Diabetes and Dental Caries Prevalence: Is There an Association?

by

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Abstract

Increasing prevalence of diabetes mellitus, along with its co-morbidities, in the population has made it an important public health issue. While the relationship between diabetes mellitus and periodontal disease has been previously established, the relationship between diabetes mellitus and dental caries prevalence is less clear. People with diabetes mellitus appear to have predisposing factors that may place them at an increased risk for dental caries. In addition, people with diabetes may also be more prone to infections, including dental abscesses that result from progressive dental caries. Using data from a nationally-representative sample of adults 20 years and older in the U.S. from the 2003-2004 cycle of the National Health and Nutrition Examination Survey, the presence of a potential association between diabetes mellitus and prevalence of severe dental caries (DMFS ≥101, DFS percentage ≥ 60), prevalence of at least one root surface caries or filling (DFS-R present), and prevalence of severe untreated caries (DS ≥4), was explored in this study. Crude bivariate analyses showed statistically significant associations between DMFS ($p < 0.0001$), DFS percentage ($p=0.0033$), and DFS-R ($p=0.0004$). However, no significant associations were evident after multi-variable logistic regression analyses for any of the four outcomes. Other covariates remained significantly associated, such as age, gingival recession, current health status, and smoking status. Therefore, these factors may be useful as predictors of sub-optimal dental health.
Diabetes Mellitus

Insulin, produced by the β-cells of the pancreas, is the hormone for regulating glucose levels in the blood. Insulin is essential to the body's processing of carbohydrates, fats and proteins. Insulin regulates blood glucose levels by converting glucose to glycogen and storing it in liver and muscle cells, in a process known as glycogenesis. Insulin also inhibits the release of stored glucose from glycogen in the liver, a process known as glycogenolysis, and slows down the breakdown of fat into fatty acids, triglycerides, and ketones. It can also reverse the process and simulate fat storage, and prevent fat and protein breakdown for glucose production in the kidneys and liver, or gluconeogenesis.¹

Diabetes mellitus consists of a set of symptoms associated with abnormal carbohydrate, fat, and protein metabolism, due to defects in insulin production, insulin action, or both. Type 1 diabetes (formerly known as insulin-dependent diabetes mellitus), which is caused by a deficiency of insulin, usually affects children and young adults. Among adults, Type 1 diabetes accounts for 5 to 10 percent of diagnosed cases.² The absolute insulin deficiency observed among patients with Type 1 diabetes results from destruction of the pancreatic β-cells, which secrete insulin.³⁻⁶ Risk factors for Type 1 diabetes may be genetic, autoimmune, or environmental in nature.² The current theory for the pathogenesis of Type 1 diabetes assumes that everyone is born with a degree of susceptibility to the disease, which is
inherited. Exposure to one or more environmental “triggers” alters the immune function, initiating the destruction of the pancreatic β-cells.4-6 These “triggers” may include viruses (enteroviruses, coxsackie, congenital rubella),7,8 environmental toxins (nitrosamines),9 and food (early exposure to milk proteins in cow’s milk, cereals, or gluten).10-14 Although there has been increased understanding of the pathogenesis of Type 1 diabetes mellitus, a single unifying theory of disease causation has not been found.15

Type 2 diabetes (formerly known as non-insulin-dependent diabetes mellitus) accounts for 90 to 95 percent of all diagnosed cases of diabetes and is caused by insulin resistance and an insulin secretory defect. In patients with normal insulin function, a decrease in insulin action triggers a corresponding increase in insulin secretion by the pancreatic β-cells.16 When insulin action decreases, as is the case with increasing body weight, pancreatic β-cell function increases as a compensatory mechanism, resulting in slightly increased insulin levels that may result in pancreatic β-cell dysfunction from glucose toxicity.17 Type 2 diabetes is associated with older age, obesity, family history of diabetes, history of gestational diabetes, impaired glucose metabolism, physical inactivity, and race/ethnicity. African-Americans, Hispanic/Latino Americans, American Indians, some Asian-Americans, Native Hawaiians and Pacific Islanders are at particularly high risk of Type 2 diabetes. In general, Type 2 diabetes is rare in children and adolescents, but it is being diagnosed more frequently among children in the
The aforementioned populations. Lifestyle and overeating are primary risk factors for Type 2 diabetes, but genetics may also play a role. People with a family history of Type 2 diabetes has 2.4-fold increased risk in developing the disease. In 2007, an estimated 23.6 million people (7.8 percent of the US population) had diagnosed or undiagnosed diabetes mellitus. Among adults 20 years and older, 23.5 million people (10.7 percent) had diabetes mellitus – 12 million men (11.2 percent) and 11.5 million women (10.2 percent). Among non-Hispanic whites and non-Hispanic blacks 20 years and older, 14.9 million (9.8 percent) and 3.7 million (14.7 percent) had diabetes, respectively. Among people younger than 20 years, 186,300 people (0.2 percent) had diabetes. In the US in 2007, a total of 1.6 million new cases of diabetes were diagnosed in people aged 20 years and older. Data from the World Health Organization and United Nations estimate that the number of adults with diabetes worldwide will increase from 135 million in 1995 to 300 million in 2025.

**Diagnosis of Diabetes Mellitus**

The National Diabetes and Data Group and the World Health Organization recommendations for diabetes mellitus diagnosis have both been modified by the Expert Committee on the Diagnosis and Classification
of Diabetes Mellitus. The diagnosis of diabetes mellitus is based on the following revised criteria:

1. Classic symptoms of diabetes mellitus and casual plasma glucose concentration of $\geq 200$ mg/dL (11.1 mmol/L), or
2. Fasting (no caloric intake for at least 8 hours) plasma glucose of $\geq 126$ mg/dL (7 mmol/L), or
3. Two hour plasma glucose $\geq 200$ mg/dL during Oral Glucose Tolerance Test.\textsuperscript{20}

A positive response on any of these needs to be confirmed by another positive response on any of the same criteria on a subsequent day.\textsuperscript{20}

A panel of experts in the diagnosis, monitoring, and management of diabetes mellitus recently reviewed existing literature for the possible utility of glycosylated hemoglobin level for the diagnosis of diabetes mellitus.\textsuperscript{21}

