Impact of Treating Oral Disease on Preventing Vascular Diseases: A Model-Based Cost-effectiveness Analysis of Periodontal Treatment Among Patients With Type 2 Diabetes

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OBJECTIVE

Previous randomized trials found that treating periodontitis improved glycemic control in patients with type 2 diabetes (T2D), thus lowering the risks of developing T2D-related microvascular diseases and cardiovascular disease (CVD). Some payers in the U.S. have started covering nonsurgical periodontal treatment for those with chronic conditions, such as diabetes. We sought to identify the cost-effectiveness of expanding periodontal treatment coverage among patients with T2D.

RESEARCH DESIGN AND METHODS

A cost-effectiveness analysis was conducted to estimate lifetime costs and health gains using a stochastic microsimulation model of oral health conditions, T2D, T2D-related microvascular diseases, and CVD of the U.S. population. Model parameters were obtained from the nationally representative National Health and Nutrition Examination Survey (NHANES) (2009–2014) and randomized trials of periodontal treatment among patients with T2D.

RESULTS

Expanding periodontal treatment coverage among patients with T2D and periodontitis would be expected to avert tooth loss by 34.1% (95% CI −39.9, −26.5) and microvascular diseases by 20.5% (95% CI −31.2, −9.1), 17.7% (95% CI −32.7, −4.7), and 18.4% (95% CI −34.5, −3.5) for nephropathy, neuropathy, and retinopathy, respectively. Providing periodontal treatment to the target population would be cost saving from a health care perspective at a total net savings of $5,904 (95% CI −6,039, −5,769) with an estimated gain of 0.6 quality-adjusted life years per capita (95% CI 0.5, 0.6).

CONCLUSIONS

Providing nonsurgical periodontal treatment to patients with T2D and periodontitis would be expected to significantly reduce tooth loss and T2D-related microvascular diseases via improved glycemic control. Encouraging patients with T2D and poor oral health conditions to receive periodontal treatment would improve health outcomes and still be cost saving or cost-effective.

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More than 30 million Americans, 9.4% of the U.S. population, are now living with type 2 diabetes (T2D) (1). T2D is associated with microvascular complications, a leading cause of blindness, renal failure, and nerve damage, and significantly contributes to the increasing incidence of myocardial infarction (MI) and stroke (2). Periodontitis, which is a common chronic inflammatory disease that affects the gum tissue and bone supporting the tissue, is highly prevalent in the U.S. (47.2% of U.S. adults 30 years old and older have periodontitis, with severe periodontitis affecting 8.5% of adults) (3). Periodontitis has multiple negative impacts on quality of life, and several studies have confirmed that T2D is a major risk factor for periodontitis (4). The risk of periodontitis is increased by approximately threefold in individuals with diabetes compared with individuals without diabetes (5).

Randomized controlled trials have found that treatment of chronic periodontitis improves glycemic control in patients with T2D by reducing hemoglobin A_{1c} (HbA_{1c}) and, furthermore, reduces the risks of cardiovascular disease (CVD) (6–9). Despite growing awareness of periodontal treatment benefits for T2D and other chronic diseases, only a small percentage of the population with diabetes seeks periodontal care due to the cost of nonsurgical periodontal treatment and the artificial division between dentistry and medicine that hinders comprehensive care for these patients (10). With a growing body of evidence on links between periodontitis and other chronic conditions, a number of insurance companies started offering 100% coverage for nonsurgical periodontal treatment (periodontal scaling and root planning) to those with chronic conditions, such as diabetes, CVD, rheumatoid arthritis, and HIV/AIDS (11,12).

Findings from prior retrospective studies using insurance claims data found that periodontal treatment among patients with T2D was associated with lower medical costs and hospitalization in patients with chronic conditions, such as T2D, CVD, and coronary artery diseases, compared with untreated control subjects (13,14). However, these empirical studies of claims data do not provide itemized sources of cost reduction in total medical cost and are vulnerable to shared risk factors, such as smoking, that could confound the relationship between periodontal treatment and health care spending. A prior cost-effectiveness analysis study in the U.K. suggests that periodontal treatment may be cost-effective based on cohort-based simulation modeling results (15). This prior work took into consideration the average quality-adjusted life years (QALYs) gained associated with absolute decrease in HbA_{1c} (%) and not the differential QALYs of specific diseases without individual risk factors incorporated in the model. Therefore, several questions remain unanswered: Do the cost savings from averted downstream medical costs outweigh the up-front costs of periodontal treatment? Do differences in patient characteristics among patients with T2D alter the long-term effectiveness of the periodontal treatment in terms of reducing chronic disease risks of the U.S. population? How does variation in periodontal treatment coverage rates impact the cost-effectiveness in light of the complex interrelationship between T2D, microvascular diseases, and CVD? Here, we sought to answer these questions by evaluating the effectiveness and cost-effectiveness of covering periodontal treatment among patients with T2D in the U.S., using a mathematical model-based analysis.

