Scientific Research Report

Oral Health, Diabetes, and Inflammation: Effects of Oral Hygiene Behaviour

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ARTICLE INFO

Article history:
Received 23 June 2021
Received in revised form
28 September 2021
Accepted 4 October 2021
Available online 29 November 2021

Key words:
Tooth loss
Periodontal disease
Diabetes
Inflammation

ABSTRACT

Introduction: The aim of this research was to assess the association between inflammation and oral health and diabetes, as well as the mediating role of oral hygiene practice in this association.

Methods: Data were from the 2009–2010 National Health and Nutrition Examination Survey. The analytical sample consisted of 2,191 respondents aged 50 and older. Poor oral health was clinically defined by significant tooth loss (STL) and periodontal disease (PD). Diabetes mellitus (DM) was determined by glycemic levels. The outcome variable was serum C-reactive protein (CRP) level, dichotomised as ≥1 mg/dL (elevated CRP) vs <1 mg/dL (not elevated CRP). Two path models, one using STL and DM as the independent variable, the other using PD and DM as the independent variable, were estimated to assess the direct effects of having poor oral health and DM on elevated CRP and the mediating effects of dental flossing.

Results: In path model 1, individuals having both STL and DM (adjusted odds ratio [AOR], 1.92; 95% confidence interval [CI], 1.30–2.82) or having STL alone (AOR, 2.30; 95% CI, 1.68–3.15) were more likely to have elevated CRP than those with neither STL nor DM; dental flossing (AOR, 0.92, 95% CI, 0.88–0.96) was associated with lower risk of elevated CRP. In path model 2, no significant association was found between having both PD and DM and elevated CRP; dental flossing (AOR, 0.91; 95% CI:, 0.86–0.94) was associated with lower risk of elevated CRP.

Conclusions: Findings from this study highlight the importance of improving oral health and oral hygiene practice to mitigate inflammation. Further research is needed to assess the longer-term effects of reducing inflammation.

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Introduction

Poor oral health (e., tooth loss and periodontal disease [PD]) and diabetes mellitus (DM) are common health problems amongst adults in the US.[1,2] About 10.5% of the US population are estimated to have DM.[2] PD affects as many as 57.2% of adults aged 50 or older.[1] The overall prevalence of a lack of a functional dentition (i.e., <20 teeth out of 28 teeth) is 31.8% amongst adults aged 50 or older in the US.[3]

PD is a major cause of tooth loss in adults.[4] Research has shown that PD and tooth loss both are risk factors for cardiovascular disease (CVD) and stroke.[5,6] Repeated and prolonged oral infections can increase the inflammatory burden.[7] In individuals with type 2 DM, the human body becomes less sensitive to insulin and the resulting insulin resistance also leads to inflammation.[8] Furthermore, there is a bidirectional

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https://doi.org/10.1016/j.identj.2021.10.001

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relationship between DM and periodontal disease: DM has an adverse effect on periodontal health, and periodontal disease has an adverse effect on glycemic control and DM complications.[9,10]

Serum C-reactive protein (CRP) is commonly used as a biomarker of acute and chronic inflammation.[11] Although previous studies have examined the association between PD and CRP,[12-14] to our knowledge, no research has assessed the joint contribution of poor oral health and DM to CRP. Because of the shared mechanism (ie, chronic inflammation) between DM and poor oral health,[9] it is plausible that having these 2 conditions concurrently would potentially increase the level of systemic inflammation. Given the high prevalence of poor oral health and DM in the aging population, and their role as significant risk factors for CVD,[15] a study of the joint contribution of these 2 conditions to inflammation is warranted.

