preventive Dental Service and Oral Health Outcomes in All Participants With Diabetes Mellitus

Variable	Preventive dental service		Oral health outcomes		
	No preventive dental services	No self-dental cleaning	≥10 missing teeth	Self-rated oral health as fair or poor	PD ^a (severe, moderate, or mild)
Age, y					
18–49/30–49 ^a	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
50–69	0.82 (0.68–0.98)	1.11 (0.92–1.35)	6.34 (5.25–7.66)	1.09 (0.98–1.22)	2.25 (1.78–2.84)
≥70	0.91 (0.73–1.14)	1.74 (1.46–2.12)	16.76 (13.54–20.75)	0.80 (0.69–0.93)	2.01 (1.54–2.64)
Sex					
Men	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Women	0.84 (0.72–0.98)	0.59 (0.51–0.68)	1.33 (1.14–1.55)	0.96 (0.86–1.08)	0.55 (0.44–0.69)
Race/ethnicity					
Non-Hispanic White	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Mexican American	1.34 (1.00–1.79)	0.68 (0.53–0.88)	0.55 (0.44–0.69)	1.42 (1.20–1.70)	N.A.
Other Hispanic	1.18 (0.88–1.58)	0.59 (0.45–0.79)	1.24 (0.97–1.59)	1.22 (1.01–1.48)	N.A.
Non-Hispanic Black	1.45 (1.18–1.78)	1.02 (0.84–1.24)	2.22 (1.86–2.65)	1.40 (1.20–1.63)	1.72 (1.33–2.23)
Other race ^a	0.97 (0.75–1.26)	1.07 (0.82–1.39)	1.08 (0.85–1.38)	0.96 (0.78–1.18)	1.64 (1.23–2.20)
PIR					
PIR ≥ 4	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
1 ≤ PIR < 4	3.20 (2.51–4.08)	2.85 (2.26–3.60)	2.73 (2.07–3.61)	2.90 (2.41–3.48)	1.37 (1.06–1.78)
PIR < 1	2.39 (1.95–2.93)	1.92 (1.61–2.29)	2.29 (1.87–2.8)	2.14 (1.84–2.48)	1.45 (1.09–1.93)
Education level					
≥High school	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
<High school	1.87 (1.49–2.34)	2.08 (1.7–2.55)	2.32 (1.9–2.84)	1.74 (1.49–2.05)	1.25 (1.01–1.54)
Body mass index, kg/m²					
≥25	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
<25	0.92 (0.76–1.12)	1.05 (0.88–1.25)	0.85 (0.71–1.02)	0.93 (0.82–1.05)	1.16 (0.86–1.56)
Smoking status					
Never smoker	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Ever smoker	1.02 (0.85–1.23)	0.86 (0.72–1.03)	1.82 (1.57–2.11)	1.25 (1.07–1.45)	1.07 (0.83–1.38)
Current smoker	2.02 (1.56–2.6)	1.68 (1.32–2.15)	4.05 (3.35–4.89)	2.14 (1.86–2.46)	1.60 (1.2–2.15)
Health insurance					
Yes	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
No	3.08 (2.33–4.09)	1.28 (1.07–1.67)	1.02 (0.83–1.26)	1.38 (1.19–1.59)	1.73 (1.28–2.35)
Glycemic control					
Controlled, HbA1C level of <7%	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Uncontrolled, HbA1C level of ≥7%	1.46 (1.16–1.84)	1.34 (1.07–1.67)	1.87 (1.54–2.26)	1.20 (1.03–1.41)	1.44 (1.07–1.93)

Abbreviations: HbA1C = hemoglobin A1C; N.A. = not applicable; PD = periodontitis; PIR = poverty-income ratio.

^a For calculating PD-associated odds ratios, the age group was started with adults aged ≥30 years, and other race was defined as combined race groups expect for non-Hispanic White and non-Hispanic Black.

findings were consistent with previous observations and, importantly, highlighted that UnDxDM group is the most susceptible to severe periodontitis.^{3,27} This is alarming because periodontitis is significantly associated with DM complications such as cardiovascular disease, stroke, and chronic kidney failure.²⁷

We found that low education, low income, smoking, no insurance, and poor glycemic control are consistently associated with a higher risk of not accessing preventive dental services or poor oral health outcomes for people with DM.^{28–32} Our findings also confirmed that uncontrolled HbA1C levels are significantly associated with oral health-related indicators in patients with DM.³³ Individuals aged ≥70 years have an increased risk of lacking self-dental cleaning, ≥10 missing teeth, and periodontitis due to limited physical function and age-dependent risk of periodontal disease.³⁴ We also observed that older participants were less likely to rate their oral health condition as fair or poor. This result is inconsistent with previous studies suggesting better self-reported oral health in younger adults.^{35,36} However, some evidence also indicated that older people consider an impaired oral health status as being part of the ordinary aging process and, therefore, less likely to be dissatisfied with their oral health compared with younger people.³⁷ Our results showed that in individuals with DM, women tend to have a higher risk of missing teeth than men. One possible explanation is that women are at higher risk of bone density loss than men because of the estrogen deficiency after menopause.³⁸

Meanwhile, studies have also shown that men have significantly higher odds of harboring salivary and subgingival periodontal pathogens, therefore increasing susceptibility to periodontitis.^{39,40}

Interestingly, we found that Mexican Americans with DM were less likely to have ≥10 missing teeth,⁴¹ or lack self-dental cleaning, compared with their non-Hispanic White counterpart. Previous work has suggested that Hispanic populations are more susceptible to poor oral health and less access to preventive dental practices than non-Hispanic Whites.⁴² We found, however, the opposite finding regarding self-dental cleaning. Hispanics (Mexican Americans/other Hispanics) with DM are less likely to lack self-dental cleaning (*Supplementary Table 5*). In our sensitivity analyses additionally accounted for acculturation, we found that the association between Hispanic background and self-dental cleaning no longer holds (*Supplementary Table 6*). This indicates the confounding effect of the acculturation. When stratified acculturation status, we found that those who are more acculturated have lower odds of lacking dental self-cleaning; this indicates a shift in oral health practice among ethnic minorities, where more acculturated individuals may have higher awareness of self-dental care.⁴³ More work is required to better understand how racial disparities in access to dental flossing are distributed within the Hispanic populations with and without DM.

Our study has several strengths. To our knowledge, this is the first study to characterize the trends and risk factors associated

with oral health conditions in people with DM with disaggregation of DM subgroups. The present analysis is based on a nationally representative cohort from the NHANES spanning 2 decades, ensuring that the findings are generalizable to the U.S. population. However, several limitations merit consideration. The observational, cross-sectional design of this study precludes causal inferences. Preventive dental services, self-conducted dental cleaning, and self-rated oral health were all based on self-reported data rather than objective measurement, which is subject to self-report bias. Additionally, the status of periodontitis was determined by a single oral measurement, which may not accurately reflect its long-term status.

Conclusion

In summary, our study highlights the persistent oral health disparities in individuals with DM. Specifically, lack of preventive dental care and suboptimal oral health outcomes were consistently higher in the DM or PreDM groups than in people without DM over 2 decades. Low education attainment, low income, no insurance, current smoking status, and uncontrolled glycemic status were common risk factors for all oral outcomes included in this study. Our results highlight the unmet needs in oral health education and care in the DM populations, particularly among those socioeconomically deprived subgroups with DM. Efforts to promote the awareness of oral health targeting modifiable risk factors such as smoking cessation and glycemic control among people with DM are critical to prevent or delay oral health-related complications in this group.

Disclosure

The authors have no conflicts of interest to disclose.

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