RESEARCH DESIGN AND METHODS

We constructed a computer-based simulation model of periodontitis based on data from several recent studies of periodontal treatment and eight associated health outcomes (2,7,8,16,17): T2D, periodontitis, microvascular complications of T2D (retinopathy, neuropathy, nephropathy), CVD (MI and stroke), and tooth loss. Our model incorporated detailed health risk factors for a representative U.S. population (Fig. 1). We used a microsimulation modeling approach, as detailed in Supplementary Text 1, which simulates individuals rather than an aggregate population average (i.e., a Markov cohort model), because microsimulation allows us to account for complex covariations in key traits (e.g., correlations between demographic characteristics and chronic disease risks) that may critically impact the cost-effectiveness of expanding enhanced dental benefit programs among patients with T2D nationwide.

Data Sources and Disease Risk

Table 1 summarizes the key model parameters and data sources, further detailed in the Supplementary Data. Baseline population characteristics and oral health data were obtained from the National Health and Nutrition Examination Survey (NHANES) (2009–2014; N = 26,056). Disease incidences for microvascular diseases and CVD were estimated based on previously validated risk equations incorporating individual risk factors as well as age and time trends within each demographic group (18–22) (Supplementary Texts 2–4 and Supplementary Tables 1–14). T2D incidence data were obtained from the Centers for Disease Control and Prevention (CDC) and National Heart, Lung, and Blood Institute (NHLBI), based on independent cohort studies (1,23). Periodontal disease (moderate or severe periodontitis: moderate periodontitis, when patients presented two or more interproximal sites with clinical attachment level $\geq$4 mm and probing pocket depths $\geq$5 mm; severe periodontitis, when patients had two or more interproximal sites with clinical attachment level $\geq$6 mm [not on the same tooth] or one or more interproximal sites with probing pocket depths $\geq$5 mm, regardless of distribution and extent per patient [localized or generalized periodontitis]) incidence rates were estimated by calibrating them to match the overall periodontitis (moderate and severe) prevalence rates by age from NHANES (24,25) (Supplementary Table 15 and Supplementary Fig. 1). Other model parameters, including mortality associated with disease outcomes (CVD, T2D, microvascular diseases) and other causes and periodontal treatment effectiveness, were obtained from published literatures (22,26–28) (Table 1). Deaths attributable to these disease outcomes (CVD, T2D, microvascular diseases) and other causes were taken into account as a function of age and sex (Supplementary Text 3 and Supplementary Table 16).

Model Validation Procedures

Following the guidelines for good modeling practice, we performed model calibration, face validation, internal validation, and external validation exercises to demonstrate the ability of our simulation model to predict outcomes as intended (29,30). We calibrated the

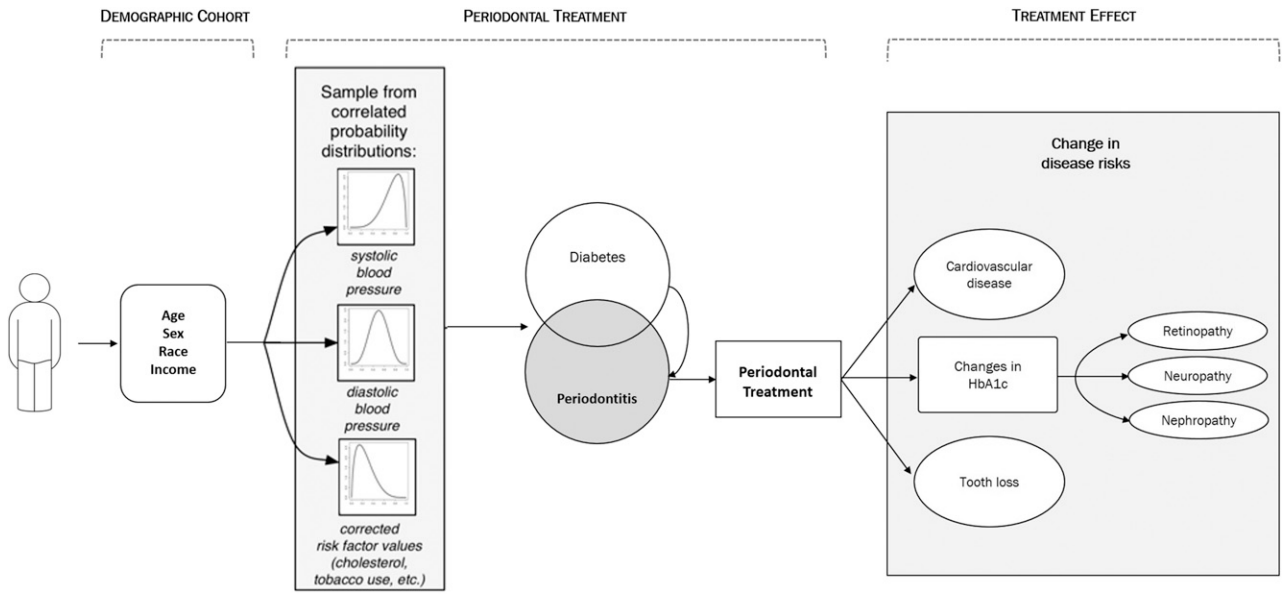

Figure 1—Model schematic.