Good oral hygiene practice (eg, brushing and flossing) can effectively remove plaque and decrease gingival inflammation.[16,17] Maintaining good oral hygiene is critical for preventing periodontal disease. The current study aimed to assess direct and indirect relationships between having both poor oral health and DM and CRP levels as well as test the mediating effect of oral hygiene practice (i.e., flossing) on the relationship. We treated dental flossing as the mediator variable because it may decrease gingival inflammation, which may lower the likelihood of elevated CRP. We hypothesise that (1) having both poor oral health and DM concurrently is associated with higher CRP levels, in comparison to having just one of these conditions, and (2) oral hygiene practice mediates the association of poor oral health and DM with CRP levels.

Methods

Data

Data were derived from the 2009–2010 National Health and Nutrition Examination Survey (NHANES), the most current wave that includes all the data needed for this analysis: CRP data, oral hygiene practice, and updated clinical oral health parameters.[18] NHANES is a stratified multistage probability sample of the civilian non-institutionalised population in the US. NHANES includes both interviews and physical examinations. The examination protocol consists of medical, dental, and laboratory tests administered by highly trained medical personnel. Additional information about the survey can be found elsewhere.[19] The data used in this analysis are in the public domain. Thus, the study is exempted from institutional review board review.

Sample

We limited the sample to respondents aged 50 and older who had the data from the clinical oral examinations and blood tests. Respondents with a CRP value >10 mg/dL (n = 3) were excluded as such values may reflect acute conditions. The analytical sample included 2,191 respondents with dentition (tooth count) data and 1,876 with complete periodontal examination data.

Outcome variable

In the 2009–2010 NHANES, serum CRP was measured by latex-enhanced nephelometry.[19] We treated CRP as a dichotomous variable: elevated CRP (yes/no) (≥1 mg/dL vs <1 mg/dL).[12]

Independent variables

Clinically classified periodontitis. The 2009–2010 NHANES survey used a full-mouth periodontal examination protocol. The presence of PD was determined based on the Centers for Disease Control and Prevention and the American Academy of Periodontology total PD case definition, defined as the sum of severe, moderate, and mild PD cases. A detailed definition can be found elsewhere.[20] In our analysis, periodontitis was categorised as a binary variable (yes = 1 [mild, moderate, or severe periodontitis]/no = 0).

Significant tooth loss. The number of teeth were counted, excluding the third molars. The number of missing teeth ranged from 0 to 28. Significant tooth loss (STL) was defined as lack of functional dentition (i.e., <20 teeth out of 28 teeth, yes/no) .[3]

Diabetes. Diabetes status was ascertained from lab results using diagnostic thresholds for glycated hemoglobin (hemoglobin A1c >6.5%) or fasting glucose (>126 mg/dL) measures recommended by the American Diabetes Association.[21] These data are collected at the time of the NHANES survey.

Grouping by DM and poor oral health status. We created 4 groups as the independent variable by poor oral health (STL or PD) and DM status. First, grouping by STL (yes/no) and DM (yes/no) status: Group 1 = neither STL nor DM, Group 2 = with STL but no DM, Group 3 = no STL but with DM, and Group 4 = with both STL and DM. Second, grouping by PD (yes/no) and DM (yes/no) status: Group 1 = neither PD nor DM, Group 2 = with PD but no DM, Group 3 = no PD but with DM, and Group 4 = with both PD and DM.

Mediator

Oral hygiene practice was the mediator variable, measured by dental flossing in this study. In NHANES 2009–2010, respondents were asked “Aside from brushing teeth with a toothbrush, in the last 7 days, how many days did you/the survey participant use dental floss or any other device to clean between your/his/her teeth?” In this analysis, the number of days the individual used dental floss was the mediator variable (“flossing” for short).

Covariates

Choice of covariates was guided by previous studies.[12,13,22] We included the following covariates: age; sex; race/ethnicity (Non-Hispanic White [Whites], Non-Hispanic Black [Blacks], Mexican Americans/other Hispanic groups [Hispanics], and other); family income level assessed on the basis of the poverty index ratio, the ratio of total family income to the US poverty level classified into 4 quartiles with the first quartile being the lowest and the fourth quartile as the highest income level; college education (yes/no), health insurance coverage (yes/no), smoking status (current smokers, former

smokers, and never smoked); and obesity status (yes [body mass index (BMI) ≥ 30]/no [BMI < 30]).