\textit{Glycosylated Hemoglobin (HbA$\textsubscript{1c}$)}

Self-monitoring using glucose monitors records daily variations in blood glucose concentrations. The best measure of long-term control of diabetes is glycosylated hemoglobin (HbA$\textsubscript{1c}$) concentration, since it is a good indicator of average glycemic concentrations during the previous 90 to 120 days.\textsuperscript{22} However, since there are currently no standards to calibrate individual assays, the laboratory HBA$\textsubscript{1c}$ assay needs to be standardized with
either the Diabetes Control and Complications Trial (DCCT) or another internationally recognized reference laboratory.\textsuperscript{22-24}

Among adults with diabetes, the target is to maintain HBA\textsubscript{1c} levels of 7 percent or lower. The normal HbA\textsubscript{1c} level among individuals without diabetes falls between 4 and 6 percent. HbA\textsubscript{1c} levels above 9 percent reflect poorly controlled diabetes, which will need more aggressive management.\textsuperscript{25}

The use of glycosylated hemoglobin levels (HBA\textsubscript{1c}) as screening and diagnostic criteria for diabetes mellitus has been recommended because it is convenient, reflect long-term hypoglycemia, and reliable when standardized.\textsuperscript{21}

Dental Caries

Dental caries, or tooth decay, is the localized destruction of susceptible dental hard tissues by acids produced by bacterial fermentation of dietary carbohydrates.\textsuperscript{26, 27} Dental caries is a multi-factorial disease that commonly affects people of all ages throughout their lifetimes.\textsuperscript{28} Endogenous bacteria, primarily \textit{Streptococcus mutans}, \textit{Streptococcus sobrinus}, and \textit{Lactobacilli} spp., in the dental plaque produce weak organic acids from as by-products of fermentable carbohydrates from our diets. This causes a drop in local pH in the mouth below a critical value, which results in demineralization of the tooth structures.\textsuperscript{29-31} Without remineralization from saliva acting as buffer and restoring pH, this process will eventually result into cavitation.\textsuperscript{28} In the tooth enamel, dental caries first manifests as white spot lesions which are small
areas of sub-surface demineralization. In root surfaces, caries also starts as
demineralization, but as the area is softened, it is further penetrated by
bacteria. This occurs earlier in the stage of caries development. Recession
of the gingival margin from poor oral hygiene and loss of attachment from
periodontal disease exposes the tooth root surface to the development of
more dental caries.\textsuperscript{26}

Dental caries is the most prevalent infectious disease in humans.\textsuperscript{31}
Data from the National Health and Nutrition Examination Survey (NHANES)
showed that from 1999-2002, 42 percent of the US children and adolescents
under 20 years old, and almost 90 percent of the US adults had dental caries
in their permanent teeth.\textsuperscript{32} According to the 1999-2002 surveillance data for
dental caries, the mean number of decayed, missing, and filled teeth (DMFT)
for adults 20 years and older was 11.58 (SE: 0.16), while the mean number of
decayed, missing, and filled surfaces (DMFS) was 38.00 (SE: 0.63). The
mean number of decayed and filled teeth (DMFT) was 7.99 (SE: 0.12), and
the mean number of decayed and filled surfaces (DMFS) was 20.86 (SE:
0.44).\textsuperscript{33}

The effect of dental caries and its sequelae can cause significant pain
among patients.\textsuperscript{28} Oral-facial pain can greatly reduce the quality of life and
restrict many daily functions of individuals. It is associated with sleep
deprivation, depression, and multiple adverse psychosocial outcomes,
including limitations in both verbal and nonverbal communications, social
interaction, and intimacy. Treatment may get expensive, since the burden of dental caries may last a lifetime. Global frequency and distribution of dental caries is difficult to determine because of the use of various diagnostic criteria in studies. Despite the apparent decline in caries prevalence and severity in permanent teeth observed in many developed countries, many children and adults still develop dental caries. In the US and elsewhere, dental caries is increasing in frequency among older adults, since more people are retaining more teeth.

Physical and biologic risk factors for caries include inadequate salivary flow and composition, high numbers of caries-producing bacteria, insufficient fluoride exposure, gingival recession, immunological factors, the need for special health care, and genetic factors. Lifestyle and behavioral risk factors for dental caries include poor oral hygiene, poor dietary habits, frequent consumption of refined carbohydrates, frequent use of oral medications that contain sugar, and inappropriate methods of feeding infants. Other related factors include poverty, deprivation, or social status, number of years of education, dental insurance coverage, use of dental sealants, use of orthodontic appliances, and use of poorly designed or ill-fitting partial dentures.
*Diagnosis of Dental Caries*

The diagnosis of dental caries is done through a comprehensive assessment of all patient information by a visual examination of tooth surfaces. A dental probe or explorer is sometimes used to provide tactile information.\(^{49-52}\) Caries in between adjacent teeth are visualized using bitewing radiographs or using light sources via transillumination. Caries diagnosis is based principally on clinical examination and review of radiographs.\(^{52}\)

*Diabetes Mellitus and Dental Caries*

People with diabetes are at an increased risk of developing oral conditions such as gingivitis, periodontal disease, and alveolar bone loss, which has been associated with persistent poor glycemic control.\(^{53,54}\) Periodontal disease can lead to recession of the gingival margin, which can expose more tooth surfaces to caries attack.\(^{26}\) People with diabetes can also experience hyposalivation\(^{55}\) and they may suffer from salivary dysfunction.\(^{56,57}\) Hyperglycemia in children, adolescents, and adults with insulin-dependent diabetes mellitus have also been associated with decreased salivary secretion and high salivary glucose.\(^{58}\) Aside from calcium and phosphates that help remineralize tooth enamel, saliva also contains components that can directly attack cariogenic bacteria. The absence of copious saliva may result in minimizing buffer activity which promotes
remineralization of tooth structures early in the caries process. The reduction in saliva thus decreases resistance to caries-producing bacteria.\textsuperscript{28, 59} In addition, high glucose levels in the saliva can increase the amount of fermentable carbohydrates by oral bacteria, leading to production of acidic by-products that cause teeth demineralization in dental caries.\textsuperscript{29-31} Abundant glucose in the saliva may also promote the growth of cariogenic bacteria and facilitate the frequency and duration of acidic episodes.\textsuperscript{60}