model against MI and stroke incidence rates from the Atherosclerosis Risk in Communities study and the Greater Cincinnati/Northern Kentucky Stroke Study (Supplementary Figs. 2 and 3); specifically, we adjusted intercept and coefficient terms in the underlying MI and stroke risk functions in the simulation model such that modeled outcomes fell within plausible ranges from the observed data sources (31,32). We assessed face validity of the model by tracking how HbA_{1c} levels change over a 10-year period by initial HbA_{1c} levels (Supplementary Fig. 4) to check whether these changes followed expected trajectories in terms of rank orderings and magnitudes of change. Also, individual characteristics were updated annually to ensure that they were changing as expected based on age and time trends available from NHANES (Supplementary Tables 1–14). For interval validation, model-projected T2D incidence rates were compared with CDC estimates (1) (Supplementary Table 17), and due to lack of independent data on the population incidence or prevalence of periodontal diseases, the model-projected prevalence was compared with moderate and severe periodontitis prevalence estimates from NHANES (24,25) (Supplementary Table 15 and Supplementary Fig. 4). For cross-validation, we compared our simulation model outputs for microvascular diseases against previously published modeled estimates from the UK Prospective Diabetes Study (UKPDS) OM2 models (33). Cumulative disease incidence (T2D, microvascular and macrovascular diseases) and mortality (all-cause and CVD specific) were externally validated against independent observed data from clinical trials and cohort studies (Supplementary Table 18). We considered good model fit to be $<5\%$ absolute error between our model and the independent data for each demographic cohort.

Simulated Population

Currently, only 27% of patients with periodontitis are receiving periodontal treatment in the U.S. (24). The intervention that we evaluated in our base case scenario expands this periodontal treatment coverage rate among the population with diabetes to 88%, which is the observed health care utilization rate among the population with diabetes in the U.S. (24). A nationally representative sample of 10,000 Americans aged 30–85 years old was simulated to estimate the impact of expanding the periodontal treatment among T2D patients, including those who have been diagnosed and those who will develop T2D over the course of life. While our base case modeling approach implies that any patients with T2D visiting health care professionals would be encouraged to receive periodontal treatment with perfect adherence, we modeled ranges of treatment expansion upper bounds (40%–100%) and adherence rates (50%–100%) in sensitivity analyses to assess the impact of these assumptions on cost-effectiveness results.

Following current cost-effectiveness analysis guidelines (34), we simulated a nationally representative sample of 10,000 Americans aged 30–85 years old and estimated the impact of expanding periodontal treatment coverage rates on costs and QALYs over their remaining life courses. The simulated individuals were stratified by age (30–49, 50–64, and 65+ years old), sex, race/ethnicity (NHANES categories of non-Hispanic white, non-Hispanic black, Mexican American, or other), and income ($\leq$130% of the federal poverty level (FPL), 130–300%, or $>$300%, adjusted for household size).

Health-related risk factors for seven diseases of interest (periodontitis, T2D, retinopathy, nephropathy, neuropathy, MI, and stroke) were assigned to each simulated individual to match the distribution of risk factors among each demographic group according to NHANES (Supplementary Tables 1–14): history of prior MI and stroke, systolic blood pressure, medication use, smoking status, diabetes status, total and HDL cholesterol, HbA_{1c}, serum creatinine, and urine albumin-to-creatinine ratio. Risk factors were updated annually for each simulated individual to reflect age and time trends accounting for correlation among risk factors (Supplementary Text 1). Survey sample weights were used to correct

for differential sampling and nonresponse in NHANES (24).

Periodontal Treatment Effectiveness

A number of trials found that periodontal treatment among patients with T2D would reduce risk of microvascular and macrovascular diseases. While both microvascular and macrovascular diseases were included in our model, due to more robust evidence around the link between HbA_{1c} levels and microvascular diseases, only microvascular disease risk was mediated through changes in HbA_{1c} level from periodontal treatment. For microvascular diseases, periodontal treatment was found to reduce HbA_{1c} level by 0.29% (95% CI −0.48, −0.10) at 3–4 months according to a robust Cochrane review and meta-analysis of 35 randomized trials (35). Changes in HbA_{1c} would then affect the incidence of T2D-related microvascular complications according to the validated equations (18,19). A 1% reduction in HbA_{1c} level decreased the risk of retinopathy, nephropathy, and neuropathy by 15.6%, 14.7%, and 20.8%, respectively. For macrovascular diseases, we used published risk reduction estimates for the reduction in CVD events (MI and stroke) associated with periodontal treatment among patients with T2D (28); periodontal treatment may reduce the rates of MI (hazard ratio [HR] 0.92; 95% CI 0.85, 0.99) and stroke (HR 0.95; 95% CI 0.85, 1.06) (8). If periodontitis was left untreated, the rate of tooth loss was 0.32 teeth/patient/year (36). Relative risk estimates of T2D on CVD and periodontal disease incidences were also incorporated (28,37) (Supplementary Table 16).