Statistical analysis

Chi-square tests and *t* tests were performed to examine the differences in sample characteristics by elevated CRP status. We used generalised structural equation modeling to assess the direct relationships between the independent variables (groupings by poor oral health and DM) and the outcome variable (elevated CRP) as well as the mediating effects of dental flossing on the relationships. Two path models were estimated: in path model 1, the independent variable was classified by STL and DM status; in path model 2, the independent variable was classified by PD and DM status. The reference group for the independent variable in path model 1 was those with neither STL nor DM, and in path model 2, it was those with neither PD nor DM. Within each path model, we fitted a linear regression model to assess the association between the independent variable and the mediator and a logistic regression where both the independent variable and the mediator were included to model the odds of having elevated CRP. To account for the possible coexistence of PD and STL (ie, someone may have both PD and STL at the same time), we controlled for PD (yes/no) in path model 1 and STL (yes/no) in path model 2. Other covariates were the same in both models. We accounted for the complex survey design of NHANES using sampling weights in analyses. We bootstrapped 500 times for estimation and used the *nlcom* (nonlinear combination) command to calculate the indirect effects. *P* values < .05 were considered statistically significant. Analyses were conducted in Stata 15 (StataCorp).

Results

Sample characteristics by elevated CRP status are presented in Table 1. Older respondents, Blacks, respondents with lower family income, and current smokers (all $P < .001$) were more likely to have elevated CRP than their counterparts. Respondents who flossed more frequently were less likely to have elevated CRP ($P = .048$). Respondents with DM alone were most likely to have elevated CRP ($P = .002$) compared to the other 3 groups classified by PD and DM status; respondents with both STL and DM ($P < .001$) were most likely to have elevated CRP compared to the other 3 groups classified by STL and DM status.

Path model results

Figure 1 displays path model 1 results. The path coefficients (i.e., raw coefficients from the logit model) show that having both STL and DM ($b = 0.65$) and having STL but no DM ($b = 0.83$) were directly related to elevated CRP, suggesting that having STL and DM concurrently reduced the strength of the relationship with elevated CRP more than having STL alone.

The paths between the independent variable and flossing show that having both STL and DM ($b = -2.64$), having STL alone ($b=-2.08$), and having DM alone ($b=-1.09$) were negatively associated with flossing, suggesting that those with STL or DM were less likely to floss frequently. Flossing was negatively related to elevated CRP ($b=-0.09$), indicating that frequent flossing was associated with lower risk of having elevated CRP (Figure 1).

The 3 indirect effects were significant, indicating a significant mediating role of the flossing variable. Specifically, having both STL and DM ($b=[-2.64]*[-0.09] = 0.24$, $P < .001$), having no STL but having DM ($b= [-1.08]*[-0.09] = 0.10$, $P < .001$), and having STL but no DM ($b= [-2.08]*[-0.09]) = 0.19$, $P < .001$) were associated with less flossing, which in turn was associated with higher risk of having elevated CRP (Figure 1).

Figure 2 displays path model 2 results. Different from path model 1, no significant direct relationship was found between the independent variable and the outcome variable, which suggests that PD had a weaker association with elevated CRP than STL.

The path coefficients show that having both PD and DM ($b=-1.78$), having no PD but with DM ($b=-0.75$), and having PD but no DM ($b=-0.64$) were negatively associated with flossing. Further, flossing was negatively related to elevated CRP ($b=-0.09$) (Figure 2).

