Community Dent Oral Epidemiol 2002: 30: 182–92
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COMMUNITY DENTISTRY AND ORAL EPIDEMIOLOGY
ISSN 0301-5661

Glycemic control of type 2 diabetes and severe periodontal disease in the US adult population

Carlene Tsai[1], Catherine Hayes[1] and George W. Taylor[2]

[1]Harvard School of Dental Medicine, Boston, MA, and [2]Department of Cariology, Restorative Sciences, and Endodontics, University of Michigan School of Dentistry, Ann Arbor, MI, USA

Tsai C, Hayes C, Taylor GW. Glycemic control of type 2 diabetes and severe periodontal disease in the US adult population. Community Dent Oral Epidemiol 2002; 30: 182–92. ©Blackwell Munksgaard, 2002

Abstract – *Objective:* We investigated the association between glycemic control of type 2 diabetes mellitus (type 2 DM) and severe periodontal disease in the US adult population ages 45 years and older. *Methods:* Data on 4343 persons ages 45–90 years from the National Health and Nutrition Examination Study III were analyzed using weighted multivariable logistic regression. Severe periodontal disease was defined as 2 + sites with 6 + mm loss of attachment and at least one site with probing pocket depth of 5 + mm. Individuals with fasting plasma glucose $>$126 mg/dL were classified as having diabetes; those with poorly controlled diabetes (PCDM) had glycosylated hemoglobin $>$9% and those with better-controlled diabetes (BCDM) had glycosylated hemoglobin $\leq$9%. Additional variables evaluated in multivariable modeling included age, ethnicity, education, gender, smoking status, and other factors derived from the interview, medical and dental examination, and laboratory assays. *Results:* Individuals with PCDM had a significantly higher prevalence of severe periodontitis than those without diabetes (odds ratio = 2.90; 95% CI: 1.40, 6.03), after controlling for age, education, smoking status, and calculus. For the BCDM subjects, there was a tendency for a higher prevalence of severe periodontitis (odds ratio = 1.56; 95% CI: 0.90, 2.68). *Conclusion:* These results provide population-based evidence to support an association between poorly controlled type 2 diabetes mellitus and severe periodontitis.

Key words: adults; diabetes mellitus; epidemiology; glycosylated hemoglobin; logistic models; periodontal diseases; type 2 diabetes mellitus; United States

Address:
George W. Taylor, Department of Cariology, Restorative Sciences, and Endodontics, University of Michigan School of Dentistry, 1011 N. University, Ann Arbor, MI 48109–1078, USA
Tel: +1 734 7641737
Fax: +1 734 9361597
e-mail: gwt@umich.edu

Submitted 4 November 2000, accepted 19 June 2001

Type 2 diabetes mellitus (formerly designated as noninsulin dependent diabetes) (1) is a common chronic disease and is the more prevalent of the two major categories of overt diabetes in the US (2). Of the 7.8 million people in the US diagnosed with diabetes, 90–95% have type 2 diabetes, while 5–10% have type 1 (the other major type of overt diabetes) (2). Among individuals over 45 years old with diabetes, more than 95% have type 2 diabetes (3).

The generally recognized complications of diabetes include accelerated atherosclerosis (macrovascular disease), microvascular disease-related retinopathy, nephropathy, and neuropathy (4). The incidence and progression of these complications are recognized to be due, in large part, to persisting poor glycemic control (5–8).

There is substantial evidence to support considering diabetes as a risk factor for poor periodontal health (9–12), although some studies have reported no association (13–16). Several biologic mechanisms have been proposed and include microangiopathy, alterations in gingival crevicular fluid, alterations in collagen metabolism, altered host response, altered subgingival microflora, and hereditary predisposition (12, 17–21).

Previous studies have predominantly been conducted using subjects with either type 1 diabetes (22–38), a combination of both type 1 and type 2 diabetes (39–45), or where the diabetes type was not specified (15, 46–50). While the majority of these studies have reported an association between poorer glycemic control and poorer periodontal health (22–28, 33–35, 39–41, 44, 46, 51–54), a substantial number have found no differences in periodontal health related to glycemic control (15, 29–32, 36–38, 42, 43, 45, 47–50). Only three studies have investigated the association between glycemic control specifically in type 2 diabetes and periodontal disease (52–54). Each of these studies found poorer glycemic control to be a significant factor associated with poorer periodontal health.