**Epidemiological Studies of Diabetes Mellitus and Dental Caries**

Among oral health problems, periodontal disease is often encountered among patients with diabetes mellitus.\textsuperscript{53, 54, 61} The relationship between diabetes and dental caries has been previously investigated, but no clear association was determined. Studies have found that patients with diabetes are more susceptible to oral sensory, periodontal, and salivary disorders, which could increase their risk for developing new and recurrent dental caries.\textsuperscript{62}

A study of 42 older adults with Type 2 diabetes and controls found a statistically significant difference between the mean number of decayed, missing, and filled crown and root surfaces (DMFS) and filled surfaces (FS) between the two groups. However, converting the scores to percentage to account for missing teeth revealed no significant difference in the percentage of decayed and filled surfaces (DFS) and filled tooth surfaces (FS) between
diabetics and non-diabetics. The same comparisons were made among well-controlled diabetics, poorly-controlled diabetics, and non-diabetics, and found no significant difference as well. These findings suggest that after accounting for missing teeth, diabetes and poor glycemic control may not be associated with increased caries prevalence (percent decayed and filled surfaces and percent decayed surface). However, this may be due to the small sample size used in this study.

In 2005, a study in Iran explored the associations between factors related to diabetes and dental status among 299 adults. The investigators found among men Type 1 diabetes have 40% increased risk of having poor dental health (decayed, missing, filled teeth score >15) as compared to those with Type 2 diabetes. The same increased risk was found for males with poorly controlled diabetes. Women with Type 1 diabetes appeared to be 1.3 times more likely to have poor dental health compared to women with Type 2 diabetes, but these findings were not statistically significant.

Among 25 patients with newly diagnosed non-insulin-dependent (Type 2) diabetes mellitus and 40 controls, no association was found between metabolic control of the disease (as determined by analysis of blood HbA1c) and dental caries. Similarly, the occurrence of dental caries did not significantly differ between patients with NIDDM and patients without diabetes. There was also no statistically significant difference between the two groups in the number of microbes known to cause caries. Furthermore,
there was no association found between caries and the prevalence of coronary heart disease or hypertension in both groups as well. However this study was limited in statistical power to detect a statistically significant difference due to small sample size.

A cross-sectional study on 149 insulin-dependent (Type 1) diabetes mellitus patients showed no association between number of carious teeth surfaces and glycemic control of diabetes. After stratifying by glycemic control, a positive association was found between the number of carious teeth and with higher levels of \textit{Streptococcus mutans} and lactobacilli, two cariogenic bacteria, among subjects with poor glycemic control (HBA$_{1c}$ >8.5). This suggests that poor glycemic control, as reflected by HBA$_{1c}$ level, may have a modifying effect on the relationship between dental caries and salivary factors, by strengthening the positive association between dental caries and cariogenic bacteria. Previous studies have also found higher concentrations of glucose in saliva among subjects with high blood glucose levels. As discussed above, increased glucose in saliva may promote the growth of cariogenic bacteria and may facilitate the frequency and duration of acidic episodes.

Multiple logistic regression models using data from 105 Type 2 diabetes patients and 103 non-diabetes patients were constructed to determine the effect of Type 2 diabetes mellitus and caries on both the crown and root parts of teeth and investigate the factors that may be related to
diabetes mellitus and dental caries. After adjustment for smoking status, wearing removable prosthesis, lactobacilli counts, age, number of missing teeth, saliva buffer capacity, and the presence of at least one carious lesion, Type 2 diabetes was shown to be significantly associated with the prevalence of root caries.66

Looking at a larger sample of 390 patients with Type 1 diabetes mellitus and 202 recruited controls showed no significant difference in decayed, filled surfaces (DFS) between the diabetes group and the controls. The DFS values were also compared to the mean overall DFS values of an external control population (age-adjusted NHANES III Phase 1 survey participants) and also found no difference between the two groups. In this cohort of patients, dietary behaviors or glycemic control was not found to be associated with coronal or root caries.67

Results of these studies have shown conflicting results, and have suggested further study of the potential association between diabetes mellitus and dental caries.

**Significance**

The prevalence of dental caries and its burden on the general population is of significant public health interest since dental caries is the most common infectious disease known to man.31 Untreated dental caries can lead to pain, abscess and infection, and tooth loss. Reduction of
untreated dental caries among adults, and reduction of tooth extractions as a consequence of dental caries among adults by 15 percent are among the Healthy People 2010 objectives for oral health. Dental caries and its sequelae can cause severe pain, and according to the report of the Surgeon General, orofacial pain can adversely impact the quality of life of an individual. In addition, oral disease is among the most expensive disease to treat in most industrialized countries. In 2004, the expenditures for oral health care was 81.5 billion dollars.

Therefore, it is important to identify patients who may be at particularly high risk of dental caries. Diabetes mellitus, a significant public health problem in its own right, may increase one’s susceptibility to dental caries. In addition, people with diabetes are also more prone to infections, including dental abscesses that result from progressive dental caries. Unfortunately, there is sparse longitudinal population-based data that would allow a temporal evaluation of the association between diabetes diagnosis and subsequent risk of dental caries. However, cross-sectional data may provide information regarding this relationship that may prove valuable for clinical practitioners to identify subpopulations at high risk of suboptimal oral health, such as a greater prevalence of severe dental caries among diabetic patients.

The association between diabetes mellitus and dental caries prevalence has been explored in several cross-sectional and case-control studies, though most have had small sample sizes. Findings of these studies
have been conflicting and have been fraught with methodological difficulties, such as small sample size, the absence of standard criteria for caries evaluation, and non-conventional cut-offs to classify good and poor diabetes control. We aimed to address these limitations in a study with nationally-representative subjects.

**Objectives**

This study aimed to answer the research question, “Is there an association between diabetes mellitus and prevalence of severe dental caries in adults?” The null hypothesis for this study was that prevalence of severe dental caries, as measured by the number of decayed, missing, and filled surfaces (DMFS) did not differ between adults with diabetes mellitus and adults without diabetes mellitus. Furthermore, we had several secondary hypotheses. First, we hypothesized that prevalence of severe caries, as measured by the percent decayed and filled surfaces (% DFS) did not differ between adults with and without diabetes. Second, we speculated that prevalence of subjects with at least one root surface caries or filling (DFS-R) did not differ between adults with and without diabetes mellitus. Lastly, we hypothesized that the prevalence of severe untreated caries (DS) did not differ between the two groups.