The 3 indirect effects from the independent variables to the outcome variable were significant: having both PD and DM ($b=[-1.78]*[-0.09] = 0.16$, $P < .001$), having PD but no DM ($b=[-0.64]*[- 0.09] = 0.06$, $P < .001$), and having DM but no PD ($b = [-0.75]*[- 0.09] = 0.07$, $P < .01$) were associated with less flossing, which in turn was associated with higher risk of having elevated CRP, indicating a significant mediating role of the flossing variable (Figure 2).

Table 2 presents the adjusted odds ratios (AORs) from the path models. In model 1, those having both STL and DM (AOR, 1.92) and having STL alone (AOR, 2.30) were more likely to have elevated CRP than those with neither STL nor DM. Flossing (AOR, 0.92) was negatively associated with elevated CRP. PD was not significant. In model 2, no significant association was found between the independent variable (grouping by PD and DM) and the outcome elevated CRP. However, similar to model 1, flossing (AOR, 0.91) was negatively associated with elevated CRP. STL (AOR, 2.33) was positively associated with elevated CRP.

Discussion

Using data from the 2009–2010 NHANES, we assessed the magnitude of the joint contribution of poor oral health and DM to elevated CRP as well as the mediating role of flossing in these associations. Our study results do not support the first hypothesis that having both poor oral health and DM concurrently is associated with higher risk of elevated CRP than having just one of these two conditions alone. But the results support the second hypothesis that flossing has a significant mediating effect.

Our results show that STL was associated with higher CRP levels, which is consistent with prior findings that tooth loss was associated with a higher level of systemic inflammation.[22,23] STL reflects accumulated dental disease, and oral inflammation over time. But our study results do not

Table 1 – Sample characteristics by CRP status (*N* = 2192).

Variables	Elevated (CRP ≥1 mg/dL) N = 218			Not elevated (CRP <1 mg/dL) N = 1973			*P* value†
	% (or mean)*	95% CI		% (or mean)*	95% CI		
Age (mean)	64.5	63.2	65.7	62.4	61.8	63.0	.005
Sex							
Male	6.2	4.7	8.2	93.8	91.8	95.3	.050
Female	9.7	7.0	13.3	90.3	86.7	93.0	
Race/ethnicity							.004
Non-Hispanic White	7.3	5.7	9.5	92.7	90.5	94.3	
Non-Hispanic Black	14.5	11.1	18.7	85.5	81.3	88.9	
Mexican Americans/other Hispanics	9.6	7.3	12.5	90.4	87.5	92.7	
Other	4.1	1.3	12.7	95.9	87.3	98.7	
Poverty income ratio							.012
1st quartile	12.5	9.3	16.6	87.5	83.4	90.7	
2nd quartile	12.5	9.2	16.8	87.5	83.2	90.8	
3rd quartile	6.4	4.4	9.4	93.6	90.6	95.6	
4th quartile	5.4	3.0	9.6	94.6	90.4	97.0	
College education							.737
No	8.4	6.3	11.2	91.6	88.8	93.7	
Yes	7.7	5.4	11.0	92.3	89.0	94.6	
Health insurance							.463
No	6.9	4.9	9.6	93.1	90.4	95.1	
Yes	8.2	6.4	10.4	91.8	89.6	93.6	
Obese							<.001
No	5.4	4.3	6.6	94.6	93.4	95.7	
Yes	12.1	9.0	16.1	87.9	83.9	91.0	
Smoking status							<.001
Current smokers	9.9	7.3	13.2	90.1	86.8	92.7	
Former smokers	9.9	7.9	12.4	90.1	87.6	92.1	
Never smoked	6.2	3.9	9.6	93.8	90.4	96.1	
Days of having flossing in the past 7 days	2.6	1.7	3.4	3.4	3.2	3.7	.048
Grouping by DM and PD							.002
Neither DM nor PD (*N* = 503)	5.4	3.5	8.2	94.6	91.8	96.5	
No DM but with PD (*N* = 1069)	7.0	5.4	8.9	93.0	91.1	94.6	
With DM but no PD (*N* = 71)	16.8	10.0	27.0	83.2	73.0	90.0	
With both DM and PD (*N* = 233)	9.6	5.9	15.4	90.4	84.6	94.1	
Grouping by DM and STL							<.001
Neither DM nor STL (*N* = 1108)	4.9	3.5	6.9	95.1	93.1	96.5	
No DM but with STL (*N* = 699)	12.7	9.8	16.4	87.3	83.6	90.2	
With DM but no STL (*N* = 174)	9.4	4.3	19.4	90.6	80.6	95.7	
With both DM and STL (*N* = 210)	17.6	10.8	27.4	82.4	72.6	89.2	