No studies have investigated the relationship between glycemic control in type 2 diabetes and periodontal disease using a national, population-based representative sample. The current study extends previous investigations conducted in more restricted populations by using a subset of the sample of the US population participating in the Third National Health and Nutrition Examination Survey (NHANES III). The purpose of this study was to determine whether an association exists between glycemic control of type 2 DM and severe periodontal disease in adults aged 45 years and older in the US population.

Material and methods

Study source population

Subjects included adults who were at least 45 years old and who completed each portion of the dental examination in NHANES III. NHANES III was conducted between 1988 and 1991 and 1992 and 94 by the National Center for Health Statistics. This nationally representative sample was selected using a complex, stratified, multistage cluster sampling design. Both the 1988–91 and 1992–94 phases of this survey were used in this analysis. The data were obtained from the National Center for Health Statistics (NCHS) (55–57). Details of the protocol for the dental examination and other aspects of NHANES III have been described previously (58–61). Subjects were excluded from the dental examination if they presented with specific conditions (e.g. heart murmurs) that would require antibiotics prior to dental examination.

Study variables

Diabetes status and degree of glycemic control were assessed by laboratory assays for fasting plasma glucose and hemoglobin A1c, respectively. Subjects with fasting plasma glucose >126 mg/dL were classified as having diabetes. Among subjects with diabetes, those with hemoglobin A1c $>9\%$ were classified as poorly controlled and those with hemoglobin A1c $\leq 9\%$ were considered better-controlled.

Severe periodontitis was defined as at least two sites with 6 mm or more attachment loss and at least one site with probing pocket depth of 5 mm or more in one of these sites. This is a modification of a definition for 'established periodontitis' derived from a large, population-based study (62).

Additional sociodemographic, dental, and medical variables were evaluated to control for confounding and effect modification. Sociodemographic variables obtained from the face-to-face interview included age (specified as both continuous and categorical with four categories: 45–54, 55–64, 65–74, and 75–90), gender, education (less than high school, high school, some college, college graduate, and more than college education), race (non-Hispanic white, non-Hispanic black, Mexican American, and any other groups), and poverty income ratio (unitless measure calculated as a ratio of annual family income to the federal poverty level). The federal poverty level is a threshold based on an estimate of the annual income required to purchase an adequate diet for a specific household size in the US, taking into account the calendar year of the interview and the age of the household head. The self-reported oral health-related variables included frequency of visiting dentist (at least once a year, every 2 years, less often than every 2 years, and whenever needed), length of time since last visit to the dentist (continuous in days), perceptions of need for gum treatment (yes/no) and condition of teeth (excellent, very good, good, fair, and poor). Categorical specifications were used for selected continuous variables to aid in interpretation (e.g. years of education) and to test for or demonstrate nonlinear effects (e.g. age, education) or significant effects in some but not all subgroups.

Additional variables obtained from the dental examination included the number of teeth (continuous), calculus extent (specified as the percent of teeth with subgingival calculus) and gingival bleeding (specified as the percent of teeth with gingival bleeding). The periodontal measures were performed on randomly assigned half-mouths, one maxillary quadrant and one mandibular quadrant selected at the beginning of the examination. The buccal and mesial–buccal aspects of each tooth were scored separately for each periodontal measure: gingival bleeding, calculus, gingival recession, and pocket depth.

The medical clinical examination provided systolic blood pressure (dichotomized at $\geq$140 mmHg), and the medical laboratory assays included white blood cell count (continuous), C-reactive protein (continuous in mg/dL), albumin:creatinine ratio (dichotomized at $>$0.3 mg/L), body mass index (dichotomized at $>$27 kg/m$^{2)}$, cholesterol (dichotomized at $\geq$240 mg/dL), and triglycerides (dichotomized at $\geq$400 mg/dL). Each of the medical laboratory variables were tested using both continuous and dichotomous specifications that were consistent with recognized cut-off points used in clinical management or epidemiological studies. The self-reported medical indicators consisted of smoking status (current, former, and never smoked), tobacco use (ever versus never), number of past allergy episodes in past 12 months (continuous) and whether there was a past history of osteoporosis, stroke, congestive heart failure, pain in the chest, and heart attacks.