Costs and Utilities

Following current cost-effectiveness guidelines (38), we integrated costs and QALY estimates over the life course for all simulated individuals. Annual disease-specific health care costs were taken from the U.S. Medical Expenditure Panel Survey (39) (Supplementary Table 19), and periodontal treatment costs were obtained from the American Dental Association survey of dental fees (40). For periodontal treatment costs, we assumed that patients undergoing nonsurgical periodontal therapy would visit a dental clinic annually for periodontal maintenance for the rest of their lives. Net costs were calculated by summing overall disease and periodontal treatment costs with expanding periodontal treatment minus total costs under status quo treatment. The disutility of disease states to calculate QALYs was based on large-scale survey data (41) (Supplementary Table 19). All costs were expressed in 2019 U.S. dollars using the Consumer Price Index (42), and costs and QALYs were discounted at a 3% annual discount rate.

Sensitivity and Uncertainty Analyses

First, we varied the coverage rates of periodontal treatment among the population with diabetes with periodontitis. In the base case, we used the NHANES estimate in which 27% of periodontitis in the U.S. is being treated, and among patients with T2D, we increased the treatment coverage rate to 88%, the estimate of the population with diabetes receiving medical care from physicians in a given year according to NHANES (24). We varied the expanded periodontal treatment coverages rates among patients with T2D from 40% to 100%.

In the base case, we used annual cost of periodontal scaling and root planning to be $368, combined with periodontal maintenance for the 1st year, and $580 annually ($145 per periodontal maintenance received every 3 months) for the subsequent years, assuming that patients continue to receive maintenance after the treatment (40) (Supplementary Table 19). We varied the 1st-year one-time periodontal treatment cost estimates from $400 to $5,000 (approximately the sum of costs of providing full-mouth scaling and root planning with maintenance plus active periodontal therapy, which typically consists of a locally administered antimicrobial agent delivered into the gum pockets, costs ~$75 per tooth, with the upper limit representing a potential need for surgery for advanced periodontitis) (17,40). Full-mouth scaling

Table 1—Model parameters and sources

Parameters	Source (reference numbers)
Population size of demographic cohorts	NHANES 2009–2014
Treatment effectiveness	
Periodontal treatment benefit for HbA_{1c} reduction	(7,8,16,35)
Disease risk	
Risk of T2D (Supplementary Table 17)	CDC (1)
Risk of periodontal diseases (Supplementary Table 15)	Calibrated to NHANES
Risk of CVD by demographic group (Supplementary Text 2)	Model-based estimates (21,22)
Risk of microvascular diseases (Supplementary Text 4)	Validated risk equations (RECODe) (19)
MI or stroke mortality rate (Supplementary Text 3)	Model-based estimates (21,22)
HRs of diseases on all-cause mortality (Supplementary Table 16)	(26–28)
All-cause mortality rate	CDC (54)
Cost and utilities	
Cost of periodontal scaling and root planning (Supplementary Table 19)	ADA (40)
QALYs for disease states (Supplementary Table 19)	GBD (41)
Cost for disease states (Supplementary Table 19)	MEPS (39)
Baseline characteristics	
Baseline disease: T2D, periodontitis, CVD (Supplementary Tables 1–4)	NHANES 2009–2014
Baseline health risk factors (Supplementary Tables 5–14)*	NHANES 2009–2014

ADA, American Dental Association; GBD, Global Burden of Diseases; MEPS, Medical Expenditure Panel Survey. *Risk factors include smoking, HbA_{1c}, systolic blood pressure, cholesterol levels (total and HDL), serum creatinine, urine albumin-to-creatinine ratio, and drug use (hypertension, statin, anticoagulant).

and root planning would normally cost ~$1,000. We also varied the periodontal maintenance cost for the subsequent years from $150 to $250 per maintenance ($600–$1,000 annually).

Third, in the base case, we assumed that all patients with T2D and periodontitis would adhere to routine periodontal maintenance treatment every 3 months and that HbA_{1c} reduction would be sustained once they initiated the treatment. In this sensitivity analysis, we varied adherence rates from 50% to 90%. For those who did not adhere to the treatment, HbA_{1c} levels were assumed to be reinstated.

Fourth, recent randomized trials of periodontal treatment among patients with prediabetes and those with T2D followed for 12–27.5 months observed HbA_{1c} reductions of 0.6% maintained at the 12-month time point among high-risk T2D patients and 0.3% among patients with prediabetes ($5.7\% < HbA_{1c} < 6.5\%$) (7,16). In this sensitivity analysis, patients with poor metabolic control ($HbA_{1c} \geq 7.0\%$) experienced HbA_{1c} reduction of 0.6% from periodontal therapy (43).