CI, confidence interval; CRP, C-reactive protein; DM, diabetes mellitus; PD, periodontal disease, STL, significant tooth loss.

* Weighted percentage (except weighted mean for age).

† Chi-square or *t* tests.

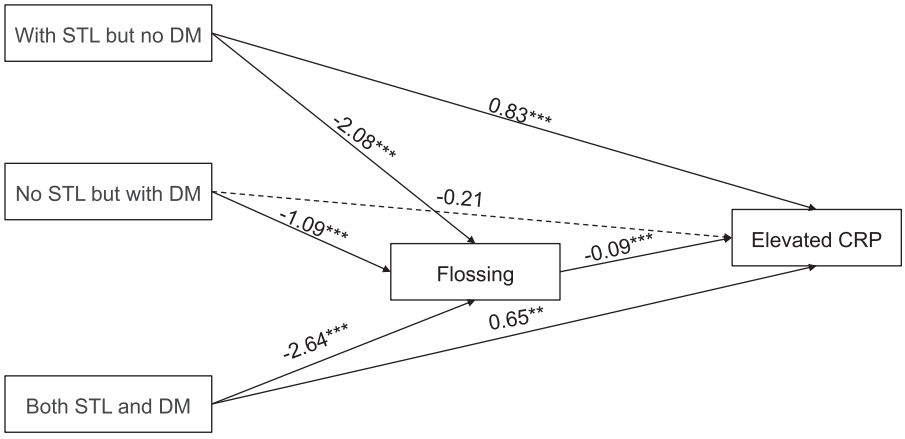

Fig. 1 – Relationship between diabetes mellitus (DM) and significant tooth loss (STL), flossing, and elevated C-reactive protein.

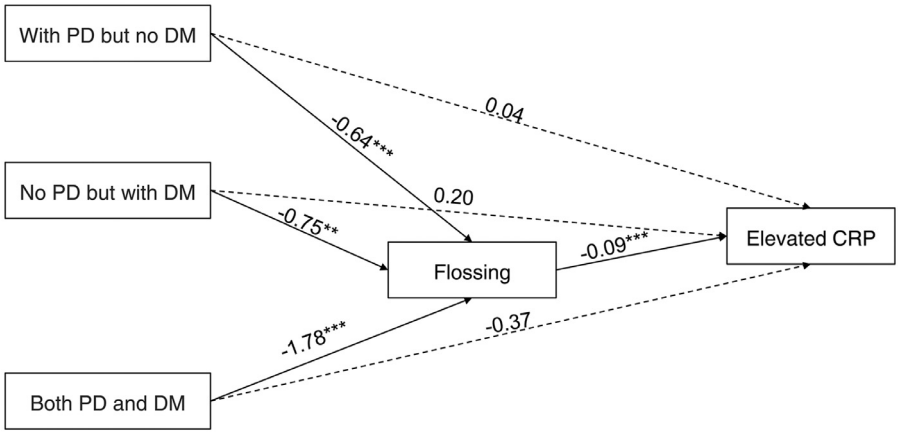

Fig. 2 – Relationship between diabetes mellitus (DM) and periodontal disease (PD), flossing, and elevated C-reactive protein.

show a significant effect of PD on elevated CRP. Similar findings were reported in prior research. An earlier study[24] reported that PD was not associated with higher CRP levels in older adults. One recent study[22] also found that periodontal disease was not associated with the increased risk of being in the top CRP tertile amongst older adults, whereas partial tooth loss (with fewer than 21 teeth) was significantly associated with the highest CRP level. It should be acknowledged, however, that most previous studies have found that PD was associated with higher CRP levels.[12-14] For example, in an analysis of data from the Atherosclerosis Risk in Communities Study (ARIC), Slade et al.[12] found that extensive periodontal disease was associated with increased CRP levels in adults aged 52 to 74 years.