Statistical methods

The specific question addressed in this analysis was whether the odds of severe periodontitis were greater for those with poorly controlled or better-controlled type 2 diabetes mellitus (DM) than for those without DM. All analyses incorporated population estimate weighting. Initially, potential risk indicators, confounders, and effect modifiers were analyzed univariately to describe the variables and distributions, and to examine the data for sparseness. Secondly, a two-way table analysis was conducted to determine the crude odds ratio for the relationship between each of the two levels of glycemic control, and the outcome, severe periodontitis. Next, stratified analysis was performed to assess changes in the odds ratio (ΔOR), controlling for each third variable of interest (63). The ΔOR was calculated as the difference between the crude odds ratio and adjusted odds ratio divided by the crude odds ratio. The crude odds ratio is the odds ratio using glycemic control without the variable of interest (OR_{crude}) and the adjusted odds ratio is the odds ratio using glycemic control adjusted for the specific variable of interest ($OR_{adjusted}$). The ΔOR was calculated separately for the poorly controlled and better controlled groups. The ΔOR can be expressed as a percent using the formula:

$$\Delta OR = [(Or_{crude} - OR_{adjusted})/OR_{crude}] \times 100.$$

If the absolute value of ΔOR was at least 10%, then the variable was included in the candidate logistic regression model. Additional covariates that did not meet the change in odds ratio criterion were included in the final model if they had been previously recognized in the literature as important. Ordinary logistic regression models were constructed using PC-SUDAAN (64) to adjust variances and standard errors for the complex sampling design used in this survey. After the final set of main effect terms were identified, terms specifying interactions between the main effects and glycemic control were then estimated and evaluated as described by Hosmer & Lemeshow (65).

Results

There were 8209 participants in the NHANES III survey aged 45 years and older for which there were interview, laboratory and examination components. Of these persons, 4343 had dental examination data and comprised the study sample. The comparisons between the groups with and without dental examinations are presented in Table 1. There are some differences in the distributions among the age categories, levels of education, and ethnicity. No noteworthy differences appear among the gender, smoking status, or diabetes status categories.

Table 2 shows the distribution of risk indicators that were in the final multivariable model and presents their bivariate association with severe periodontitis. In general, the prevalence of severe periodontitis among the categories for each of the variables follows an expected pattern. Each of the bivariate associations is statistically significant, with prevalence of severe periodontitis generally higher in the older age categories, lower education categories, those with greater percent of teeth with subgingival calculus, and smokers. Participants with diabetes had a higher prevalence of severe periodontitis than those without diabetes; those with poorly controlled diabetes had the highest prevalence ($P = 0.003$).

Other variables with statistically significant bivariate associations with severe periodontitis (results not shown) were participant self reports of frequency of visiting the dentist, perception of the condition of their teeth, any tobacco use, past history of osteoporosis, and length of time since last

Table 1. Selected descriptors of NHANES III participants aged 45 years and older with complete ($n = 4343$) and incomplete dental examinations ($n = 4866$), 1988–94

Characteristic	No. with complete dental examination (weighted percentage)[a]	No. with incomplete dental examination (weighted percentage)[a]
Ages (years)		
45–54	1442 (42.3)	544 (21.3)
55–64	1221 (28.2)	890 (27.2)
65–74	1070 (20.4)	1103 (28.4)
75–90	610 (9.2)	1329 (23.1)
Gender		
Male	2188 (48.8)	1758 (42.1)
Female	2155 (51.2)	2108 (57.9)
Education		
Less than H.S.[b]	1872 (23.6)	2261 (45.9)
Graduate H.S.[b]	1197 (33.0)	946 (32.5)
Some college	584 (18.9)	359 (11.7)
College graduate	325 (11.7)	140 (5.4)
>College graduate	334 (13.0)	132 (4.6)
Ethnicity		
White	2106 (81.0)	2233 (83.3)
Black	941 (8.5)	924 (9.4)
Mexican American	1138 (4.0)	568 (1.9)
Other	158 (6.8)	141 (5.3)
Smoking status		
Never smoked	2060 (47.4)	1605 (41.5)
Former smoker	1461 (33.6)	1405 (36.3)
Current smoker	822 (18.9)	856 (22.1)
Diabetes mellitus status		
No diabetes	3841 (89.9)	3329 (87.9)
DM (better control)	260 (6.1)	304 (8.0)
DM (poorly controlled)	170 (4.0)	152 (4.0)

[a]The differences in the total N's for each examination category and the subtotals for each of the variables are due to missing data.
[b]H.S., High School.

dental visit. Measures of participants' poverty income ratio, percent of teeth with gingival bleeding, systolic blood pressure, white blood cell count, and C-reactive protein were also statistically significant in bivariate tests. The other variables tested did not demonstrate a significant bivariate association with severe periodontitis prevalence.