Next, while it was suggested that the inflammatory nature of periodontitis negatively affects atherogenesis, the biological mechanism for the relationship between periodontal treatment and CVD is not well established (44). In this sensitivity analysis, we excluded MI and stroke from the model to assess the impact of expanding treatment coverage on health outcomes and costs without incorporating the periodontal treatment benefits on CVD. In addition, while glucose lowering remains important to prevent microvascular complications in adults with T2D, its impact was found to be significantly associated with only retinopathy and nephropathy, according to a recent meta-analysis of four trials (Action to Control Cardiovascular Risk in Diabetes [ACCORD], Action in Diabetes and Vascular Disease: Preterax and Diamicron MR Controlled Evaluation [ADVANCE], UKPDS, and Veterans Affairs Diabetes Trial [VADT]) (45). In the sensitivity analysis, we used the HRs from this meta-analysis (without significant impact on neuropathy) to evaluate how this change in model parameters alters our study results; for 0.90% reduction in HbA_{1c}, the relative risk was reduced by 20% for nephropathy and 13% for retinopathy, but the reduction was not statistically significant for neuropathy.

Lastly, we performed a probabilistic sensitivity analysis by sampling from the probability distributions of all input parameters (Supplementary Table 20). In each scenario, the model was rerun 10,000 times while repeatedly Monte Carlo sampling from the probability distributions of all input parameters to capture uncertainties in our estimates, generating 95% credible intervals around all outcomes as per cost-effectiveness modeling guidelines (46). Supplementary Data detail all input data, equations, and complete technical details. All analyses were performed in R (version 3.2.1; The R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Model Calibration and Validation

If there were no changes to current health risk factor profiles, our model estimated that the cohort currently aged 30–85 years old in the U.S. would be expected to experience average annual incidence rates of ~94.9 T2D cases (95% CI 93.5, 96.3), 40.0 new MIs (95% CI 39.8, 40.2), and 34.3 strokes (95% CI 34.0, 34.5) per 10,000 persons. Consistent with the model-based results, independent National Center for Health Statistics and NLHBI data estimated a current annual incidence of 101.5 new T2D cases per 10,000 persons (95% CI 8.0, 12.2) aged 45 years or older and 40.0 new MIs and 34.5 new strokes per 10,000 persons aged 35–74 years old (1,23,47). Additional validation results are given in Supplementary Figs. 1–4 and Supplementary Table 18, which also show that model-predicted values matched outcomes from the observed data on incidence and prevalence within <5% absolute error by age-group.

Base Case Results

When 88% of the patients with T2D and periodontitis receive periodontal treatment, tooth loss was expected to decline substantially compared with relatively smaller declines in CVD, followed by microvascular diseases given the relatively small impact of the periodontal treatment on the overall risk (Fig. 2). Expanded coverage in the target population (individuals with T2D and periodontitis) was expected to avert possible tooth loss by 34.1% (95% CI −39.9, −26.5) and reduce CVD incidence by 7.3% (95% CI −20.3, −0.3) and 5.0% (95% CI −20.8, 3.9) for MI and stroke, respectively. Nephropathy, neuropathy, and retinopathy incidence would be expected to decline by 20.5% (95% CI −31.2, −9.1), 17.7% (95% CI −32.7, −4.7), and 18.4% (95% CI −34.5, −3.5), respectively.

In the model, expanded periodontal treatment coverage produced an estimated gain of 0.6 discounted QALYs per capita (95% CI 0.5, 0.6) among the target population over the life course. From a health care perspective, expanding treatment coverage was cost-saving at a net savings of $5,904 per capita (95% CI −6,039, −5,769) and had an incremental cost-effectiveness ratio (ICER) of $10,542 saved per QALY gained; in other words, expanding treatment was dominated (cost saving and health improving) in the base case analysis (Table 2). These QALY gains and cost savings would be expected to translate into an estimated gain of 0.2 QALYs (95% CI 0.2, 0.3) and a net savings of $2,466 per capita (95% CI −2,634, −2,297) among the overall U.S. population (Supplementary Table 21). Patients with poor metabolic control (higher HbA_{1c} levels) at the beginning of simulation experienced more QALY gains compared with those with lower HbA_{1c} levels via greater HbA_{1c} reduction (Table 2 and Supplementary Fig. 4). Patients with initial HbA_{1c} of >8% experienced 0.9 QALY gains per capita (95% CI 0.7, 1.0), and patients with initial HbA_{1c} of <7% experienced QALY gains of 0.3 per capita (95% CI 0.2, 0.4).

The largest expected cost savings for future disease states were from reduced health care costs incurred from averted tooth loss, followed by averted microvascular diseases (T2D complications). The dollars saved from averting tooth loss among the target population amounted to $6,476 (95% CI −7,002, −6,352) per person over a simulated life course (Supplementary Table 22). The cost saved from averting microvascular diseases from untreated periodontitis was $1,933 (95% CI −2,220, −1,689).