Using data from NHANES 2003-2004 dataset, a multiple regression model and controlling for potential confounders, the study aimed to:
1. determine if there is a difference in the frequency of individuals with a high burden of decayed, missing and filled surfaces between adults with diabetes and those without diabetes, using the 90\textsuperscript{th} percentile of the decayed, missing, and filled surface (DMFS) score as the cut-off for high burden dental caries;

2. determine if there is a difference in prevalence of severe caries between adults with diabetes and adults without diabetes after adjusting for missing teeth by looking at percentage of decayed and filled surface (\% DFS);

3. determine if there is a difference in prevalence of at least one root surface caries or filling (DFS-R) between adults with diabetes and adults without diabetes; and

4. determine if there is a difference in prevalence of severe untreated dental caries (DS) between adults with and without diabetes.

Methods

Study Population

Data from the National Health and Nutrition Examination Survey (NHANES) conducted from 2003-2004 were used for the analysis. A more recent cycle of NHANES data (2005-2006) is currently available, but it contained little information on the oral health examination component about the presence of caries and fillings on individual teeth. The 2003-2004 cycle of
NHANES was the most recent survey that collected oral health examination information that are of interest to the proposed study. Looking at the most recent data was important, because we were interested in the current oral health status of adults, as trends in oral health status among adults may change over time. In addition, presence of occlusal contacts, amount of incisal opening, general tooth wear and surface-specific erosion data, and perceived impact of oral health status on quality of life data were added to the NHANES 2003-2004 Oral Health Exam and Interview, making it one of the most comprehensive assessments of oral health in the United States to date.

NHANES is an ongoing series of cross-sectional surveys of representative sample of the civilian, non-institutionalized United States population. Data were obtained from household interviews, standardized examinations, and various laboratory examinations at mobile examination centers throughout the United States. In NHANES 2003-2004, low-income persons, adolescents 12 to 19 years old, adults older than 60 years, African-Americans, and Mexican-Americans were sampled at higher rates than the rest of the population, so sample weights were used in the data analysis. Detailed description of the sample design and methods used in the NHANES are described elsewhere.

Subjects included in the analyses were adult men and women 20 years and older who reported being diagnosed with diabetes. Glycosylated
hemoglobin (HbA\textsubscript{1c}) levels, which were available for a full sample of subjects in this cycle of NHANES, were used to determine diabetes status for subjects who did not report being diagnosed with diabetes.

**Diabetes Status**

For epidemiological studies, the American Diabetes Association recommended that estimates of diabetes prevalence and incidence be based on fasting blood glucose levels of 126 mg/dL or greater.\textsuperscript{20} For this study, this recommendation was not followed, since in this cycle of NHANES, fasting blood glucose values were only obtained from subjects 12 years and older who attended the morning session of the examination.\textsuperscript{73} Limiting our study to this population would have substantially reduced our sample size by almost 50 percent. Instead, subjects were considered diabetic if they responded “Yes” to the question “(Other than during pregnancy) have you ever been told by a doctor or health professional that you have diabetes or sugar diabetes?” For those who reported not being told by a health care provider that they had diabetes, who did not know the answer to the interview question, or who refused to disclose the information, glycosylated hemoglobin levels were used to determine diabetes status. Subjects with glycosylated hemoglobin (HbA\textsubscript{1c}) levels greater than 6 percent were considered to have diabetes.
The laboratory method used to obtain glycosylated hemoglobin (HbA$_{1c}$) levels were standardized to the reference method used in the Diabetes Control and Complications Trial (DCCT).$^{74}$

**Oral Health Measures**

Diabetes status based on self-report of diagnosis or glycosylated hemoglobin levels was determined for 5,041 adults 20 years and older who participated in the NHANES 2003-2004. However, only 4,337 subjects (86 percent) had available dental examination data for calculation of decayed, missing, and filled surfaces (DMFS) score. For the secondary analysis of decayed and filled surface percentage (% DFS), data from 3,838 subjects were used, after excluding 499 subjects (12 percent) with total teeth surfaces of 0. For the secondary analysis of the presence of decayed and filled root surfaces (DFS-R), 3,290 adult subjects had available filled and root surface data, since subjects who needed antibiotic premedication, subjects who had cardiac pacemakers, automatic defibrillators or artificial materials in their hearts and veins, and subjects with specific medical conditions, such as congenital heart murmurs, heart valve problems, congenital heart disease, rheumatic fever, kidney disease requiring dialysis, and hemophilia, did not undergo periodontal and root caries assessments. For the secondary analysis of the presence of untreated carious surfaces (DS), 4,337 subjects with DMFS data were available.
Decayed, Missing, and Filled Surfaces (DMFS)

Caries status was measured by decayed, missing, filled surfaces (DMFS) scores. There are four surfaces on each of the 12 anterior teeth, and five surfaces on each of the 17 posterior teeth, including the third molars. However, caries information about the third molars on each subject was not available in the NHANES 2003-2004 dataset, thus the maximum DMFS score per subject will be 128, corresponding to the total number of surfaces for 28 teeth. Furthermore, third molars are usually excluded from the calculation of the DMFS score. “Decayed” teeth surfaces were crown and root surfaces with:

1. gross cavitations;
2. deep pits and fissures that catch the tip of the metal explorer, with softness at the base of the area, and/or opacity adjacent to the area;
3. decalcification or demineralization (white spots) with softness of the area when penetrated or scraped by metal explorer;
4. loss of translucency on proximal surface when an examining light is passed through the teeth; or
5. break in enamel surface is detected with the metal explorer.75

“Missing” teeth were teeth that were lost or missing due to caries. Data that were available from this cycle of NHANES made no distinction between teeth that were extracted due to caries and teeth that were extracted
due to periodontal disease, and for the DMFS measure, we assumed that these teeth were lost due to caries. However, teeth that were lost or were missing for other reasons aside from caries or periodontal disease were categorized separately and will not be used in our calculation.75

“Filled” teeth surfaces were crown surfaces that were restored with permanent or temporary fillings due to dental caries. Distinctions were made between teeth that were restored due to caries and teeth that were restored for other reasons in this cycle of NHANES.75 The total number of decayed, missing, and filled surfaces will be calculated for each subject, and will be the DMFS score.