Table 3 shows the percent change in odds ratio score between the variable tested and severe periodontitis. Age, gender and smoking status, all variables considered important in studies of periodontal disease prevalence, did not demonstrate a greater than 10% odds ratio change. The other variables shown in the table are those from all variables tested in this study that met this criterion with greater than 10% change in either the poorly controlled or better controlled groups.

Table 4 presents the final multiple logistic regression model evaluating the association between glycemic control status and severe periodontitis adjusting for covariates. Persons with poorly controlled diabetes were 2.90 (95% CI: 1.40, 6.03) times as likely to have severe periodontitis as those without diabetes, controlling for age, education, smoking status, and extent of subgingival calculus. For the subjects with better controlled diabetes, there was a tendency for a higher prevalence of severe periodontitis (odds ratio = 1.56; 95% CI: 0.90, 2.68), though this was not statistically significant. Subjects in the age groups 55–64 and 65–74 had greater odds for having severe periodontitis than the youngest age group (45–64), though this association was only significant for those aged 65–74 (OR = 2.16; 95% CI: 1.26, 3.70). Notably, the odds ratio for those in the oldest age group was not substantially different from the youngest age group. Those with higher levels of education had smaller odds ratios for severe periodontitis than those with

Table 2. Descriptors and weighted bivariate analysis comparing subjects' severe periodontitis status by selected indicators, among adults 45 years and older, NHANES III, 1988–94

Characteristics	N (weighted %)	Severe periodontitis status		P-value[a]
		Severe periodontitis, N (weighted %)	No severe periodontitis, N (weighted %)	
	4343	303 (4.6)	4040 (95.4)	
Age categories				0.02
45–54	1442	75 (3.46)	1367 (96.5)	
55–64	1221	98 (5.06)	1123 (94.94)	
65–74	1070	99 (6.53)	971 (93.47)	
75–90	610	31 (4.03)	579 (95.97)	
Education				< 0.001
Less than H.S.	1872	196 (8.57)	1676 (91.43)	
Graduate H.S.	1197	66 (4.74)	1131 (95.26)	
Some college	584	23 (3.08)	561 (96.92)	
College graduate	325	10 (1.36)	315 (98.64)	
> College graduate	334	8 (2.27)	326 (97.73)	
Gender				< 0.001
Male	2188	214 (6.42)	1974 (93.58)	
Female	2155	89 (2.84)	2066 (97.16)	
Subgingival calculus[b]				< 0.001
At or below the median	1564	11 (0.47)	1553 (99.5)	
Above the median	2779	292 (8.67)	2487 (91.33)	
Smoking status				< 0.001
Never smoked	2060	74 (1.99)	1986 (98.01)	
Former smoker	1461	120 (5.61)	1341 (94.39)	
Current smoker	822	109 (9.05)	713 (90.95)	
Diabetes control				0.003
No DM	3841	240 (4.06)	3601 (95.94)	
Better-controlled	332	33 (8.76)	299 (91.24)	
Poorly controlled	170	30 (15.32)	140 (84.68)	

[a]Comparisons were carried out using a Chi-Square test.
[b]Median percent of teeth with subgingival calculus.

the lowest education level, although only those graduating from college (but not postgraduates) had a statistically significant lower odds ratio. Those who were current smokers were more likely (OR = 3.31, 95% CI: 1.55, 7.05) to have severe periodontal disease than those who never smoked. Former smokers were 2.93 times (95% CI: 1.98, 4.34) more likely to have severe periodontitis than never smokers. A strong association for severe periodontitis was also seen with extent of subgingival calculus present. The odds for severe periodontal disease increased as the percent of teeth with subgingival calculus increased, with an odds ratio of 1.03 (95% CI: 1.03, 1.04).