While individuals in most demographic cohorts would be expected to benefit from expanded coverage, the projected benefits varied by demographic group (Supplementary Fig. 5). The largest relative benefits in QALY gains and health care cost reduction were experienced among the

low-income non-Hispanic black population, followed by Mexican Americans, due to their high baseline risk of periodontitis, diabetes, and CVD, which produced the largest absolute disease reductions and associated health care cost reduction for this group. From an overall population perspective, the most benefited group was the non-Hispanic black male population with low income with QALY gains of 0.6 (95% CI 0.5, 0.7). The oldest age-group (65 years or older) received the most benefit in QALYs experienced across the ethnicity groups (Supplementary Fig. 6).

Sensitivity Analyses

First, we varied the treatment coverage from 40% to 100%, and the QALY gains were only statistically significant when treatment coverage rate was 40%. When treatment coverage rates were varied from 40% to 100% among the population with diabetes with periodontitis, the total net savings ranged from $575 (95% CI −653, −497) to $10,979 (95% CI −11,057, −10,900), and associated QALY gains were from 0.0 per capita (95% CI 0.0, 0.2) to 0.8 per capita (95% CI 0.7, 0.8), respectively (Table 2).

Even when the target population adhered to the routine periodontal maintenance from 50% to 90%, the patients were expected to experience significant increase in QALY gains; QALY gains per capita varied from 0.1 (95% CI 0.1, 0.2) to 0.5 (95% CI 0.4, 0.5) with the total net savings ranging from $699 (95% CI −777, −620) to $3,965 (95% CI −4,043, −3,886).

When the cost for subsequent periodontal maintenance after the main periodontal treatment remained <$150 per maintenance, expanding treatment coverage was cost saving as long as first-time annual periodontal treatment costs remained <$4,150 (Table 2). At a first-time periodontal treatment cost of $5,000, expanding treatment coverage was still cost-effective, with an ICER of $2,621 per QALY gained. Even at the highest cost estimates evaluated for both the first-time treatment and maintenance ($5,000 and $250 per maintenance, respectively), expanding treatment was cost-effective, with an ICER of $4,416 per QALY gained among the target population, which translate into $7,713 per QALY gained among the overall U.S. population. If full-mouth scaling and root scaling (~$1,000 for the first-time cost) is performed for all patients (compared with annual treatment costs <$375 in the base case analysis), expanding treatment coverage was cost saving, with the total cost net savings $4,889 (95% CI −4,970, −4,825) among the target population and $1,971 (95% CI −2,006, −1,888) per capita among the overall U.S. population (Supplementary Table 21).

When periodontal treatment benefits for CVD were excluded, expanding periodontal treatment coverage produced an estimated gain of 0.5 QALYs per capita (95% CI 0.4, 0.5) among the target population over the life course with a net savings of $5,731 per capita (95% CI −5,813, −5,648) (Table 2). Moreover, incorporating results from a recent meta-analysis, when the impact of HbA_{1c} on microvascular diseases was only on retinopathy and nephropathy, with periodontal treatment benefits for CVD still excluded, the estimated QALY gains were 0.4 (95% CI 0.3, 0.4). With differential HbA_{1c} reduction levels (reduction of 0.6% from periodontal treatment) among patients with poor metabolic control (HbA_{1c} >7%), patients experience 0.01 higher QALY gains over the life course. In a probabilistic sensitivity analysis, expanding treatment coverage was the preferred strategy in >50% of iterations at all willingness-to-pay (WTP) thresholds (Supplementary Fig. 7). The probability that expanding periodontal treatment coverage is most cost-effective ranged from 63% to 84% within the WTP ranges between 0 and $150,000 per QALY.

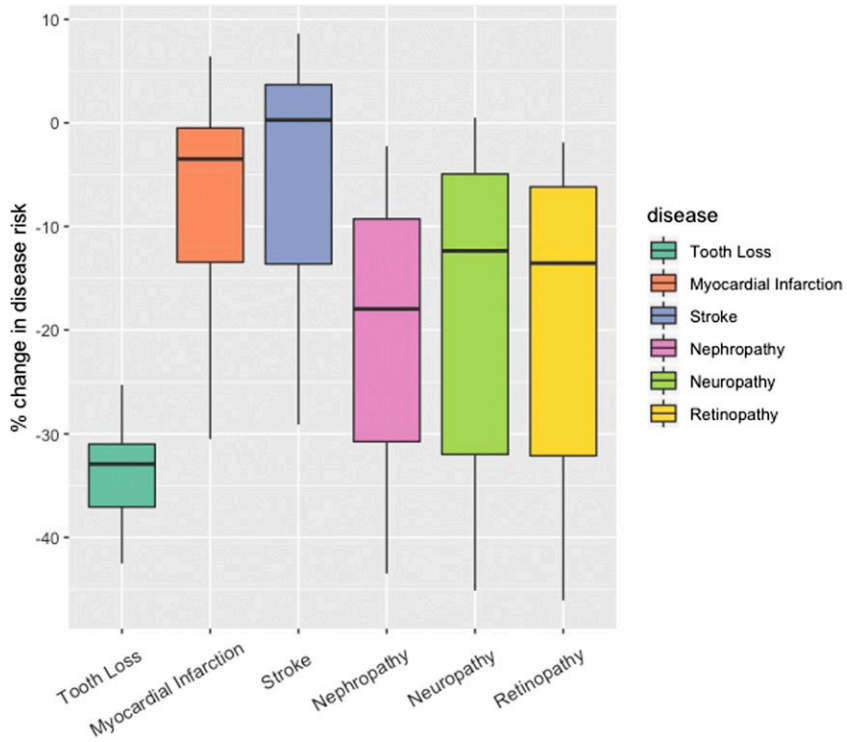

Figure 2—Percentage change in systemic disease risk among patients with T2D and periodontitis.