DMFS score was the primary outcome variable. This was dichotomized at 101, the weighted 90th percentile, to determine high and low prevalence of severe caries.

Decayed and Filled Surfaces Percentage (% DFS)
Since “missing” teeth data in this cycle of NHANES may have been extracted due to either carious or periodontal reasons, the percentage of decayed and filled surfaces were calculated to account for this. The number of decayed and filled surfaces were divided by the number of teeth surfaces present and multiplied by 100, resulting in a DFS percentage.63 The weighted 90th percentile of % DFS was 60, and was the cut-off value used for high and low prevalence of severe caries.
**Decayed and Filled Root Surface (DFS-R)**

In the NHANES 2003-2004 cycle, DMFS and % DFS represented findings on the crown surfaces of teeth. Caries and fillings on at least one root surface of teeth (DFS-R) were recorded simply as present or absent, and were included among the secondary outcomes for analysis.

**Decayed Surfaces (DS)**

Among the Healthy People 2010 objectives for oral health are 15 percent reduction in untreated dental caries and extractions from dental caries among adults. It is therefore a clinically meaningful outcome to look at the number of untreated teeth surfaces per subject, as represented by the decayed surfaces (DS) of teeth. This was dichotomized at 4, the weighted 90th percentile.

**Potential Confounders**

Covariates that were included in the analysis were age, gender, race/ethnicity, poverty status, education, use of dental services, body mass index, dietary sugar intake, presence of dry mouth, presence of gingival recession, medications taken, current health status, and smoking status. Age was dichotomized at 46 years old to facilitate bivariate analyses, since using cut-offs from previously reported surveillance data resulted in cells with 0
counts. However, age was considered a continuous variable in the logistic regression models. Race/ethnicity was based on the subjects’ self-report (Mexican-American, other Hispanic, non-Hispanic white, non-Hispanic black, and other/multi-racial). Poverty status was determined using the poverty income ratio (PIR), which is the ratio of income to the family poverty threshold.\textsuperscript{76,77} PIR values below 1.0 indicate income below the official poverty threshold level, and values 1.0 or greater indicate income above the poverty threshold level. Education level was represented by the highest education level completed by the subjects, categorized as less than high school, high school graduate, and greater than high school. Time since last dental visit was dichotomized as one year or less, or more than one year.\textsuperscript{78}

Body mass index (BMI) was included in the model since obesity is a risk factor for diabetes mellitus. It has been found to be associated with dental caries prevalence in children,\textsuperscript{78} and may also be associated with dental caries prevalence in adults because of behavioral factors such as frequency of consumption of and prolonged exposure to refined carbohydrates. Normal BMI values fall between 18.5 and 24.9. BMI values less than 18.5 were considered underweight. BMI values between 25.0 and 29.9 were considered overweight, and BMI values of 30.0 and higher were considered obese.\textsuperscript{79} Dietary sugar intake was taken from the total intake of sugars derived from the two-day dietary interview component of NHANES 2003-2004. The first day of the dietary interview was conducted in person, and the
second day was conducted over the telephone 3 to 10 days later. Previous cycles of NHANES have conducted one-day dietary interviews, but a minimum of two non-consecutive days of dietary intake data was necessary in order to obtain a more accurate estimates. Dietary intake was obtained from all participants and recorded in milligrams (mg). Two-day dietary sugar intake was dichotomized around the mean for bivariate analyses, but was included in the logistic regression model as a continuous variable.

The actual amount of salivary flow was not obtained in this cycle of NHANES. However, presence of dry mouth was determined from the subjects' self-report, based on their response to the interview question, “Does your mouth feel dry when you eat a meal?” Subjects who answered “Yes” were classified as subjects with dry mouth (xerostomia), and subjects who answered “No” were classified as subjects without dry mouth (no xerostomia).

The generic name of prescription medications that subjects reported taking was available. Prescription medications that were known to cause reduced salivary flow as a side effect were identified using a list of pharmacologic agents known to induce xerostomia or dry mouth and hypofunction of salivary glands. Newer medications that were not on the list were checked against listed side effects or adverse reactions on the medication labels for xerostomia, dry mouth, or salivary dysfunction. The total number of medications that may cause these conditions was determined
for each subject and was included in the model, but was dichotomized as taking or not taking at least one of the medications for bivariate analyses.

Periodontal assessment was performed during the oral health examination on randomly selected upper and lower quadrants of the mouth on all subjects 13 years and older who do not need antibiotic pre-medication prior to dental treatment and reported absence of heart murmurs, heart valve problems, congenital heart disease, or bacterial endocarditis, rheumatic fever, kidney disease needing dialysis, hemophilia, and pacemaker, automatic defibrillators, or artificial material on their heart valves or veins. Distal, mid-facial, and mesial sites of each tooth were assessed using a periodontal probe. The distance from the gingival margin to the cement-enamel junction was measured in millimeters, and a negative value denotes gingival recession potential exposure of the root surface to the caries process. Positive values denote the absence of gingival recession. The total number of teeth with gingival recession was calculated for each subject, and was categorized as having no gingival recession, 1 to 2 teeth with gingival recession, and 3 or more teeth with gingival recession.

Current health status was included in the analysis since there appeared to be a significant association between oral health and general health (p<0.001). Individuals who report poor or fair oral health also report fair or poor general health. Subjects’ self-reported perception of general health was categorized as excellent, very good, good, fair, and poor.
Previous studies have found statistically significant associations between tooth caries and smoking.\textsuperscript{19} Smoking status, as reported by the subjects, was categorized as never smoker, former smoker, and current smoker.

\textit{Statistical Analysis}

Descriptive analyses were performed by calculating the mean DMFS, % DFS, and DS. The proportion of subjects with at least one DFS-R was also calculated. These descriptive statistics were stratified by age, gender, and race for descriptive purposes. Bivariate analyses were performed on data to see if there are crude differences in the prevalence of subjects with DMFS scores, % DFS, and DS score at or above the 90\textsuperscript{th} percentile, or at least one DFS-R between those with and without diabetes mellitus. Bivariate analyses were also performed on potential confounders to determine crude associations with DMFS scores, % DFS, and DS score at or above the 90\textsuperscript{th} percentile, or at least one DFS-R.