Table 5 shows the mean number of teeth for subjects with no diabetes, better controlled, and poorly controlled diabetes, stratified by age group. These counts are based on random half-mouth examinations, as per the NHANES III protocol. As expected, those in the oldest age group had the smallest mean number of teeth (10.12 ± 0.2), particularly those with poorly controlled diabetes (mean = 8.2 ± 0.78). Those without diabetes consistently had a greater mean number of teeth for each age group compared to the other better-controlled and poorly controlled glycemic level groups.

Discussion

This analysis provides evidence for an association between glycemic control and the prevalence of severe periodontal disease in the US population 45 years of age and older. To minimize bias due to misclassification of diabetes type, this study included only those subjects 45 years of age and older because it is recognized that over 95% of individuals with diabetes who are 45 years of age and older have type 2 DM (2). To test the extent of mis-

Table 3. Change in odds ratio analysis for the association between the glycemic control and severe periodontitis adjusting for selected third variables, US adults 45 years and older, NHANES III, 1988–94

Variable[a]	Poorly controlled (crude OR = 4.28)		Better controlled (crude OR = 2.27)	
	Adjusted OR	% change	Adjusted OR	% change
Age[b]	4.14	3.3	2.09	7.9
Gender[c]	4.18	2.3	2.09	7.9
Education level[d]	3.72	13.1	1.98	12.8
Smoking status[e]	4.56	− 6.5	2.31	− 1.8
Race/ethnicity[f]	3.67	14.3	2.14	5.7
Poverty income ratio[g]	3.52	17.8	2.18	4.0
Frequency of dental visits[h]	3.71	13.3	2.21	2.6
Subgingival calculus[i]	2.74	36.0	1.61	29.1
Gingival bleeding[j]	3.0	29.9	2.04	10.1
Serum creatinine[k]	4.58	− 7.0	2.01	11.5
Urinary creatinine[k]	4.65	− 8.6	2.04	10.1
Serum LDL-cholesterol[k]	5.7	− 33.2	2.0	11.9
Serum triglycerides[k]	4.8	− 12.4	2.46	− 8.4
History of CHF[l]	4.12	3.7	2.03	10.6

[a]All other variables tested that are not in the table did not have a 10% or larger change in the odds ratio.
[b]Age: categories (As shown in Tables 1 and 2).
[c]Gender: females are the referent group.
[d]Education level: categories (as shown in Tables 1 and 2).
[e]Smoking status: categories (current smoker, former smoker, never smoked-referent group).
[f]Race/ethnicity: categories (non-Hispanic white-referent group, non-Hispanic black, Mexican American, other).
[g]Poverty income ratio: continuous.
[h]Frequency of dental visits: categories (at least once per year-referent group, once per 2 years, less often than once per 2 years, only when needed).
[i]Subgingival calculus: continuous (percent of teeth with calculus).
[j]Gingival bleeding: continuous (percent of teeth with gingival bleeding).
[k]Serum creatinine, urinary creatinine, serum LDL-cholesterol, serum triglycerides: continuous.
[l]History of CHF: categorical (no history of congestive heart failure versus positive history).

classification, we applied the method used by Harris (78) to define subjects with type 1 diabetes as those <30 years of age at diagnosis who had continuous insulin use since diagnosis of diabetes. This procedure resulted in identifying one subject with type 1 diabetes (who was 29 years old at time of diabetes diagnosis) out of the 500 subjects with diabetes who were included in the logistic regression model. Re-analysis of the logistic regression model with this one individual excluded resulted in estimates for glycemic control and all other covariates that were essentially identical to those originally obtained (results not shown).

These findings support three previous studies (52–54) that demonstrated a relationship between poorly controlled diabetes and greater periodontal disease prevalence in people with type 2 diabetes. These results have extended previous findings to a national, population-based sample. Our initial analysis did not demonstrate a significant difference in severe periodontitis prevalence between those with and those without diabetes (results not shown). The significant association was identified only when glycemic control status was considered.