CONCLUSIONS

Expanding nonsurgical periodontal treatment among patients with T2D and periodontitis would likely have meaningful public health benefits based on our simulation results. Substantial reductions in morbidity would most likely be observed, largely from long-term reductions in tooth loss and microvascular diseases (T2D complications), with less significant impact on CVD that are consistent with findings from prior empirical studies (6–9). We found that none of the sensitivity analyses substantially changed our fundamental finding of cost savings from expanding the treatment coverage when at least 50% of the patients adhere to the routine periodontal maintenance treatment and the periodontal treatment cost remained <$4,150. Prior trials typically focused on short-term outcomes such as HbA_{1c} level and, hence,

Table 2—Cost-effectiveness results among patients with T2D and periodontitis, per capita

Scenario	Total QALYs†	Total cost (USD)†	Incremental QALYs gained†	Incremental cost (USD)†
Base case				
Overall*				
Status quo	39.32 (0.04)	51,712 (79)		
Expanded coverage	39.89 (0.04)	45,808 (74)	0.57 (0.02)	−5,904 (40)
Initial HbA_{1c} <7%				
Status quo	31.59 (0.04)	113,745 (118)		
Expanded coverage	31.93 (0.04)	101,749 (123)	0.34 (0.02)	−11,997 (172)
Initial HbA_{1c} 7–8%				
Status quo	28.10 (0.04)	117,490 (551)		
Expanded coverage	27.60 (0.04)	103,430 (611)	0.50 (0.02)	−14,060 (221)
Initial HbA_{1c} ≥8%				
Status quo	23.04 (0.05)	105,479 (387)		
Expanded coverage	22.19 (0.05)	85,840 (461)	0.85 (0.03)	−19,638 (364)
Sensitivity analyses				
Treatment coverage rate (%)				
40	39.40 (0.04)	51,137 (70)	0.08 (0.02)	−575 (40)
60	39.57 (0.04)	50,093 (68)	0.25 (0.02)	−1,619 (40)
80	39.77 (0.04)	47,662 (69)	0.45 (0.02)	−4,050 (40)
100	40.11 (0.04)	40,733 (70)	0.79 (0.02)	−10,979 (40)
Adherence rate (%)				
50	39.41 (0.04)	51,013 (69)	0.09 (0.02)	−699 (40)
70	39.58 (0.04)	49,995 (69)	0.26 (0.02)	−1,717 (39)
90	39.77 (0.04)	47,747 (69)	0.45 (0.02)	−3,965 (40)
Treatment cost (USD)‡				
500 + 150/maintenance	39.89 (0.04)	46,602 (74)	0.57 (0.02)	−5,687 (40)
1,000 + 150/maintenance	39.89 (0.04)	47,771 (75)	0.57 (0.02)	−4,889 (40)
2,000 + 150/maintenance	39.89 (0.04)	50,110 (74)	0.57 (0.02)	−3,293 (40)
3,000 + 150/maintenance	39.89 (0.04)	52,449 (72)	0.57 (0.02)	−1,697 (40)
4,000 + 150/maintenance	39.89 (0.04)	54,788 (75)	0.57 (0.02)	−101 (40)
5,000 + 150/maintenance	39.89 (0.04)	57,127 (75)	0.57 (0.02)	1,494 (40)
500 + 200/maintenance	39.89 (0.04)	47,899 (75)	0.57 (0.02)	−5,175 (39)
1,000 + 200/maintenance	39.89 (0.04)	49,069 (78)	0.57 (0.02)	−4,377 (40)
2,000 + 200/maintenance	39.89 (0.04)	51,408 (74)	0.57 (0.02)	−2,751 (40)
3,000 + 200/maintenance	39.89 (0.04)	53,746 (75)	0.57 (0.02)	−1,185 (38)
4,000 + 200/maintenance	39.89 (0.04)	56,085 (75)	0.57 (0.02)	410 (40)
5,000 + 200/maintenance	39.89 (0.04)	59,370 (75)	0.57 (0.02)	2,328 (40)
500 + 250/maintenance	39.89 (0.04)	49,196 (79)	0.57 (0.02)	−4,663 (40)
1,000 + 250/maintenance	39.89 (0.04)	50,366 (75)	0.57 (0.02)	−3,865 (40)
2,000 + 250/maintenance	39.89 (0.04)	52,705 (78)	0.57 (0.02)	−2,269 (37)
3,000 + 250/maintenance	39.89 (0.04)	55,044 (75)	0.57 (0.02)	−673 (38)
4,000 + 250/maintenance	39.89 (0.04)	57,383 (74)	0.57 (0.02)	921 (40)
5,000 + 250/maintenance	39.89 (0.04)	59,722 (75)	0.57 (0.02)	2,517 (40)
Treatment benefits‡				
HbA_{1c} reduction (0.6%) among those with poorly controlled diabetes	39.90 (0.04)	45,713 (75)	0.58 (0.02)	−5,999 (45)
Without benefits for CVD	39.85 (0.04)	45,981 (69)	0.53 (0.02)	−5,731 (42)
Without benefits for neuropathy§	39.76 (0.04)	46,009 (72)	0.52 (0.02)	−5,463 (42)
Without benefits for CVD or neuropathy§	39.71 (0.04)	46,361 (74)	0.39 (0.02)	−5,374 (45)