A multivariable logistic regression model was constructed with dichotomized DMFS score (DMFS \textgeq 101 vs. DMFS <101) as the main outcome variable, and diabetic status as the main predictor variable. Potential confounders that were included in the model were age, gender, race/ethnicity, socio-economic status, education, use of dental services, body mass index, dietary sugar intake, presence of dry mouth, presence of gingival
recession, medications taken, current health status, and smoking status. A second multivariable logistic regression model was constructed with DFS percentage (% DFS ≥60 vs. % DFS <60) as the main outcome variable, because missing teeth may have been extracted because of caries or periodontal disease. The same potential confounders were included in the model. A third multivariable logistic regression model was constructed with the presence or absence of at least one root surface caries or filling (DFS-R present vs. DFS-R absent) as the outcome, since DMFS and % DFS only accounted for caries and fillings on coronal surfaces of teeth. Lastly, a fourth multi-variable logistic regression model was constructed with untreated dental caries, represented by decayed surfaces (DS ≥4 and DS <4), as the outcome. In all analyses the same potential confounders were included in the model, and those with p-values of <0.05 were considered significant and kept in the model.

Data analysis was performed using Statistical Analysis Software (SAS) 9.1 (SAS Institute, Cary, NC). Since several subgroups were oversampled in NHANES 2003-2004, appropriate weights provided in the NHANES dataset were used to account for this. Sampling cluster variables were used because of the complex multi-stage sampling design of the survey. P-values of less than 0.05 were considered statistically significant. All statistical tests were two-sided.
Results

DMFS

For the primary outcome DMFS, data from 701 subjects with diabetes and 3,636 subjects without diabetes were used. The mean number of DMFS, overall and stratified for descriptive purposes by race, gender, and age, is shown in Table 1. Non-Hispanic white subjects had the highest mean DMFS scores among the other racial/ethnic groups. Females had slightly higher DMFS scores compared to males. Subjects older than 46 years had higher DMFS scores compared to subjects 46 years old and younger.

Results of bivariate analyses for covariates in relation to prevalence of severe caries burden (DMFS $\geq 101$ vs. DMFS $<101$) are shown in Table 2. Age, gender, race/ethnicity, education level, poverty status, time since last dental visit, two-day dietary sugar intake, dry mouth, gingival recession, current health status, and smoking status were all significantly associated with DMFS score.

Crude differences in prevalence of severe caries burden (DMFS $\geq 101$ vs. DMFS $<101$) between subjects with and without diabetes are shown in Table 3. A statistically significant association between prevalence of severe caries burden and diabetes status was found.

Results of the multi-variable logistic regression for prevalence of severe caries burden (DMFS $\geq 101$ vs. DMFS $<101$) are shown in Table 4. After accounting for all the risk factors included in the model, diabetes status
was no longer significantly associated with prevalence of severe caries burden (DMFS ≥101). Age was significantly and positively associated with DMFS. Subjects with 3 or more teeth with gingival recession had 83 percent reduction in risk of severe dental caries (DMFS ≥101) compared to subjects with no gingival recession, and subjects with fair health status had a 74 percent reduction in risk of severe dental caries (DMFS ≥101) compared to subjects with excellent health status. On the other hand, current and former smokers have significantly increased risk of severe dental caries (DMFS ≥101) four-fold.

% DFS

For the secondary analyses of % DFS, data from 528 subjects with diabetes and 3,310 subjects without diabetes were used. The mean % DFS, overall and stratified by race, gender, and age for descriptive purposes, are shown in Table 1. As in mean DMFS score, mean % DFS was also highest among non-Hispanic white subjects, slightly higher among females than males, and higher among subjects 47 years and older.

Bivariate analyses for covariates and prevalence of severe caries burden after removing the missing teeth component from the analysis (% DFS ≥60 vs.% DFS<60), in Table 2, shows that age, race/ethnicity, education
level, poverty status, time since last dental visit, dietary sugar intake, prescription medications, gingival recession, and smoking status were significantly associated with the outcome.

Crude differences in prevalence of severe caries burden after removing the missing teeth component from the analysis (% DFS $\geq 60$ vs.% DFS <60) between subjects with and without diabetes, in Table 3, shows that diabetes status was significantly associated with DFS percentage.

Results of the multi-variable logistic regression for prevalence of severe caries burden (% DFS $\geq 60$ vs.% DFS <60) and covariates included in the model are shown in Table 4. After accounting for all risk factors included in the model, diabetes status was no longer significantly associated with the risk of severe caries (% DFS $\geq 60$). In addition, risk of severe caries (% DFS $\geq 60$) was 25 percent less in males, 67 percent and 77 percent less in Mexican-Americans and non-Hispanic blacks, respectively, compared to non-Hispanic whites, and almost 50 percent less for subjects who reported very good compared to excellent health status.

DFS-R

For the secondary analyses of the presence of at least one DFS-R, data from 411 subjects with diabetes and 2,879 subjects without diabetes were used. Table 1 shows the proportion of subjects with at least one DFS-R, overall and stratified for descriptive purposes by race, gender, and age.
The proportion of subjects with least one DFS-R was highest among non-Hispanic blacks. Males had slightly higher DFS-R compared to females, and adults older than 46 years had higher DFS-R compared to adults 46 years and younger.

Results of bivariate analyses of covariates and prevalence of DFS-R are shown on Table 2. Age, education level, poverty status, time since last dental visit, dietary sugar intake, prescription medications, gingival recession, and smoking status were significantly associated with the outcome.

Table 3 shows the crude differences in the prevalence of at least one DFS-R (DFS-R present vs. DFS-R absent) among subjects with and without diabetes. The prevalence of at least one DFS-R was significantly associated with diabetes status.