The different findings across studies may be due to different study designs and patient populations. In addition, different definitions of PD may also account for inconsistent findings. For example, in our study, respondents were classified as having PD if they had mild, moderate, or severe periodontitis.[20] Kotronia et al. defined periodontal disease by periodontal pocket depth loss of attachment at >20% of sites.[22] Slade et al. defined periodontal disease as having periodontal pocket depth ≥4 mm at more than 30% of sites.[12]

Table 2 – Path model results of the association between poor oral health/DM status and elevated CRP.

Variables	Model 1 (*n* = 2191)				Model 2 (*n* = 1876)			
	AOR	95% CI		*P* value	AOR	95% CI		*P* value
Groups (vs Group 1)*								
Group 2	2.30	1.68	3.15	<.001	1.05	0.69	1.57	.831
Group 3	0.81	0.44	1.52	.514	1.23	0.50	3.03	.657
Group 4	1.92	1.30	2.82	.001	0.69	0.43	1.10	.120
Age	1.01	1.00	1.02	.098	1.01	1.00	1.02	.125
Female	2.09	1.59	2.75	<.001	2.08	1.58	2.73	<.001
Race/ethnicity (vs non-Hispanic White)								
Non-Hispanic Black	1.82	1.49	2.22	<.001	1.81	1.48	2.20	<.001
Mexican American	1.45	0.99	2.13	.055	1.47	0.99	2.19	.056
Other	1.01	0.14	7.40	.992	0.99	0.14	7.18	.994
Poverty income ratio (vs 1st quartile)								
2nd quartile	1.00	0.73	1.38	.989	1.00	0.72	1.39	.990
3rd quartile	0.47	0.35	0.63	<.001	0.47	0.35	0.63	<.001
4th quartile	0.62	0.41	0.92	.017	0.62	0.42	0.93	.020
College or above	2.01	1.54	2.63	<.001	2.02	1.54	2.65	<.001
Having health insurance	1.20	0.84	1.70	.316	1.19	0.84	1.70	.329
Smoking status (vs never smoked)								
Current smokers	1.22	0.93	1.60	.147	1.21	0.93	1.58	.164
Former smokers	1.57	1.11	2.22	.011	1.54	1.09	2.18	.015
Obese	2.16	1.65	2.82	<.001	2.15	1.64	2.82	<.001
Days of having flossing in the past 7 days	0.92	0.88	0.96	<.001	0.91	0.88	0.96	<.001
PD	0.95	0.71	1.27	.718				
STL					2.33	1.78	3.04	<.001

* In Model 1: Group 1 = neither STL nor DM; Group 2 = with STL but no DM; Group 3 = no STL but with DM; Group 4 = with both STL and DM.In Model 2: Group 1 = neither DM nor PD; Group 2 = with PD but no DM; Group 3 = no PD but with DM; Group 4 = with both PD and DM.AOR, adjusted odds ratio; CI, confidence interval; CRP, C-reactive protein; DM, diabetes mellitus; PD, periodontal disease; STL, significant tooth loss.

In our analysis, the independent contribution of DM alone to elevated CRP was not significant and in fact was in a negative direction. As a result, the magnitude of the joint contribution of both DM and STL/PD was not greater than that of STL or PD alone. As such, these results do not support our first hypothesis. The explanation for these findings is unclear; thus, more research is needed to investigate these relationships.