In this study we evaluated several risk indicators in the multivariable modeling procedures to control for factors that may influence the association between glycemic control and severe periodontitis. Our analysis found that both smoking status and amount of subgingival calculus had significant associations with severe periodontal disease. While the role of cigarette smoking as a risk factor for periodontal disease is firmly established (10, 12, 65–70), the exact role of subgingival calculus as a cause or result of periodontal inflammation remains somewhat open to conjecture (71). However, substantial evidence from clinical, experimental, morphologic and epidemiologic studies conducted over the past 30 years supports a clear role for the presence of subgingival calculus in having a pathogenic effect on the progression of periodontal disease and its removal as an effective measure in treating periodontal infection (71, 73, 74). Hence, a measure of calculus extent was included as a risk

Table 4. Logistic regression model of the association between glycemic control and severe periodontitis, controlling for selected indicators, in 4312 adults 45 years of age and older, NHANES III, 1988–94[a]

Covariates	Beta	Standard Error	Odds Ratio	95% CI	*P*-value
Intercept	−5.34	0.38			
Glycemic control					
No DM	Referent				
Poorly controlled	1.07	0.36	2.90	1.40–6.03	0.005[b]
Better controlled	0.44	0.27	1.56	0.90–2.68	0.108[b]
Age					
45–54	Referent				
55–64	0.45	0.34	1.56	0.79–3.08	0.191[b]
65–74	0.77	0.27	2.16	1.26–3.70	0.006[b]
75–90	0.08	0.47	1.08	0.42–2.75	0.870[b]
Education					
Less than H.S.	Referent				
H.S. graduate	−0.00	0.23	1.00	0.63–1.58	0.987[b]
Some college	−0.22	0.38	0.80	0.37–1.71	0.558[b]
College graduate	−1.05	0.51	0.35	0.13–0.96	0.043[b]
>College graduate	−0.12	0.45	0.88	0.36–2.18	0.785[b]
Smoking status					
Never smoked	Referent				
Current smoker	1.20	0.38	3.31	1.55–7.05	0.003[b]
Former smoker	1.08	0.19	2.93	1.98–4.34	0.000[b]
Subgingival calculus[c]	0.03	0.00	1.03	1.03–1.04	0.000[c]

[a]There are 4312 subjects included in this table, not the 4343 representing those 45 years of age and older because subjects with missing data for any one of the variables in the model were excluded.
[b]*P*-values were obtained for each level because separate variables (i.e. dummy variables) were specified and evaluated.
[c]Continuous variable: percent of teeth.

Table 5. Weighted mean number of teeth by age group and glycemic control status (standard error in parentheses)[a]

Age	No DM	Better controlled type 2 DM	Poorly controlled type 2 DM
45–54	11.9 (0.10)	10.9 (0.10)	10.0 (0.47)
55–64	11.3 (0.13)	10.9 (0.42)	10.9 (0.36)
65–74	11.0 (0.13)	10.1 (0.42)	10.0 (0.71)
75–90	10.2 (0.20)	9.5 (0.47)	8.2 (0.78)

[a]The values are based on random half-mouth counts.

indicator in the multivariable model presented in this analysis. The significant associations with severe periodontal disease for both smoking and calculus were consistent with previous studies (12, 71–73) and provide greater confidence in the logistic regression model estimated and presented for our analysis.

The absence of greater odds for severe periodontitis in the oldest age category may be due to an increased likelihood that teeth with severe periodontal disease were previously extracted, thus leaving relatively healthier teeth for examination in those individuals. Another consideration is that the oldest dentate group could have included a substantial proportion of individuals who were less susceptible to severe periodontitis, i.e. 'healthy survivors' (74). It has been posited that the direct relationship between age and occurrence of periodontal disease may be due to the prolonged exposure of older subjects to true etiological factors, leading to a cumulative progression of lesions over the lifetime (10, 76) rather than an age-related intrinsic deterioration of host-protective mechanisms or acceleration of host-destructive mechanisms (77), though this issue has not yet been clearly resolved. These considerations could account for our finding of an age-related gradient leading to a significant association only in the 65–74-year-old age group.

In interpreting our results, there could be a certain age differential required to demonstrate significantly greater odds of severe periodontitis prevalence in an older age group compared to the referent group. Beyond a certain age, either tooth loss, with its concomitant reduction in the number of severely periodontally involved teeth available for examination, an increased proportion of less susceptible older dentate individuals, or both could then attenuate the age-related association as seen in the oldest age group.

When the results of this study are generalized to the entire US population 45 years of age and older, the odds of glycemic control and severe periodontitis may be underestimated since only those subjects who had a complete dental examination were included in this analysis. Subjects who had certain medical conditions and those who were edentulous were excluded. Therefore, this study group was more likely to be healthier than the general US population in the age groups studied. Furthermore, an analysis of the data set showed that those who did not have a complete examination tended to be in worse health than those who had the examination (data not shown). For example, among those who were excluded from the dental examination there was a significantly higher prevalence of heart disease, hypertension and asthma than among those participants who had a dental examination.