Results of the multi-variable logistic regression for the proportion of subjects with at least one DFS-R (DFS-R present vs. DFS-R absent) and the covariates included in the model are shown in Table 4. Diabetes status was no longer associated with the presence of at least one DFS-R, after accounting for all risk factors in the model. Age remained significantly and positively associated with DFS-R. Two-day dietary sugar intake was also significantly associated with this outcome. Other factors which significantly increased the risk of having at least one DFS-R were: being non-Hispanic black compared to non-Hispanic white, completing less than high school compared to beyond high school, being poor compared to not poor, having
fair health compared to excellent, and being a current smoker compared to non-smoker.

**DS**

For the secondary analyses of DS, data from 701 subjects with diabetes and 3,636 subjects without diabetes were used. Table 1 shows the number of DS, overall and stratified for descriptive purposes by race, gender, and age. Mexican-Americans had the highest mean number of DS, while males had slightly higher DS scores compared to females. Subjects 46 years and younger had higher mean DS scores compared to subjects older than 46 years.

Table 2 shows the results of bivariate analyses for covariates in relation to the prevalence of severe untreated caries burden (DS ≥ 4). Age, race, gender, race/ethnicity, education level, poverty status, times since last dental visit, two-day dietary sugar intake, prescription medications, gingival recession, current health status, and smoking status were significantly associated with DS.

Crude differences in prevalence of severe untreated caries burden (DS ≥ 4 vs. DS <4) between subjects with diabetes and subjects without diabetes are shown on Table 3. There was no significant association between untreated caries and diabetes status.
Results of the multi-variable logistic regression for the prevalence of severe untreated caries burden (DS ≥ 4 vs. DS <4) and covariates included in the model are shown in Table 4. After accounting for all the risk factors included in the model, diabetes status was not significantly associated with prevalence of severe untreated caries (DS ≥4). Age was significantly but negatively associated with DS. The following factors increased the risk of severe untreated caries (DS ≥4): being multiracial or of other race/ethnicity compared to non-Hispanic white, being poor compared to not poor, having time since last dental visit of more than one year compared to one year or less, having three or more teeth compared to no teeth with gingival recession, having one to two teeth compared to no teeth with gingival recession, having fair health compared to excellent, and being a current smoker compared to non-smoker.

Discussion

Table 1 shows that the mean DMFS score, % DFS, DS score, and percentage of subjects with at least one DFS-R varied by racial or ethnic group. Non-Hispanic whites had the highest mean DMFS and DFS percentage. Non-Hispanic blacks had the highest proportion of subjects with at least one DFS-R, although not by a considerable margin. Mexican-Americans have the highest mean number of severe DS. These appear somewhat consistent with reported trends in oral health from 1999 to 2004,
which showed that while non-Hispanic whites and non-Hispanic blacks have similar DMFS scores, non-Hispanic whites had the highest DFS scores and non-Hispanic blacks had the highest prevalence of root surface caries or filling. However, findings of the present study were not consistent with reported trends in untreated dental caries. The present study reported highest prevalence of severe untreated caries among Mexican-Americans, while reported trends in oral health from other studies show the highest prevalence of untreated dental caries among non-Hispanic blacks. These seem to suggest that different oral health measures present varying racial pictures. Consequently, treatment needs may not be the same for all racial or ethnic groups. This merits further study, since this may have implications on public health policies.

Bivariate analyses of diabetes status and oral health measures showed that the prevalence of severe caries burden, as measured by DMFS $\geq 101$ and % DFS $\geq 60$, and the presence of at least one DFS-R varied between subjects with and without diabetes. Diabetes status may be useful as a potential indicator of caries risk for these three measures. However, after controlling for age (in years), gender, race/ethnicity, education level, poverty status (represented by poverty income ratio), time since last dental visit, obesity (represented by body mass index), two-day dietary sugar intake (in mg), presence of dry mouth, number of medications known to cause dry mouth or salivary hypofunction, gingival recession, current health status, and
smoking status, the initial significant association of diabetes status with DMFS, % DFS, and DFS-R during crude analyses, was no longer evident. For the most part, findings of this study suggest that, after controlling for other factors that may affect caries risk, adults with diabetes have the same prevalence of severe caries burden (DMFS ≥101, % DFS ≥60), prevalence of severe untreated caries burden (DFS ≥4), and prevalence of at least one root surface caries or filling (DFS-R) as adults without diabetes. This appear to be similar to the findings of Moore et al, who found no statistically significant difference in the prevalence of decayed and filled tooth surfaces between adults with Type 1 diabetes and adults without diabetes. However, the findings of this study with regard to root surface caries and fillings are not consistent with the findings of Hintao et al., which suggested that Type 2 diabetes mellitus is a significant risk factor for root caries. Since we were interested in the overall association between diabetes mellitus and dental caries prevalence in this study, we did not make a distinction between Type 1 and Type 2 diabetes mellitus. We were also unable to determine the total number of root surfaces with caries and fillings for each subject, since only dichotomous data (present/absent) were available in the dataset.

While we did not find a statistically significant association, it is interesting to note that after multivariate adjustment, there were some differences in the direction of point estimates across different measures of oral health status. Subjects with diabetes has 31 percent increased risk of
severe caries (DMFS $\geq 101$), 18 percent increased risk of having at least one root surface caries or filling (DFS-R), and 35 percent increased risk of having severe untreated caries (DS $\geq 4$) compared to subjects without diabetes, but a 35% decreased risk of having severe caries after removing missing teeth from the calculation ($\%$ DFS $\geq 60$). The difference between DMFS and % DFS may have been an effect of including missing teeth in the analysis for DMFS. Missing teeth were excluded in the analysis for DFS percentage, since data from this cycle of NHANES did not differentiate between missing teeth due to dental caries and missing teeth due to periodontal disease. While the DFS-R and DS scores did not include missing teeth, they are affected by the number of teeth present. As teeth are lost, these scores will also decrease. Lin et al. found statistically significant differences in mean DFS and mean DS between adults with Type 2 diabetes and adults without diabetes. However, after expressing the data as percentage of available surfaces in order to account for missing teeth, no statistically significant difference was found between the two groups.$^{63}$

Two-day dietary sugar intake was only associated with the presence of at least one root surface caries or filling. Papas et al., found that, in older adults, frequent consumption sugar was associated with the presence of more root surface caries, and that older adults with more root surface caries also reported to have higher total sugar and sticky sugar intake.$^{86}$ It was surprising that two-day dietary sugar intake was not associated with the
prevalence of severe caries (DMFS ≥101 and % DFS ≥60) and prevalence of severe untreated caries (DS ≥4). However, the relation between sugars and dental caries prevalence is dynamic, and there are other factors that may influence caries risk, such as fluoride exposure, eating patterns, and duration of exposure to sugars, among others, which may interact and affect caries development. We were unable to account for these factors in our study. In addition, dental caries is a chronic disease that may take years to develop.