Data are mean (SE). USD, U.S. dollars. *Results include individuals who were not diagnosed with T2D at the beginning of the simulation. †Per-person results over their lifetime, discounted using a 3% annual rate. ‡Total cost (and total QALYs with assumption of no effects of treatment on CVD outcomes) in the status quo scenario is different from the total cost (and total QALYs when CVD is excluded) in the base case status quo scenario due to varying treatment costs. §HRs associated with HbA_{1c} reduction for three microvascular diseases are from a recent meta-analysis (45).

may fail to capture the much larger and meaningful long-term chronic disease prevention benefits from increased coverage rates of periodontal treatment (6–8). Expanding treatment coverage was cost-effective in 63%–84% of probabilistic sensitivity analysis iterations using conventional WTP in the U.S. ($50,000–$150,000 per QALY).

Our model accounted for the fact that periodontal treatment–associated decreases in HbA_{1c} would only be expected while patients with T2D receive routine periodontal treatment and maintenance. After we account for the variations in disease risks among different demographic groups, and the associated correlated risk factors among patients with T2D, expanding treatment coverage would be expected to benefit low-income non-Hispanic blacks—a population for whom health care interventions alone have not been sufficient to reduce large disparities in T2D and CVD (48). Our model found that expanding periodontal treatment among the patients with T2D would be cost saving

or cost-effective in all of the subgroups that we evaluated.

Periodontitis is a chronic inflammatory disease, which often coexists with diabetes (49), and there have been concerns around whether effective control of systemic inflammation can improve glucose control in people with T2D and thereby reduce their risk of diabetes complications, especially due to short follow-up periods (6–8). However, with more recent evidence on its long-term effectiveness (12–27.5 months), and its effectiveness even among patients with prediabetes (7,16), it is suggested that routine oral health evaluation and periodontal treatment could be important for effectively managing T2D in patients. Moreover, a recent meta-analysis of four trials (ACCORD, ADVANCE, UKPDS, and VADT) with 27,049 participants found that glucose lowering is significantly associated with reduced microvascular complications (45). Thus, evaluation of much larger and meaningful long-term chronic disease prevention benefits from periodontal treatment, using simulation models, would provide helpful insights for making treatment decisions for patients with T2D.

Our study has limitations inherent to modeling based on secondary data sources. First, most trials of periodontal treatment include only short follow-up periods (6,7,35), which means data from these studies must be extrapolated to longer time periods. Although we included findings from recent trials with relatively longer follow-up periods (12–27.5 months), availability of trials with even longer follow-up periods with a large sample size remains an important need for future research. Second, we only included the effects of periodontal treatment on diabetes and CVD risks that were based on most rigorous published meta-analytic data and randomized trials, which implies that our results may be conservative but also potentially robust to the concerns around the validity of several suggested associations between periodontal treatment and other systemic conditions such as respiratory diseases, chronic kidney diseases, and cognitive impairment (50–53). Third, we used data from NHANES, which are subject to the limitations of survey studies, including recall biases, acceptability biases, and underreporting, that may lead to misestimation of baseline covariates and limit the analysis to the civilian (noninstitutionalized) U.S. population. Finally, although uncertainty analyses were performed by sampling from distributions around the input parameter data sources, all possible uncertainties in a simulation model cannot be captured; hence, the results are inevitably subject to the assumptions inherent in modeling. Among these is the use of risk factor equations to estimate risk, which may overestimate disease risk when clinical treatment and control of disease-related risk factors improve disease status over time.

Expanding nonsurgical periodontal treatment among patients with T2D would be expected to lower the risk of tooth loss, T2D complications (microvascular diseases), and CVD in the U.S. and would be cost-saving or cost-effective under a range of scenarios. The benefits would likely accumulate among demographic groups (low-income non-Hispanic blacks and Mexican Americans and older populations) that have remained the high-risk groups for T2D and periodontitis and would thus address social and economic determinants of health disparities.

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