Nonetheless, the insignificant association between DM alone and elevated CRP in our analysis should be interpreted with caution. In initial analyses using sequential models, we found that, in comparison to having neither of the conditions, having DM alone was significantly associated elevated CRP in the first model, where only the independent variable was included, and it remained significant after age, sex, and race variables were added in the second model. But having DM alone became insignificant in the third model when either socioeconomic status indicators (income, education, and health insurance status) or the obesity variable was entered into the models (results are not shown in Table 2). In the final models, higher family income was associated with lower odds of elevated CRP and obesity was associated with higher odds of CRP. One possible explanation for the insignificant findings is that access to care, and possibly access to medication, largely contribute to the association. Another explanation is the close correlation between diabetes and obesity status. Obesity is also a known risk factor for increased systemic inflammation.[25] The control of obesity in our analysis overrode the association of DM and elevated CRP. The interrelationships amongst diabetes, obesity, and oral health are complex.[25]

Our results demonstrate that the strength of association between STL and elevated CRP was stronger than the association between PD and elevated CRP. Nonetheless, STL is often the end result of PD. Moreover, in this study, STL was defined as a loss of 8 or more teeth, which indicates significant local inflammation over time; the definition for PD included mild, moderate, and severe periodontal disease. The mixture of "mild" with "severe" periodontal disease in this analysis might have diluted the association with elevated CRP. Yet, the modest number of respondents with "severe" periodontal disease prevented us from conducting a subsample analysis.

The study results show that flossing significantly mediated the association of poor oral health and diabetes with elevated CRP. Previous studies have found that dental flossing effects the subgingival microbiome and therefore local inflammation[26]; flossing is associated with lower prevalence of periodontitis[27] and fewer decayed and missing teeth.[28] Prior research has also found that good oral health is strongly related to quality of life.[29] Having regular dental checkups and good oral hygiene care are key to the prevention of oral diseases. Maintaining good oral hygiene becomes essential because many older adults do not access professional dental care due to financial limitations and functional dependency.[30]

Our findings demonstrate that dental flossing may mitigate inflammation, which may have important implications for diabetes management. Diabetes management is a complicated process and requires extensive self-care. To this end, most of diabetes self-care has focused on physical exercise, diet, and medication adherence,[31] whereas dental care and good oral hygiene practices have not been given adequate attention. Both dentists and physicians need to recommend regular dental care for their patients with diabetes. The importance of oral hygiene practice needs to be further emphasized to patients with diabetes.

We acknowledge several limitations inherent in the data set used in this study. First, given the cross-sectional nature of the survey, we cannot ascertain the sequential order of poor oral health, dental flossing, and elevated CRP. Second, CRP is a highly sensitive biomarker, which can be influenced by a small injury, such as a minor cut, or an acute and temporary health condition (e.g., flu). These conditions were not accounted for in our study, albeit with probably a small impact. Also, CRP was measured only once, so it may not capture the actual CRP status. Third, institutionalised individuals, often with more severe PD and more tooth loss, were not included. Thus, our results may underestimate the association between poor oral health and systemic inflammation. Fourth, oral hygiene behaviour was limited to flossing because the NHANES 2009–2010 did not collect information on tooth brushing. In addition, dental flossing is self-reported and thus subject to recall bias and social desirability bias. Furthermore, flossing, as a proxy, may be related to a whole host of individual, social, and economic conditions that may mediate the relationships and which we did not test (other than controlling for covariates such as income and education).

Conclusions

Our results show that in US adults, STL was associated with higher systemic inflammation. Flossing, an important oral hygiene behaviour, may contribute to reducing this inflammation. The study findings highlight the importance of improving oral health and oral hygiene practice to mitigate inflammation.

Conflict of interest

None disclosed.

Acknowledgements

This study was supported by a grant from NIH/NIA (1R56AG067619–01).

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