Age, gingival recession, current health status, and smoking status were found significantly associated with all or most of the oral health measures of interest. Increasing risk of prevalence of severe caries based on DMFS score, % DFS, and at least one DFS-R with increasing age was consistent with reported trends of oral health status from 1999 to 2004. Older adults had higher mean scores for similar measures. Older adults also had decreasing mean number of untreated caries, a reported trend that was consistent with the findings of the present study. In this study, gingival recession decreased the risk for dental caries, as measured by DMFS, but increased the risk for having DS and the risk of having at least one DFS-R. Locker et al., found more mean surfaces with gingival recession among subjects with decayed root surfaces and decayed or filled root surfaces. Locker et al. also showed that gingival recession was a strong predictor for the presence of at least one root surface caries, as well as for the presence of at least one root surface caries or filling. However, we could not explain the
protective effect of gingival recession on caries risk as measured by DMFS, and the opposite effect on DS. Beck et al. found an association between coronal and root surface caries among blacks, and found that people who experience both types of caries had more gingival recession at baseline.\textsuperscript{88}

The oral health measures of interest varied with subjects’ self-reported current health status in this study. While fair health status appeared to confer a protective effect on severe caries prevalence (DMFS \( \geq 101 \)), it increased the risk for the presence of at least one root surface caries or filling (DFS-R), as well as the risk for severe untreated dental caries (DS \( \geq 4 \)). Findings of Richmond et al., showed that among people who reported fair-poor oral health, most of them also reported fair-poor general health.\textsuperscript{85} However, we could not explain why self-reported fair health status decreased the risk for severe dental caries (DMFS \( \geq 101 \)). When \% DFS was used as the oral health measure of interest, however, self-reported good health was significantly associated with decreased risk of severe dental caries. Self-reported health status appears to present different pictures of oral health status, depending on the oral health measure used.

Smoking was significantly increased the risk of severe dental caries (DMFS \( \geq 101 \) and DS \( \geq 4 \)) and the presence of at least one root surface caries or filling (DFS-R). Smoking also increased the risk of severe dental caries (\% DFS \( \geq 60 \)), but this was not found to be statistically significant. Smoking status as a risk factor for increased risk of severe dental caries is consistent
with the findings of Aguilar-Zinser et al., who showed that higher exposure to tobacco (pack-years) was significantly associated with high DMFT (decayed, missing, and filled teeth) score.\textsuperscript{89}

These findings suggest that factors that increased the risk for any of the outcomes may be used as predictors of sub-optimal dental health in clinical practice.

\textbf{Limitations and Strengths}

The increasing prevalence of diabetes in the U. S. and worldwide and its implications on oral health have led to the investigation of the potential association between diabetes mellitus and dental caries prevalence. Most studies which looked at this association were cross-sectional studies which had small sample sizes, and no conclusive results were found. One study by Moore et al., in 2001, looked at a larger cohort of diabetic subjects and compared their crown and root DFS scores to a control group and to published values from NHANES III Phase 1 survey.\textsuperscript{67} Moore et al. used caries prevalence data from the NHANES III Phase 1 survey for comparison, without regard to the subjects’ of diabetes status.\textsuperscript{67} To date, the association between diabetes mellitus and dental caries in a nationwide study using representative subjects of subjects with and without diabetes has not yet been explored. The National Health and Nutrition Examination Survey 2003-2004 dataset have provided plenty of information for that purpose. The oral
examination and interview component of the NHANES 2003-2004 is one of the most comprehensive assessments of oral health in the United States, and it provided data from a nationally representative sample of the U. S. population. This ensured that the findings of this study are generalizable. However, because a secondary dataset was used, the study of potential factors that may be associated to diabetes mellitus and dental caries prevalence was limited to what was collected for the primary purpose of NHANES. Oral microbial counts, quantity and flow rate of saliva, fluoride exposure, oral hygiene data, and total number of root surfaces with caries and fillings, for example, which may be useful in this study, were not available. Similarly, limited data were available for fasting blood glucose in adults and children since this was obtained only from a subsample of the subjects. Most importantly, since NHANES data are cross-sectional in nature, it was not possible to determine caries incidence after the diagnosis of diabetes mellitus among diabetic patients.

Our findings did not provide evidence to suggest an association between diabetes status and prevalence of severe dental caries, which is an indicator of sub-optimal dental health. While we attempted to include risk factors that were associated to diabetes mellitus and/or dental caries in our analyses, we did not include glycosylated hemoglobin (HbA1c) levels in the model, since we used this to define subjects with and without diabetes. Therefore, we were not able to address the possible association of glycemic
control and prevalence of severe dental caries. We recommend that future studies explore this possibility.

**Conclusion**

Findings of our study suggest that prevalence of severe caries, prevalence of severe untreated caries, and prevalence of at least one root surface with caries or filling did not differ between adults with and without diabetes. However, we identified several factors that may be used as predictors of sub-optimal dental health.
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Tables

Table 1. DMFS, % DFS, and DS, and percent of DFS-R by race, by gender, and by age

Table 2. Bivariate analyses of covariates and prevalence of severe caries (DMFS ≥ 101 and DFS percentage ≥60), prevalence of at least one root surface caries or filling (DFS-R present), and prevalence of severe untreated caries (DS ≥4)

Table 3. Bivariate analyses of diabetes status and prevalence of severe caries (DMFS ≥ 101 and DFS percentage ≥60), prevalence of at least one root surface caries or filling (DFS-R present), and prevalence of severe untreated caries (DS ≥4)

Table 4. Multi-variable logistic regression models for prevalence of severe caries (DMFS ≥ 101 and DFS percentage ≥60), prevalence of at least one root surface caries or filling (DFS-R present), and prevalence of severe untreated caries (DS ≥4)