There are several other potential limitations to consider when interpreting the results of this study. First, there may be differences in testing the hypothesis depending on the criteria used for severe periodontitis. It is important to note that there is no standard way to classify severity of periodontal disease status for epidemiologic studies (74). Studies have used a variety of definitions including differences in mean values of attachment loss, radiographic bone loss, periodontal pocketing; mean score of periodontal index, and several categorical specifications of clinical and radiographic measures. In this study, severe periodontitis was defined as at least two sites with 6 mm loss of attachment and at least one of those sites with probing pocket depth of at least 5 mm. This was chosen because a recent study derived a similar definition based on analysis of periodontal status in a population across the adult age spectrum (62). However, our requirement for one of the sites with attachment loss to have probing pocket depth ≥5 mm is slightly different and more restrictive than that definition**.**

Another consideration is the method of classifying glycemic control. The cut-off point for hemoglobin A1c (>9%) used to distinguish those who were more poorly controlled from those with better control was based on findings reported by McCance et al. (75). A potential limitation is choosing a cut-off point for the hemoglobin A1c measures. By dichotomizing hemoglobin A1c, subjects with values slightly above or below the cut-off point would tend to be similar with respect to glycemic control status, although classified as having a different exposure in the analysis. This imposed dichotomous classification of better versus poorer control could weaken the power to detect an association with severe periodontitis by assigning subjects with similar baseline glycemic control characteristics to different exposure categories. Because of the significant association estimated for poorer glycemic control in our model, it is not likely that misclassification of glycemic control status had a substantial role in these analyses. Further, choice of number of categories and specific cut-off points results in an arbitrary classification by categorizing the continuous values for HbA1c. However, in this analysis it was necessary to establish categories of glycemic control status among subjects with diabetes to allow a comparison of the associations between both better and poorer glycemic control and the odds of severe periodontal disease with the odds of severe periodontal disease for those subjects who did not have diabetes. In addition to the dichotomous specification for glycemic control presented in this report, separate analyses were also performed (results not shown) using both a 3- and a 4-category specification for degree of glycemic control. In those auxiliary analyses, the pattern and estimated association for those with better and poorly controlled diabetes remained consistent with the associations presented here; hence the conclusions were identical to those presented in this report. The dichotomous specification for glycemic control was retained because it was the simplest specification that conveyed the significant association between poorly controlled diabetes and severe periodontal disease, while providing an opportunity to also evaluate the association for better glycemic control.

In the dental examination, we are assuming that the half-mouth assessment can be extrapolated to the full mouth. Since periodontitis does not necessarily occur symmetrically in the mouth, and tooth loss was greater in individuals with type 2 DM, the number of subjects with severe periodontal disease may be underestimated. Taking these considerations together, it is likely that the association observed in the present study may be an underestimate of the true association between glycemic control and periodontal disease.

Additional, potential limitations of this study, as with many clinical studies, include the possibility of measurement error as well as inter- and intraexaminer variations that affect the classification of periodontal disease status. Albandar et al. describe details of measurement reliability specific to the periodontal examination for NHANES III in their recent report (59). Lastly, because this is a cross-sectional analysis, only an association between periodontal disease and glycemic control of diabetes can be assessed. This study design does not permit causal inference in that the measurements are made at a single point in time, hence preventing establishment of the time sequence for exposure and outcome occurrence and accounting for potential variation in covariate values over time.

There have been previous studies on the relationship between periodontal disease and glycemic control in type 2 DM in select populations with a high prevalence of DM (53) and a smaller age range (52–54). The national data set used and the modeling procedures applied in this analysis allowed us to test the prevalence of severe periodontitis in the US population and led us to conclude that these observations were consistent with the results from the Gila River Indian Community (53). Taken together, these findings suggest that poorly controlled type 2 diabetes is associated with greater prevalence of severe periodontitis.

Acknowledgments

The authors gratefully acknowledge Drs Woosung Sohn and Keith Heller for their generous consultation in conducting the data analysis; Drs Richard Niederman, Chester W. Douglass, and Kaumudi Joshipura for their support and critical review of the manuscript; and the Harvard School of Dental Medicine/Medical School summer research program and the University of Michigan School of Dentistry for funding to support this project.

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